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ORIGINAL RESEARCH ARTICLE

# Comparative progressive composting, evaluation and profiling of minerals and heavy metals in human solid waste collected by green toilet system, cow dung, poultry droppings, and goat waste composts

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## Abstract

The value of human excreta, a resource that is available in all societies is underestimated in present agriculture. In parts of South East Asia, the use of human excreta as fertilizer in agriculture is a common practice benefiting production. The excreta contain chemical elements that circulate in biogeochemical cycles necessary in plant nutrition. This study aimed to progressively detect, quantify, and profile minerals (micro, macro and heavy metals) levels in human solid waste from Green Toilet System and compare with cow dung, poultry droppings, and goat waste composts at different stages of composting for a time duration of six months (183 days). Green Toilet System, developed by LIXIL destined solid and liquid human wastes to different collection points with negligible or zero interaction. Micro (Mn, Cu, Zn, and Fe), macro nutrients (Ca, K, P, N, and Mg) and heavy metals (Pb, Cd and Cr) analysis was done after every 21 days. Individual means were compared and separated using Duncan's multiple range test with a significant level at $p<0.05$. There were significant differences between the means recorded for micro/macronutrients, and heavy metals between all composts analyzed. Micronutrients levels increased with increase in composting time. Lead and chromium reached an optimal level of 28.000±0.000mg/Kg and 35.000±0.000mg/Kg on days 168 and 105 respectively. The findings showed that composts contained different profiles of macro- and micronutrients that may contribute to soil enrichment and have agronomic value. Green Toilet System for collection of human solid waste and progressive composting of cow dung, poultry droppings, and goat waste can be used to determine optimal levels of micro/macronutrients and heavy metals at different composting stages. In conclusion, human solid waste compost should be considered for use when the levels of micro/macronutrients are optimal and heavy metal levels are minimal after composting.

**Keywords**: Human solid waste, Green Toilet System, composting, micro/macro elements, heavy metals, organic compost.

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## 1.0 Introduction

The proportion of anthropogenic waste including human feaces in urban centers is directly proportional to population density (Srinivasamurthy and Yogeeshappa, 2012). As the current world population continues to increase, the onerous task of waste disposal becomes more voluminous and challenging. Organic wastes could be one of the sources for renewable energy and organic matter as the global demand increases (Beyene, Werkneh and Ambaye, 2018). Historically, human excreta was used as an organic soil amendment and as a fertilizer (Mackie Jensen *et al.*, 2008). Elser & Bennett (2011) posit that comprehensive recycling leads to better management of nutrients from human excreta. Recycling of organic wastes is environmentally sustainable and economically viable compared to land refilling and waste handling. It lessens health and waste treatment costs. According to European Commission concept, the preferred hierarchy for waste management is “reduce, reuse, and recycle” strategy (Sakai *et al.*, 2011). The intensive and widespread use of sewer networks and water closets have contributed to the blatant departure from this practice and pervasive use of synthetic fertilizers (Rockefeller, 1998; Ferguson, 2014). Sewer networks use water as a conveyor of human excreta to municipal sewage treatment plants. Sewage sludge, one of the output of treatment permits partial nutrients recycling to agriculture (Margesin and Schinner, 1989). Long time sustainability and adequacy of water for conventional flush sanitation models has been called into question. In developing countries, high initial cost of set-up is a prohibition for extensive adoption (Moya, Sakrabani and Parker, 2019).

Japanese and Chinese recognize human faces and urine euphemistically referred to as night soil as important feature of agricultural practice (Heinonen-Tanski & Van Wijk-Sijbesma, 2005; Ferguson, (2014). Similarly, the practice is widespread in Vietnam despite the potential health rise (Phuc *et al.*, 2006). Sustainable nutrient management and future fertilizer availability challenges can be addressed by human excreta. According to Klingel et al., (2015) and Mnkeni & Austin, (2009), both human feaces and urine consist of a wide array of micro-nutrients. Dietary intake determines nutrients excreted while partitioning nutrients between urine and faeces is determined by digestibility (Mesgaran, 2020). Feaces consist of undigested while urine consist digested portions of the diet. Human waste is biologically active if it consist of organic matter, live and dead micro-organisms, organic and inorganic salts, and toxic contaminants including heavy metals (Klingel *et al.*, 2015). Elemental analysis of feaces provides a direct indication of dietary exposure to toxic metals and an indirect information about the potential for toxic metal burden (Abdulla and Chmielnicka, 1989). Chronic, low-level assimilation of toxic metals can result in accumulation in the body. Harder et al., (2019) showed that human excreta contain organic pollutants and heavy metals. Compared to urine, human excreta have a higher load of heavy metals (Abdulla and Chmielnicka, 1989). Water supply system through flush water can add heavy metals such as copper (Cu) and lead(Pb) released from metal pipes and organic and organic pollutants from polymeric pipes (Harder *et al.*, 2019). Contamination levels are compounded by further mixing with storm water at the point of discharge to commercial sector (Klingel *et al.*, 2015). To eliminate variability related to water content of human excreta, elements are measured and expressed in dry weight (Harder *et al.*, 2019).

The use of these wastes for agricultural purposes would achieve twin objectives of disposal and reduction on over-reliance on unsustainable scarce/costly pollutant inorganic fertilizers. Hence, the best mechanism of disposal. Additionally, directing use of wastes in crop production would confer other benefits such as eco-friendly, enhance soil nutrition, reduce pollution and prevent diseases associated with contaminated food (Mariwah, Drangert and Adams, 2022). Ferguson, (2014) reported that in the past human excreta was extensively utilized in rural areas to enhance soil fertility. Andreev et al., (2017) identified the potential of human waste as fertilizer. This proposition was further supported by the findings of (Harder *et al.*, 2019) and are in tandem in with earlier findings of (Sangare *et al.*, 2015). However, a more detailed examination of the research efforts and findings show that they focused on macro-nutrients contents and yields from different systems of sanitation. The present system of accumulation, collection and disposal has no possibility of achieving the use of anthropogenic waste in agriculture. Therefore, there is need to redesign toilets and collect fecal matter separately from urine (Rose *et al.*, 2015).

According to Winblad & Simpson-Hébert, (2004) and Esrey et al., (2001), drop and store and flush and forget are water based sanitation systems used in most parts of the world. These sanitation models are based on negative perception that human fecal are wastes, repulsive, should not be touched and are only suitable for disposal. These conventional sanitation systems mix relatively small amount of human waste with large amount of water used for flush. This further enhances the magnitude of the problem. Additionally, heavy financial burden is incurred during waste water and drinking water treatment, sewer maintenance among other costs (Guo, Englehardt and Wu, 2014).

The current conventional and energy technologies can convert organic wastes into not only power and heat but also substrate for soil fertilization. In this study, Green Toilet System, developed by LIXIL, a Japan based company. The toilet was designed to achieve separation and collection of solid human waste and urine at source. It has the ability to separate human solid waste from urine with negligible or zero contact. It directs the waste into different holding containers. Green toilet system collects the wastes and does not compost. Composting is done outside. Urine collection takes place at the front part piped through a toilet outlet. Further, saw dust is used to flush the toilet instead of water.

Measurements were taken to detect, quantify, and profile minerals (micro, macro and heavy metals) levels in human solid waste, cow dung, poultry droppings, and goat waste composts progressively at different stages of composting for a time duration of six months (183 days). Qualitative detection and quantification was done using atomic absorption spectrophotometer (AAS). It further aimed to unfold new knowledge on optimal composting duration for maximum recovery of nutrients from human solid waste, cow, poultry and goat composts. The findings will help to determine optimal composting duration that would present the highest levels of nutrients beneficial for crop production.

## 2.0 Materials and methods

### 2.1 Experimental site

Human solid waste deposition and collection were done at the Kenya Institute of Organic Farming (KIOF) in Kenya (1.0975° S, 37.0354° E). Laboratory analysis was done at the Biochemistry and Molecular Biology Research Laboratory at Jomo Kenyatta University of Agriculture and Technology located in Juja – Kenya (1.0891° S, 37.0105° E).

### 2.2 Construction of composting cages

Composting shade was constructed using an iron sheet roof, concrete floor, and 4 foot walls, leaving 4 feet of space above and below the roof for ventilation. Composting cages were constructed under composting shade according to (Román, Martinez and Pantoja, 2015). A total of eight composting cages measuring 2.5ft by 2.5ft by 2.5ft (length*width*height) were constructed using 6 plywood lined on the inside by a damp proof coat (DPC) of black polythene gauge 10. Cypress timber measuring 2.5ft*2.5ft*2.5ft was used to reinforce the cages. An open space measuring 2.5ft in length was left between the cages. All cages were covered with half-inch poultry mesh. An entrance door measuring 2ft*4ft (length*height) made of cypress wooden frame and half-inch poultry mesh was constructed. Appropriate labeling of cages was done using a laminated piece of A5 white printed paper stuck using an adhesive at the front side of each cage. Labeling information included compost site, pile, and time duration (start and stop date) of composting.

### 2.3 Green toilet system

Green Toilet System was constructed at Kenya Institute of Organic Farming (KIOF). It had a separator for both the solid and liquid wastes with negligible contact. Two different collection barrels for solid and liquid human waste respectively were set up. Saw dust was used to flush the toilet using a propeller shaft with a lever. Human solid waste was directed towards production of an organic fertilizer.

### 2.4 Composts set up

The composts were designed to compare parameters in human solid waste, poultry droppings, goat waste, and cow dung (Persiani, Montemurro and Diacono, 2021). The experiment was laid out in a split-plot using the Randomized Complete Block Design (RCBD) as described by (dela Cruz *et al.*, 2006) (Irshad *et al.*, 2013).

### 2.5 Compost generation and sampling

Human solid waste was generated using the Green Toilet System (GTS) at the Kenya Institute of Organic Farming (KIOF) at Juja in Kiambu County in Kenya. The toilet separated human solid waste and urine by directing them to different sealed collection barrels. Separation was important in creating a disposal waste and curbing smell generated when poop and pee mix together, to enable the nutrient content to be recycled unmixed and to allow sanitization of human solid waste before they are used in agriculture due to presence of enteric pathogens. Fresh cow dung was collected from the zero-grazing unit at Jomo Kenyatta University of Agriculture and Technology. Poultry droppings were collected from the OGAO poultry farm located in Githurai, Kiambu County in Kenya. Goat waste was collected from a goat unit at a goat farm in Utawala in Nairobi Kenya (Latitude: -1.288818/S1°17'19.744"; Longitude: 36.976302/E 36° 58' 34.685"). Sampling was done after mixing on day 1 and after every 21 days. Sterile stainless steel spatulas were used to dispense 100g of each compost into separate well-labelled sterile 9cm*4cm zip-lock sealed biohazard polythene bags. The bags were transported in a cooler box to the laboratory for analysis.

## 2.6 Determination of minerals

Analysis of micro and macronutrients and heavy metals was done by dry ashing and atomic absorption spectrophotometer (AAS), according to AOAC Official Method 975.03 (AOAC, 2000). The minerals under study were calcium, iron, zinc, magnesium, copper, lead cadmium, chromium and manganese. Clean dry crucibles were weighed. Each mineral was analyzed in triplicates. Five grams of each sample were weighed and added into the crucibles. The crucibles were placed on a hot plate under a fume hood and the temperature increased slowly until smoking ceased and samples thoroughly charred. Samples were then put in a muffle furnace and temperature increased gradually to 250°C and heated for 1 hour. The temperature was increased to 550°C and incinerated to complete ashing. The temperature was then decreased to 300°C the crucibles removed and cooled to room temperature. The ash was transferred quantitatively to 100 mL beaker using 20 mL of 0.5N $HNO_3$, and heated at 80-90°C on a hot plate for 5 minutes. Sample was transferred to 100 mL volumetric flask and filled to the mark using 0.5N $HNO_3$. Insoluble matter was filtered using Whatman filter paper number 1 paper and the filtrate kept in a labeled polyethylene bottle. The absorbance of the solutions was read by Atomic Absorption Spectrophotometer (AAS) with a limit of detection (LOD) of 0.01ppm. For determination of Calcium, 0.3 % Lanthanum chloride was added to avoid amalgamation. Respective mineral standards were also prepared to make the calibration curve.

## 2.7 Data management and analysis

Data on micro/macro nutrients and heavy metals were recorded in Microsoft Windows Version 13 Excel sheet and exported to SPSS for Windows, Version 26 for analysis. The data was analyzed to determine the mean of the triplicates and standard deviation. The obtained means were used to draw bar graphs for each compost. One-way analysis of variance (ANOVA) was carried out considering the variability factors of human solid waste, cow dung, poultry-droppings, and goat waste. Individual means were compared and separated using Duncan's multiple range test with a significant level at $p<0.05$. Duncan's multiple range test compact letter display (CLD) was assigned to analyzed values that showed least significant difference (LSD) (Permanasari, Rambli and Dominic, 2010). Pearson coefficient of correlation was conducted to measure the strength and direction of the relationship between variables.

## 3.0 Results and discussion

According to Bolan et al., (2004) and Brown et al., (2022) plants and animals require elements that are considered biologically essential. These metals in addition to non-essential minerals are contained in composts. Further, (Bolan, Adriano and Mahimairaja, 2004) posit that the type of livestock e.g. poultry, swine or cattle determine the variability in concentration of minerals in compost. The amount of minerals used in animal feed and health remedies determine the content of elements in composts (Bolan, Adriano and Mahimairaja, 2004). The results were reported on dry weight basis.

## 3.1 Micronutrients levels in human solid waste, cow dung, poultry and goat composts

### 3.1.1 Manganese

Figure 1 shows manganese levels for human waste, cow dung, poultry and goat composts during composting. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of p<0.001. Generally, Manganese levels increased with increase in days of composting as shown in Figure 1. There was high positive correlation between variables especially controlling for time. The presence of manganese in different compost such as human, cow dung, poultry and goat compost controlling for time. The analysis shows strong positive correlation coefficients for all variables when controlling for time. The coefficients (r) are; human compost (r = 0.969), cow dung compost (r = 0.971), whereas for poultry (r = 0.971) and goat compost (r = 0.801). This indicates a linear relationship and a high positive relationship between variables. Manganese trend is similar to finding of Larney et al., (2008) and Inbar et al., (1993). Majority of trace elements in manure by products come from animal diet. Soil contamination during manure sample collection may contribute indirectly to trace elements as reported by Bolan et al., (2004).

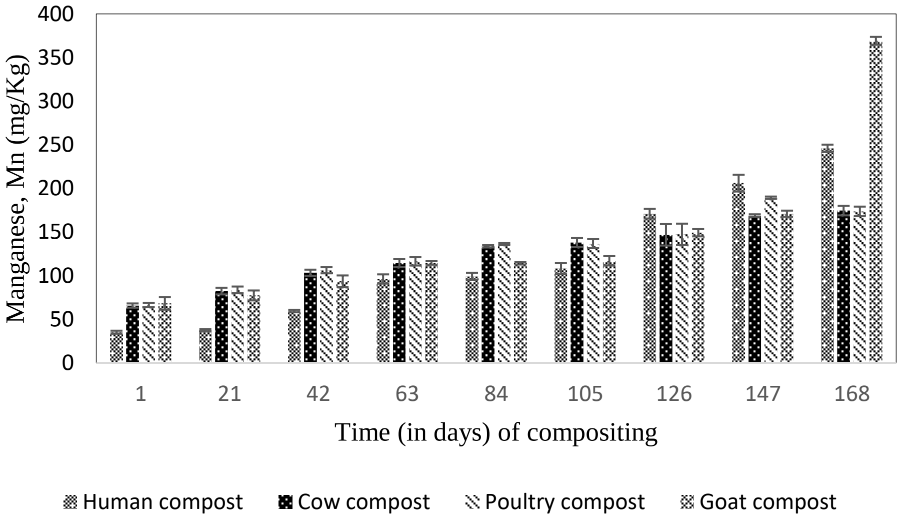

*Figure 1: Manganese profile in human solid waste, cow dung, poultry and goat composts*

### 3.1.2 Copper

Figure 2 shows copper levels for human waste, cow dung, poultry and goat composts during composting. ANOVA showed that the mean values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. There was significant positive relationship between variables in question. The presence of copper in different compost such as human, cow, poultry and goat compost controlling for time. The analysis shows positive coefficients for all variables when controlling for time. The coefficients (r) are; human compost r = 0.0.654, cow compost r = 0.515, whereas for poultry r = 0.510 and goat compost revealed a low positive correlation of r = 0.657. This indicates a linear relationship and positive relationship between variables.

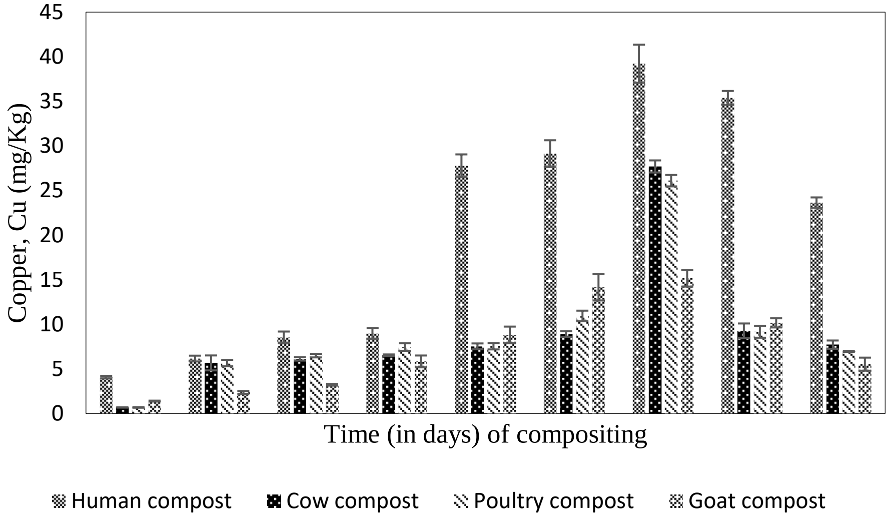

*Figure 2: Copper profile in human solid waste, cow dung, poultry and goat composts*

### 3.1.3 Zinc

Figure 3 shows zinc levels for human waste, cow dung, poultry and goat composts during composting. Both human waste, cow dung, and goat waste composts reached optimal levels after 126 days of composting while poultry waste reached optimal after 147 days of composting as shown in Figure 3. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. There was significant positive relationship between human waste, cow dung, poultry and goat composts controlling for time. Pearson correlation analysis showed a strong positive correlation coefficient for all variables when controlling for time. The coefficients (r) were, human compost (r = 0.858), cow dung compost (r = 0.626), poultry (r= 0.958) and goat compost (r = 0.552). This indicates a linear relationship and positive relationship between variables. Compositing trend observed in zinc was also reported by Larney et al., (2008). According to Bolan et al., (2004) improving food efficiency and animal health lead led to addition of mineral in the animal diet. Abdullah, (2022) reported that As, Co, Cu, Fe, Mn, Se and Zn are among the food additives that prevent diseases, improve egg production in the case of poultry, improve weight gain and the feed conversion. Therefore, this reason account for the levels of zinc reported in the study.

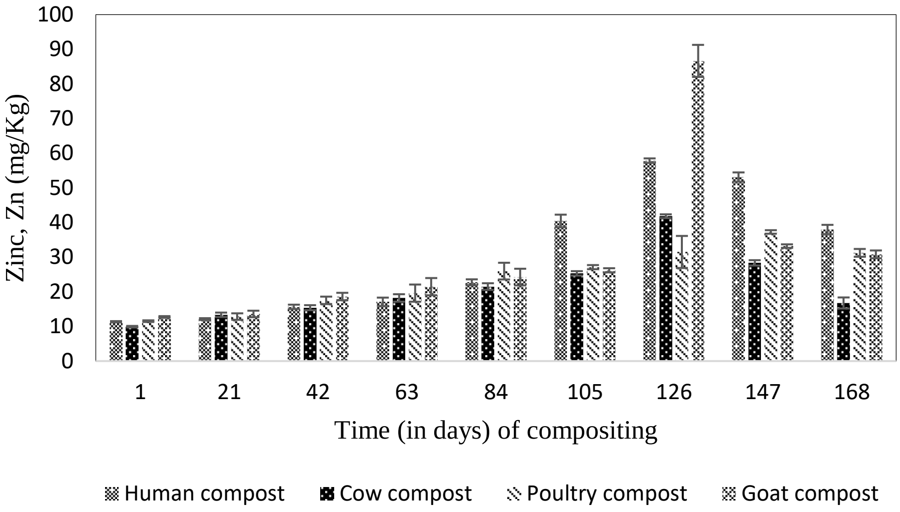

*Figure 3: Zinc profile in human solid waste, cow dung , poultry and goat composts*

### 3.1.4 Iron

Figure 3 shows iron levels for human waste, cow dung, poultry and goat composts during composting. Iron levels trend was similar to copper and zinc levels trends. However, the values and time duration (in days) the composts took to achieve optimal levels were different among the minerals and individual composts as shown in Figure 4. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. Human waste, cow dung, poultry and goat composts showed a significant positive relationship. Further, Pearson correlation analysis indicated strong positive correlation coefficients for all variables. The coefficients (r) were; human compost r = 0.872, cow dung compost r = 0.677, whereas for poultry r = 0.756 and goat compost positive correlation of r = 0.773. This infers a linear relationship and a high positive relationship between variables.

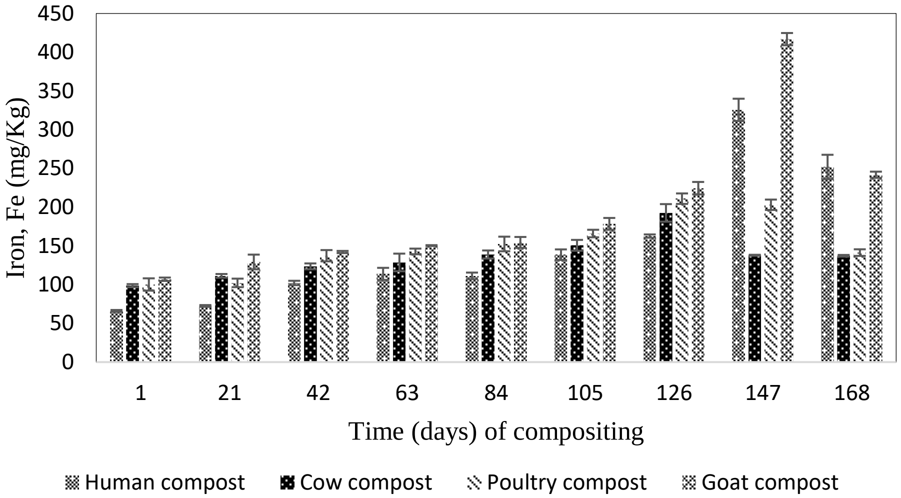

*Figure 4: Iron profile in human solid waste, cow dung, poultry and goat composts*

## 3.2 Macronutrients levels in human solid waste, cow dung, poultry and goat composts

### 3.2.1 Magnesium

Figure 1 shows magnesium levels for human waste, cow dung, poultry and goat composts during composting. ANOVA showed that the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. Poultry droppings compost registered higher levels of 0.221±0.007g/100g at the end of composting compared to the initial levels. Human waste, cow dung, poultry droppings, and goat composts attained an optimal Mg levels on days 63, 63, 84 and 84 respectively as shown in Figure 5. A negative correlation between time and magnesium levels in human waste, cow dung, poultry and goat was observed. The coefficient (r) were weak negative correlation registered in human compost (r = -0.205), and Goat compost (r = -0.310). A strong negative correlation was observed in cow dung compost (r = -0.779). Pearson’s correlation coefficient for poultry compost was weak positive correlation (r = 0.170). Therefore, the presence of magnesium in different composts such as human, cow dung, poultry and goat gave a negative linear relationship as shown in Figure 5.

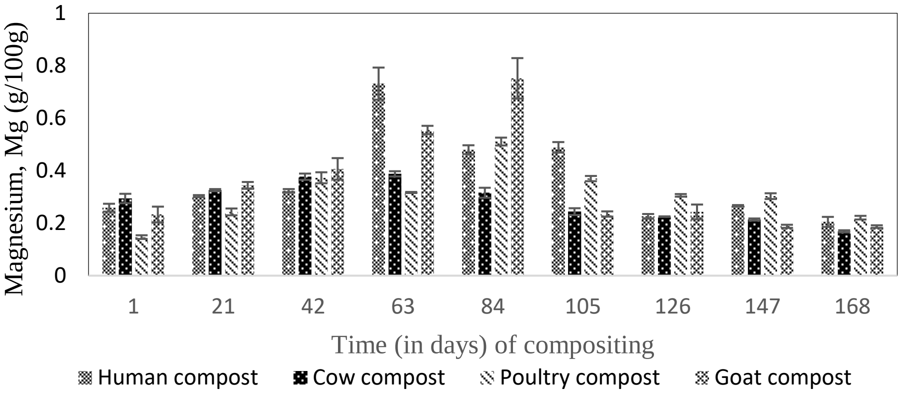

*Figure 5: Magnesium profile in human solid waste, cow dung, poultry and goat composts*

### 3.2.2 Calcium

Figure 6 shows calcium levels for human waste, cow dung, poultry and goat composts during composting. Generally, an initial increase to optimal levels followed by a decline was observed in all composts. However, human solid waste, cow dung, poultry and goat waste composts attained optimal levels after different durations of composting as shown in Figure 6. ANOVA showed that the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. There was a negative correlation between time and human solid waste, cow dung, poultry and goat waste composts controlling for time. The coefficient (r) were as follows; human compost ($r = -0.759$), cow dung compost ($r = -0.805$), goat compost ($r = -0.181$). Pearson's coefficient correlation for poultry compost and time was positive ($r = 0.162$) and hence a positive linear relationship. Conversely, the presence of calcium in different compost such as human, cow dung, poultry and goat gave a negative linear relationship.

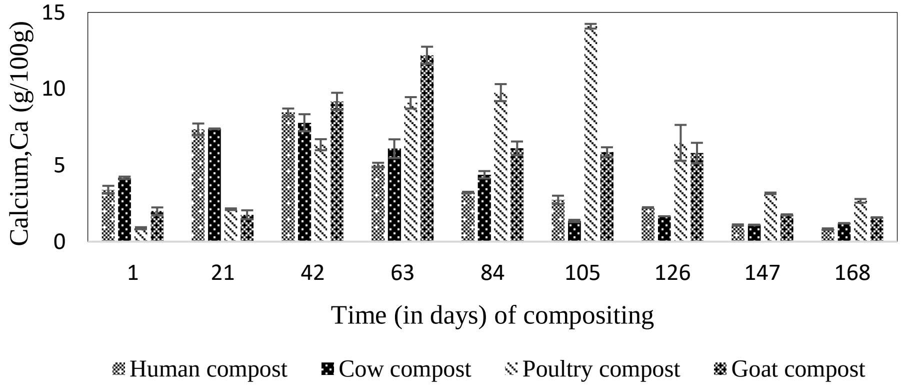

*Figure 6: Calcium profile in human solid waste, cow dung, poultry and goat composts*

### 3.2.3 Potassium

Figure 6 shows potassium levels for human waste, cow dung, poultry and goat composts during composting. Human solid waste showed the highest levels of potassium, during the entire composting duration. The trend was increasing from the initial to the final stages of composting in all composts under study. Cow dung compost levels were lower than human waste, poultry droppings and goat composts throughout the composting duration as shown in Figure 7. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. Pearson correlation analysis indicated that there was a linear and highly positive relationship between human solid waste, cow dung, poultry and goat waste composts. The presence of potassium in various compost like human, cow dung, poultry and goat was established controlling for time. The analysis shows positive coefficients for human solid waste, cow dung, poultry and goat waste when controlling for time. The coefficients (r) are; highly positive correlation for human compost $r = 0.906$, cow compost $r = 0.732$, whereas for poultry $r = 0.805$ and goat compost positive correlation of $r = 0.659$. This indicates a linear relationship and a high positive relationship between variables. Correlation was significant at both 0.01 and 0.05 levels of significance. Heinonen-Tanski and Van Wijk-Sijbesma, (2005) reported that human feaces are rich in potassium and phosphorus which are important plant nutrients. Inbar et al., (1993) found that potassium concentrations increase in cattle manure during the first 60 days of composting. Therefore, the findings agree with Inbar et al., (1993) in respect to poultry and goat compost and partly with cow dung during compost as at day 63 of composting. Human solid showed the contrary results. This may be attributed to the fact that Inbar et al., (1993) used a mixture of feaces, urine and serial straw bedding that alters the composting environment. Potassium levels increased with composting time in all composts. Human solid waste had the highest levels of potassium followed by poultry and goat compost had the least potassium levels. Similar patterns were also reported in a study by Suhartini et al., (2020). This trend may be due to effect of acid production during composting of organic matter by microorganism that convert insoluble potassium into soluble form (Suhartini *et al.*, 2020).

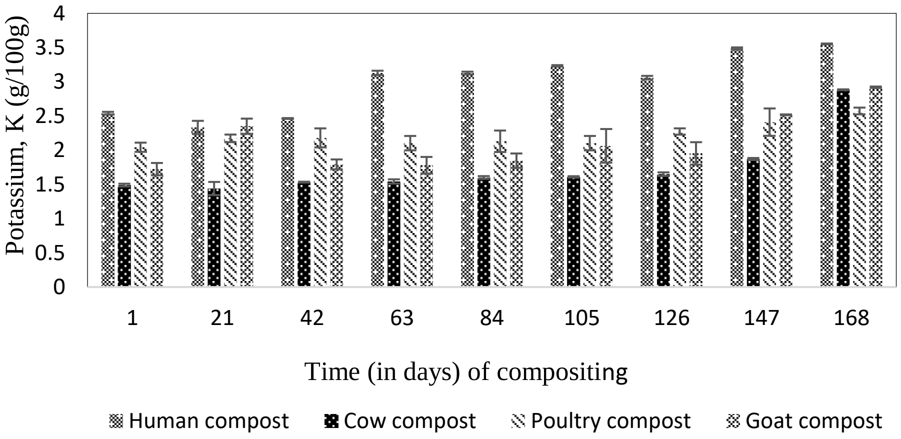

*Figure 7: Potassium profile in human solid waste, cow dung, poultry and goat composts*

### 3.3.4 Phosphorus

Figure 8 shows phosphorus levels for human waste, cow dung, poultry and goat composts during composting. Each successive composting sampling time showed a significantly higher total phosphorus (TP) concentration than the previous in all composts under study. Human compost showed initial and final phosphorus value of 0.22±0.01 g/100g and 0.33±0.01 g/100g respectively. This represents a 50% increase in phosphorus in the compost compared to fresh samples. Phosphorus levels in human waste were the lowest and highest in poultry droppings throughout the entire compost duration as shown in Figure 8. ANOVA showed that the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. Pearson Correlation analysis indicated that there was a linear and highly positive relationship between human solid waste, cow dung, poultry and goat composts controlling for time. The presence of phosphorous in various compost like human, cow dung, poultry and goat was established controlling for time. The analysis showed positive coefficients for all variables when controlling for time. The coefficients (r) were strong positive correlation for human compost r = 0.959, cow dung compost r = 0.956, whereas for poultry r = 0.884 and goat compost positive correlation of r = 0.957. This indicated a linear relationship and a high positive relationship between variables. Correlation was significant at 0.01 level of significance. As compared to carbon and nitrogen, in the environment, phosphorus is not as mobile and is not likely to be lost during composting process (Parkinson *et al.*, 2004). Hence, phosphorus levels are preserved in finished compost. Mineralization in dry mater during composting result in the increase in the concentration of phosphorus. Eneji et al., (2001) also reported an increase in phosphorus levels by 31%. The findings of the study are supported by Larney et al., (2008), where phosphorus levels in poultry droppings compost was higher that human solid waste, cow dung and goats compost. This can be associated to the diet as reported by Eneji et al., (2001) while composting cow dung, poultry dropping and pig sly.

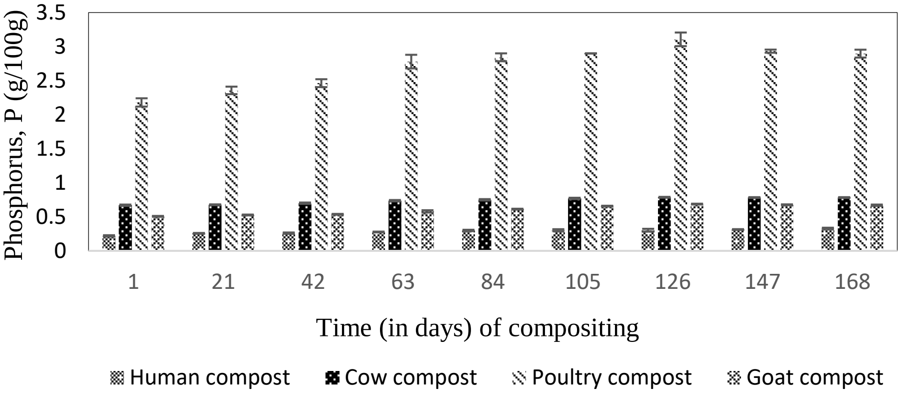

*Figure 8: Phosphorus profile in human solid waste, cow dung, poultry and goat composts*

### 3.4.5 Total nitrogen

Figure 8 shows total nitrogen levels for human waste, cow dung, poultry and goat composts during composting. Total nitrogen levels were higher in human waste than in other composts throughout composting duration. Final composting values were lower than the initial composting values in all compost as shown in Figure 8. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. There was negative correlation between time and in human solid waste, cow dung, poultry and goat composts controlling for time. The coefficient (r) was a weak negative correlation for human compost ($r = -0.033$) and cow dung compost ($r = -0.276$), and a highly negative correlation for Goat compost ($r = -0.865$). Pearson's coefficient correlation for poultry compost and time was strong positive correlation of ($r = 0.779$). Therefore, the presence of nitrogen in different compost such as human, cow dung, and goat gave a negative linear relationship. Similar trends were reported in previous studies by Eneji et al., (2001). However, poultry droppings showed a contrary trend and the reasons remain unclear. According to Kelova, Eich-Greatorex and Krogstad, (2021b), nitrogen is the nutrient with the highest turnover and losses during microbial transformation of organic matter. The trends of available nitrogen in human solid waste, cow dung and goat waste are typical of a composting process. During composting, readily decomposable organic matter produces ammonia which either volatizes into the atmosphere or is converted to $NH_4$-N depending on the PH levels, porosity, and air movement. The $NH_4$-N is oxidized to $NO_2$-N and further to $NO_3$-N during nitrification resulting in a decline in $NH_4$-N and an increase in $NO_3$-N (Kelova, Eich-Greatorex and Krogstad, 2021). Low levels of ammonium nitrogen at the end of composting is an indication of a relatively stable organic matter (Kelova, Eich-Greatorex and Krogstad, 2021)

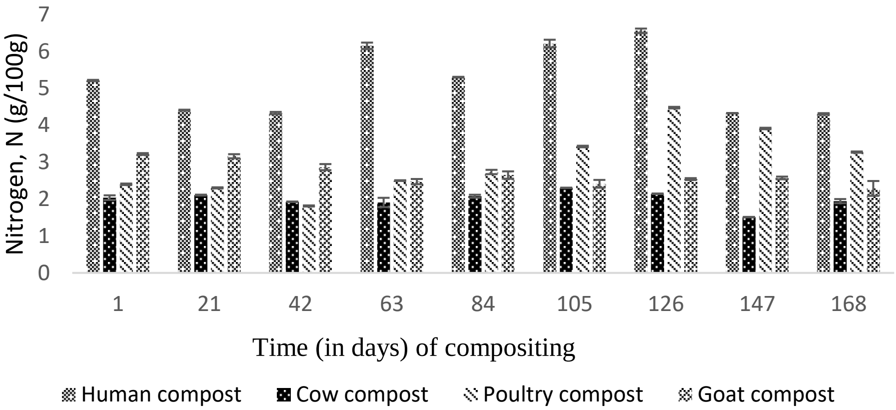

*Figure 9: Nitrogen profile in human solid waste, cow dung, poultry and goat composts*

## 3.3 Heavy metals

### 3.3.1 Chromium

Figure 10 shows chromium levels for human waste, cow dung, poultry and goat composts during composting. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a P-value of $p<0.001$. There was significant positive relationship between variables in question. The presence of Chromium in different compost such as human, cow dung, poultry and goat composts controlling for time. The analysis shows positive coefficients for human compost (r = 0.654), cow dung compost (r = 0.910), whereas for poultry (r = 0.820) and a weak positive correlation for goat compost (r = 0.380) when controlling for time. This indicates a linear relationship and positive relationship between variables. Chromium concentration observed trend was similar to the trend reported by Sager, (2007) who attributed the increase to abrasion of tools such as Windrow turners used in the reproduction of compost. However, Larney et al., (2008) reported lower chromium concentrations at the end of compositing that do not support these findings. States, (1985) reported detection and quantification of chromium in municipal sludge. Chromium, a heavy metal, is an essential trace element in man that can improve insulin sensitivity and enhance carbohydrate, protein, and lipid metabolism. Biological function of chromium is majorly associated with insulin function. However, chromium is more toxic in its hexavalent form than its trivalent form which is the predominant state in waste water and soil. According to Brown, (2004), a majority crops uptake relatively little chromium from the soil.

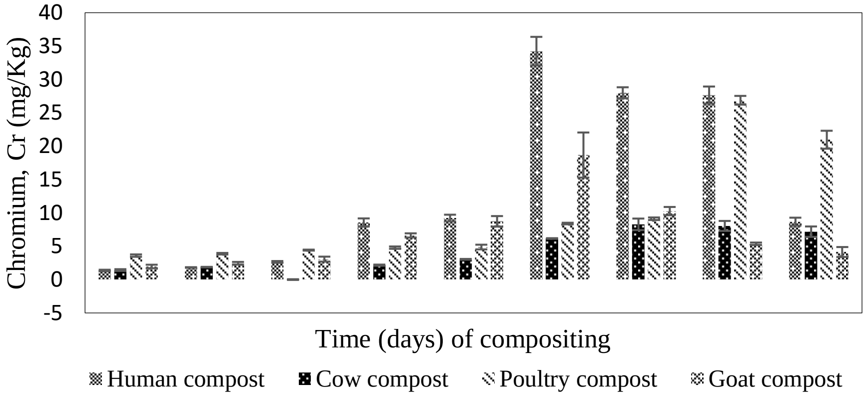

*Figure 10: Chromium profile in human solid waste, cow dung, poultry and goat composts*

### 3.3.2 Lead

Figure 11 shows lead levels for human waste, cow dung, poultry and goat composts during composting. The quantities of lead in all composts was directly proportional to composting days. At the end of composting, human waste compost lead levels were higher than other composts while poultry lead levels were lowest as shown in Figure 11. ANOVA showed the means values of human waste, cow dung, poultry and goat composts were statistically significant with a p-value of $p<0.001$. There was strong positive correlation between human compost (r = 0.911), cow dung compost (r = 0.877), whereas for poultry (r = 0.955) and goat composts (r = 0.971) controlling for time. This implies a linear relationship and a strong positive relationship between variables. A study by (States, 1985) showed the presence of heavy metals i.e. lead, cadmium, chromium, mercury, arsenic in municipal sludge. Cadmium and lead are regarded as most common in man. Lead pose relatively little hazard to crop production and plant accumulation when composts are applied to soil because it has low solubility in slightly acidic or neutral soils and in well aerated soil (Brown, 2004). Ding *et al.*, (2017) posit that farm manure and sewage sludge used as raw materials for composts contain variable amount of heavy metals including Pb, Cd, Cr, As, Hg and Cu originating from industrial wastewater and food additives. Further, (Ding *et al.*, 2017) found that the concentration of these metals vary greatly in composts and with sources and regions. The persistence and accumulation of lead in the composts was also reported by (SHAN and ZHANG, 2012). Proper application of composts and fertilizers with low heavy metals contents may slow down heavy metal accumulation in soils. Their accumulation may thus decrease potential threats to soil quality when it reaches a consumption – accumulation balance (Ding *et al.*, 2017).

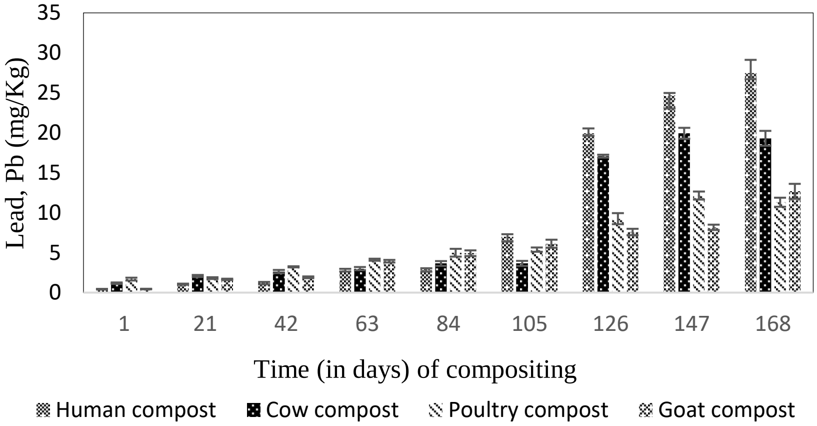

*Figure 11: Lead profile in human solid waste, cow dung, poultry and goat composts*

### 3.3.3 Cadmium

In contrast to other elements, cadmium was not detected in all composts between day one (1) to day 42 with 0.01 limit of detection. Detection was observed between day 63 and 168. Cadmium levels differed significantly between at the wastes at P≤0.001 on the other days except in cow dung on day 84 and 105 where the samples showed no significant difference. Further, cow dung and poultry droppings indicted no significant difference on day 126 as shown in Table 1. Below detection limit during the initial 43 days of compositing may be attributed to low cadmium concentration in compost wet matter basis. Below detection limit observed in the study for cadmium was also reported by (Pujar *et al.*, 2012). Cadmium concentration detection trend observed was due to mineralization in dry matter basis. The finding on increase in cadmium concentration was also reported by (Sager, 2007) that attributed higher cadmium concentration to phosphates. Under ordinary circumstances, cadmium, is the only trace element likely to be of human health concern as a result of the application of municipal sludge to agricultural land with the exposure through food plants and organ meat. This is because of the potentially high concentrations in sludge compared with normal soil concentrations (States, 1985).

*Table 1: Mean and standard deviation of three replicates showing effect of time duration of composting (days), on cadmium levels in human solid waste, cow dung, poultry droppings and goat waste.*

| Time (Days) | Human solid waste mean± stdev (mg/kg) | Cow dung mean± stdev (mg/kg) | Poultry droppings mean± stdev (mg/kg) | Goat waste mean± stdev (mg/kg) | P-value |
|---|---|---|---|---|---|
| 1 | BDL | BDL | BDL | BDL | |
| 21 | BDL | BDL | BDL | BDL | |
| 42 | BDL | BDL | BDL | BDL | |
| 63 | $2.910\pm0.106^{aC}$ | $0.057\pm0.010^{aA}$ | $0.105\pm0.002^{aAB}$ | $0.166\pm0.014^{aB}$ | ≤0.001 |
| 84 | $3.307\pm0.042^{abA}$ | $3.685\pm0.065^{bB}$ | $7.602\pm0.160^{eD}$ | $4.879\pm0.351^{cC}$ | ≤0.001 |
| 105 | $3.525\pm0.085^{bA}$ | $3.968\pm0.077^{bB}$ | $5.699\pm0.320^{dC}$ | $3.813\pm0.110^{bA}$ | ≤0.001 |
| 126 | $4.412\pm0.116^{cA}$ | $4.949\pm0.182^{cB}$ | $5.027\pm0.180^{cB}$ | $8.096\pm0.140^{fC}$ | ≤0.001 |
| 147 | $4.754\pm0.649^{eD}$ | $7.303\pm0.355^{eC}$ | $3.850\pm0.200^{bA}$ | $6.334\pm0.647^{eB}$ | ≤0.001 |
| 168 | $4.942\pm0.222^{dB}$ | $5.909\pm0.354^{dC}$ | $3.693\pm0.117^{bA}$ | $5.493\pm0.278^{dC}$ | ≤0.001 |
| P-value | ≤0.001 | ≤0.001 | ≤0.001 | ≤0.001 | |

Limit of detection (LOD) = 0.01ppm; Below detection limit (BDL)

## 4.0 Conclusion

The comparative evaluation progressively detected, quantified, and profiled minerals (micro, macro and heavy metals) levels in human solid waste from Green Toilet System in comparison with cow dung, poultry droppings, and goat waste composts at different stages of composting for a time duration of six months (183 days). The findings showed that composts contained different profiles of macro- and micronutrients that may contribute to soil enrichment and have agronomic value. All composts under study contained chromium, lead and cadmium heavy metals traces that persisted in all composts until the end of composting. Further, lead levels were higher in human solid waste compost than cow dung, poultry droppings and goat waste compost. Therefore, before application of organic composts as a soil amendment, heavy metal analysis should be done to reveal permissible levels. Through progressive monitoring of compositions human solid waste compost and other composts under study and cumulative application, health risks of toxic heavy metals can be minimized. Progressive composting and green toilet system combined should be adopted to determine optimal composting duration for maximum exploitation of nutrients contained in human solid waste composts.

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## 5.3 Conflict of interest

This research study had no conflict of interest.

## 5.4 Ethical Approval

None

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