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Bio-solids from a wastewater treatment plant in Uganda do not meet the minimum standards for land application

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Abstract

Land application of bio-solids is the cheapest and most convenient method of disposal of bio-solids worldwide, but it is unclear if the bio-solids in Uganda are safe for land application. The objective of this study was to establish the impact of ageing on quality and safety of bio-solids from Bugolobi Wastewater Treatment Plant (BWTP) in Uganda's capital city, Kampala, for land application. Nine out of 14 beds in each of the four blocks (Block 1: fresh bio-solids; Block 2: settling bio-solids; Block 3: maturing bio-solids and Block 4: mature bio-solids) were randomly sampled for quality and for bio-safety. For quality, bio-solids were analysed for electrical conductivity (EC), N, P and K concentrations, and their respective stocks; organic matter (OM) content and bio-solid organic carbon (BOC) stocks. For bio-safety, bio-solids were screened for *Escherichia coli* and *Salmonella*. Data were subjected to ANOVA after checking for normality and equal variance assumptions, using GenStat statistical package 14th edition. Ageing of bio-solids had a significant impact on EC; OM and *E.* coli. The EC was highest in the mature bio-solids (4556±173) μS cm^{-1} and smallest in fresh bio-solids (3494±124) μS cm^{-1}. These EC values exceed the maximum permissible limits. Similarly, microbial counts were highest for *E. coli* in the mature sludge (3946±86) '000' CFU g^{-1} and smallest in the fresh bio-solids (633±22.9) '000' CFU g^{-1}. Out of the 36 bio-solid samples, one tested positive for salmonella. The bio-solids are not safe for use as agricultural input, nor for general release into the environment.

Key words: Bio-safety, electrolytic conductivity, *Escherichia coli*

Introduction

Wastewater contains high levels of organic matter, germs, nutrients and toxic compounds, which can pollute soils, with potentially serious human and environmental health hazards. Wastewater treatment is, therefore, recommended to ensure that pollutants from the resulting sewage sludge (hereafter, bio-solids), do not contaminate the food chain *via* polluted soils (UN-HABITAT, 2008; Tukar *et al*., 2011; Rawlinson, 2012).

Since the early 1970s, the United States Environmental Protection Agency (USEPA) and wastewater treatment industries have promoted the recycling of bio-solids (EPA Victoria 2004; Suzanne *et al*., 2007) to cope with increasing volumes of wastewater (NETWAS UGANDA, 2011). By early 2000, approximately 1,500 Km^3 of wastewater was generated annually worldwide, about six times the water in all rivers in the world (UNWWAP, 2003). Land application for agriculture; large-scale landscaping, lawn gardening, remediation of abandoned mining sites, and soil-surface re-vegetation are the commonest methods for disposal of bio-solids worldwide. In the USA, for instance, over 40% of bio-solids produced annually are disposed of by land application (Evans, 2009) as are hundreds of thousands of metric tonnes of bio-solids produced annually in Australia (Rawlinson, 2012).

The bio-solids, should meet the minimum standards for disposal by land application. With respect to pathogen levels, bio-solids are classified in two, each with its own application rules. Class A bio-solids should ideally, not have detectable levels of *Salmonella sp*, enteric viruses and viable helminth ova; and less than 1,000 CFU faecal coliform bacteria g^{-1} (USEPA, 1995). These can be land applied without any pathogen-related restrictions, except when used in bulk (Suzanne *et al*., 2007). For class B bio-solids, site restrictions on land application are aimed at minimising the potential for human and animal contact until environmental factors have suppressed pathogens to undetectable levels. Faecal coliform bacteria should be less than 2 million CFU g^{-1} and the potential to attract vectors that can transport pathogens should be reduced (USEPA, 1995).

Class B restrictions target 99% pathogen reduction. Australia has established four treatment grades (T1 to T4) of bio-solids with maximum permissible limits (EPA Victoria, 2004). Grade T1, the highest quality bio-solids are suitable for unrestricted use whereas Grade T4 bio-solids are not suitable for land application unless subjected to site-specific risk assessment (EPA Victoria 2004).

In Uganda, there is no evidence in literature associatiated with the pathological safety of bio-solids to meet the minimum standards for land application. The objective of

this study, therefore, was to establish safety of the bio-solids from Bugolobi Wastewater Treatment Plant (BWTP), the major wastewater treatment plant in Kampala City in Uganda. The thrust was to evaluate the impact of ageing on the quality of the bio-solids and examine the safety of the bio-solids for land application.

Methodology

Bio-solids sample collection and handling

We sampled nine out of the 14 beds, denoted by numbers 1 to 9 in each of the four bio-solid blocks, with the age of bio-solids as the basis for blocking: Block 1 (fresh bio-solids), Block 2 (settling bio-solids), Block 3 (maturing bio-solids) and Block 4 (mature bio-solids). In each of the selected beds, bio-solids sampling was done for quality (EC; OM and bio-solid organic carbon (BOC) stocks; and N and P concentrations and their respective stocks) and bio-safety (*E. coli* and *Salmonella*). For quality and biosafety, four sampling spots were randomly located in each of the selected beds. From each of the sampling spots, the caked layer on the surface of the bio-solids was carefully scrapped off. Bio-solid samples were, thereafter, carefully scooped mid-way the freshly exposed surface and the bottom of the bio-solids drying bed, using a trowel. Each of the four bio-solid samples scooped was emptied into a plastic basin and manually homogenised and quarter-sampled to get a representative composite sample per bed, giving a total of 36 composite samples (4 blocks * 9 beds * 1 composite sample). Each composite sample was immediately split into two: one for quality and the other for bio-safety tests. Each of the samples for bio-safety analyses was emptied into a well-labelled and sterile zip-lock polyethene bag, fastened tightly (to minimise moisture loss) and packed into an ice cooler box.

The second batch of 36 samples for quality tests were also similarly packed, but in a separate ice cooler box. For samples for estimation of stocks of N, P and BOC in the bio-solids at BWTP annually, the dimensions (length, width and depth) of bio-solids in each of the selected beds were taken. An open-ended plastic PVC tube of internal diameter 0.05 m was then used to extract core bio-solid samples from three spots randomly located in each of the selected bio-solid beds by driving the PVC tube into the bio-solids from top to bottom of the bio-solids bed, followed by carefully trimming the top part of the PVC tube so that the exact space left was that occupied by the bio-solids. Each of the bio-solid samples extracted using the PVC tube from each spot were emptied into a large polyethene bag and fastened tightly to minimise moisture loss. This gave a total of 108 samples (3 core samples x 9 beds x 4 blocks). Fresh weights of the samples were taken using a digital weighing scale.

Bio-solids sample processing and laboratory analysis

For biosafety, the bio-solids samples were immediately transported to the Microbiology Laboratory, College of Veterinary and Biosciences, Makerere University. Here, the bio-solid samples were tested for *E. coli* and S*almonella typhii,* following standard procedures (Refai 1979; USEPA 2003; USEPA, 2011). Samples for bio-solid quality and for estimation of total bio-solids generated and moisture content were transported to the Soil, Water and Plant Analytical Laboratory in the College of Agricultural and Environmental Sciences, Makerere University. The samples for chemical analyses were tested for EC, organic matter content (OM) and subsequently, organic carbon stocks; and N, P and K concentrations following the methods compiled by Okalebo *et al*. (2002).

Estimation of the N, P and K stocks and moisture content

The core bio-solid samples were oven-dried at 60 °C to constant weigh, and cooled in a desiccator before the dry weights (W_d) were taken. The density of bio-solids (B_d) was estimated by dividing respective W_d of the bio-solids by volume of the PVC tube (V_{pvc}). V_{pvc} was estimated using the formula:

$$\text{Vpvc} = \frac{\pi d^2}{4} * h \quad \text{......} \quad 1$$

Where:

h: height =0.3 m, d: diameter of the PVC =0.05 m, $\pi = 22/7$

To estimate the total mass of bio-solids generated at BWTP, the volume of each of the beds (V_b) was estimated from the formula:

$$Vb = l * w * h \quad \text{......} \quad 2$$

Where:

l = length of the bed =10 m, w = width of the bed =10 m, and h = height of the bed = 0.3 m

The mass of the bio-solids in each of the beds was estimated by multiplying respective B_d by volume of the beds (Equation 2). The total mass of bio-solids was obtained by multiplying the mass in one bed by 14 (the total number of beds in each block) and by 4 (the total number of blocks). To correct for moisture content of the bio-solids, the weight of moisture was subtracted from total weight of bio-solids in each block using the formula:

$$DMY = w - (w * \%m) \quad \ldots\ldots 3$$

Where;

DMY= Dry matter yield, w = estimated total weight, %m = percentage moisture of bio-solids

Consequently, the nutrient stocks (NS): N, P and K were estimated by multiplying the total dry matter yield (DMY) of the bio-solids by the respective percent nutrient concentration (%N) as follows:

$$NS = DMY * \%N \quad \ldots\ldots 4$$

Estimation of organic carbon stocks of the bio-solids

We modified the equation that Olupot *et al.* (2015, 2017) used to estimate soil organic carbon (SOC) and soil organic nitrogen (SON) stocks to estimate bio-solid organic carbon (BOC) stocks as follows:

$$\text{BOCstock} = \sum_{Blocki}^{Blockn}(BOC * DMY) \quad \ldots\ldots 5$$

Where:

BOC stock is the BOC stock (t cycle^{-1}); Block$_i$ is the block with fresh bio-solids whereas Block$_n$ is the block with mature bio-solids; BOC is the BOC concentration (% bio-solids on dry weight basis).

Data were subjected to ANOVA after checking for normality and equal variance assumptions, using GenStat statistical package 14th edition.

Results

Impact of ageing on electrolytic conductivity

Age of bio-solids had a significant impact on EC with the highest (4556±173) µS cm^{-1} in the mature bio-solids and smallest (3494±124) µS/cm in the fresh bio-solids (Fig. 1), pointing to increasing salinisation of the bio-solids with ageing. The impact of ageing of bio-solids on OM concentration was also significant, with a progressive decrease in OM concentrations from the fresh bio-solids (46.6±0.92 %) to mature bio-solids (42.2±1.44 %) (Table 1). However, there was no significant impact of ageing on bio-solid organic carbon (BOC) stocks (Fig. 2).

Figure 1. Effect of age of bio-solids (x-axis) on electrolytic conductivity, EC (y-axis) from Bugolobi Wastewater Treatment Plant as of March 27, 2014. T1, T2, T3 and T4 denote: fresh, settling, maturing and mature bio-solids, respectively.

Table 1. Effect of age of bio-solids on % OM, N, P and K of bio-solids from Bugolobi Wastewater Treatment Plant, Kampala, Uganda

Age of bio-solids	Parameters of bio-soids measured			
	%OM	%N	%P	%K
Fresh	46.6±0.92^{b}	0.29±0.01^{a}	0.74±0.02^{b}	0.87±0.05^{a}
Settling	44.1±0.82^{ab}	0.28±0.02^{a}	0.71±0.04^{ab}	0.79±0.04^{a}
Maturing	43.8± 0.96^{ab}	0.28±0.02^{a}	0.67± 0.01^{a}	0.77±0.03^{a}
Mature	42.2±1.4^{b}	0.26±0.01^{a}	0.68±0.01^{ab}	0.77±0.03^{a}

Means with the same later within a column are not significantly different ($P < 0.05$)

The ageing of bio-solids had no significant impact on concentrations and stocks of N, P and K with the bio-solids being generally low in nutrient concentrations (Table 1). Despite the low nutrient concentrations, the nutrients stockpiled in these bio-solids in excess of 400 kg N yr^{-1} (Fig. 3) and 1,000 kg P yr^{-1} (Fig. 4), potentially threaten the Wetland meant to naturally treat the effluent from BWTP, where these bio-solids are located before its discharge into Lake Victoria.

The impact of ageing of bio-solids was also significant on *E. coli*; with the highest populations in the mature bio-solids (3946±86) '000' CFU g^{-1} and smallest in the fresh bio-solids (633±229) '000' CFU g^{-1} (Fig. 5). One out of the 36 bio-solid samples tested positive for *Salmonella*, implying that the bio-solids were not safe for land application.

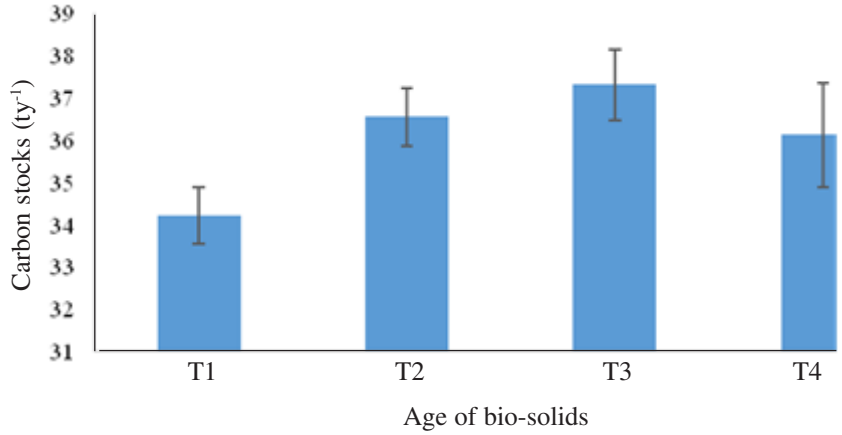

Figure 2. Effect of ageing of bio-solids (x-axis) on bio-solid organic carbon stocks (y-axis) from Bugolobi Wastewater Treatment Plant as of March 27, 2014. T1, T2, T3 and T4 denote: fresh, settling, maturing and mature bio-solids, respectively.

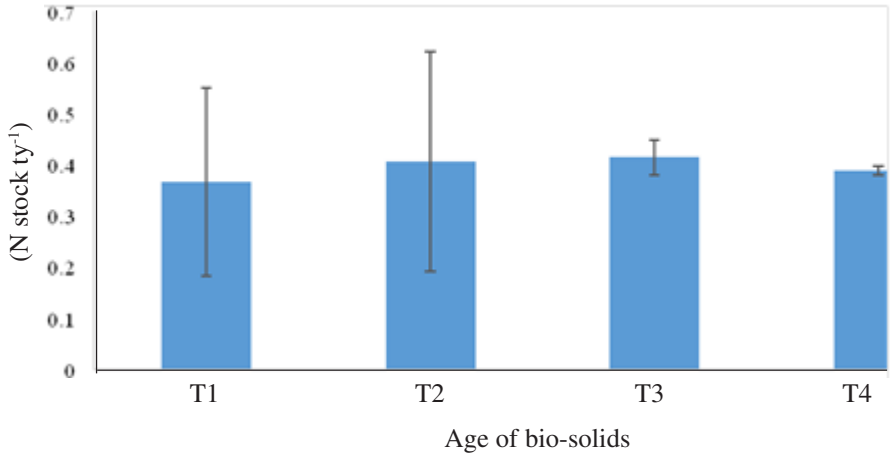

Figure 3. Effect of ageing of bio-solids (x-axis) on bio-solid organic nitrogen stocks (y-axis) from Bugolobi Wastewater Treatment Plant as of March 27, 2014. T1, T2, T3 and T4 denote: fresh, settling, maturing and mature bio-solids, respectively.

Discussion

Electrical conductivity

The EC values of the bio-solids tested in this study exceed the 4000 µS cm^{-1} MPL for soils (USDA, 2011), especially for the settling, maturing and mature bio-solids. Salt tolerance limits of even the most tolerable plants are 3000 µS cm^{-1} (Doulaye *et al.*, 2010). The EC > 4000 µS cm^{-1}, restrains plant growth by inducing high osmotic pressures in the roots (Garrido *et al.*, 2005). The increase in EC with ageing of bio-

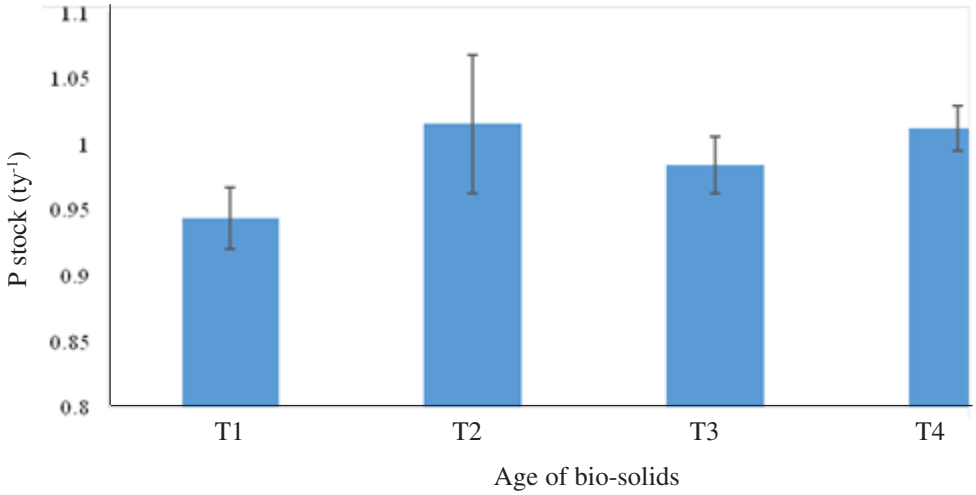

Figure 4. Effect of ageing of bio-solids (x-axis) on bio-solid phosphorus stocks (y-axis) from Bugolobi Wastewater Treatment Plant in Kampala, Uganda. T1, T2, T3 and T4 denote: fresh, settling, maturing and mature bio-solids, respectively.

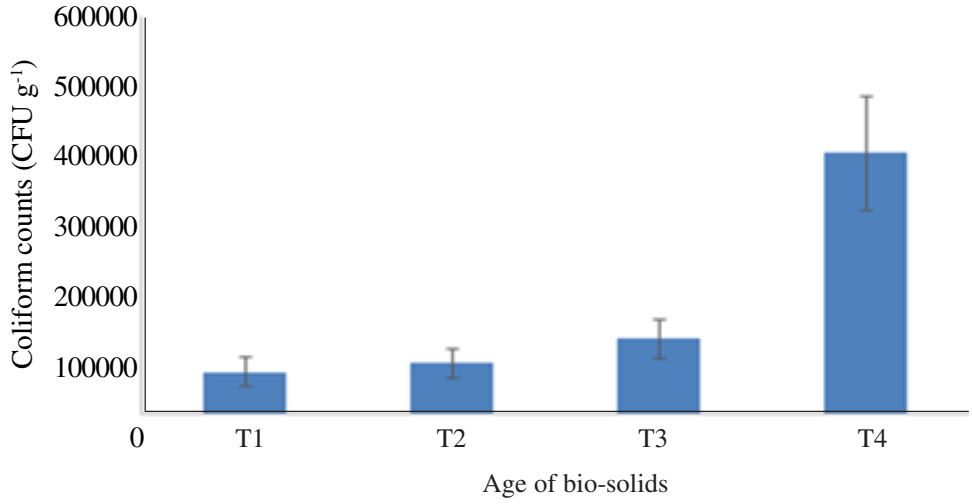

Figure 5. Effect of age of bio-solids (x-axis) on E. coli x 10^1 (y-axis) from Bugolobi Wastewater Treatment Plant in Kampala, Uganda. T1, T2, T3 and T4 denote: fresh, settling, maturing and mature bio-solids, respectively.

solids could be due to (i) increasing solubilisation and mobility of ions of salts (Kiely, 1998; Ngole *et al*., 2006); (ii) increasing organic matter humification and formation of carboxyl and phenolic functional groups, onto which cations could be adsorbed (El-Naim and El-Houseini, 2002), and (iii) the inevitably increasing dewatering with ageing of bio-solids which concentrates total solids. According to Irene *et al.* (2001) the final solid content of bio-solids increases almost linearly with salinity. In most

cases, where the possibility of recycling bio-solids into agriculture exists, the salt content is often a limiting factor. Continued use of the bio-solids at BWTP without de-salinisation could lead to soils salinisation, a chemical type of toxic soil pollution (Byron and Calvin, 2012)**.**

Organic materials

The decrease in OM with ageing of bio-solids occurs naturally due to humification and mineralisation of the bio-solids-derived OM by microorganisms (Leifeld *et al*., 2001). These processes convert organic materials in the sludge in inorganic forms, resulting in a reduction of the amount of OM accumulated with age. The initial tendency of carbon stocks to increase with ageing of the bio-solids, could be due to dewatering, which has been found to concentrate solids to between 50 and 90% *(*Bresters *et al*.,1997). This OM can potentially improve soil physical and biological properties: water retention capacity and soil organic matter (FAO, 2003), soil aggregation, buffering of soil pH, increased cation exchange capacity and rejuvenation of microbial populations and activities in the soil (USEPA, 1995; Leonie *et al*., 2009). However, if not disposed of well, it could also be a source of greenhouse gases and atmospheric pollution.

Total nitrogen and phosphorus

Although the N and P nutrients of the BWTP bio-solids were generally low, they can become formidable enough in stockpiles of bio-solids, to trigger eutrophication. Eutrophication had devastating impacts on hydropower, water transport, fisheries and water supply sectors of Lake Victoria in the early-to-mid 1990s (NEMA, 1996).

Escherichia coli

The presence of *E. coli* in water is a pointer to presence of pathogenic bacteria, including strains of *E. coli*, viruses and protozoa (USEPA, 2002; Stevens *et al.,* 2003) that can pose serious human and environmental health risks (Saha *et al.,* 2011). All the counts for *E. coli* in the bio-solids were above the 10000 CFU g^{-1} MPL for *E .coli* in wastewater (WHO, 1998; NEMA, 1999; UNBS, 2014). Unregulated use of these bio-solids could be one of the reasons for sporadic outbreaks of cholera in and around Kampala City especially during heavy rains.

Conclusion

Bio-solids from the Bugolobi Wastewater Treatment Plant do not meet the minimum standards for land application and general release into the environment. The bio-solids contain high concentrations of salts and, therefore, could potentially lead to soil salinisation with repeated application. The microbial load is also above the maximum permissible limits. One in 36 bio-solid samples tested positive for

Salmonella sp. Without desalinisation to lower the EC to MPL and disinfection to eliminate or lower potentially pathogenic organisms such as *E.coli* and *Salmonella* sp to recommended MPL, alternative disposal methods for the bio-solids to land application for agricultural and related purposes should be sought.

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