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Terra preta sanitation: recovering plant nutrients and organic matter from faeces

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Abstract

Current sanitation system ignore the potential of human excreta as sources of plant nutrients and organic matter which are useful in improving degraded soils. Terra Preta Sanitation (TPS) uses bio-char and converts faeces into soil amendment. This study investigated the chemical characteristics of stored faecal substrate (mixture of faeces and bio-char). Standard methods in the German "Methods Book for the Analysis of Compost" were used. Total Nitrogen (TN) and total Phosphorous (TP) in faeces have decreased while pH increased from 7.42 to 8.68. The total organic carbon (TOC) has increased from 1480 to 1545 milligram per liter (mg/l). In conclusion, TPS is a promising technology in recovering plant nutrients and organic matter in faeces for agricultural application.

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Introduction

Soil degradation is becoming more and more serious worldwide and poses a threat to agricultural production and terrestrial ecosystem (Jie *et al.*, 2002). It is the loss of the intrinsic physical, chemical, and/or biological qualities of soil either by natural or anthropic processes, which result in the diminution or annihilation of important ecosystem functions (Nunes *et al.*, 2020). Unfortunately, around 1.9 billion hectares of land worldwide have been severely affected and almost 24 billion tons of soil is irrevocably washed or carried away every year (Yousuf *et al.,* 2022). This is an extremely alarming concern for global food security as degraded soil reduces yield, forces farmers to use more inputs, and may eventually lead to soil abandonment (Gomiero, 2016).

On the other hand, human excreta contains loads of nutrients that can be utilized as fertilizers for crops but the current sanitation system simply ignore this. In urban centres of developing countries, on-site sanitation systems (septic tanks, unsewered toilets and aqua privies) are the predominant form of excreta disposal and these have zero concept for nutrient recovery (Buzie, 2010). Sanitation concepts should take responsibility for the future of nature as well as human beings into consideration (Otterpohl, 2000). Blackwater (urine and faeces from the toilet) has a composition where most of the organic matter and particulate nutrients are in the solids (Otterpohl, 2002). To recover the nutrients, the first essential step is the separate collection and treatment of toilet waste in households (Otterpohl *et al.*, 2003).

TPS is a developing sanitation technology that uses lactic acid fermentation and vermicomposting in the treatment and conversion of faeces to produce organic matter as soil amendment (Factura *et al.*, 2010). It deals with nutrient recycling from human excreta for agricultural crop production. TPS was inspired by the discovery of the Terra Preta soils in the Amazon Basin created by Amerindian populations between 500 and 2500 years ago (Lehmann and Rondon, 2006). These soils have maintained high amounts of organic carbon even several thousand years after they were abandoned (Lehmann *et al.*, 2003b). Such huge amount of black carbon can only be obtained from partially combusted biomass carbon, like used wood from household cooking with fire or from field clearing by burning (Hecht, 2003) considering that burning above-ground biomass is a common practice in tropical smallholder agriculture. Terra Preta soils were highly valued by farmers for their sustainable fertility and production potential (Lehmann *et al.*, 2003). In TPS, bio-char, the biomass-derived black carbon using incompletely combusted organic matter such as charcoal (Glaser *et al.*, 2002), was used to cover the separately collected faeces and provides the link to the ancient method of creating Terra Preta soils.

Faeces may be considered as clean fertilizer (Schonning *et al.*, 2002; Niwagaba *et al.,* 2009) since it contains lower concentrations of heavy metals in comparison to farmyard manure and artificial Phosphorus fertilizers. Previous studies have investigated nutrient contents in faeces that are useful in agriculture. Of the nutrients from the food consumed, 10-20% of the Nitrogen, 20-50% of the Phosphorus and 10-20% of Potassium will be found in the faecal fraction, while the rest is found in urine (Lentner *et al.*, 1981; Guyton, 1992; Frausto da Silva and Williams, 1997). Faechem *et al* (1983) showed the chemical composition of human faeces (based on percent of dry weight) as follows: Nitrogen 5.0-7.0, Phosphorous (P_2O_5) 3.0-5.4, Potassium (K_2O) 1.0-2.0 and organic matter 88-97. Conventional sanitation systems misplace these nutrients, dispose them off and turn the cycle into a linear flow (Winblad and Simpson-Hébert, 2004). Among the recently developed low-cost sanitation technologies, TPS is among the first few that makes use of bio-char in separately collected faeces. In developing this technology, it is necessary to know the details of the faecal substrate which undergoes treatments. Therefore, this paper presents findings of a preliminary TPS study on the chemical characteristics of the faecal substrate stored in short (1 month) and long term (12 months) periods.

Materials and methods

This experiment was part of the author's doctorate studies on TPS at the Institute of Wastewater Management and Water Protection – Hamburg University of Technology (TUHH) in Germany during the period 2008 – 2011. A laboratory scale experiment was conducted where faeces were collected using a bucket toilet (waterless) from the male members of the institute. Urine was separately collected as well as used toilet paper. Ground charcoal (bio-char) was used to cover faeces after defecation and the bucket was closed with its lid. From the faecal substrate, two groups of samples were stored separately (for 1 month and for 12 months) using plastic buckets under room temperature. Storage started during winter season. After storage, the substrates were analyzed using standard chemical parameters following the methods described in the German "Methods Book for the Analysis of Compost" (BGK, 1994), whereby extractions with $CaCl_2$ solution (for determination of pH, TOC and Nitrogen compounds) and CAL solution (for Phosphorus compounds) were used.

Results and discussion

After 12 months of storage, TN and TP decreased while pH increased from 7.42 to 8.68. Changes in Nitrogen content could be attributed to ammonia losses. About 10% of the faecal Nitrogen is found as ammonia from degradation of urea, peptides and amino acids (Vinneras, 2001). Of the nutrients from the food consumed, 10-20% of the Nitrogen will be found in faeces and that Nitrogen is about 50% water-soluble (Vinneras, 2001).

Table 1. Chemical characteristics of the substrate.

	pH	TN (mg/l)	Ammonium (mg/l)
Before storage	7.42	523	275
After 1 month	7.23	495	307
After 12 months	8.68	478	341

For Phosphorous, around 20-50% (of the nutrients from the consumed food) will be found in faeces and it is mainly found as granular Calcium-Phosphates (Vinneras, 2001). Recovering Phosphorous from faeces for crop production should be considered as one of the vital tasks of sanitation engineers. It is due to the fact that Phosphorus rock is a limiting, non-renewable resource, and it is estimated that the global phosphate rock reserves will be depleted in 50–100 years (Cordell *et al.,* 2009). When this happens, it will drastically affect crop production causing tremendous decline in food supply which will seriously impact global food security. By using appropriate sanitation technologies, around 3 million tons of Phosphorous per year (worldwide) can be possibly recovered from human excreta and that is equivalent to 21% of the total amount of artificial Phosphorous fertilizer produced per year from mining phosphate rock (Cordell *et al.*, 2009).

Table 2. Chemical characteristics (*continuation*).

	TP (mg/l)	Phosphate (mg/l)	TOC (mg/l)
Before storage	282	280	1480
After 1 month	302	291	1870
After 12 months	194	191	1545

The TOC (Table 2) has increased from 1480 to 1545 mg/l after 12 months of storage. Linear and quadratic equations for the correlations between organic matter and carbon have shown high values of r, significant at the 99·9% probability (Navarro *et al.,* 1993). In this case, faeces can be a good source of organic matter that is extremely important for degraded soils. Organic matter as well cation and anion exchange capacities are chemical indicators used in assessing soil degradation (Ribeiro *et al.*, 2009). The fact is, organic matter itself can retain nutrients in the soil by providing the said exchange capacities (USDA Natural Resources Conservation Service, 1996).

The bio-char used in this study for covering faeces also have advantageous effect for the soil. Additions of bio-char to soil have shown definite increases in the availability of major cations and Phosphorus as well as in total Nitrogen concentrations (Lehmann *et al.,* 2003a). With bio-char application, increase in both cation exchange capacity and pH were observed (Topoliantz *et al.*, 2002). Although the substrates were not subjected to any further treatment, TPS process actually uses vermicomposting to produce compost out of faeces that is hygienically safe for agricultural use. Faecal vermicomposting studies at the TUHH have shown concrete scientific basis to support the use of vermicomposted human faeces as soil amendment (Buzie, 2010). The World Health Organization (WHO, 2006) and the Stockholm Environment Institute through the EcoSanRes Programme (2004) created guidelines and presented treatment options for the safe reuse of faeces in crop production.

Conclusion

TPS is a promising technology that utilizes faeces as valuable sources of nutrients for plants as well as organic matter for soil applications. Implementing TPS makes it highly possible to address soil degradation. Massive campaign and awareness raising are extremely necessary in encouraging a paradigm shift in the structure and processes of the current sanitation system transforming from conventional to practical, multi-dimensional and innovative approach.

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