Nutrient value of human waste to plants

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Summary

Human sewage can be an important source of macro-nutrients for plants. In the UK, over 100,000 hectares of agricultural land are beneficially treated with sewage sludge per year. However, in many countries in the Global South, this waste is not captured and used, depriving the land of a sustainable source of nutrients for plant growth. Using Sierra Leone in West Africa as an exemplar country, this paper details the calculations and assumptions made to quantify the main plant nutrients that can be potentially found in the biofertiliser produced by treating human waste in an anaerobic digestion system such as the Flexigester™ system (Sustainable OneWorld Technologies CIC).

Introduction

One method of producing biofertiliser is from the anaerobic digestion (AD) of organic material. This paper deals specifically with human waste collected from pour-flush toilets. The use of human waste as a fertiliser for fields is not a new idea. The sludge from sewage treatment works has been used to fertilise agricultural land in the UK for decades. In 2007 in the UK, over 100,000 hectares of agricultural land was treated with sewage sludge (DEFRA website). By contrast, in the Global South, human sewage is seldom collected and rarely used as fertiliser.

The calculations presented here are for the three primary nutrients required by plants. It is acknowledged that these nutrients alone are not sufficient for healthy plant growth and that there are many other factors which affect growth and health of the crop, including water availability, seed variety, pests and disease. Plants also require additional secondary nutrients (*eg* sulphur, magnesium and calcium) and a number of other micro-nutrients, as well as carbon, hydrogen and oxygen for growth. Human waste contains micro-nutrients, but they are not considered here as there is limited published quantifiable data of their presence in sewage.

SOWTech are involved with projects for the collection and treatment of sewage in Sierra Leone, which have been chosen to illustrate the potential of sewage as a form of biofertiliser.

The scale of the potential in Sierra Leone

The human digestive system requires waste products to be removed from the body in the form of urine and faeces. In an ideal world, all of this waste would be collected and treated. The population of Sierra Leone, as estimated by the World Bank (World Bank website), is over 6 million people. This equates to around 3.3 million tonnes of sewage per year. At the present time, it is unrealistic to use these figures due to the problems associated with the collecting of such waste. This article focuses on three case study examples of the potential benefits of such waste from the Flexigester projects in Sierra Leone. They include: Freetown, the country's capital; Bombali District, a rice growing area; and Makeni, the capital town of Bombali and close to a rice mill.

The populations of these areas are given in Table 1 below. Assumptions, based on the best available field data, have been made as to the amount of waste produced per person per day and the amount of macro-nutrients in such waste. Details of these assumptions are given later in this article. The amount of macro-nutrients that could be recovered if the sewage was collected from various percentages of the population are given in Table 2.

Table 1. Population statistics for areas of Sierra Leone

Population of Sierra Leone	6,000,000
Population of Makeni	112,000
Population of Bombali District	440,000
Population of Freetown	773,000

Table 2. Potential nutrients available in t/year from exemplar areas of Sierra Leone from the sewage output from different percentages of the populations in those areas

Percentage of population	tN/yr	tP/yr	tK/yr
From Makeni			
25%	128	15	36
50%	256	31	72
75%	383	46	107
100%	511	61	143
From Bombali district			
25%	502	60	141
50%	1004	120	281
75%	1506	181	42
100%	2008	241	562
From Freetown			
25%	882	106	247
50%	1763	212	494
75%	2645	317	741
100%	3527	423	988

As can be seen from Table 2, the quantity of plant nutrients (fertiliser) that could be recovered from human sewage in Sierra Leone is large enough to be significant. For example, the total quantity of nitrogen could be as much as 500 tonnes per year for the Makeni district, from a population of 112,000. However, it would clearly be difficult to achieve 100 percent 'capture, treatment and reuse' of the sewage. So, for example, if only 50 percent of the sewage was included, this would still capture over 250 t/yr of N. Table 2 illustrates what plant nutrients would be captured for varying levels of sewage capture.

The potential financial value of human waste as fertiliser has been documented in a paper by the Norwegian NGO, *GRID-Arendal* (Caldwell & Rosemarin, 2008), part of the United Nations Environment Programme. Mauritania was used as an example of the financial value of fertiliser in sewage. The paper states *"In Mauritania, which has a population of about 3 million, the excreta from the entire population is worth annually about EUR 25 million for the equivalent amount of chemical fertilizer"*.

Nutrients in human waste

The volume of sewage produced per person per day varies according to diet, but figures quoted in literature for Africa range from 69 to over 500 g faeces, and around 1.2 litres of urine per person per day (Aalbers, 1999; Caldwell & Rosemarin, 2008; Stanwell-Smith, 2002).

Equally, the amounts of nutrients in that sewage vary according to diet, but an illustration of the amounts that could be expected are given below (Caldwell & Rosemarin, 2008; Esrey, 2001; Timmer & Visker, 1998).

In order to extrapolate these data to a population, it is necessary to assume a single set of figures for waste arisings. The data sources show a wide range of faeces arising: 69 - 520 g/person/day. For the purpose of this article, a mid-range assumption of 300 g/p/day has been used. The figure for urine generation is consistent between data sources, so a figure of 1.2 l/p/day (equivalent to 1.2 kg/p/d) has been used. The figures used in the per capita calculations are therefore summarised in Table 4.

Table 3. Macro-nutrients in human sewage in g per person per day taken from three different data sources

	N (g/p/d)			P_2O_5 (g/p/d)			K_2O (g/p/d)		
	(Esrey, 2001)	(Timmer & Visker, 1998)	(Vogeli *et al,* 2014)	(Esrey, 2001)	(Timmer & Visker, 1998)	(Vogeli *et al,* 2014)	(Esrey, 2001)	(Timmer & Visker, 1998)	(Vogeli *et al,* 2014)
Urine		11.0	15-19		1	2.5-5		2.5	3-4.5
Faeces		1.5	5-7		0.5	3-5.4		1	1-2.5
Urine + Faeces	10.9	12.5		1.4	1.5		2.7	3.5	

Table 4. Quantity of macro-nutrients excreted per person per year

Amount of waste production	
Faeces	0.3 kg/p/d
Urine	1.2 kg/p/d
Faeces + Urine	1.5 kg/p/d
Therefore in one year each person will produce	
Faeces + Urine	548 kg
containing	4.6 kg N
	0.5 kg P
	1.3 kg K

Table 5. Macro-nutrients captured anually by a Flexigester V10 from human waste from 50 persons

A Flexigester V10 will therefore output:	228 kg of N/year
	27 kg of P/year
	64 kg of K/year
% nutrient value in digestate	0.31% N
	0.04% P_2O_5
	0.09% K_2O

These figures are in close agreement with those published by Caldwell & Rosemarin (2008) which state that *"Humans produce roughly 500 litres of urine and 50 litres of faeces per person per year. These contain about 4 kg of nitrogen, 0.5 kg of phosphorous and 1 kg of potassium"*.

Treating sewage by anaerobic digestion in a Flexigester

The process of anaerobic digestion (AD) will decompose sewage and render it suitable for reuse as a fertiliser. The Flexigester V10 (Sustainable OneWorld Technologies CIC) is an example of a modest scale AD system, designed to be connected to pour-flush toilets and capture all waste from those toilets. Water at approximately 2.5 l/day is needed to flush the waste away from the toilet. Although, this can be grey water, (including from cooking *etc*) and will contain additional nutrients, clean water has been used for the following calculations. So the total input to the Flexigester will be 1.5 kg of excrement and 2.5 kg of flush water, making a total of 4 kg input per person per day.

The breakdown of sewage in a digester requires time, which is dependent on factors such as temperature. A Flexigester V10, with a nominal capacity of 10 m^3 (10,000 kg of waste), being used by 50 people each day in a subtropical climate without additional heating, would have an annual input of 73,000 kg of waste, including flush water, and a retention time of around 50 days for the waste.

During the process of anaerobic digestion, biogas is produced and removed, but this has an insignificant effect on the volume of material in the digester or the annual output of 73,000 kg of digestate or biofertiliser, which is equivalent to the input. Table 5 shows the nutrient content of this biofertiliser captured and recycled in a year for a Flexigester V10 system treating waste from 50 persons.

How the process of AD affects the capture and form of plant nutrients

Sewage left untreated and exposed will lose nitrogen due to the loss of volatile ammonia, however, the gas tight Flexigester means that all the potential nitrogen is captured, although the form of nitrogen changes during the AD process. In fresh excreta, 75 percent of the nitrogen is in the form of organic macromolecules and 25 percent as available ammonium compounds. During anaerobic digestion, the organic macromolecules are broken down to give more ammoniacal nitrogen, which can be readily used by the plants (Vögeli *et al*, 2014).

The plant-available form of phosphate (P_2O_5) is around 50 percent of the total phosphorus content and it is not adversely affected through losses or conversion by the AD process (Vögeli *et al*, 2014). Plant-available potassium (K_2O) is also unaffected by anaerobic digestion. It is estimated that 75-100 percent of the total potassium would be available to plants (Vögeli *et al*, 2014).

Discussion and Conclusion

Human waste can be a rich source of macro-nutrients for plant growth. However, it should be noted that around 70 percent of the nutrients are found in the urine fraction compared to faeces. For the highest levels of nutrient recovery, the use of latrines is important to capture as much as possible of urine produced.

This paper illustrates the significant scope of the potential for sewage-derived fertiliser, but the figures quoted can only be indicative due to the variability of the source data. Nevertheless, reference to third party assessments show our projections are in line with other similar studies. The AD process can be a key tool in the capture, treatment and reuse of human sewage making it possible to utilise the fertiliser potential of this abundant and under-utilised resource. The Flexigester system is one example of how this can be achieved in hot low-income countries.

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