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Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment

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HIGHLIGHTS

- Environmental impacts of using blackwater and urine as fertilisers were assessed.
- Three scenarios assessed blackwater, urine and chemical fertilisers, respectively.
- Toilet fraction nutrients not recycled as fertiliser were removed in enhanced WWTP.
- Blackwater and urine proved better for GWP and energy use than chemical fertiliser.
- Blackwater and urine caused more eutrophying emissions than chemical fertiliser.

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ABSTRACT

Human excreta are potential sources of plant nutrients, but are today usually considered a waste to be disposed of. The requirements on wastewater treatment plants (WWTPs) to remove nitrogen and phosphorus are increasing and to meet these requirements, more energy and chemicals are needed by WWTPs. Separating the nutrient-rich wastewater fractions at source and recycling them to agriculture as fertiliser is an alternative to removing them at the WWTP. This study used life cycle assessment methodology to compare the environmental impact of different scenarios for recycling the nutrients in the human excreta as fertiliser to arable land or removing them in an advanced WWTP. Three scenarios were assessed. In blackwater scenario, blackwater was source-separated and used as fertiliser. In urine scenario, the urine fraction was source-separated and used as fertiliser and the faecal water treated in an advanced WWTP. In NP scenario, chemical fertiliser was used as fertiliser and the toilet water treated in an advanced WWTP. The emissions from the WWTP were the same for all scenarios. This was fulfilled by the enhanced reduction in the WWTP fully removing the nutrients from the excreta that were not source-separated in the NP and urine scenarios. Recycling source-separated wastewater fractions as fertilisers in agriculture proved efficient for conserving energy and decreasing global warming potential (GWP). However, the blackwater and urine scenarios had a higher impact on potential eutrophication and potential acidification than the WWTP-chemical fertiliser scenario, due to large impacts by the ammonia emitted from storage and after spreading of the fertilisers. The cadmium input to the arable soil was very small with urine fertiliser. Source separation and recycling of excreta fractions as fertiliser thus has potential for saving energy and decreasing GWP emissions associated with wastewater management. However, for improved sustainability, the emissions from storage and after spreading of these fertilisers must decrease.

1. Introduction

Eutrophication is caused by excessive inputs of nutrients to a water body. These nutrients cause large algal growth and sometimes algal blooms, with oxygen depletion when the algae die and decay. Eutrophication threatens many coastal ecosystems around the world (Randall, 2003; UNEP, 2006). The main sources of these nutrients are anthropogenic, such as wastewater systems, agriculture and atmospheric deposition largely due to the burning of fuels. One eutrophied water is the Baltic Sea, where the Baltic Sea Action Plan (BSAP) aims at recovering good environmental status. To achieve this, the surrounding countries have agreed on sharp decreases in eutrophying emissions by 2021 (HELCOM, 2011).

The direct nutrient discharges from Swedish municipal wastewater treatment plants (WWTPs), account for about 20–30% of the Swedish anthropogenic nitrogen and phosphorus discharges to the Baltic Proper

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(SEPA, 2009). In Sweden, WWTPs already reduce about 60% of incoming nitrogen and 95% of incoming phosphorus (SEPA, 2013a). To achieve the reductions required by the BSAP, WWTPs have been suggested to reduce at least 80% of incoming nitrogen and to emit a maximum of 0.2 mg phosphorus per litre outgoing water (SEPA, 2009). This will increase the use of resources such as precipitation chemicals, carbon sources and energy at WWTPs (SEPA, 2009). Current target for reduction of the Swedish emissions are 9240 tonnes of nitrogen and 530 tonnes of phosphorus (HELCOM, 2013).

The global population is expected to grow by about 35% by 2050 (UN, 2013), increasing the demands on agricultural production and use of chemical fertilisers. Today human excreta are almost universally looked upon as a hazardous waste to be disposed of. However, the nutrients in urine and faeces derive from ingested food and, if recycled, might be important as fertiliser in future agriculture. This would be in line with the waste hierarchy in the Waste Directive of the European Union (EC, 2008a), where re-use and recycling are given higher priority than disposal, thus promoting a change of view on human excreta from waste to resource. It would also agree with Rockström et al. (2009), who claim that the global flows of reactive nitrogen are ought to be reduced.

The urine fraction (excluding flush water) contributes about 1% to the total flow of urine, faeces and greywater (Jönsson et al., 2000), but gives the largest contribution to the flow of macronutrients, about 80% of the nitrogen and 60% of the phosphorus. Blackwater (urine, faeces, toilet paper and flush water) contains about 90% of the nitrogen and 90% of the phosphorus in the excreta (Jönsson et al., 2005). The nutrient content, before losses, in urine and faeces excreted by the Swedish population corresponds to 28% of the total nitrogen and 44% of the total phosphorus in chemical fertilisers sold in Sweden 2010/11 (Statistics Sweden, 2012a). The nitrogen in urine mainly consists of ammonium and has 85–100% of the plant availability of the nitrogen in chemical fertilisers (Jönsson et al., 2000). The phosphorus in urine is mainly in the form of phosphate ions and is as available to plants as soluble phosphorus fertilisers (Kirchmann and Pettersson, 1995). The nutrients in faeces are somewhat less available, since some of them are bound to non-degraded organic material. About 50% of the nitrogen in faeces is water-soluble and thus immediately available for plants (Jönsson et al., 2005). The phosphorus in faeces is largely bound to calcium and is comparable to that in chemical fertilisers, although with slower solubility (Frausto da Silva and Williams, 1997).

There is no law controlling the use of human excreta as fertiliser in conventional farming in Sweden, although to a certain extent it is covered by the regulation regarding safe use of sewage sludge (EEC, 1986). According to the EU Directives on organic production, human excreta are not allowed as fertilisers in organic farming (EC, 2008b), even though human excreta well fulfil the intention of the Directive that “in order to minimise the use of non-renewable resources, wastes and by-products of plant and animal origin should be recycled to return nutrients to the land” (EC, 2007).

Over recent years, a number of source-separation techniques, especially for urine separation, have been investigated. One review by Maurer et al. (2006) concluded that there are many urine treatment processes available both for hygienisation and nutrient-recovery, e.g. struvite precipitation and ammonia stripping, but that further work is needed to optimise the processes. For separating urine, special toilets have been developed with a front bowl collecting the urine and a rear bowl collecting the faeces and toilet paper. The urine is piped to a storage tank for further treatment. Collection of source-separated blackwater (urine, faeces, flush water and toilet paper) in collection tanks for vehicle transport to a WWTP is fairly common in Sweden and many other countries.

Proper hygiene control is important when using human excreta as fertiliser. Urine is sterile in the bladder of healthy individuals, and after excretion it contains low counts of normal skin flora (Jönsson et al., 2000). The hygiene risk of faeces, which frequently contain bacterial, virus and parasitic pathogens, is high. Therefore, for urine the main hygiene risk is associated with faecal cross-contamination (Schönning and Stenström, 2004). For hygienisation of urine, storage is a low-tech and low resource-demanding alternative. The recommendations are storage for 1 to 12 months depending on storage temperature and crop to be fertilised (Schönning and Stenström, 2004; WHO, 2006).

A low-tech hygiene treatment of faeces is storage for at least 2 years (WHO, 2006). The storage time can be greatly reduced by adding e.g. pH-increasing additives such as lime or urea, which could come from urine (Fidjeland et al., 2013; Schönning and Stenström, 2004). The excreta fractions are relatively low in heavy metals (Jönsson et al., 2005), and urine contains far smaller amounts of heavy metals than faeces. The concentrations of most metals are much lower, by at least 10-fold, in urine than in animal manure (Winker et al., 2009). Excreta are the main contributor of pharmaceutical substances and hormones to wastewater, where the problems caused by sex hormones emitted with wastewater effluents are very well documented (Liney et al., 2006; Vajda et al., 2008).

Ammonium nitrate is the most commonly used compound for chemical nitrogen fertiliser in Europe (Fertilizers Europe, 2013). About 80% of the global ammonium nitrate production is by fixation of atmospheric nitrogen using natural gas as a source of both hydrogen and energy (Brentrup and Pallière, 2008). The global warming impact from nitrogen fertiliser production is mainly due to the large emissions of carbon dioxide (CO_2) when using natural gas and of nitrous oxide (N_2O) from the nitric acid production, a step within the nitrate production process (Brentrup and Pallière, 2008). The use of phosphate rock for the production of chemical fertilisers is also a concern, as the life time of economic reserves of phosphate rock is finite and is estimated to be exceeded in the next 30–370 years (Cordell and White, 2011; USGS, 2013). Another environmental issue regarding fertiliser use is the cadmium flow to arable land. Cadmium exposure in Sweden, mainly from smoking and food intake, is many times above or at safety levels that can have harmful effect on bones and kidneys (KEMI, 2008). This not only emphasises the health risk to humans but also that humans excrete relatively large amounts of cadmium. KEMI, the Swedish Chemical Agency, recommends a limit of 12 mg cadmium per kg phosphorus added to soil to keep safe levels (KEMI, 2008), but analyses of chemical fertilisers sold in Europe show median concentrations of 87 mg per kg phosphorus (Nziguheba and Smolders, 2008).

Recycling the nutrients in human excreta to arable land as fertiliser can reduce the use of energy and non-renewable resources for production of chemical fertilisers. It can also reduce the use of energy and chemicals at WWTPs, both because less nutrients need to be removed and because the biological wastewater process, and especially the nitrogen removal process, function more efficiently when urine is source-separated from the influent to the WWTP (Wilsenach, 2006; Wilsenach and van Loosdrecht, 2003).

A number of studies have demonstrated the environmental benefits of using human excreta as fertiliser on arable land (Benetto et al., 2009; Remy and Jekel, 2008; Tidåker et al., 2007a, 2007b). However, most of these studies focus on the urine fraction and no previous study has compared systems with the same direct emissions of nutrients from wastewater to water. The present study aimed to fill this gap.

2. Goal and scope

The goal of this study was to assess the environmental impact of separating and recycling nutrients in human urine and faeces for use as fertiliser on arable land, compared with treating these fractions at a WWTP with enhanced treatment and fertilising the arable land with chemical fertilisers. Three scenarios in a Swedish setting were evaluated in a life cycle perspective for a new housing district in the Stockholm area. In the blackwater scenario, ultra-low-flush vacuum toilets were used and the blackwater was hygienically treated and later spread on arable land. In the urine scenario, the urine was separated at source, stored and spread on arable land while the faeces were piped to and