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TRANSFORMATION TOWARDS SUSTAINABLE
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**Assessment of heavy metals in sewage sludge and their
accumulation in cabbage (*Brassica oleracea var capitata*)**

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Heavy metals accumulation in sewage sludge is a major concern to the environment especially when it is considered to be used for crop production. This research aimed at checking the levels of heavy metals in faecal matter based fertiliser products and if there is any subsequent absorption by cabbage when used in the field. Sewage sludge was used as major raw material to produce sludge, biochar, normal compost and vermi compost. Tests were done on the products and later on cabbage tissues. The results obtained showed that the products had no alarming levels of heavy metals as well as the levels in the tissues were not beyond the permissible levels. This indicates these products as safe for cabbage production.

Introduction

Globally, 2.4 billion people do not have access to improved sanitation in spite of the fact that from 1990 to 2014, 2.1 billion people gained access to improved sanitation facilities (WHO/UNICEF, 2015). There are significant sanitation gaps in regards to services offered to rural and urban populations, gender inequalities, and exclusion of the poor from water and sanitation services (Onda et al., 2012, WHO/UNICEF, 2015). According to joint monitoring program (JMP), between 1990 and 2015, the least developed countries failed to meet the sanitation targets. Only 27% of their current populations gained access to improved sanitation facilities. In Sub-Saharan Africa, less than 20% of the current population have access to improved sanitation facilities. Most use on-site pit latrines. When the on-site facilities fill up, they lead to the management burden of either emptying or building a new pit latrine. Due to space limitation in urban areas, emptying is the most appropriate management option in urban areas.

The faecal sludge emptied from pit latrines is disposed into the municipal waste water treatment plants (WWTP) without any co treatments. Municipal WWTPs are not designed for treatment of sludge because of the high organic load and solids in the faecal sludge. Disposal of faecal sludge in its state without pre-treatment has a causal effect on the poor functioning of the WWTP (Lopez-Vazquez et al., 2004). Faecal matter based fertiliser products can be used to fill the gap of nutrients deficiency in the soil since they contain up to 0.7% nitrogen a percentage of wet weight (Rose et al., 2015) which is about 5 to 11 g per day. Also about 11% nitrogen, 25% phosphorus and 21% potassium can also be recycled from the faeces (Vinnerås et al., 2006).

Despite the positive attributes of faecal matter based fertiliser products, contamination of heavy metals in sludge from faecal matter is a major concern. When applying these products, there is a danger of these elements accumulating in the soil (Singh and Kalamdhad 2012). There are various sources of heavy metals that find their way in to faecal matter sludge and they include man made sources like paint chips, used motor oils, batteries, ceramics, consumer electronics and natural sources like soil erosion (Oghenerobor et al., 2014).

Soils are the major sink for heavy metals released into the environment and unlike organic contaminants which are oxidised to carbon (IV) oxide by microbial action, most metals do not undergo microbial or chemical degradation, and their total concentration in soils persists for a long time after their introduction. Changes in their chemical forms (speciation) and bioavailability are, however, possible. The presence of toxic metals in soil can severely inhibit the biodegradation of organic contaminants (Adriano, 2003). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through: direct

ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal human), drinking of contaminated ground water, reduction in food quality (safety and marketability) via phytotoxicity, reduction in land usability for agricultural production causing food insecurity, and land tenure problems (Wuana & Okieimen, 2011). Alternative use of faecal sludge and closing the sanitation loop was advocated for as viable venture in a project spearheaded by Nakuru Water and Sanitation Services Company Ltd (NAWASSCO) and Egerton University. This research is part of the Nakuru County Sanitation Programme whose overall objective is to demonstrate and implement a commercially viable sanitation value chain, benefiting residents of unserved (peri-) urban low income areas in Nakuru County through production of faecal sludge related products like compost manure for crop growing and soil conditioning.

Materials and methods

Study area

The experiment was set up at NAWASSCO's domestic treatment plant located near Nakuru National Park within the former Nakuru Municipality now Nakuru town which is one of the fastest growing towns in Kenya. It is the fourth largest urban centre with a population of about 307,990 inhabitants. The experimental site lies 0°19'22"N 36°3'46"E and in Lower Highland III Agro Ecological Zone (LH3) with altitude of 1850 meters above sea level. Average maximum and minimum temperatures range from 19 to 22°C and 5 to 8°C respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well drained, deep to very deep dark brown to greyish brown friable and smeary clay loam, with thick humic topsoil (Zachary et al., 2013).

Compost making

Market waste was obtained from Nakuru town market, sorted out to ensure only degradable materials are composted and large particles like banana stalks were chopped in to smaller pieces. Faecal sludge was sourced from septic tanks in homesteads. The ratio of market waste: sludge was 3:1. For normal compost it was let to compost for 5 months with frequent turning and addition of water and maintenance practices. For vermi-compost, worms were introduced after one month and the conditions maintained in a level that worms can thrive i.e. temperature at 150 – 250 Fahrenheit with moisture at 75%, pH at slightly acid and finally maintaining an aerobic environment. It was composted for a period of three months then ready for use.

Cabbage experiment

This experiment compared the above faecal sludge, vermi-compost and normal compost with biochar, cow manure, struvite, Di-ammonium phosphate and untreated control to determine their suitability for growing cabbage. Cabbage 'Copenhagen' was grown in two sites: Horticulture Teaching and Research Field, Egerton University and Lanet, Nakuru in different seasons using randomized complete block design with four replications. Leaves of randomly sampled cabbage per plot were obtained at head formation stage (Figure 1) and comprehensively analysed for the concentration of heavy metals in a Soil Science Laboratory, Egerton University.

Sampling and analysis

Sample analysis was done in accordance with the standard methods of analysing wastewater according to APHA (2005). Samples were homogenised to make representative sample, then a 0.3g sample was obtained from this and digested in digestion tubes using a digestion mixture comprising of HCl, HNO₃, HF and H₃BO₃. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analysed using Varian spectra AA10 AAS machine (210 VGT). For data analysis, descriptive statistics was used to organise the data and ANOVA was undertaken to ascertain if there was statistical difference among the concentrations at 95% confidence level.

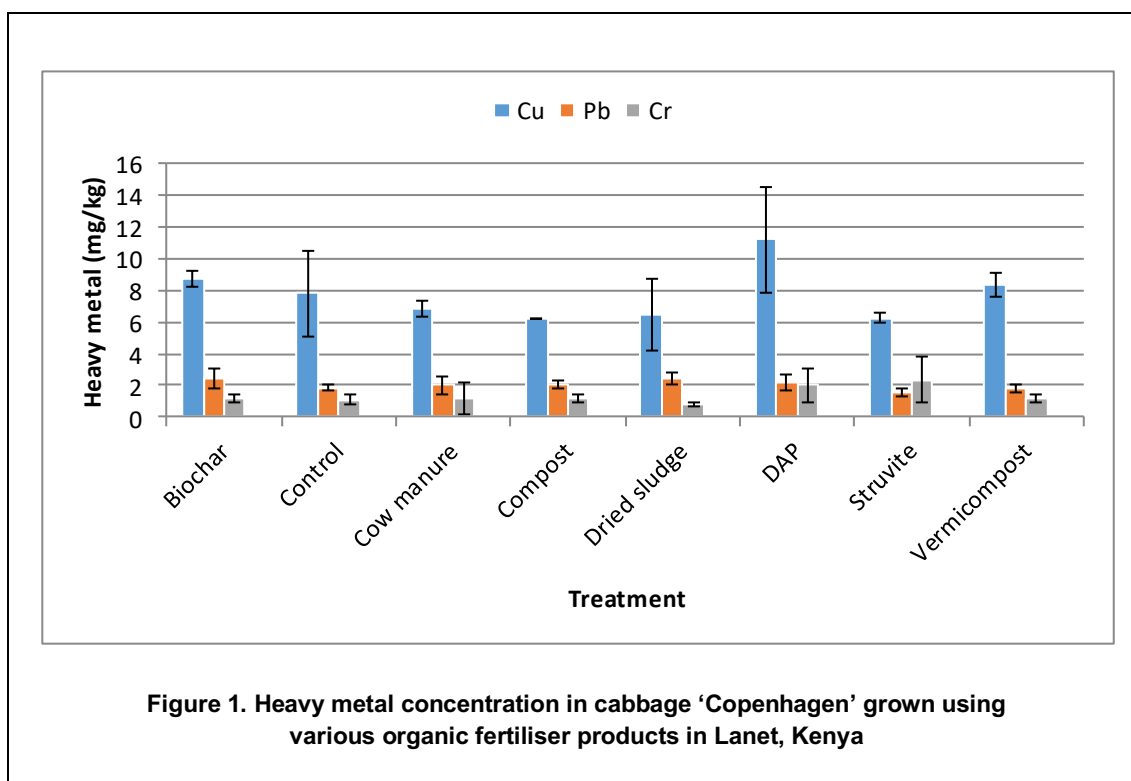
Results and discussion

There was no significant difference in lead concentration between sludge, normal compost and vermi-compost as shown in Table 1 which is contrary to expectations, since the worms in vermi-compost bio-accumulate heavy metals and thus expected to reduce heavy metal concentration. However, since some of the worms could have died off during the composting process, they could have been assimilated in the compost such that the lead contained within them was reflected in the compost. There was no significant

difference in concentration of zinc between vermi-compost and sludge. However, the concentration was significantly lower in normal compost. Copper concentration in normal compost was higher and statistically different from sludge ($p < 0.05$) but it was not statistically higher than for vermi-compost. For cadmium, there was no statistically significant difference in concentration between sludge and normal compost. However, it was statistically different for vermi-compost ($p < 0.05$) having a lower concentration. The concentration of Cr in vermi-compost was lowest but was not statistically significant from that of normal compost. However, it was statistically different from that of sludge. These results are similar to those from a study undertaken by Singh and Kalamdhad (2012) in California who found lower concentrations of Cd and Cr in vermi-compost. Concentrations for all the heavy metals were below the USEPA (1993) guidelines. There are no documented standards for Kenya. This is an indication that they are safe for use as manure.

Elements	Sludge	Vermicompost	Normal compost	Permissible level in sludge by USEPA (1993)
Pb	13.9±1.2	14.8±2.1	12.5±1.5	840
Zn	51.6±4.8	48.2±4.2	35.7± 3.2	7500
Cu	68.5±4.0	77.4± 8.1	83.7± 8.2	4300
Cd	2.3±0.1	1.2±0.1	2.3± 0.6	85
Cr	42.4±4.3	25.1± 3.1	31.6±3.7	Not indicated

Means in a column whose SD values do not overlap are significantly different at $\alpha=0.05$



Heavy metal accumulation in edible plant parts is a health concern especially in leafy vegetables like cabbage (*Brassica oleracea* var *capitata* L.), which are consumed fresh or with minimum cooking. Cabbage is widely grown in Kenya and there is increasing demand for organic cabbages due environmental and

health hazards associated with inorganic fertilizers. In this study, special attention was focused on Cadmium (Cd), Lead (Pb) and Chromium (Cr), which are extremely toxic and associated with sewage sludge. Contrary to the usual perception, cabbages from both sites did not contain cadmium which is the most dangerous heavy metal in human food (Figure 1). Low Cd concentration in cabbage could be due to absence of free Cd ions in the soil solution which are recognized as the most unavailable metal form. This may have been caused by competition of Cd with organic matter in the sludge. In all the treatments including the untreated control, lead (Pb) content was generally higher than the maximum level (0.1 mg/kg) recommended for cabbage by Codex Standards. This suggests that the soils in the sites where the experiments were conducted had high contents of lead (Pb). Chromium (Cr) content in the cabbages grown with the organic fertiliser products was similar to those grown without the products. Besides, all the treatments recorded similar contents of manganese (91.9 -114.6 ppm), iron (31.0 - 54.9 ppm) and zinc (20.7- 48.2 ppm), which were below the permissible levels in sludge (Table 1). The results indicate that cabbages grown using faecal matter fertilizer materials are safe for human consumption. The results are similar to the finding of Czech et al. (2011). Dried sludge is therefore recommended for production of cabbage 'Copenhagen' without any health risk. Although, heavy metal accumulation capacity varies with vegetable species (Czech et al., 2011), these results may be applicable to other vegetables as the safety of the cabbages is largely attributed to the low contents of heavy metals in the faecal matter fertilizers used (Table 1).

Conclusion

There was no significant difference in lead concentration between sludge, normal compost and vermi-compost. Normal compost was higher than sludge and vermi-compost for concentrations of copper. It had lower concentrations for zinc. Vermi-compost had higher concentrations of lead however it was lowest for Cd and Cr. Concentrations for all the heavy metals were below the USEPA (1993) guidelines, an indication that they can safely be used for growing crops especially cabbage.

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