Investigation of the effectiveness of source control sanitation concepts including pre-treatment with Rottebehaelter

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Abstract

High levels of nutrients recovery can be achieved with source control sanitation,-technologies are already available. Separation toilets for example separate urine that can be used in agriculture with some crop restrictions as a fertiliser after about 6 months of storage. The grey water has very low loads of nitrogen and can be treated in different combinations of biological and physical treatment and reused. Faecal matter with flush water from the separation toilet can be discharged into Rottebehaelter (an underground pre-composting tank) that retains solid material and drains liquid to a certain extent. Investigation of Rottebehaelter in the different sites and laboratory experiments showed that retained faecal material still contained a high percentage of water. However, odour was not noticed in those Rottebehaelters that have been examined. One of the major advantages of this system over other forms of pre-treatment as the septic tanks is that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta. It has to be stated that maintenance is a crucial factor. As an intermediate result of the intensive research of Rottebehaelter it seems that these systems are rather a way of solids retaining, de-watering and long-term storage before the contents are further treated.

Keywords

Brown water, Grey water, Nutrients, Rottebehaelter, Source control sanitation, Yellow water

Introduction

The linear flow of nutrients from farming land to water bodies due to flush sanitation results in high demands of mineral fertiliser. Production of fertiliser is energy intensive and causes environmental problems. Generating nitrogen from air requires a considerable amount of energy; and mining and refining the raw materials for Phosphate production generates huge amount of hazardous wastes. Reserves of Phosphate (P), Potassium (K) and also Sulphur (S) are definitely limited on a time scale of a couple of human generations especially with regard to economic constraints. Therefore, nutrients present in wastewater should rather be reused instead of discharging them into the water body in order to minimise the production of mineral fertiliser.

It is well recognised that transfer of nutrients from terrestrial to aquatic ecosystem causes on one hand, eutrophication in water bodies and on the other hand nutrient deficiency in agricultural land. These problems are tremendously increasing particularly in developing world, where there is hardly any provision to interrupt the nutrients discharge into water body and, in return, loss of nutrients from agricultural land is compensated only with hardly affordable commercial fertiliser in order to feed a rapidly growing population. In developed world, nutrient transfer to water bodies through wastewater has been relatively controlled by costly high technology for the larger treatment plants. However, even with high investment, which is not affordable for most of the developing countries, more than 20% of nitrogen, more than 5% of Phosphorus and more than 90% of Potassium are still emitted from wastewater treatment plants into the aquatic environment (Lange and Otterpohl,1997).

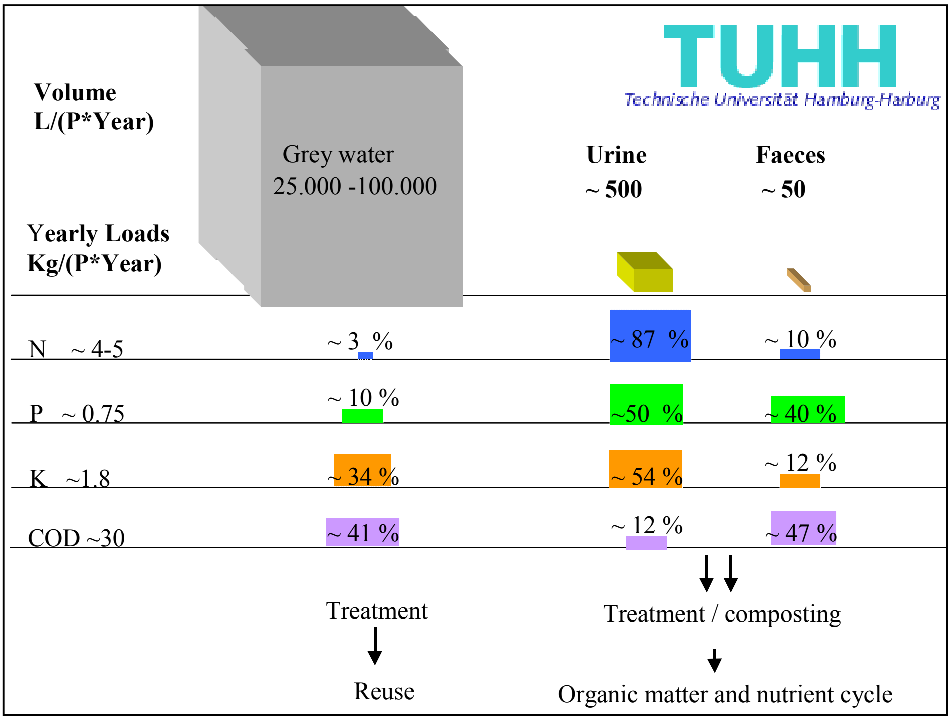
Those nutrients, which are captured in sludge are often contaminated with heavy metals such as Cadmium (Cd) and organic compounds such as PCB (polychlorinated Biphenyle), which pose potential toxic risks to plants, animals and humans (Metcalf and Eddy, 1991). Therefore, large amounts of sewage sludge are disposed of in landfills or incinerated. A very small part is applied to the agricultural land.

In order to recover and reuse nutrients ecologically and economically, household wastewater should be treated separately. High levels of nutrients recovery are possible with the concept of the source control sanitation (Henze et al., 1997; Esrey et al., 1998; Jönsson et al., 1999; Larsen et al. 1999; Otterpohl, 2001 and 1999). This paper does show the effectiveness and limitations of source control sanitation concepts with pre-treatment by pre-composting tanks (Rottebehaelter) to recover the particulate fraction of nutrients from household wastewater.

Source control sanitation

A vision of source control sanitation for household wastewater is based on the fact of very different characteristics of grey water (washing water from kitchen, shower, washbasin and laundry), yellow water (Urine with or without flush water) and brown water (faeces, toilet paper and flush water). The typical characteristics of the streams of household wastewater, shown in table 1, clearly reveal that urine contains most of the soluble nutrients, whereas grey water, despite very large volume compared to urine, contains only small amount of nutrients. Furthermore, faeces, which is about 10 times smaller in volume than urine, contains nutrients, high organic load and the largest part of pathogens.

Table1: Typical characteristics of household wastewater components (Compiled from: Geigy, Wissenschaftliche Tabellen, Basel 1981, Vol.1, Larsen and Gujer, 1996 and Fitschen and Hahn, 1998)



If urine is separated and reused in agriculture, not only nutrients will be reused fully, but also high level water protection will be reached. Unlike wastewater containing urine and faeces, grey water can be treated with simple and low cost processes and reused. There are many cost efficient biological treatment and membrane technology that can produce high quality water. Even with the combination of ground infiltration grey water can be processed to tap water. If faeces is separated and kept in small volume with non or low-flush toilet, it will be a favourable condition for high hygienisation and production of soil conditioner. Therefore, separated treatment of different flows according to their characteristics can lead to full reuse of resources and a high hygienic standard. In order to realise the source control, technologies have already been developed in Europe (Esrey et al, 1998, Otterpohl et al.,1999a and 2001). Separation toilet which has been increasingly used in Sweden, Denmark and Germany, for example, is a suitable technology to separate the urine and faeces at source. The toilet has two bowls, the front one for urine and rear one for faeces.

Treatment of separated flows

Yellow water treatment. Urine is relatively sterile and can be reused without further treatment (Wolgast, 1993). However, due to faecal contamination, pathogens have been found in yellow water; but in low concentration, which will pose low hygienic risk of using yellow water as a fertiliser, if it is stored at least for 6 months before being used in agriculture (Jönsson et al., 1999; Hellström and Johansson, 1999). Since the practising of separated collection of yellow water, farmers in Sweden have been collecting it in the underground storage tank for applying to their agricultural land (Esrey et al., 1998). This practice is good for a region where the farmland is near to the housing area; otherwise, transportation of large amount of urine solution for longer distance has many negative environmental impacts (Hellström and Johansson, 1999).

Recently, many methods for treatment and reduction of volume of collected yellow water have been studied. One method is dewatering by evaporation with and without nitrification and freeze concentration (Gulyas, 2000). By freezing, it is possible to concentrate 80% of nitrogen and phosphorus in 25% of the original volume (Ban et. al, 1999). By nitrification in combination with drying, it is possible to concentrate over 70% of the nitrogen in 10% of the original volume (Hellström and Johansson, 1999). These methods could be beneficial, when a larger volume of urine solution has to be transported a long way to the agriculture farm. These methods have been investigated only in small scale so far.

Grey water treatment. Since grey water contains very low nitrogen concentrations (Table1), nitrification and de-nitrification processes are not necessary for grey water treatment. Therefore, unlike total domestic wastewater, grey water is relatively easy to treat although concentrations are not necessarily lower than in end-of-pipe systems due to a far lower dilution. Choice of household chemicals that can be mineralised (degradable is no useful indicator) is helpful for achieving good quality. Grey water treatment with vertical constructed wetlands with sizes of 2 m^2 per inhabitant in the Flintenbreite settlement has shown good performance (Otterpohl, 2001). Constructed wetlands are cheap in construction and operation. However, because of space scarcity, it is not always appropriate for the densely settled urban areas. For these areas, among other methods, SBR can be suitable. Treatment of grey water from the Flintenbreit settlement in small scale SBR was studied. Details are given in Li at el., 2001. Result showed that, SBR can greatly reduce organic matter, nutrients and turbidity. For reuse purposes, tertiary treatment is needed. Treatment with slow sand filter can meet quality requirements for groundwater recharge. E-coli was greatly eliminated to acceptable levels for recharge. Therefore, grey water treated with the combination of SBR and slow sand filter is suitable for ground water recharge. Treatment with membrane-bioreactors will probably be the choice of the future especially if reuse is intended.

*Brown water treatment***.** A relatively new technology called Rottebehaelter or pre-composting tank, which is usually an underground concrete tank having two filter beds at its bottom or two filter bags that are hung side by side and used alternately in an interval of 6-12 month, has been increasingly applied in Austria, Switzerland and Germany for domestic wastewater pre-treatment (Figure1). Those investigated in Germany have demonstrated to be beneficial and can be combined with concept of source separation (Gajurel et al. 2001). One of the major advantages of this system over other forms of pre-treatment systems is that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta. The retained materials that have already been de-watered and pre-composted in the Rottebehaelter for 8-12 months can be further composted with biological kitchen and/or garden waste in a local composter at least for a year and used in agriculture. It avoids expensive tanker-trucks which is extensively used in conventional system to transport sludge. Moreover, compare to septic tanks methane emission can be very low as outer parts of retained material maintains aerobic condition. However, handling of the bags or the material is not a simple task and should be improved for the future. There are concepts in Austria in areas with strong gradients in the ground where the tanks are accessible with agricultural fork-lifters and can be removed and emptied in a simple way.

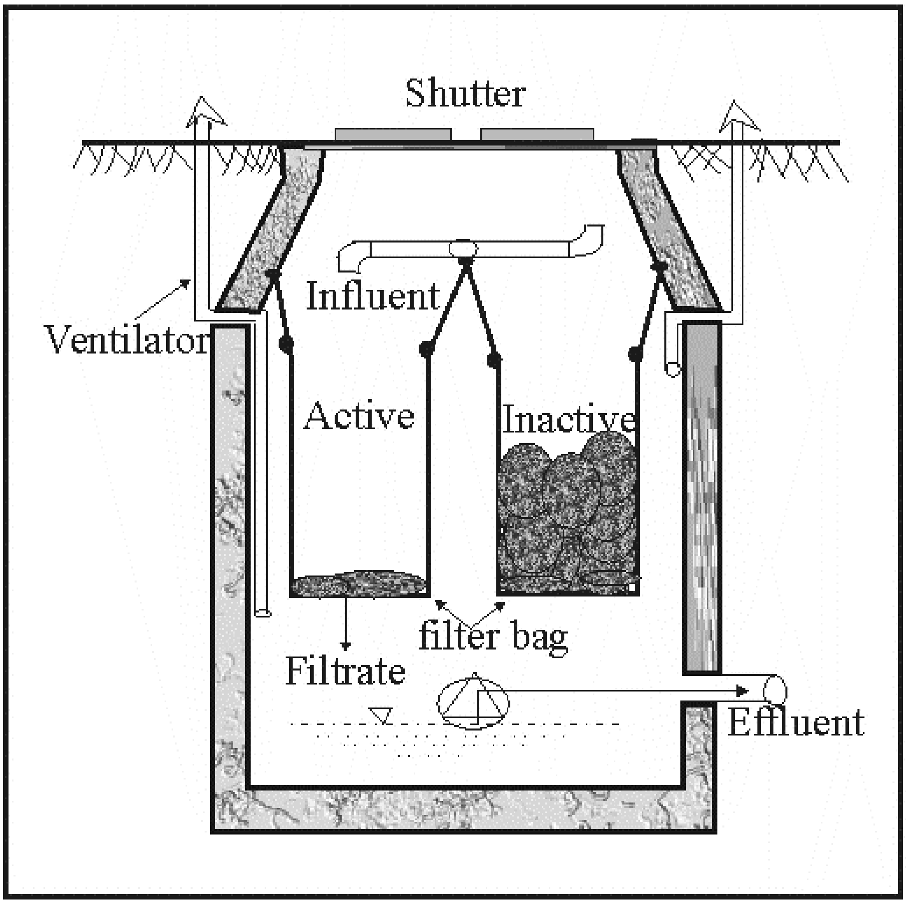


Figure1: Rottebehaelter (Pre-composting tank)

Investigation of existing Rottebehaelter in Lambertsmuehle pilot project

Background

The source control sanitation system has been installed in the pilot project in Lambertsmuehle near Cologne city in Germany since the summer of 2000. Detail can be found in Otterpohl et al. 2001a. The yellow water, with the means of separating toilet, is collected separately in an underground tank, where it is kept till it is ready for use in the agriculture. The brown water is discharged into the Rottebehaelter, which is made up of concrete monolithically and constructed underground outside the building (Figure 2). It is covered with a prefabricated concrete slab and provided with ventilation. A shutter of a concrete slab for changing filter bag, inspection and cleaning has been provided on the covering of the Rottebehaelter. Inside the Rottebehaelter, two filter bags are hung side by side in such a way that when one is full, the influent is manually diverted with the help of diversion pipe into the next empty bag. The filtrate, due to urine separation, is nutrient poor, and is mixed with grey water and treated in constructed wetland.

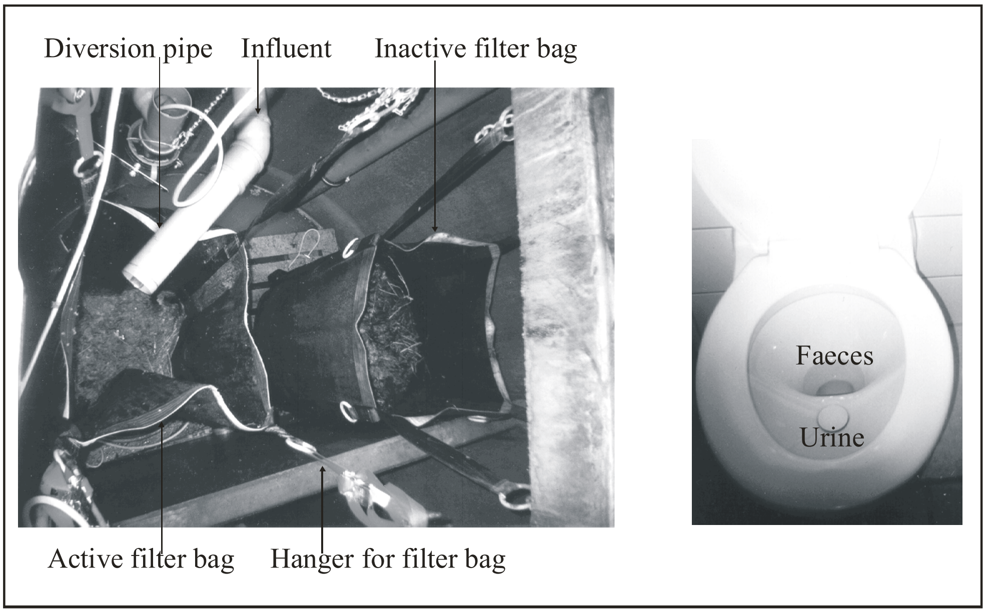


Figure 2: Lambertsmuehle project: Rottebehaelter with filter bag and separation toilet

Performance of the Rottebehaelter

In September 2001, samples from both active and inactive filter bags were analysed. The results are shown in table 2. In both filter bags- active as well as inactive-moisture content was higher than optimal range (40-60% for composting). Moisture content above 70% leads to anaerobic condition (Bidlingmaier, 1983). Thus, anaerobic condition must have taken place in both bags. However, no odour was noticed during the sampling. Also people living in the house have not complained about odour problem so far. Low temperature and low reduction of volatile solids suggest that slow decomposition process took place in both filter bags. It might have caused slow and low emission of odour, which was not detected with human nose in the open air.

Table 2: Characteristics of retained materials (FM: Fresh matter , DM: Dry matter)

Parameter / Sample from	Water Content (% FM)	Loss on Ignition (% DM)	C (% DM)	N (% DM)	C/N	P (% DM)	K (% DM)	pH	Temp ^{0}C
Active filter bag	87.72	95.48	46.60	6.74	6.91	0.69	1.07	7.21	18
Inactive filter bag	83.14	93.26	50.30	7.16	7.025	0.61	1.61	6.30	20

Low C:N ratio showed that structural bulking agent was not added sufficiently in order to maintain C:N ratio of composting material in filter bags in between 20:1 and 30:1. Structural material also helps to reduce water content and increase air circulation inside the material. In inactive filter bag, pH was lower than optimal range, 7-8. It was most probably due to formation of volatile organic acids. Phosphor and Potassium concentration in both retained materials were lower than concentration in faeces. It was mostly due to loss through filter bag with filtrate.

Investigation of the performance of Rottebehaelter in controlled condition

Method and material

Aim of this investigation was to find out the effectiveness of filter bag in separating and pre-composting solid stuff from brown water. For this, two small scale experiments, one with straw as structural additive and another without straw, were carried out in small container of volume 30l with filter bag having pore size of 1 mm (Figure 3).

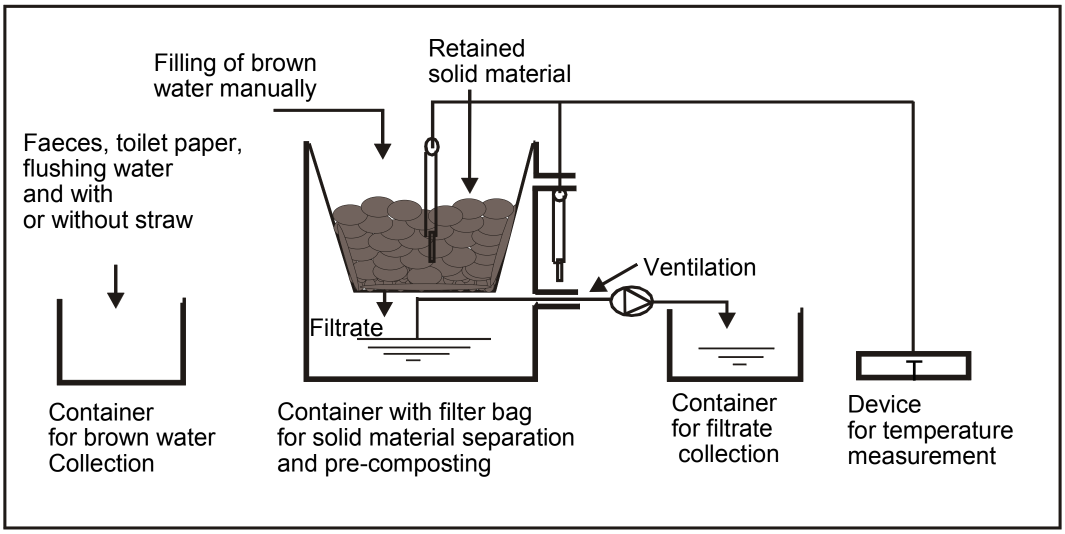


Figure 3 Experimental set up

For the experiments, faeces was collected directly in the plastic bag at the time of excretion and weighted prior to filling into small container where toilet paper (10g) and flush water (6l) were also added. After that, the mixture, called brown water, was filled manually into the container having filter bag inside once a day. The filtrate that fell at the bottom of the container was pumped out everyday. Temperatures in the filter bag and surrounding were measured. Experiment was carried out in two phases- filling phase for 30 days and silence phase for 45 days. After silence phase, the pre-composting materials were mixed thoroughly and analysed. In experiment 1, only brown water was filled; whereas in experiment 2, 2.5g of straw as structural additive was added at every filling.

Results and discussions

Effectiveness of Rottebehaelter in pre-composting

Table 3 shows the characteristics of retained materials. Water content of the material was too high in both the experiments and the water content in the lower part was higher than that in the upper part. Therefore, anaerobic decomposition must have occurred at the inner of the lower part. Slightly odour near the container during the experiment also supports this idea.

Table 3: Characteristics of retained materials (FM: Fresh matter, DM: Dry matter)

Parameter Sample from	Water Content (%FM)	Loss on Ignition (% DM)	C (% DM)	N (% DM)	C/N	pH

Experiment1:withoutstraw						
• Upper Part	66.81	85.95				7.15
• Lower Part	81.67	85.87				7.85
• Mix of both parts			44.2	7.15	6.12	
Experiment2:with straw						
• Upper Part	74.14	83.29				8.61
• Lower Part	82.12	85.57				8.51
• Mix of both parts			38.5	6.3	6.11	

pH value was relatively lower in upper part of the experiment 1- without straw whereas higher in upper part of the experiment 2 - with straw. Loss of organic substance was more in experiment 2- with straw than experiment 1 without straw. Therefore, addition of sufficient amount of dry structural bulking agent e.g. straw, bark etc. is required for the composting. It does provide optimal C/N ratio, water content and air circulation of the pre-composting material, which are prerequisite parameters for the composting. In both experiments, these parameters were not optimal. In experiment 2, straw was added, but too little. Therefore, further investigation with addition of sufficient amount of dry structural bulking agent is needed.

Effectiveness of Rottebehaelter in retaining carbon and nutrients

Figure 4 shows the percentage of carbon and nutrients retained in the filter bag. Among nutrients, nitrogen was retained above 60% of the total influent in both experiments. Despite the loss due to anaerobic condition, nitrogen retained in the filter bag was considerably higher than phosphor and potassium. However, in experiment-1, phosphorus retained was above 40% of the influent. In general, the performance of filter bag in retaining carbon and nutrient was satisfactory.

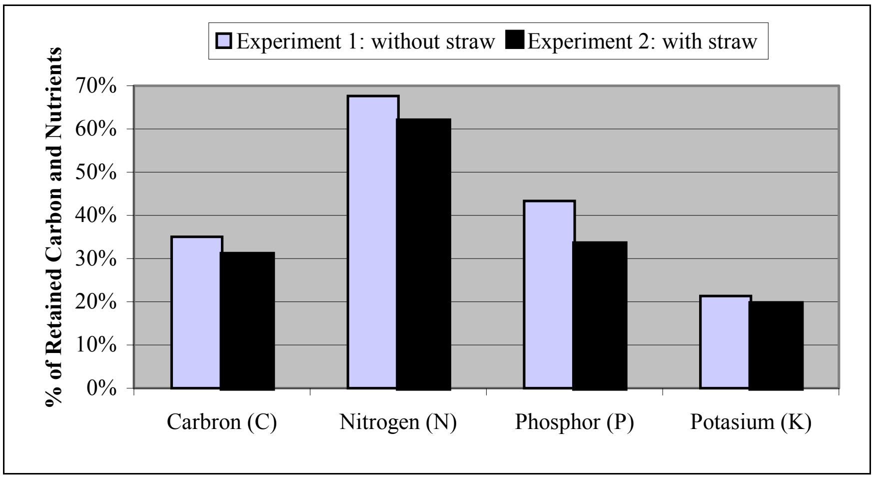


Fig. 4 Carbon and nutrients retained in the filter bag

Conclusions

Technologies for source separation and treatment have been developing rapidly. So far, performance of the small scale experiments and pilot projects have given a positive impression. Investigation of Rottebehaelter has shown its potential for solids-liquid separation and pre-treatment (de-watering to a certain extent) and collection/storage of solid stuff in household wastewater. One of the major advantages of this system over other systems is that it does not deprive agriculture of the valuable nutrients and soil conditioner from human excreta and does not require expensive tanker-trucks. However, water content of the retained material was very high, which must be lowered to optimal level. Moreover, measures such as prevention of heat loss from the

Rottebehaelter and good ventilation are important for effective performance. Last but not least, addition of sufficient amount of structural bulking agents such as bark, straw etc. into the retained material are important factors for maintaining optimal C:N ratio, moisture and oxygen required for composting. Combination of urine source separation concept with Rottebehaelter has demonstrated to be effective to recover nutrients. It can be the most appropriate system for application in the regions where there is a demand for local reuse of the end product. It has to be stated that maintenance is a crucial factor, removal and handling of the pre-composted material has to be improved. In addition, proper procedures of further composting and usage will have to be established. Compared to septic tanks, there are a couple of advantages that make further development worthwhile.

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