New Fertilizers from Advanced Wastewater Treatment: Their potential Values and Risks

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Introduction

Decentralised treatment of domestic wastewater streams is of increasing importance especially for areas experiencing water scarcity or high prices for fertilizer. Water usage can be drastically reduced as flush water becomes nearly negligible by separation of wastewater streams and implementation of new techniques as dry toilets or vacuum systems. Aside, wastewater streams can be collected and treated appropriate to their specific needs and nutrient recovery is easily possible. New wastewater products emerged with promising characteristics to be used directly or through respective treatment as fertilizers in agriculture. Additionally, recovery of nutrients becomes more and more important due to finiteness of resources particularly phosphorous (Driver et al, 1999).

Engineers already designed even larger pilot projects for >100 inhabitants as e.g. Lübeck-Flintenbreite (Otterpohl et al., 1997) or Linz SolarCity (Steinmüller, 2006), Erdos Eco-Town (Lixia et al. 2007). Although, usage of nutrient rich fractions as fertilizers is implemented in these projects, overall little is known about their quality, their nutrient availability, and their potential risk in form of pollutants. Their nutrient contents and other characteristics differ significantly from sewage sludge which is very well-known and thoroughly investigated. Additionally, it is important that existing techniques can be used for application. Equipment of liquid fertilizers needs a product its quantity is applied between 10-50 m^3 ha^{-1}, in case of solids up to 40 t DM ha^{-1} as well as for mineral fertilizers between 100-600 kg ha^{-1} (Finck, 1979). Nutrient availability is mainly defined according to the product's organic (like compost) or mineral (like mineral fertilizer) characteristic.

Hence, nowadays wastewater products originating from these systems are thoroughly investigated for those aspects. Currently, urine, blackwater, compost from faecal matter, and struvite seem to be the most important new fertilizers derived from wastewater and may cover e.g. in Germany and in Sweden more than 10-20% and 20-30%, respectively, of the fertilizer demand (Clemens, 2007).

Material and methods

Data on products was collected by a literature review of scientific papers and reports discussing the characteristics nutrient content and availability, concentrations of pollutions such as heavy metals, pharmaceuticals, and pathogens, quality of the product, and its solid/liquid as well as mineral/organic properties. Additionally, a model was developed designing mass flows (Hammer und Clemens, 2007). With of the model, estimations of pollutant fluxes reaching agricultural fields along with the provided nutrients became possible. As first indicator substance urine was chosen as it is the only product knowledge is available for all categories (see Table 1).

Results and discussion

Nutrients and heavy metals

Detailed information for fertilizer products derived from wastewater streams and identified as important during the literature screening is given in Table 1. The products were sorted according their specific fertilizer type.

Table 1: Wastewater products present along their fertilizer types and with their specific nutrient concentrations. Additionally, the level of knowledge is indicated by + (well known), (+) (known to some degree), and - (unknown) for these products

Fertilizing type	Product	Level of knowledge	DM [%]	CSB [g/l]	N [g/l]	P [g/l]	K [g/l]	Reference
Liquid mineral	Urine and Oldenburg, 2008	+	1.5-3	4-11	1.8-17.5	0.2-3.7	0.7-3.3	Meinzinger
	Concentrated urine e.g. Urevit	(+)	10	11	0.65	5.7	Boller, 2007	
	Ammonium sulphate	(+)			80			own experience
	Biochemical treated urine	-						
Liquid organic mineral	Digestate	-		4	≤ 2	≤ 0.2	≤ 0.4	Oldenburg
	Untreated sludge blackwater	-						
Solid mineral	Struvite	(+)			60	130	-	Calculated stochiometrically
Solid organic	Compost	-		100	5-20	2-4	3-10	Simons et al. (2005)
Solid organic mineral	Sludge with DM >20	-						

Urine is perhaps the most promising product as it contains relatively high concentrations of urea (up to 9 g N l^{-1}), P (around 0.7 g P l^{-1}) and other nutrients such as K and S. Although, its pH is around 9 after storage, it shows low NH$_3$-emissions (< 10 % of applied N) after field applications compared to liquid slurry (Simons, 2008). Urine can be used as a multi component mineral fertilizer. Additionally, its characteristics are the most investigated one of all products.

Struvite is a precipitation product of urine (Mg(NH$_4$)PO$_4$) after addition of Mg^{2+} and increase of pH. Struvite can substitute mineral fertilizer; however it should be used as P-fertilizer to avoid over fertilization. The type of minerals present and grade of crystallisation of “struvite products” available after treatment of urine tested so far vary considerably (unpublished data), resulting in different plant availabilities of the nutrients.

Blackwater– a liquid mixture of urine, faeces, and water – has a higher share of carbon and shows normally lower nutrient concentration compared to urine, mainly due to dilution during collection. Similar counts for compost, but here the nitrogen content, especially the plant available part, is low.

Little is known about the plant availability of nutrients from wastewater products. A rough range is given in Table 2. As can be seen the different macro nutrients were discussed along different time periods to give an overall picture. While nitrogen availability is given on an annual basis, phosphorous and potassium were considered for a crop rotation of 3 years. Due to their low N availability digestate and compost normally are used as soil conditioner instead of fertilizer.

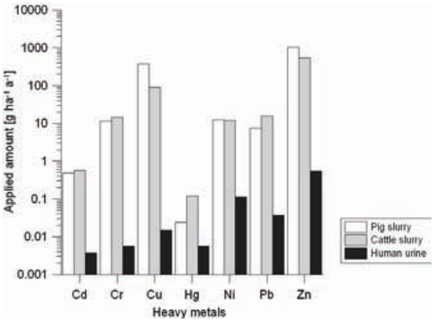
Table 2: Expected nutrient availability of the various fertilizing types presented for the three macro nutrients N, P, and K

	Expected availability		
Fertilizing type	N (in year of application)	P (3 year crop rotation)	K (3 year crop rotation)
Liquid mineral	100	100	100
Liquid organic mineral	$N_{mineral}$ + approx. 10 % of $N_{organic}$	100	100
Solid mineral	100	100	100
Solid organic	< 10	100	100
Solid organic mineral	$N_{mineral}$ + approx. 10 % of $N_{organic}$	100	100

Liquid substrates may show ammonia emissions, as they may contain relative high ammonium concentrations and high pH up to 9. However, the liquids infiltrate fast into the soil and then ammonia emissions stop. Ammonia emissions from the most sensitive product urine are lower as compared to liquid animal slurry (Simons, 2008). However, the application technique needs to be adapted to the high ammonia content, e.g. application close to soil preferably in combination with soil incorporation.

Heavy metal concentrations are low in all products with household origin, i.e. no industrial wastewater included, with the exceptions of sludge from septic tanks and of compost (Simons et al. 2005). Threshold values of heavy metals in composts may be reached, because of the decreased content of organic matter. Nevertheless, fluxes to agricultural fields are significantly lower in comparison with animal slurries as shown in Figure 1. Of course, this is a very narrow view, as only urine was compared in the model and use of heavy metals in households can result in large impact on the urban derived fertiliser (Vinnerås et al., 2006).

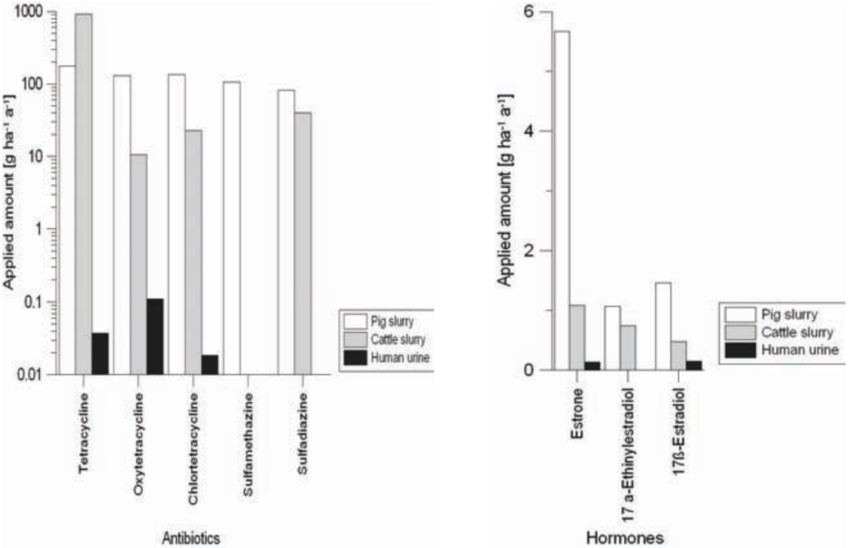
Figure 1: Concentration of heavy metals applied via different fertilizers (adapted according Hammer and Clemens, 2007)



Organic micropollutants

All products can contain organic micropollutants such as hormones, antibiotics, or other pharmaceuticals used for human medication as the original wastewater streams brownwater, yellowwater, and greywater contain those (Lienert et al., 2007, Ronteltap et al., 2007, Tettenborn et al., 2007, Eriksson et al., 2003). Hence, it depends on the correct treatment to eliminate them (Gajurel, 2007, Tettenborn et al., 2007, Maurer et al., 2006). Until now, no detailed investigations of concentrations of organic micropollutants in fertilizer products took place aside of urine and further products originating from this source such as struvite. In this aspect, further research is urgently needed and recommended. Especially, as certain treatment techniques show very good results to create clean products such as struvite precipitation (Ronteltap et al., 2007) and steam stripping (Tettenborn et al., 2007). Even so fluxes of antibiotics and hormones would be much lower compared to animal slurries (see Figure 2). However, in the household derived fractions there are possibilities to find other pollutants not found in animal manure, e.g. antineoplastics, that needs to be considered when larger proportions of human excreta is recycled.

Figure 2: Fluxes of antibiotics (left) and hormones (right) applied via different fertilizers (adapted according Hammer and Clemens, 2007)



Pathogens

Pathogens are well-known as one of the major constraints when using wastewater products in agriculture since a long time. Introducing recycling of human manure will always include a risk for new transmission routes for infectious diseases. Source separation has the advantage that the wastewater streams are separated and in most cases only somewhat diluted keeping the volume to treat manageable. The main proportion of the pathogens is found in the faeces and only very few are excreted in the urine (Höglund, 2001). By enclosed collection of the faeces the management of urine and greywater can be kept simple. Nevertheless, due to faecal cross-contamination in the toilet or urine excreted by infected persons, the risk of contamination with bacteria, viruses, and parasites exist for yellowwater as well (Schönning et al., 2002). Consequently, treatment is necessary to minimize the risk of infection. For urine the present recommended minimum treatment is storage for 6 months without introducing fresh liquid. For faecal matter and sludge a thermal treatment (70°C for 1 h) or an equivalent treatment is necessary (WHO, 2006). Recent research looking closer into the effect of uncharged ammonia, which is present in urine and can be added to the fecal matter in the form of urea for efficient sanitization (Vinnerås et al., 2008; Nordin, 2007). This in combination with the low content of pathogens in urine the storage needed for undiluted urine is considerably shorter than current recommendations as long as the urine contain >2g N L^{-1} and holds a pH >8.8 still having a very high safety level. For usage on crops not consumed raw or for fodder crops one month of storage is enough. For usage on crops consumed raw, e.g. lettuce and cucumber, the storage needs to be performed at temperatures from 20°C and up for safe removal of helminth eggs and viruses, >20 and >30°C storage for two and one months, respectively, is enough for safe unrestricted use (Vinnerås et al., 2008). Similar treatment of fecal matter is possible by external addition of urea for sanitization, the treatment is also used for treatment of salmonella infected manure as the urea in contact with manure is enzymatic degraded into ammonia that efficiently inactivate the salmonella (Ottoson et al., 2008).

Moreover, further protection measures such as direct implication into soil, immediate coverage of matter originating from feces assuring minimal surface run off, one month resting times between last application and harvest, protection clothes for field workers, as well as awareness raising and monitoring of treatment methods are tools to minimize the risks drastically and allow the usage of these new fertilizer products (WHO, 2006).

Conclusion

Along the characteristics presented and the data analyzed, it can be concluded that new fertilizers from advanced wastewater treatment have a high potential to introduce a new and promising handling of our water and nutrient (re)sources. To be kept in mind is that these new products have to be adapted to applications techniques available.

As long as we are aware of the risks coming alongside and include them by appropriate measures into our actions, usage of the fertilizers in agriculture is possible. Implementing a new organic fertilizer will introduce a new route of transmission of infectious diseases but appropriate management will minimize these risks. Nevertheless, in many aspects further research is required to fill gaps of knowledge and gain further information to optimize handling and usage of these fertilizer products.

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