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Impact of Composting and Vermicomposting of Three Types of Animal Manure on the Dynamics of Macronutrients Nitrogen, Phosphorus, and Potassium

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Abstract

The management of animal manure remains a major environmental challenge, sparking growing interest in valorization methods such as composting and vermicomposting. However, the efficiency of the composting method largely depends on the type of organic substrate used. This study aims to evaluate the impact of composting methods on the final concentrations of nitrogen (N), phosphorus (P), and potassium (K) in three types of animal manure. Three types of animal manure (horse dung, cow dung, and poultry droppings) underwent a five-week pre-composting phase, followed by seven weeks of vermicomposting. Two earthworm species, *Eudrilus eugeniae* and *Eisenia fetida*, were used in the vermicomposting process. Soluble concentrations of N, P, and K were measured at the end of the composting and vermicomposting processes, and the impact of composting method on nutrient dynamics (N, P, and K) in the soil was assessed both before transplanting and after harvesting a lettuce crop. During composting, cow dung and poultry droppings showed similar nitrogen levels (0.3 kg N/ha), which were significantly higher than those of horse manure (0.2 kg N/ha). Poultry droppings displayed the highest phosphorus (0.18 kg P/ha) and potassium (0.25 kg K/ha) concentrations, compared to cow dung (0.12 kg P/ha, 0.1 kg K/ha) and horse manure (0.1 kg P/ha, 0.1 kg K/ha). In vermicomposting, nutrient differences between manure types were less pronounced. Nitrogen levels were higher in compost than in vermicompost for poultry droppings (0.38 kg N/ha vs. 0.33 kg N/ha), while P and K levels remained similar between the two processes for cow dung. This study highlights the differential impact of composting and vermicomposting on the nutrient content of organic amendments. Composting appears to be more effective for poultry droppings, while vermicomposting yields comparable nutrient levels for horse and cow manure. These findings provide valuable insights for optimizing organic waste recycling to enhance soil fertility.

Keywords: Composting, vermicomposting, animal manure, fertilization, nutrients (N, P, K), organic recycling

Introduction

The management of urban waste, particularly that of animal and organic origin, represents a major challenge in modern cities. High population density and the limited availability of spaces dedicated to waste treatment hinder the adoption of sustainable practices (Nanda & Berruti, 2021). Organic waste accounts for approximately 67% of municipal residues, which are often disposed of in landfills due to a lack of proper valorization. Among recognized treatment methods, traditional composting remains widely used. This process has been the subject of numerous studies aimed at improving its performance and optimizing its sustainability (Policastro & Cesaro, 2022). Innovations such as biodrying processes have been proposed to reduce nutrient losses. However, the strict monitoring required (control of moisture, temperature, and aeration), along with space constraints in densely populated areas, limits the applicability of this technique. In this context, vermicomposting emerges as a promising alternative. This method harnesses the activity of earthworms, which ingest and decompose organic matter while secreting enzymes that enhance nutrient mineralization and stabilization (Ducasse et al., 2022; Fernando et Arunakumara, 2021; Sharma & Garg, 2023). The resulting organic amendments possess a structure and N, P, and K contents that are favorable to plant growth (Liegui et al., 2021). Several studies have highlighted that the agronomic characteristics of vermicomposts vary significantly depending on the raw materials used and the parameters of the transformation process (Zhou et al., 2024). Recent research has also demonstrated the impact of manure type on the agronomic efficiency of vermicomposts (Ndiaye et al., 2022). Composting and vermicomposting are

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frequently compared in the literature, with many studies concluding that vermicompost is richer in nutrients. However, this is not always the case, as the final composition depends heavily on the type of animal waste used and the processing conditions. Moreover, these studies do not always clearly highlight their relative effectiveness based on these parameters. It remains to be determined whether one of these transformation methods ensures better preservation and release of macronutrients (N, P, K), taking into account nutrient losses. A better understanding of these factors would help guide the selection of organic materials and the most appropriate composting method to optimize nutrient availability and crop growth. The objective of this study is to evaluate the impact of composting and vermicomposting of three types of animal manure on the dynamics of macronutrients N, P, and K.

Materials and Methods

The study was conducted at the Laboratory of Integrated Production and Protection in Agroecosystems (L2PIA), located in the Department of Animal Biology (14°41'05.14" N and 17°27'43.28" W) of the Faculty of Science and Technology (FST), Cheikh Anta Diop University of Dakar (UCAD), Senegal. The laboratory houses a composting and vermicomposting platform.

Selection and preparation of organic waste

Three types of organic waste were selected for this study: horse manure, cow dung, and poultry droppings. Following collection and sorting, compost piles measuring two (2) meters in diameter and one (1) meter in height were formed for each type of waste. To meet the appropriate carbon-to-nitrogen (C/N) ratio, the animal waste was mixed with plant residues at a ratio of 2 parts animal waste to 1 part plant waste. The plant material consisted of a mixture of dead leaves, grass clippings, and straw residues.

Composting process

The composting and vermicomposting processes were conducted on the platform under semi-controlled conditions, from June 2024 to October 2024. After the piles were established, each compost heap received two weekly waterings, spaced three days apart. Two weeks after the initial setup, the piles were turned once a week, and this was maintained until the end of the process. A five-week pre-composting phase was observed, corresponding to the thermophilic stage, during which the pile could not yet support macro-organisms due to the high temperature. The product obtained at the end of this five-week period was used as pre-compost for the earthworms. The composting process was monitored over a 12-week period.

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Vermicomposting process

The vermicomposting process was carried out using wooden bins in which pre-compost samples were decomposed by earthworms.

Organic Material

Samples of each of the three substrates pre-composted over a five-week period were used in this experiment. For each sample, six bags of pre-compost were prepared.

Biological Material

The earthworm species used were *Eudrilus eugeniae* and *Eisenia fetida*. *Eisenia fetida* is an exotic species adapted to temperate environments and was bred on the study platform. *Eudrilus eugeniae*, on the other hand, is naturally abundant in Senegal, particularly around the wetlands of zoological parks.

Vermicomposting Monitoring

Three pre-composts were prepared from horse manure, cow dung, and poultry droppings, each composted for five weeks. These were then placed on composting tables (two bags per table) and moistened with 11 liters of water. Two kilograms of earthworms (distributed between the two species) were introduced per table. The experiment included three treatments with a total of nine tables. The leachate drained after moistening was collected and reused one week after the start of the process, then regularly throughout the experiment. The vermicomposting process lasted seven weeks.

Laboratory measurement of soluble macronutrient contents (N, P, and K) from composts and vermicomposts

At the end of the process, samples were collected to analyze the soluble nitrogen (N), phosphorus (P), and potassium (K) contents in the compost and vermicompost. A composite sampling method was used, involving the collection of subsamples from different depths and positions to ensure optimal representativeness. These subsamples were mixed in equal proportions, then air-dried in the shade to remove excess moisture. After sieving to eliminate debris, the samples were placed in airtight bags with precise labeling and transported to the laboratory.

For analysis, 50 grams of sample were mixed with 250 ml of distilled water, shaken, and then left to settle for 24 hours. The supernatant was filtered and analyzed using a compact photometer, which measured the soluble fractions of nitrogen (N), phosphorus (P), and potassium (K). These values reflect the immediately available nutrient content for plants, rather than the total nutrient stock in the composts.

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Statistical Analysis

In line with the specific objectives of this study, advanced statistical techniques were used to analyze the collected data, using XLSTAT software (2016). Data were checked for independence, and normality tests (such as the Shapiro–Wilk test) and homogeneity of variance tests (such as Levene's test) were conducted to verify that the assumptions required for a valid ANOVA were met. When the normality conditions were not satisfied, appropriate data transformations were applied.

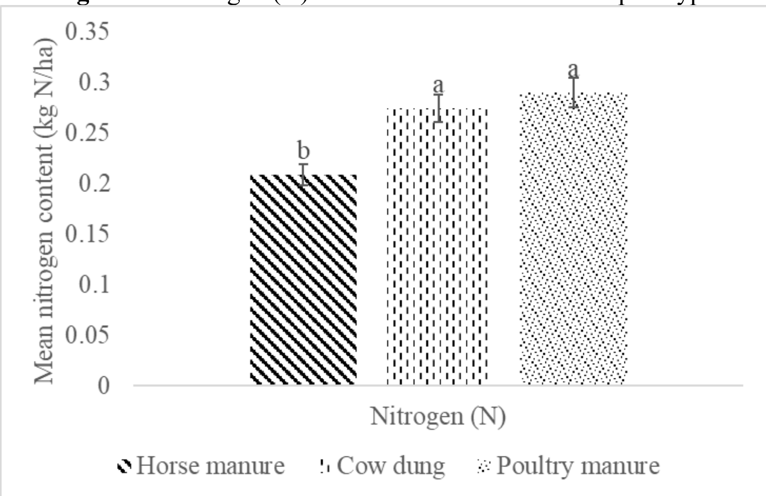
RESULTS

Nitrogen (N), Phosphorus (P), and Potassium (K) contents during the composting process

- **Nitrogen (N) content during composting**

Nitrogen content varied significantly depending on the type of waste composted. The results indicate that cow dung and poultry droppings exhibited similar nitrogen levels, with an average of approximately 0.3 kg N/ha, which was significantly higher than that of horse manure, which averaged around 0.2 kg N/ha. These differences were statistically significant, as shown by the distinct letters (a, b) above the bars in the figure, indicating that horse manure (b) had a significantly lower nitrogen content compared to cow dung and poultry droppings (a) (Figure 1).

Figure 1: Nitrogen (N) content as a function of compost type



df = 2 ; F = 7.984 ; P = 0.001, Histograms sharing the same letters are not significantly different at the 5% level according to Newman-Keuls test.

- **Phosphorus (P) content during composting**

Regarding phosphorus, poultry droppings have a significantly higher P content (approximately 0.18 kg P/ha) compared to cow dung and horse manure, which show average values of about 0.12 kg P/ha and 0.1 kg P/ha,

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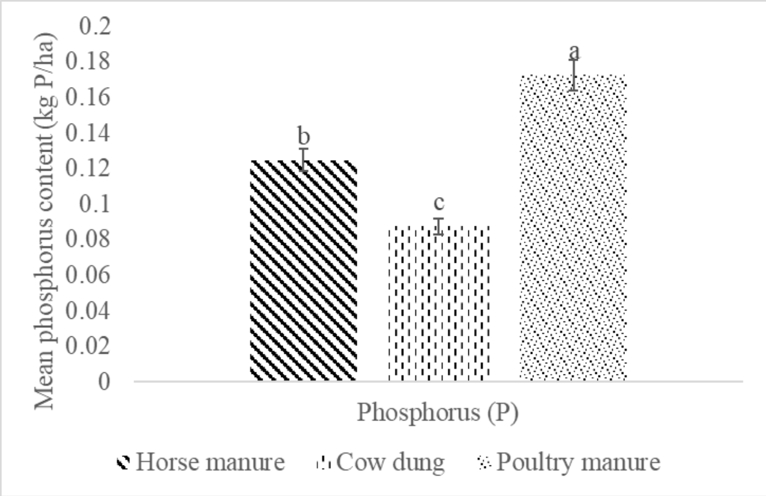
respectively. The differences are also indicated by the letters above the bars, with poultry droppings (a) being distinct from the others, and a notable difference between cow dung (c) and horse manure (b) (Figure 2).

Figure 2: Phosphorus (P) content as a function of compost type

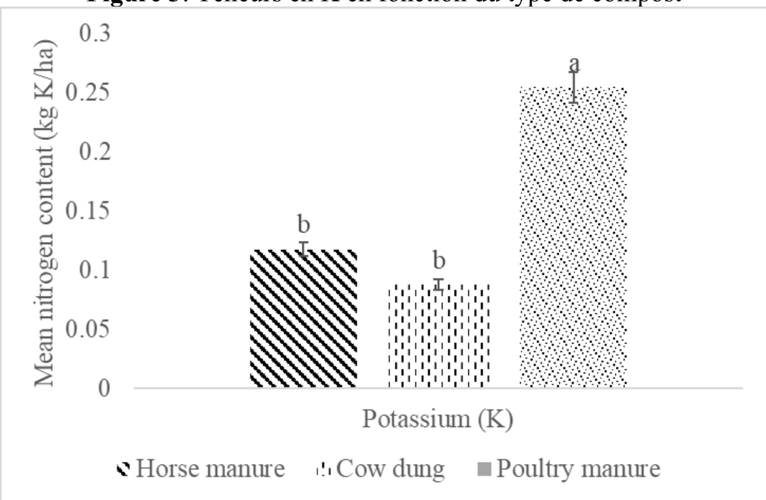


df = 2 ; F = 13.307 ; P = 0.0001. Histograms sharing the same letters are not significantly different at the 5% level according to Newman-Keuls test.

- **Potassium (K) content during composting**

The potassium content reveals that poultry droppings have the highest K concentration (approximately 0.25 kg K/ha), while horse manure and cow dung have similar and lower concentrations (around 0.1 kg K/ha). Poultry droppings are statistically distinct (a) from the two other types of waste (b) (Figure 3).

Figure 3: Teneurs en K en fonction du type de compost



df = 2 ; F = 16.060 ; P = 0.0001, Histograms sharing the same letters are not significantly different at the 5% level according to Newman-Keuls test.

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Nitrogen (N), Phosphorus (P), and Potassium (K) contents during the vermicomposting process

Table 1: Nitrogen (N), Phosphorus (P), and Potassium (K) contents during the vermicomposting process

Vermicompost	Nitrogen Content (kg N/ha)	Phosphorus Content (kg P/ha)	Potassium Content (kg K/ha)
Horse	0.23 a	0.12 a	0.12 a
Cow	0.21 a	0.10 a	0.11 a
Poultry	0.33 a	0.14 a	0.13 a

The nitrogen content for horse manure is 0.23 kg N/ha. This level is statistically similar to that observed for cow dung (0.21 kg N/ha) and poultry droppings (0.33 kg N/ha), as indicated by the letter "a" in Table 1 for all waste types. The P-value for this analysis is 0.789, which indicates no statistically significant difference between the waste types (Tab. 1). The phosphorus content for horse manure is 0.12 kg P/ha**.** The phosphorus contents for cow dung (0.10 kg P/ha) and poultry droppings (0.14 kg P/ha) are also statistically similar, with all values marked by the letter "a". The P-value for this analysis is 0.972, confirming the absence of a significant difference between the waste types (Tab. 1). The potassium content for horse manure is 0.12 kg K/ha**.** Cow dung shows a slightly lower K content (0.11 kg K/ha), while poultry droppings exhibit a slightly higher K content (0.13 kg K/ha). However, these differences are not statistically significant, as indicated by the common "a" letter for all waste types. The P-value for this analysis is 0.929 (Tab. 1).

Comparison of average nitrogen (N), phosphorus (P), and potassium (K) contents based on the composting method

Table 2 presents the average nitrogen (N), phosphorus (P), and potassium (K) contents based on the composting method.

Table 2: Average nitrogen (N), phosphorus (P), and potassium (K) contents based on the composting method

Chemical Elements	Treatments	Horse Manure	Poultry Droppings	Cow Dung
N	Compost	0,22 (a)	0,38 (a)	0,26 (a)
	Vermicompost	0,22 (a)	0,33 (b)	0,21 (b)
P	Compost	0,15 (a)	0,17 (a)	0,09 (a)
	Vermicompost	0,12 (a)	0,14 (b)	0,11 (a)
K	Compost	0,14 (a)	0,26 (a)	0,10 (a)
	Vermicompost	0,11 (a)	0,13 (b)	0,10 (a)

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For horse manure, the levels of N, P, and K are similar between compost and vermicompost, with values of 0.22 kg/ha for N in compost compared to 0.22 kg/ha in vermicompost. This lack of significant difference ($P = 0.884$) suggests that the vermicomposting process does not improve the availability of these nutrients compared to traditional composting for horse manure (Tab. 2). For poultry droppings, the results show higher levels of N, P, and K in compost compared to vermicompost. For example, for N, the content is 0.38 kg/ha in compost, compared to 0.336 kg/ha in vermicompost, which is significantly different ($P = 0.0001$) (Tab. 2). For cow dung, the P and K contents are similar between compost and vermicompost, with very close values, indicating no significant difference ($P = 0.981$). However, there is a slight difference for N, where compost has a higher value (0.26 kg/ha) compared to vermicompost (0.21 kg/ha), but this difference is relatively small (Table. 2).

Discussion

Composting and vermicomposting processes differ in how they transform essential nutrients, thus influencing their availability to plants. Numerous studies have examined these differences and highlighted the mechanisms governing nutrient dynamics in these two organic waste treatment systems. The transformation of nitrogen differs significantly between composting and vermicomposting. In composting, the organic nitrogen in wastes undergoes mineralization, producing ammonium (NH_4^+) as a transitional stage before ammonia (NH_3) volatilization, a phenomenon accentuated under high-temperature and alkaline pH conditions (Chastain, 2022). In contrast, vermicomposting tends to promote a more effective conversion of ammonium into nitrates (NO_3^-), which are directly assimilable by plants. Earthworm activity, supported by their digestive enzymes, accelerates the oxidation of ammonium by nitrifying bacteria, thereby reducing gaseous losses and improving nitrogen retention in the final product (Alipour et al., 2023; Angmo et al., 2024; Hossen et al., 2022). Regarding phosphorus, several studies indicate that, in composting, organic phosphorus gradually becomes soluble, but some may be lost through leaching (Aronsson et al., 2022), particularly when moisture levels are excessive and pH conditions fluctuate (Ge et al., 2022). Conversely, vermicomposting minimizes these losses by forming stable organo-phosphate complexes, a phenomenon favored by the microbial activity induced by earthworms' ingestion of the waste (Gonçalves et al., 2021). Potassium, a highly soluble element, is particularly prone to losses through leaching. The physical structure of the compost plays a decisive role in potassium retention, as excessive porosity may promote these losses. In vermicomposting, earthworm activity helps stabilize K^+ ions within the decomposing organic matter, an

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effect that can be enhanced by the addition of biochar or volcanic rocks, as demonstrated by Gashua et al. (2022). Differences observed in the N, P, and K contents of composts and vermicomposts are strongly influenced by the nature of the organic wastes used. Studies have highlighted that the mineralization and release of fertilizing elements vary depending on the intrinsic characteristics of the feedstocks. For instance, Addo et al. (2022) demonstrated the conversion of municipal waste into compost via black soldier fly bioconversion, while Yuan and Dickinson (2022) emphasized the potential of vermicomposting for processing food waste. Similarly, Maharjan et al. (2022) noted that the initial composition, particularly the cellulose and lignin content, modulates the kinetics of nutrient release. Our findings confirm and expand upon these theoretical observations. During composting, we observed that nitrogen levels vary depending on the type of waste. For example, cow dung and poultry droppings contain higher N levels than horse manure, a finding also reported by Fatah et al. (2025). Concerning phosphorus, poultry droppings exhibit higher values than cow dung and horse manure, echoing the observations of Dang et al. (2024) on the P-enrichment of substrates with a high initial concentration. As for potassium, poultry droppings - owing to their high solubility - show higher concentrations, whereas horse manure and cow dung present more moderate levels, consistent with the results of Lahbouki et al. (2024). In the case of vermicomposting, differences among waste types are less pronounced. The values recorded for horse manure, cow dung, and poultry droppings tend to converge, corroborating the studies of Ndiaye et al. (2022) on the agronomic efficiency of vermicomposts produced from various manures, as well as those of Syarifinnur et al. (2023), who directly compared compost and vermicompost. Furthermore, Patra et al. (2022) pointed out that manure-based amendments can yield products of similar nutrient quality, particularly when composting and vermicomposting processes are optimized. The obtained results allow us to differentiate amendments based on their effectiveness and how nutrients are supplied, thereby offering prospects for optimized management of organic fertilization. The marked decrease in nitrogen after harvest - also confirmed by Ravindran et al. (2022) - indicates high uptake by lettuce, suggesting that these amendments provide an effective supply of plant-available nitrogen. The uniform reduction in phosphorus levels post-harvest may reflect rapid plant assimilation or weak soil retention, as noted by Rizzo et al. (2022). As for potassium, its relative stability, with better retention in certain treatments such as cow dung vermicompost, aligns with the findings of Lahbouki et al. (2024) and Kızılkaya et al. (2021).

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Conclusion

The results of this study confirm that composting and vermicomposting differently influence the dynamics of macronutrients (N, P, K), depending on the type of animal manure used. Compost tends to release nutrients more rapidly, which can be advantageous for crops with high immediate nitrogen demands, while vermicompost ensures a more gradual release, promoting a prolonged availability of fertilizing elements. The variations observed depending on the type of waste indicate that poultry droppings are particularly rich in soluble nutrients, whereas horse manure and cow dung show more moderate and progressive releases. These differences suggest that the choice of processing method and raw material type should be adapted to the specific needs of crops and agronomic objectives. Consequently, a targeted management of organic amendments that integrates these parameters could enhance fertilization efficiency and contribute to more sustainable agriculture.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

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