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Physico-Chemical Analysis of Vermicompost Mixtures

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Abstract: The study evaluated the physical and chemical characteristics of vermicompost mixtures to optimize nutrient extraction. Three compost mixtures (chicken plus horse (CH+H), chicken plus cattle (CH+C), and cattle plus horse (C+H)) were selected for quality evaluation at three extraction times: 24, 48, and 72 h. The results showed differences ($p < 0.05$) in nutrient concentration of compost teas in different compost mixtures. The interaction between treatments and extraction time showed a significant effect ($p < 0.05$) on nutrients except in P, K, Ca, and EC. The nutrients were higher at 48 h after extraction. The pH was observed to increase slightly with extraction time. C+H had more percentage of moisture content (44.79%) than other mixtures. This mixture was the most preferred by worms, i.e., it had the greater size and number of worms. The results suggested that the presence of oxygen in extraction and high temperatures affects ammonium availability in compost tea as they trigger nitrifying bacteria. Due to the decrease in some nutrients' concentration (NO_3, P, K, Ca, Mg, Mn, and Cu) at 72 h, it was concluded that 48 h is the best time to extract nutrients from compost mixtures to produce good quality compost using aerobic extraction method.

Keywords: hydroponic; vermicompost; compost mixtures; quality; nutrients; aerated extraction method

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1. Introduction

The ever-increasing price of inorganic fertilizers and fungicides has led to the increase in popularity of using compost tea as an economical alternative to supply nutrients for plant growth and development [1–4]. Compost teas are a liquid phase of compost preparation produced by steeping a wide range of composts in water and brewing for a defined period [5]. On the other hand, compost is an organic matter source with a unique ability to improve the chemical, physical, and biological characteristics of soils [6]. Organic materials such as garden waste, plant leaves, manure, straw, and other organic-based materials can make good compost [7,8]. Compost tea can be brewed for a specific purpose; for example, it can be specifically brewed for use as a soil organic matter builder, a disease suppressant, or a nutrient source [2]. Most likely, compost tea has been used for centuries, and the evidence indicates that it has been used since the Roman Empire [2].

However, compost tea of good quality will depend on good quality compost. A fine-textured and pathogen-free compost containing highly beneficial microorganisms, soluble mineral nutrients, humic substances, phytohormones, and low phytotoxic compounds can be considered good quality compost. In addition, the compost feedstock, processing method, and compost maturity generally determine the final compost characteristics [9]. The quality of the final product of the composting process is conditioned by the activity of different groups of microorganisms dictated by the chemical composition of the composted materials, and it is evaluated based on biological, chemical, and physical parameters [10].

The most important physical and chemical parameters of compost are usually assessed on the parameters such as pH, carbon/nitrogen (C:N) ratio, moisture content, organic carbon, cation exchange capacity (CEC), electrical conductivity (EC), and organic matter [11]. However, certain chemical and physical characteristics of animal manure are not adequate for composting and could limit the efficiency of this process. For example, chicken manure with excess moisture, low porosity, and high N concentration versus organic C, which gives a very low C:N ratio and high pH values, is not good enough. Therefore, this results in a need to correctly balance these compounds in chicken manure. The C:N ratio must be correctly balanced so that the compost can provide better conditions for microbes to fasten the decomposition process. Nonetheless, the successful composting of animal manures, which are usually rich in nitrogen [12] with materials having a high carbon content, such as sawdust [13] and wood chips [14], has been reported. Little work has been conducted on testing mixtures of vermicomposts. Therefore, the objective of this study was to evaluate the physical and chemical characteristics of vermicompost mixtures for maturity and stability purposes in order to optimize nutrient extraction for the production of good-quality compost tea.

2. Methods and Materials

2.1. Controlled Environmental Condition

The experiment was conducted at the controlled environment research unit (CERU) facility of the University of KwaZulu-Natal, Pietermaritzburg Campus (29.6196° S, 30.3960° E, 596 m above sea level), from May to December 2018. The tunnel where the study was conducted had an average relative humidity (RH) of 80% and temperature of 28 °C during the day and 17 °C during the night.

2.2. Experiment Procedure and Experimental Design

Samples of about one-month-old chicken and horse manures were collected from Gromor® (PTY) LTD situated in Umlaas Road, KwaZulu-Natal Province (29°43.395′ S, 30°28.647′ E, 823 m above sea level). Cattle manure of about a month old was collected at Cedara Agricultural College Dairy Farm situated in Hilton, KwaZulu-Natal Province (29.5339° S, 30.2733° E, 1080 m above sea level). These samples were taken to Crop Science tunnel within CERU for further analysis. A variety of *Eisenia foetida* called Red Worm or Red Wriggler used for vermicomposting manure was sourced from Wizard Worms, Greytown, KwaZulu-Natal Province (29°07′24″ S 030°35′56″ E, 1.076 m above sea level).

The manures were vermicomposted in a closed tunnel on top of a prepared uniform bed covered with heavy-duty black polythene plastic sheeting. Three different mixture heaps were prepared where compost mixtures containing chicken manure were mixed at a ratio of 1:1.5 and one without chicken manure was 1:1. Chicken manure mixtures had less chicken manure and more of other sources because chicken manure contained high levels of salts, excess of moisture; low porosity and high N concentration which is not good enough for worm feed. Therefore, putting other sources neutralized it. Heap 1 contained 20 kg of chicken manure (CH) with 30 kg of cattle manure (C); heap 2 had 20 kg of CH with 30 kg of horse manure (H), while heap 3 had 30 kg (C) with 30 kg (H). The heaps made on the bed were separated by planks. Then the worms from 2 boxes (each box containing about 1000+ worms in a 30 cm × 10 cm × 12 cm carton) were evenly distributed on the manures as per heap. Manure was watered until, when squeezed, it took the shape of the hand without breaking, and that was achieved at 60% moisture content [6]. After that, the vermicomposts were covered with the same heavy-duty black polythene plastic sheeting used in making beds to retain compost heat. The vermicomposts were turned 3 times a week, and water sprinkling was performed, when necessary, before turning. Vermicompost temperature ranged between 25–30 °C throughout the process. The process continued until vermicompost maturity (5 weeks after incubation), where the vermicompost had dark to blackish color with an earthy aroma, and results were collected.

The experiment consisted of two treatment factors: vermicompost at three levels (CH+C, CH+H, H+C) and extraction time at three levels (24 h, 48 h, 72 h). The experiment had nine treatment combinations replicated three times to make 27 experimental units. The design was a two-factor factorial experiment (3 × 3 × 3) in a completely randomized design (CRD).

2.3. Data Recorded and Material Used

2.3.1. Moisture Content

The % moisture content was determined by the following formula as described by [15].

$$\%MC = \frac{m1 - m2}{m2} \times 100$$

where $m1$ is initial mass (wet mass), $m2$ is mass after drying (dry mass), 100 is percentage constant.

2.3.2. Particle Size, Smell, and Color

The texture of the mature vermicompost from different treatments was observed through hand feel, smell, and color.

2.3.3. Reproduction/Earthworm Growth

Earthworm (*Eisenia fetida*) reproduction was determined through a once-off sampling of 500g vermicompost from each pile and taken to the laboratory. Before compost drying, the number of worms, worm mass, and length were determined.

2.3.4. Carbon and Nitrogen

Carbon and nitrogen from animal manure vermicompost mixtures (CH+C, CH+H, and H+C) were determined using the LECO Trumac CNS Auto-analyser Version 1.1 × (LECO Corporation 2012). Measurement was performed once, after vermicompost matured, and there were no imbalances as these elements ensure nutrient balance in composting.

2.4. Nutrient Extraction

After reaching vermicompost maturity, the vermicompost was taken to the laboratory for nutrient extraction. The aerated "active" extraction method by [2] was used in this study. During this method, the vermicompost is put into a bag made from a permeable material, usually hessian or burlap. The bag effectively acts as a crude filter: the tighter the weave, the cleaner the solution [16]. Therefore, a bag containing the vermicompost is soaked in water for one or two days to obtain a nutrient solution, and the mixture requires aeration throughout the extraction period [17–19].

Briefly, a 1:10 compost-to-water ratio suggested by [20] was used, where a 50 g of vermicompost was weighed and put into an extraction bag (lot empty tea bag with string filter, 10 cm × 13 cm × 15 cm). Then, 500 mL of deionized water was measured in a 2000 mL plastic volumetric flask. Thereafter, dophin 8500 double outlet air pumps were plugged in and inserted in water for aeration about 15 min before the extraction bag was inserted. The process was performed for all 3 vermicompost mixtures. The pumps had 3.4 W power, 0.014 Mpa pressure, and 210 L/h output. The teas were left in the laboratory (room temperature). After 24 h (day 1) of aerobic extraction, about 50 mL per tea from each flask was extracted to a 50 mL plastic specimen jar and placed in a freezer. This process was performed also after 48 h (day 2) and after 72 h (day 3). The extracts were analyzed using different methods and machinery for different elements.

2.5. Chemical Analysis

2.5.1. Atomic Absorption Spectrometry

The chemical analysis involved the determination of P, K^+, Ca^{2+}, Mg^{2+}, Na^{2+}, Cu^{2+}, Fe^{2+}, $Al^{2+,}$ and Mn^{2+} in vermicompost tea extracts. K, Ca, Mg, Na, Cu, Fe, Al, and Mn

concentrations were determined using flame atomic absorption spectroscopy (FAAS) with a fast sequential absorption spectrometer (Varian AA280FS). The wavelength, lamp current, and flame profile at which elements were analyzed are summarized in (Table 1). The phosphorus absorbance was determined using an automated spectrophotometer, UV-1800 ENG 240 V, Shimadzu Cooperation Japan, at 670 nm. Briefly, phosphorus concentration to mg/L was calculated using calibration curve formula: $Y = mx + c$. Where concentrations of standards used were 0, 1, 4, and 10 ppm, resulting in an R^2 = 0.9993.

Table 1. Wavelength, lamp current, and flame profile used for elemental analysis of vermicompost tea extracts.

Element	Wavelength λ	Lamp Current	Flame Profile
K	766.5	2.0	Air/Acetylene
Mg	285.2	4.0	Air/Acetylene
Ca	422.7	10.0	N20 Acetylene
Na	589.0	5.0	Air/Acetylene
Al	309.3	10.0	N20 Acetylene
Fe	248.3	5.0	Air/Acetylene
Mn	279.5	5.0	Air/Acetylene
Cu	324.8	4.0	Air/Acetylene

2.5.2. N Analysis

The ammonium-N was analyzed by the automated continuous flow injection method [21]. The nitrate-N was analyzed by the Thermo Scientific Gallery Discrete Auto-analyser using the automated calorimetric hydrazine reduction method [22].

2.5.3. pH and EC Analysis

The pH of the extracts was measured using a pH meter, the radiometer analytical PMH 210, China. Then electrical conductivity was measured using an EC meter, CMD 210, China, in µs/cm.

2.6. Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using Genstat 18th Edition (VSN International, Hemel Hempstead, UK). Means were separated using LSD, Fisher's unprotected test at $p \leq 0.05$ significant level.

3. Results and Discussion

Experienced producers and users of compost often evaluate maturity using subjective indicators such as color, smell, and feel [23]. Dark brown, earthy-smelling, moist, and finely divided composts that lack sour or ammonia off-odors are expected to be of adequate maturity to promote plant growth. However, more quantitative measures are required to better enable end-users to determine the optimal rate and frequency of vermicompost application.

In Table 2, the percentage moisture content was measured, and it was different for all vermicompost mixtures in an order: CH+C < CH+H < H+C. The moisture ranged between 35–45%, which lies within the wide range of optimum moisture contents (25%–80%), suggesting successful animal manure composting [24–27]. This wide range of optimum moisture content reported by the authors implies that there is no commonly applicable optimal moisture level for various composting materials. Furthermore, according to [28], it is suggested to start a compost pile with a moisture content of 50–60% and finish at about 30%. Therefore, in terms of moisture check, the vermicompost was perfect for harvest.

Table 2. Physical characteristics of composts for determination of compost maturity and stability.

Compost Type	CH+C	CH+H	H+C
% Moisture content	35.87	39.28	44.79
Texture, smell, and color	Soft texture, earthly aroma, and brownish color	A bit of coarse texture, earthly aroma, and brownish color	Softer texture, earthly aroma, and dark color
No. of worms	15	21	30
Worm mass (g)	5.11	6.76	9.11
Worm length (Short, Long, longest) (cm)	3; 6.5; 8	5; 7; 9	5; 8.5; 11
C: N Ratio	20.3	21.4	23.78

Earthworm reproduction parameters were also determined, and results show that all measured parameters were lower on CH+C compared to CH+H and H+C vermicomposts. According to [29], cattle manure solids are the easiest animal wastes in which to grow earthworms successfully, while horse manure is an excellent material for growing earthworms and needs very little modification other than maintenance of good environmental factors in the waste. However, the earthworms do not grow as rapidly in horse manure as in cattle waste [29]. This is why the combination of C+H gives good results compared to others. There was a high number of worms in H+C (30), which was double the value in CH+C (15). The worm mass was greater in H+C (9.11 g) compared to CH+H (6.76 g) and CH+C (5.11 g). The worm length from short, long, and longest was measured, and H+C had the highest values (5, 8.5, 11) compared to CH+H (5, 7, 9) and CH+C (3, 6.5, 8). At harvest, H+C vermicompost turned out softer with dark brown color and earthly aroma, while CH+C vermicompost was not soft as H+C but had a dark brownish color with earthly aroma, and CH+H vermicompost had a bit of coarse texture with an earthly aroma and brownish color. Therefore, it may be concluded that worm increase in H+C vermicompost was due to reproduction and compost stability as the worms seemed to like this mixture the most.

The C:N ratios of vermicompost measured were affected by compost type and worm reaction towards each compost; results followed the order: CH+C< CH+H< H+C. The ratio was greater than 20 for all composts. By assumption, microorganisms use 15–30 parts of carbon for each part of nitrogen, wherein an optimum C:N ratio ranging between 15 and 30 is recommended for rapid composting [30–32]. The higher C:N values limit the growth of microorganisms, resulting in the composting process being slowed down. While lower C:N lead to excess available nitrogen and higher losses as ammonia in the exhaust gases [32,33]. This means this may lead to an alleviation of the odor problem that is usually encountered in full-scale composting facilities [27]. Therefore, C:N ratio in any compost is to be controlled.

3.1. Nutrient Extraction

3.1.1. Nitrogen (Ammonium and Nitrate)

The results in Figure 1 show that the treatments had a highly significant effect on NH_4-N and NO_3-N ($p < 0.001$). However, the interaction between the treatments and extraction time had no significant effect on NH_4-N concentration of CH+C and CH+H in the first two days and significantly decreased on the third day. The interaction between treatment and extraction time had no effect on NH_4-N of H+C in all three days of extraction.

The interaction between treatment and extraction time had no significant effect on CH+H, but NO_3-N has been decreasing throughout. Tea extract H+C shows a fluctuating NO_3-N concentration where the concentration increased from day one to day two and decreased on day three but is not statistically different. Lastly, in CH+C, the interaction of treatment and time had a significant effect on NO_3-N concentration as it was increasing throughout extraction.

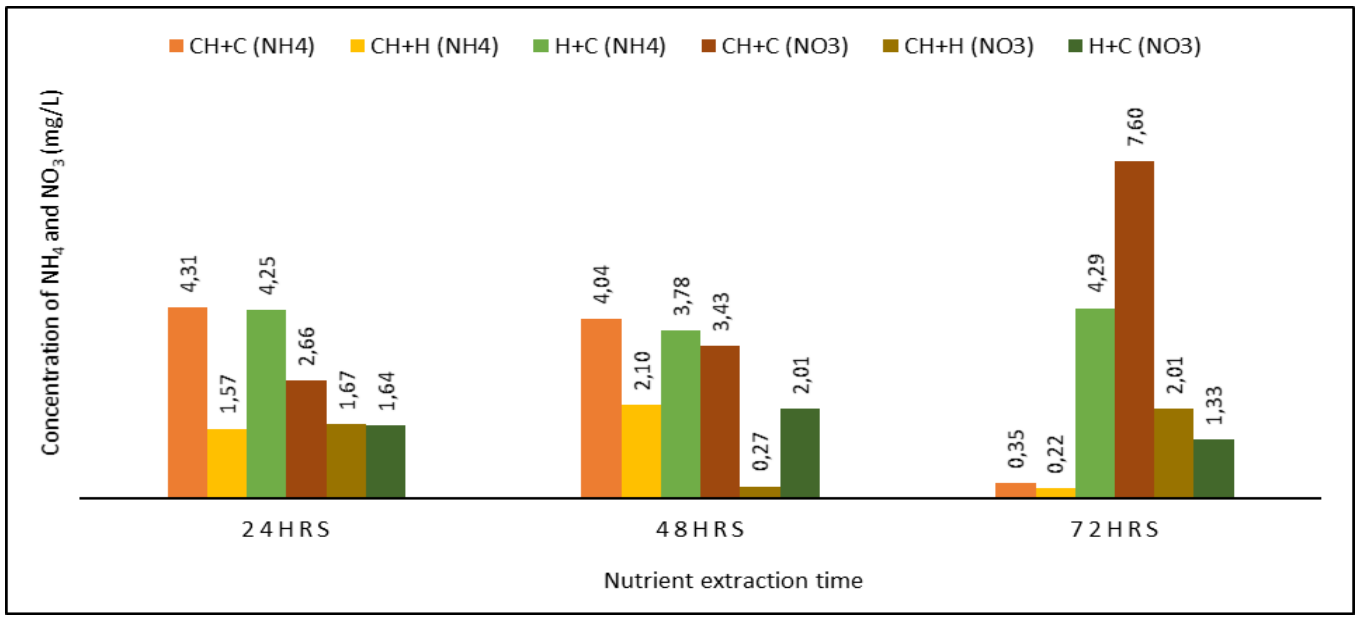


Figure 1. Determination of ammonia and nitrate in different vermicompost teas over 72-h extraction period.

There was a correlation between ammonia and nitrate except on day 3 of CH+H; when ammonia decreased, there was an increase in nitrate, and when ammonia increased, nitrate decreased. This could be due to autotrophic nitrifying bacteria that oxidize ammonium to nitrite and nitrate [34]. The rate of nitrification is controlled by environmental factors, and the most significant environmental factors include pH, temperature, and oxygen availability [35,36]. Therefore, the aerobic environment created through aeration may have resulted in the decrease of ammonia while increasing nitrate. Nitrate is the preferential form for nitrogen uptake by plants, and the relationship between nitrate uptake and plant growth in hydroponics has been previously reported [37]. Therefore, since there are fluctuations in ammonium concentration at 72 h, it appears that 48 h of extraction can be used to extract nitrate from vermicompost mixtures.

3.1.2. Phosphorus and Potassium

All treatments show a highly significant difference in P concentration (Figure 2). The interaction between treatment and extraction days shows no significant difference in P concentration of CH+H between day one and day two, day two and day three, but the day three concentration is different from that of day one. On CH+C, the interaction between treatment and extraction days shows no significant difference in P concentration on all days of extraction. However, the H+C interaction between treatment and extraction days shows a significant difference in P concentration between day one and day two; while day two and day three are the same, day one and day three are also different. In all treatments, P concentration began to drop in day three except in treatment CH+H, wherein, the increase was not significant. Therefore, two days (48 h) is seen to be the best duration to extract phosphorus from vermicompost teas.

The potassium concentration of H+C was different from that of CH+C and CH+H treatments. The interaction between treatment and extraction days shows no significant difference in K concentration of day one and day two, day two and day three of CH+H, while day three was different from day one. In CH+C, the interaction showed no significant difference in all extraction days. However, in H+C, there was a significant difference in K concentration of the interaction between treatment and extraction days on day one and day two. Wherein day two and day three were the same, but day three was different from day one. Basically, the effect of aeration on P and K concentration was not as discernible as it was

on NH_4-N and NO_3-N contents. This may be due to the lack of volatile-loss pathways for P or K, which resulted in these nutrients being highly conserved [38]. The concentration of K increased in all treatments throughout the extraction; therefore, three days (72 h) can be used to extract K from vermicompost teas.

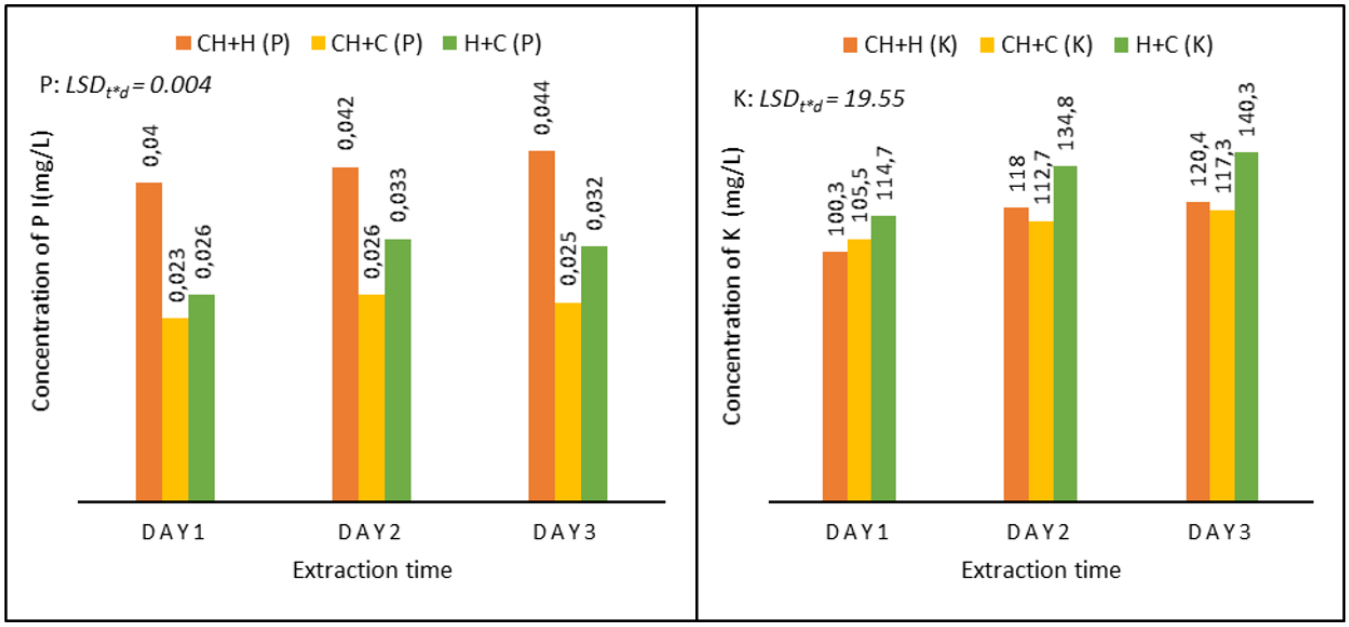


Figure 2. Determination of phosphorus and potassium in different vermicompost teas over 72-h extraction period.

3.1.3. Calcium (Ca), Magnesium (Mg)

The treatments had a significant difference in calcium concentration, but CH+C and CH+H were the same (Figure 3). The interaction of treatment and extraction time had no significant effect on calcium concentration in all treatments. H+C had the lowest calcium concentration ranging at 39–45 mg/L, while CH+C and CH+H had their concentration ranging at 67–87 mg/L. It appeared that the H+C vermicompost mixture extract had a low concentration of calcium than the recommended level of calcium in hydroponic systems, which is between 50–150 mg/L [39]. Therefore, when using this mixture, calcium should be adjusted. Magnesium concentration was different in all treatments, with an order H+C < CH+C < CH+H. The interaction also showed a significant difference, but day one of CH+H has the same magnesium concentration as day two of CH+C. The CH+C and CH+H treatments reached their maximum concentration of Mg on day two as the concentration dropped on day three. However, H+C had the same concentration throughout extraction. Therefore, 48 h can be used to extract Ca and Mg from vermicompost mixtures.

3.1.4. Iron (Fe), Manganese (Mn), Copper (Cu)

Iron concentration was different in treatments, but in CH+C and H+C, there was no significant difference (Figure 4). The interaction of treatment and extraction time also had a significant effect on iron concentration. The CH+H treatment had the highest iron concentration throughout extraction. CH+C and H+C had iron concentrations of less than 1 mg/L. The concentration in CH+C was increasing with days, then in CH+H and H+C, it decreased on day two and increased on day three though H+C was not significant. Manganese concentration was different in all treatments, with an order H+C < CH+C < CH+H. The interaction also had a highly significant difference, but in all treatments, the concentration increased from day one to day two and then suddenly dropped on day three. Copper concentration was different in all treatments, with an order H+C < CH+C < CH+H. The interaction between treatments and extraction time also shows a significant difference in Cu concentration, with H+C having the same concentration throughout extraction. The con-

centration in all treatments increased from day one till day two and then decreased again in day three. The CH+C compost tea had the highest Cu of other teas, which ranged from 0.4 to 05 mg/L. Concentrations of Cu in CH+C and H+C were below the respective target range of 0.2 to 0.5 mg /L, which is recommended for water to be used to irrigate vegetable crops grown in containers [40]. In all the measured nutrients, two days (48 h) is seen to be the best period to extract nutrients in vermicompost teas.

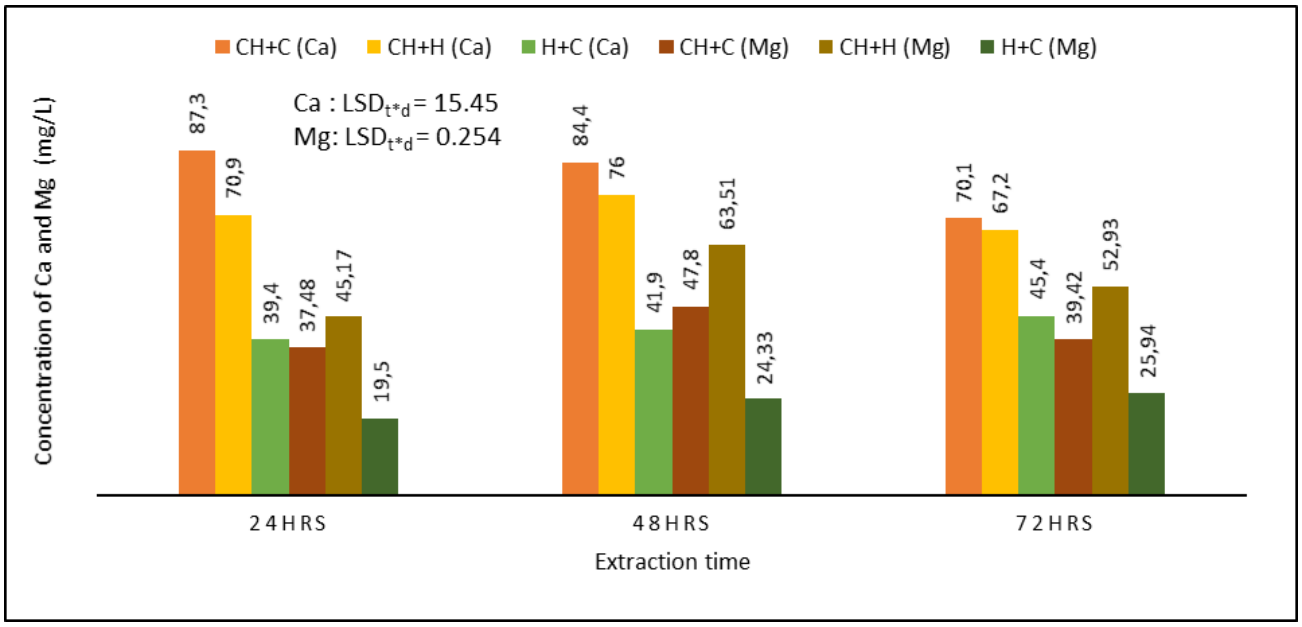


Figure 3. Determination of calcium and magnesium in different vermicompost teas over 72-h extraction period.

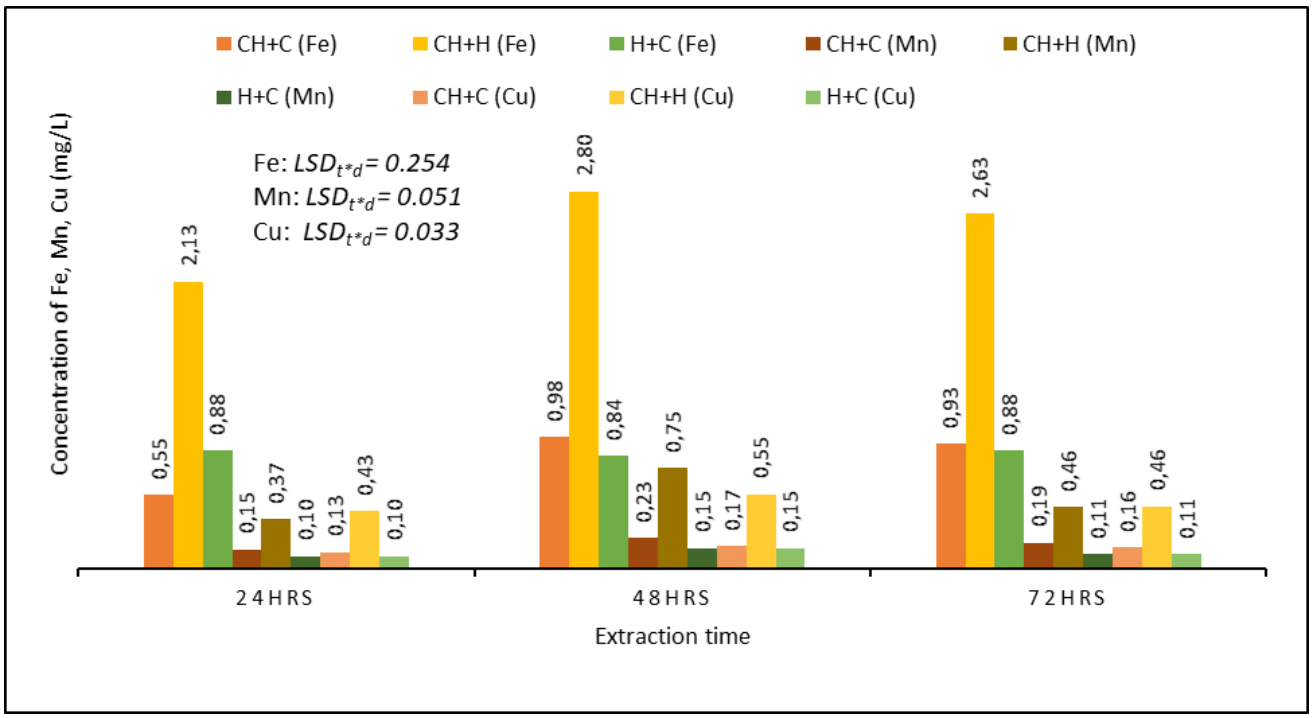


Figure 4. Determination of iron, manganese, and copper in different vermicompost teas over 72-h extraction period.

3.1.5. Electrical Conductivity and pH

Electrical conductivity was different in treatments, but in CH+C and CH+H, it was not significantly different (Figure 5). The interaction between treatment and time had no significant effect on electrical conductivity. H+C had the lowest conductivity of other treatments. Electrical conductivity values for CH+C and CH+H extracts were above the standard recommended higher limit of 500–2000 µS/cm [38], which has been reported to cause salinization of growth substrates and negatively affect crop growth and result in lower yields [41]. This means more pH-balanced water is required for the mixture to effectively dilute the concentration of salts, which will lower the EC. Furthermore, the results show that the significant decrease in NH_4-N of CH+C corresponds to the increase in EC value of day three. This suggests that EC was affected by the release of soluble salts such as ammonium [31].

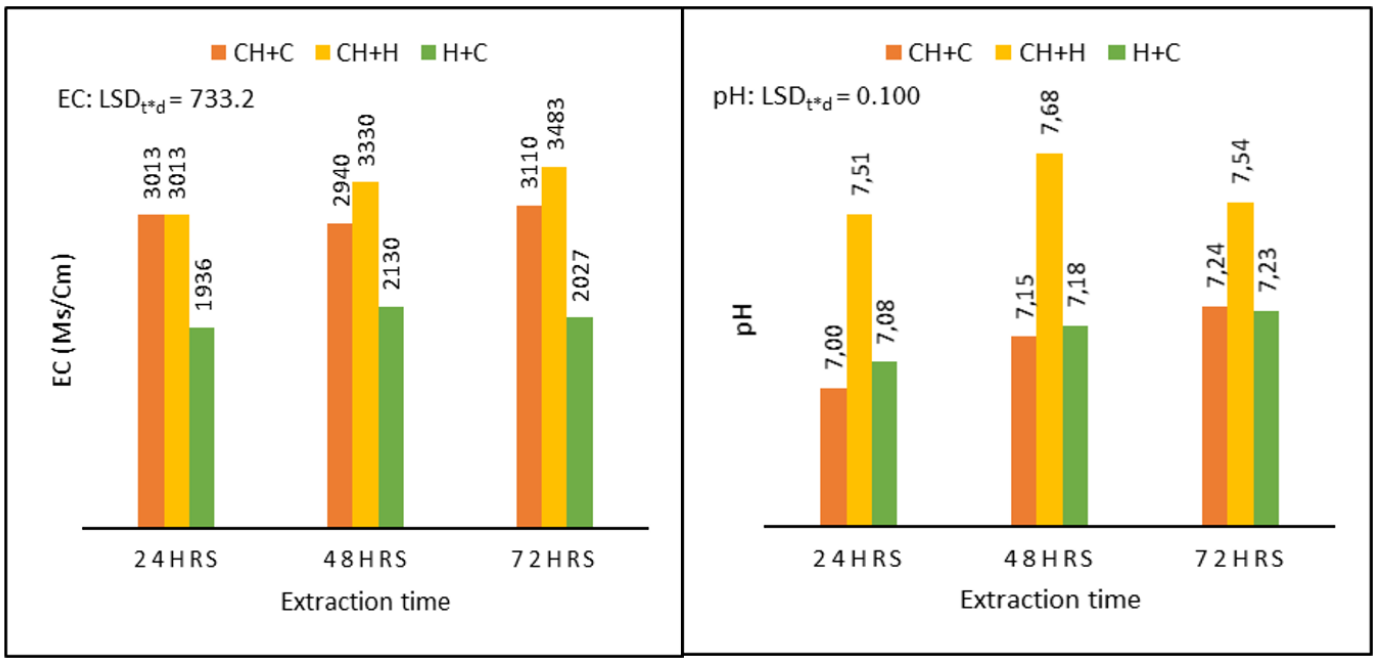


Figure 5. Measure of EC and pH in different vermicompost teas over 72-h extraction period.

The pH was significantly different in treatments, but the pH in CH+C and CH+H was not significantly different. The interaction between treatments and extraction time shows that pH was different, but in H+C, it was the same throughout extraction. Though it was increasing, it was not significant. In CH+C and CH+H treatments, pH decreased on day three though it was not that significant from day two. However, in all treatments, the pH values were above 5.3, the standard recommended lower limit for irrigation water to be used in vegetable container production systems [42]. Therefore, there is a need to add an acid to lower the pH to the required standard. With the required adjustments, two days (48 h) can be used to extract EC and pH from vermicompost teas.

4. Conclusions

Physiochemical analysis of vermicompost mixtures showed that horse plus cattle vermicompost mixture had good quality vermicompost than chicken plus cattle and chicken plus horse vermicompost mixtures. However, mixtures with chicken vermicompost addition were most likely to contain more nutrients than mixtures with no chicken vermicompost after nutrient extraction. The solubility of nutrients in the composts as well as the different rates of consumption and liberation of nutrients by microorganisms present in the compost teas, appear to be the main factors affecting the concentration of nutrients across brewing time. Increases in the concentration of nutrients across brewing time may also be

the result of a concentration effect, which occurs when water is lost during the brewing process through evaporation. This may be particularly evident in the production of aerated compost teas, where water molecules are continuously agitated by air supplied by an air pump, and evaporation is greater. Therefore, because the sum of nutrients concentrations at day three (72 h (NO_3, P, Ca, Mg, Mn, and Cu) were found to change (most likely decrease), it was concluded that two days (48 h) is the perfect time to extract nutrients from compost mixtures to produce good quality compost using aerobic extraction method.

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