Session F

Hygienic agro-reuse

Chairpersons

Caroline Schönning (Swedish Institute for Infectious Disease Control, Sweden)

Joachim Clemens (University of Bonn, Germany)

Lectures

Oral poster presentations

This paper has been peer reviewed by the symposium scientific committee

Poster presentations

The effects of sewage sludge application on the yields of berseem and forage maize in newly reclaimed soil
Ezzat M. Abd El Lateef (Field Crop Research Department, NRC, Egypt)*, J. E. Hall, S. R. Smith*

Effect of long-term application of wastewater on bioavailability of trace elements and soil contamination
Ezzat M. Abd El Lateef (Field Crop Research Department, NRC, Egypt)*, J. E. Hall, S. R. Smith*

Urine-separating toilet in popularising ecological sanitation in the peri-urban areas of Manipur, India
Rajkumar Dilip Singh (Government of Manipur, India)

Sustainability and optimisation of treatments and use of wastewater for irrigation in mediterranean countries
D.Xanthoulis et al. (Faculté Universitaire des Sciences Agronomiques de Gembloux, Belgium)

Investigation of constructed wetland performance considering water reusing
Ping Gui, Ryuhei Inamori, Wenchang Zhu, Motoyuki Mizuochi, Yuhei Inamori (National Institute for Environmental Studies, Japan)

The use of sewage fertiliser products on arable land - requirements from the farmers perspective
Pernilla Tidåker, Cecilia Sjöberg, Håkan Jönsson (Swedish University of Agricultural Sciences, Sweden)

Separation of faeces combined with urine diversion - function and efficiency*

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Keywords

Blackwater, faecal separation, nutrient recovery, nutrient recycling, urine diversion

Abstract

The main proportion of the plant nutrients in household wastewater is found in the toilet fraction, and originates from urine and faeces. Using a blackwater system, it is possible to collect these nutrient rich fractions. However, the nutrients in the blackwater are diluted by large amounts of flushwater, even if a low-flush vacuum system is used.

By using a combination of urine diversion and separation of faecal matter from the flushwater, it is possible to collect the majority of the nutrients in a much more concentrated form compared to blackwater systems. The efficiency of instant separation is higher than separation in a filter bag. The efficiency of the separation depends on the system design but if correctly designed and built, it is possible to separate 84% N, 86% P and 65% K from the faecal matter. In a system where 95% of the urine is diverted and the faecal matter is instantly separated, 93% of the nitrogen, 92% of the phosphorous and 87% of the potassium are separated into a fraction comprising half the volume of blackwater from a vacuum system.

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Introduction

In household wastewater, the main contribution of nitrogen (N), phosphorous (P) and potassium (K) originates from the urine fraction followed by the faecal fraction (Fig. 1). The fraction with the lowest concentration of nutrients is the greywater (Vinnerås, 2002). On the other hand, the greywater fraction is by volume the largest fraction, normally between 10 and 55 m^3 per person and year. The urine fraction is considerably smaller, with a flow of approximately 0.5 m^3 per person and year, while the faecal fraction is even smaller containing only approximately 50 kg of material per person and year.

The nutrients excreted in the urine and the faeces reflect the composition of the food consumed, where those found in the urine are the majority of the metabolised nutrients and those found in the faeces are the majority of the non-metabolised nutrients. The nutrients consumed and excreted are in equilibrium for adults and almost so for children, although only approximately 2% of the nutrients consumed during the first 13 years of life are built into the body.

In a normal flushed toilet system, the nutrients in the urine and faeces are diluted by large amounts of flushwater, approximately 15-20 m^3 $p^{-1}y^{-1}$. Even in systems using vacuum, the nutrients are diluted by at least 2-3 m^3 of flushwater per person and year if the system is functioning correctly, otherwise more. It is important to keep the diluting water volume as small as possible in order to make it economically viable to recycle the plant nutrients in the toilet fractions. The highest concentration of the nutrients is obtained if the urine and the faeces are

This paper has been peer reviewed by the symposium scientific committee collected without flushwater. However, this is probably not a generally acceptable option in the Western world of today.

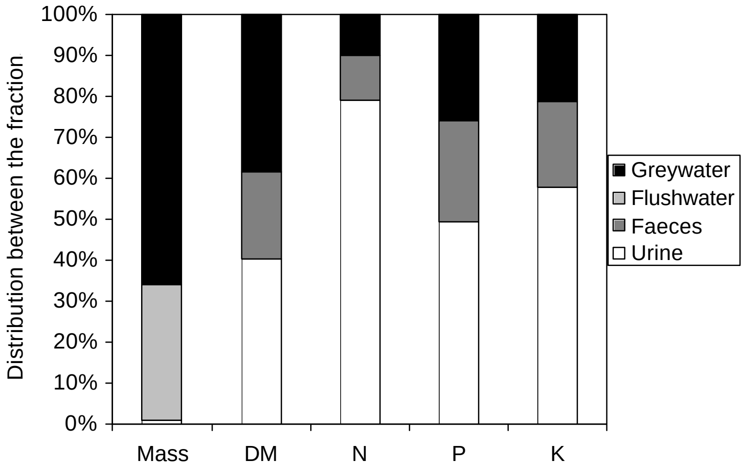

Figure 1: The amount of mass, dry matter, nitrogen, phosphorus and potassium in the different household wastewater fractions. The flushwater included represent the water usage of an average Swedish single flushed toilet (6l/flush). (Vinnerås, 2003)

However, it is possible to use a water-flushed toilet and collect the nutrients from the urine and the faeces in relatively concentrated form. The easiest way to collect the urine is to use a urine-diverting toilet (Fig. 2a-b), where the main proportion of the nutrients is collected with the urine in the front bowl of the toilet. The faecal matter should also be collected. As the faecal matter is normally solid, it is possible to collect it by solid-liquid separation after a short transport. To collect the faecal nutrients using this technique, the main proportion of the nutrients should remain in the faecal particles during the transport and separation.

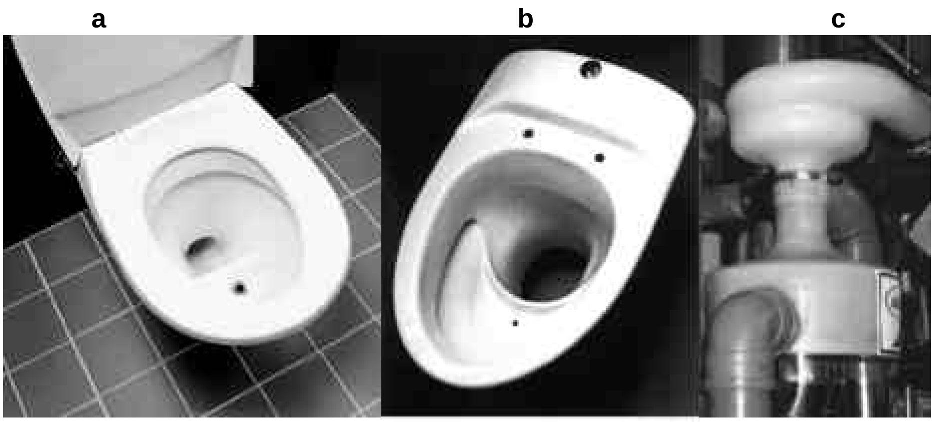

Figure 2: a) The urine diverting toilet from Gustavsberg; b) the urine diverting toilet model ES from WostMan Ecology; c) the solid liquid separator from Aquatron, which uses gravitation, surface tension and a whirlpool effect to separate the faecal matter from the water.

For this type of separation there are mainly two different separation techniques used. The first is to use a filter bag where the faecal particles and the paper are captured and where the collected matter is used as a filter medium during the coming year. Then the material is dried and composted for a year before it is used as a fertiliser or soil conditioner (Gajurel et al., 2002). The other technique is to use a separator that employs a combination of whirlpool effect, surface tension and gravitation to separate the particles and the liquids (Fig. 2c) (Vinnerås et al., 2002a). With this method, the particles are instantly separated from the liquid, thereby avoiding any risk of continued extraction of the nutrients from the particles by liquid sieving through.

Objectives

The objective of this study was to compare different techniques for separating faecal nutrients from flushwater with regards to their separation efficiency for nutrients and solid matter. Another objective was to compare the nutrient recovery potential of systems based on faecal separation and urine diversion with that of blackwater systems.

Methods

The technique of whirlpool effect, surface tension and gravitation separator combined with urine diversion was investigated with respect to its separation efficiency of the plant nutrients nitrogen, phosphorus and potassium.

The Ekoporten block of flats in Norrköping, with 35 inhabitants, is equipped with this type of faecal separation in combination with urine diversion. The apartments are equipped with urine diverting toilets and in the basement of the four-storey building, two separators are installed to separate the faecal matter (faeces and toilet paper) from the flushwater. The amount of diverted urine was also collected and measured, which made it possible to estimate the amount of urine not separated, i.e. that was misplaced (Vinnerås & Jönsson, 2002a).

Several weak spots were identified in this full-scale system. Therefore, a follow up bench-scale study was performed. In this, the sewage system consisted of a one metre vertical pipe connected via a 90° bend to a one metre horizontal pipe, at the end of which was the separator. The faecal matter was manually introduced into the vertical pipe and it was immediately followed by four litres of flushwater (Vinnerås & Jönsson, 2002b).

After the bench-scale experiment, the system was scaled up in a pilot scale experiment. The vertical drop was increased to five metres and the 90° bend was replaced by two 45° bends, thereby smoothing out the change of direction. The faeces were introduced to the system via a urine-diverting toilet located at the top of the vertical pipe. Faecal matter was first deposited in the toilet, then toilet paper and ten seconds after application of the toilet paper the toilet was flushed (Vinnerås, 2003).

The efficiency of the separation was evaluated with respect to the distribution of faecal nutrients and dry matter between the separated solids (SepS) and the separated water (SepW).

Several different studies of the collection of diverted urine, in which the urine has been collected continuously for several weeks from households, have been performed (Jönsson et al., 2000; Vinnerås, 2002). These studies combined with the study in Ekoporten make it possible to predict the collectable amounts of nutrients in the different toilet fractions.

Results and discussion

Urine diversion

There are two different types of urine diverting toilets produced today. In the first type a small urine bowl is integrated in the larger faecal bowl, examples being the toilets WostMan Ecology model DS and the urine diverting Gustavsberg toilet (Fig. 2a). The other type is based on two more defined and separate bowls, examples being the WostMan Ekology ES (Fig. 2b) and the Dubbletten. All these toilets use some water for flushing. The toilets with integrated bowls (Fig. 2a) produce a somewhat more diluted urine mixture (Höglund et al., 1999) but no significant differences in amounts of plant nutrients collected have been detected for the double flushed toilets. However, with the single flushed toilet WostMan Ekology ES, which collects the faeces dry, a significantly higher collection rate has been observed (Andersson & Jensen, 2002). This is also an indication of the effect of collecting urine by using well-functioning toilets combined with motivated users (Table 1).

The main factors regulating the urine collection rate seem to be the function of the toilet and the motivation of the users (Jönsson et al. 1998; Lindgren, 1999). With the combination of well-functioning toilets and motivated users, it seems possible to collect over 90% of the urine excreted.

The different studies indicate a collection rate between 44% and 95% of the collectable urine. When only 44% was collected, the toilets had a high degree of malfunction and non-motivated users, i.e. the users were neither informed about the system and nor aware of why it was installed (Lindgren, 1999). In a system where more than 80% of the urine was collected, the toilets were also malfunctional but the users here were extremely motivated and had chosen the system themselves (Jönsson et al., 1998). These malfunctioning toilets were produced in early stages of urine diverting systems and later models have been improved significantly.

The different systems resulted in different efficiencies of nutrient collection from the urine. The collected urine during the different collection periods was compared to the amount expected according to the Swedish default value for urine excretion (Vinnerås et al, 2003). This made it possible to estimate the amount of nutrients missed during the collection. Corrections for the time spent at home were performed, making it possible to give the values for full time persons in the different collection areas (Table 1).

Area	Motivation	Function	Type	N (g p^{-1} y^{-1})	P (g p^{-1} y^{-1})	K (g p^{-1} y^{-1})
Swedish default value[1]				4000	365	1000
Gebers[2]	+	+	A	3830	250	820
Ekoporten[3]	0	-	A	2500	230	800
Understenshöjden[3]	+	-	A	3080	265	843
Hushagen[4]	0	0	B	2800	170	580
Miljöhuset[3]	-	-	A	1852	150	450

[1](Vinnerås, 2002) [2]Wost Man Ecology ES toilet
[3]Dubbletten toilet [4]Wost Man Ecology DS toilet

Table 1: The default values for nutrient content in the diverted urine fraction compared to the amount collected in the different areas investigated. The columns showing motivation and function use +, 0 and – for indication. The toilet type refers to Fig. 2

The collection of urine in Understenshöjden and in Hushagen is reported by Jönsson et al. (2000), and that in Miljöhuset by Lindgren (1999).

Faecal separation

The initial measurements in the full-scale system indicated good separation of the faecal nutrients when non-diverted urine had been accounted for. Approximately 60% of N and P, together with 45% of K and 13% of the total mass, were collected in the separated solids (SepS). The large mass collected came from large volumes of water collected in SepS, due to many flushes per person and day combined with poorly functioning separation of the water. Therefore, the dry matter content of SepS was only 0.2%. When the misplaced urine was not deducted from the faecal water, the nutrient separation efficiency was a lot lower as the main proportion of the urine nutrients are dissolved and thereby only 13% of the nutrients of the misplaced urine ended up in SepS and the rest in SepW.

Looking closer into the system, several different factors were identified as key factors influencing the composition of the separated solids: the amount of water separated into the solid

SepS fraction; the amount of misplaced urine; the number of flushes; and the degradation of the faecal particles.

The combination of influencing factors made it necessary to look into the function of the separator. A bench-scale system was then built in the laboratory to provide good control of the influencing factors. As no urine entered the system, the evaluation of separation efficiency of faecal matter was easier.

In the bench-scale experiment, the efficiency of the faecal separation was high. Approximately 69% N, 72% P and 68% K from the faeces were separated into the SepS fraction. The dry matter content of SepS was 10%, which should be compared with that of the faecal matter introduced into the pipe, 23% of dry matter.

However even with a drop of only one metre, the disintegration of the faecal particles was high. This was identified as being caused by the sharp angle involved when shifting from vertical to horizontal transport. This was changed when scaling up the system to pilot-scale. In this, two 45° bends were used to create a smooth 90° angle, which resulted in less disintegration of the particles, even after a 5 metre vertical drop and as a result the separation efficiency increased. Approximately 82% N, 86% P and 65% K of the faeces nutrients were separated into SepS in the bench-scale experiment. The probable explanation for the increased separation efficiency was the smooth bend.

As toilet paper absorbs a lot of water, an increased number of flushes with toilet paper was shown to result in a significantly increased mass of SepS. However, when the flushes were performed with water only, without toilet paper, the volume separated into SepS was just one to two teaspoons of water for each flush. Approximately 9% of the 4 litres used per flush ended up in SepS when toilet paper only was flushed. Even if the toilet paper affects the water volume in the separated solids, it does not affect the separation efficiency of the nutrients (Vinnerås, 2003). However, the use of toilet paper increased the wet mass in SepS three times compared to when only faeces were separated.

These three system evaluations indicate that the design of the system and the installation of the different parts have a major influence on the separation efficiency. When the transition from vertical transport to horizontal is made via a gradual bend, the disintegration of particles decreases, which increases the separation efficiency. If the system is designed correctly, of the faecal nutrients it is possible to collect approximately 85% of N and P, together with 65% of K in SepS.

Other alternatives for separation of the faecal matter from the flushwater involve filtration. This can be done in two ways, either as a continuous collection where the separated matter is added to the filter cake, thereby increasing the filter volume, or by using a filter where the filter cake is removed immediately after the separation.

The separation with increasing filter cake is used in separation systems using a rottebehaelter, where the faecal matter and the toilet paper are collected over a long period, up to a year. Then the material is left and matured for another year before it is used as a fertiliser or soil conditioner. During the collection, there is a risk that the separated material is degraded and its nutrients washed out by the passing water. Vinnerås & Jönsson (2002b) have also shown increased nutrient extraction as a function of the contact time between the faecal matter and water. However, in field studies performed by Gajurel et al. (2002) it was shown that during one month of collection and one and a half months of maturation, 60% N, 40% P and 20% K were collected in the solid fraction. The advantage with this filter method is the high dry matter content (on average 30%) compared to other separation methods, but a lot of nutrients are lost. If the retention time were to be increased, even more nutrients would probably be lost.

A smaller investigation with filtration of faecal matter and instant removal of the filter cake was performed as a laboratory-scale investigation by Vinnerås & Jönsson (2002b). In that study,

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80% N, 72% P and 65% K were separated into the solid fraction. During the separation, the water content of the faecal matter increased from the initial 77% to 90%. This separation technique contains mechanical parts, which increases the risk of failure and the cost of the system. As neither the whirlpool, gravitation and surface tension separator nor the rottebehaelter have any moving parts, they are preferable for faecal separation. However, by using the filter technique with instant cake removal, it is possible to collect more of the faecal nutrients than by using continuous collection with a growing filter cake, e.g. rottebehaelter.

Collectable amount of nutrients

The combination of faecal separation and urine diversion is very promising for collection of the excreta nutrients in fractions of small volume that are easy to recycle. By using the urine diverting toilets, normally between 50% and 95% of the urine nutrients are collected. This has a major influence on the efficiency of the system, as the faecal separation can only separate the nutrients bound to, or contained in, particles.

The most efficient system from a nutrient recycling point of view is to use a blackwater system (Figure 3). However, normally these systems are highly technical, often using vacuum techniques. Another disadvantage of low flush systems is the problem of keeping the diluting water volume as low as possible. For example in mini flush systems, in reality between 2 and 4 litres of water are used after every visit instead of the few decilitres for which these systems are designed (Palm et al., 2002).

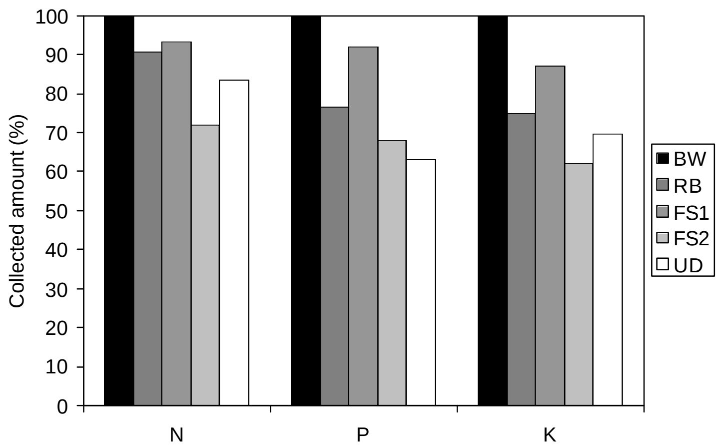

Figure 3: Estimation of the amounts of nitrogen, phosphorus and potassium collected depending on the type of system used, compared with blackwater collection, which is set to 100%. BW=Blackwater, RB=Faecal separation with rottebehaelter and 95% of urine diverted, FS1=Pilot-scale faecal separation and 95% of urine diverted, FS2= Faecal separation and urine diversion as in Ekoporten and UD=Urine diversion, 95%, only.

The scenario giving the highest nutrient recycling with faecal separation was the one where approximately 95% of the urine was diverted, as it was in Gebers (Andersson & Jenssen, 2002) combined with a separation efficiency of the faecal nutrients as in the pilot scale study (Figure 3; Vinnerås, 2003). In this scenario approximately 93% N, 92% P and 87% K were collected compared to a blackwater system.

When the faecal particles were collected in a rottebehaelter (Gajurel et al., 2002), combined with 95% of the urine being diverted, approximately 90% N, 77% P and 75% K were collected compared to a blackwater system. Compared to these results, significantly less nutrients were separated in Ekoporten (Figure 3), approximately 72% N 68% P and 62% K compared to a blackwater system (Vinnerås & Jönsson, 2002a).

The system with the urine diversion combined with faecal separation is not as sensitive as a blackwater system to the amount of flushwater used, except for the flushwater used in the urine bowl. The amount of separated solids is only slightly influenced by differences in the volume of flushwater used in the rear bowl, as it is the particles together with some water that are separated into the solids fraction (Vinnerås, 2002). When the whirlpool, gravitation and surface tension separator is used, only small amounts of water end up in the SepS fraction on flushing with water only. The main influencing factor for the water content in the SepS is the amount of toilet paper used, as the toilet paper absorbs a lot of water during the transport. This increases the water content three times compared to separation of faeces only (Vinnerås, 2003). The volume of the collected fraction is still smaller than that of blackwater systems (Figure 4). However, if the system does not function well, as is the case in Ekoporten (Vinnerås & Jönsson, 2002a), the amount of water collected in the SepS fraction can be very large (Figure 4). The amount of flushwater diluting the urine in the urine diversion scenarios was set to 0.08 litre per urination. The average flushwater volume used in Gebers was 0.07 l/flush (Andersson & Jenssen, 2002) and in Understenshöjden 0.09l/flush (Jönsson et al., 1998).

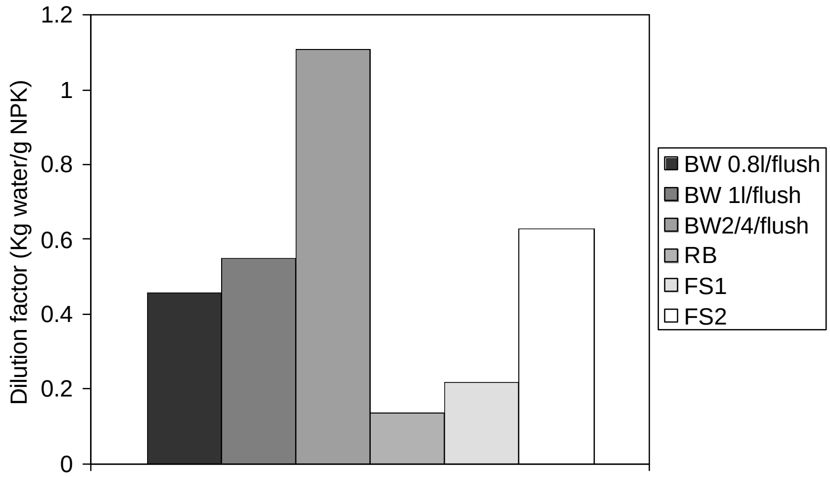

Figure 4: The amount of water collected per g of N, P and K depending on system used, BW=Blackwater systems with 0.8 litre/flush, 1 litre/flush and with 2/4 (2 litres/small flush and 4 litres per large flush), RB=Rottebehaelter urine diversion 95%, FS1=Urine diversion 95% and pilot-scale faecal separation, FS2=Urine diversion and faecal separation in Ekoporten.

The rottebehaelter and the whirlpool, gravitation and surface tension separator combined with well-functioning urine diversion gives almost as high nutrient separation as the blackwater system (Figure 3). A major difference is that the concentration of nutrients collected with a diversion and separation system is twice that of a regular blackwater system (Figure 4).

Conclusions

The preferable alternative for collection of the majority of the plant nutrients in household wastewater in relatively nutrient rich and concentrated fractions is to use a combination of urine diversion and faecal separation.

Continuous collection of the faecal matter in a filter bag, e.g. rottebehaelter, gives the smallest volumes to recycle of the systems compared. However, this system also gives significantly

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lower recycling of phosphorus and potassium compared to the whirlpool, gravitation, surface tension separator.

In a well-designed system based on faecal separation, up to 85% of the faecal nutrients can be separated. If this is combined with a well-functioning urine-diverting toilet, separating 95% of the urine, it is possible to collect 93% of the nitrogen, 92% of the phosphorus and 87% of the potassium from the toilet waste in fractions of small volume.

References

Andersson Å. & Jenssen A. 2002. Flows and composition of greywater, urine, faeces and solid biodegradable waste in Gebers. Meddelande 02:05 Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala

Gajurel, DR.,Zifu, L. & Otterpohl, R. 2002. Investigation of the effectiveness of source control sanitation concepts including pre-treatment with rottebehaelter. In Proceedings "From Nutrient Removal to Recovery". 2-4 October 2002. Amsterdam

Höglund C, Vinnerås B, Jönsson H & Stenström T A. 1999, Chemical and Microbial Composition of Source Separated Human Urine, *Proceedings "Civil and Environmental Engineering – New Frontiers and Challenges"*, November 8-12, 1999, Bangkok, Thailand

Jönsson H., Stenström T.A., Svensson J. & Sundin A. (1997). Source separated urine-nutrient and heavy metal content, water saving and faecal contamination. *Water Science and Technology* 35, pp. 145-152.

Jönsson, H., Burström, A. & Svensson, J. 1998. Measurements o two urine separating sewage systems – urine solution; toilet usage and time spent at home in an eco village and an apartment district. Report 228, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala

Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G. & Kirchmann, H. 2000. *Recycling of Source Separated Human Urine.* Rapport 2000•1, VA-FORSK (In Swedish)

Lindgren, M. 1999. Urine separating toilets – clearing of blockages, collected volume and attitudes. Meddelande 99:05 Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala

Malmen, L., Palm, O. & Norin, E. 2002. A collection and treatmnet system for organic waste and wastewater in a sensitive rural area. In Ozturk, I. & Tanik, A. (Eds.) Proceedings from "The 5th Specialised Conference on Small Water and Wastewater Treatment Systems", September 2002, Istanbul.

Vinnerås, B. & Jönsson, H. 2002a. The potential of faecal separation and urine diversion to recycle plant nutrients in household waste water. (*Bioresours Technology* 84:3, 275-283)

Vinnerås, B. & Jönsson, H. 2002b. Faecal separation for nutrient management – evaluation of different separation techniques. (*Urban Water* 04:04, 321-329)

Vinnerås B. 2002. Possibilities for Sustainable Nutrient Recycling by Faecal Separation Combined with Urine Diversion. PhD thesis Agraria 353. Swedish University of Agricultural Sciences, Uppsala

Vinnerås, B. Holmqvist, A. Bagge, E. Albihn, A. & Jönsson, H. 2003. Potential of disinfection of separated faecal matter by Urea and by peracetic acid for hygienic nutrient recycling. (*Bioresource Technology* 89:2, 155-161)

Vinnerås, B. 2003. Separation efficiency in a whirlpool surface tension separator, separating faeces and toilet pa

Urine, faeces, greywater and biodegradable solid waste as potential fertilisers*

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Keywords

Wastewater fractions, urine, faeces, greywater, potential fertiliser, metals, nutrients

Abstract

To increase the knowledge concerning the flows and compositions of wastewater fractions, field measurements were performed on the Gebers wastewater system (80 residents), which source separates the flow into four fractions of urine, dry collected faeces, greywater, and solid biodegradable waste. The flows were 1.77; 0.22; 110 and 0.18 kg per person and day respectively. The chemical compositions were reported for the following compounds: TS, COD, BOD_7, N-tot, P-tot, K, S, Ag, B, Bi, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Pd, Pt, Rh, Sb, Se, Sn, Sr, Te, W, and Zn. The NPKS relationships of urine mixture, faeces, and biodegradable solid waste at Gebers corresponded well to the crop uptake of macronutrients, which make them to potential fertilisers from a plant nutrients point of view.

A ratio of hazardous elements vs. nutrients was calculated to evaluate the potential for nutrient recycling. The lower the quotient, the better quality of the fertiliser. Obtained ratios were compared to the analogous ratios for wastewater sludge and a chemical fertiliser. The ratios of 12 non-essential elements to phosphorus and nitrogen were lower in the urine than in all of the other fractions The fertilising potential for the sludge, greywater and biodegradable solid waste was questioned in the long term perspective due to higher ratios of hazardous elements contra nutrients than the plant uptake, which implies that an accumulation of these metals may occur in the fields. To reach a mass balance on the field the fertiliser should contain lower or the same ratios than the food. Since the food is the main source of the discussed metals in urine and faeces these fractions could be potential fertilisers, provided that external sources can be restricted.

Introduction

A water and wastewater system accounts for a large portion of the flows of both water and plant nutrients in an urban society. Most plant nutrients in wastewater originate from arable land and their flow is via food and human excreta into the wastewater system. To preserve its fertility, arable land needs to be compensated for the plant nutrients removed. Today, chemical fertilisers produced by fossil resources do mostly this. In the long-term perspective we cannot securely rely on fossil resources, while the recycling of plant nutrients from human excreta to

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arable land could be another way of compensating soil fertility. Another important issue is that treated wastewater should be pure enough when it is returned to nature to not influence the ecosystem.

Stormwater, industrial discharges, and greywater are considered to be the main sources of pollution in conventional wastewater systems. Greywater is generally defined as household wastewater without any input from toilets, which corresponds to wastewater produced from bathing, showering, laundry, and the kitchen sink. While much information is available on the flow and composition, including hazardous substances, of mixed wastewater, reliable information is lacking concerning the flow and composition of its different fractions, urine, faeces, and greywater. According to Jefferson et al. (1999), Palmquist (2001), and Eriksson et al. (2002), published and reviewed literature focusing on the characterisation of greywater is very limited. The same applies to urine and faecal matter (Jönsson et al., 2000; Vinnerås, 2002). For the development and evaluation of source separating wastewater systems, reliable information is needed on the composition of the wastewater fractions. Increased knowledge concerning flows and composition, of both nutrients and hazardous substances, is necessary for assessing the quality of the fractions and the potential for nutrient recycling on arable land.

To increase the knowledge concerning the flows and compositions of wastewater fractions, field measurements were performed on the Gebers wastewater system. Gebers is a house consisting of 32 apartments, communal recreational facilities, kitchen, and dining hall, and is situated in the suburb of Skarpnäck nearby Stockholm, Sweden. Gebers has approximately 80 residents, many of them with environmental concerns, including their housing. The wastewater system of Gebers source separates the flow into three fractions of urine mixture (urine + small amounts of flush water), faeces (faeces + toilet paper collected dry), and greywater. The solid biodegradable waste is also source separated.

Objectives

This paper has two main objectives. The first is to analyse and describe the flow and chemical composition of the following four waste and wastewater fractions; urine, faeces, greywater, and solid biodegradable waste at Gebers. The four fractions cover the output waste streams from households. The second objective is to consider the potential of these fractions for nutrient recycling based on their ratios between hazardous substances and plant nutrients.

Methods

Selection of indicator substances

Today, more than 75,000 chemical compounds are present in the technosphere, with 30,000 of these being regarded as everyday chemicals that are regularly used in households (Palmquist, 2001). Due to the vast number of chemicals used in households, the high analytical costs of both organic and inorganic substances, and a limited analyses budget, a restricted number of indicator substances had to be selected for the investigation at Gebers. The choice of indicator substances was made by a group of experts. The base of the selection was ordinary wastewater variables supplemented by some hazardous organic and inorganic substances. Urine, faeces, greywater, and solid biodegradable waste were analysed for 29 metals (elements). The greywater was additionally investigated for the following organic compounds; polycyclic aromatic hydrocarbons (PAHs), poly chlorinated biphenyls (PCBs), phthalates, alkylphenol etoxilates, organotin compounds, brominated flame-retarding agents, and linear alkylbenzene sulphonate (LAS). A total number of 80 organic compounds were investigated but they will not be considered in this paper due to the restricted space.

The plant nutrients of most interest, when evaluating the recycling potential of the four fractions, are nitrogen, phosphorus, potassium, and sulphur (Swedish EPA, 2002). The four of these nutrients were measured.

Sampling

The sampling of source separated urine, faeces, greywater, and biodegradable solid waste from the households at Gebers was performed during three weeks in October 2001, divided into three periods of one week each. During this period samples of all four fractions were taken and their total mass flows were measured. In addition, during the whole period, the residents noted on a questionnaire how much time they spent at home each day. During the whole measurement period, residents were supplied with toilet paper. All samples were collected as weekly mixed samples, and were stored at -20°C until they were analysed. The solid biodegradable waste samples were ground and homogenised before they were sent for analysis.

The samples of greywater were collected proportionally to the flow. Equipment for automatic sampling was installed on the two outgoing sewage pipes from the house. For every 100 litres of greywater passing a ski board, 160 ml of sample was collected and stored in a refrigerator. The collected greywater from the two sampling points was mixed into daily samples, which were placed into -20°C. After 7 days, weekly samples were mixed from the daily mixed samples.

At Gebers, the urine is normally collected in 3 - 6 m^3 tanks in the basement of the house. During the sampling period the urine was instead piped into 3 - 25-litres plastic containers that were emptied manually twice daily into a 1 m^3 tank. At the end of each weekly measurement period, the urine was thoroughly mixed in a closed system before the samples were collected. Faeces were collected in separate bins for each of the 32 apartments; the bins were also emptied after each of the three sampling weeks. The faecal matter and the used toilet paper were mixed into a homogeneous slurry after an addition of deionised water, and then the samples were extracted. All solid biodegradable waste was collected and divided into representative samples twice weekly. These samples were later ground and homogenised before being divided into smaller samples submitted for analysis.

Analyses

Accredited contract laboratories were engaged for all the analysis work (SGAB Analytica, AnalyCen, ALcontrol). Two weekly mixed samples per fraction were analysed for TS, ash, COD, BOD_7, TOC, nitrate, and nitrite, and four weekly mixed samples per fraction for ammonia and Kjeldal-nitrogen. There were no accredited methods available for BOD_7 and COD for faeces and the biodegradable solid waste. Furthermore, two weekly mixed samples were analysed for each fraction during the first two weeks, and three samples during the last week for the total phosphorus (P_{tot}) and the elements K, Ca, Fe, Mg, Na, S, Ag, Al, B, Bi, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Pd, Pt, Rh, Sb, Se, Sn, Sr, Te, W, and Zn. The element analyses were performed by SGAB Analytica using ICP-AES/ICP-SMS. Accredited methods for the following element analyses were not available in urine; Ag, B, Bi, Fe, Hg, Pd, Pt, S, Sb, Se, Sr, and W (SGAB Analytica, 2002). For urine and greywater, the pH and conductivity was measured daily. Suspended solids (SS) and phosphate were measured on urine and greywater twice weekly (on fresh daily mixed samples).

Results

During the measurement period, residents were at home on average 15.3 hours per day. Thus, the measured flows of urine and faecal matter have been linearly extrapolated to the estimated flow during the whole day, i.e. during 24 hours. No extrapolation has been made for the flow of greywater or solid biodegradable waste. The reason for this is that the amount of showering, laundry, and cooking will only slightly be affected by the time spent at home, while the residents will most likely use other toilets when not at home.

Data for urine was denoted urine mixture, meaning that urine samples with flush water were included. The results from the faeces measurements are presented with toilet paper included. Table 1 gives the flows of ordinary wastewater variables, including seven heavy metals, in Gebers put forward as mass flows per person and year.

	Unit	Urine mixture	Faeces + toilet paper	Greywater	Biodegradable solid waste
Wet mass	kg	646	81[a]	40150	67
TS	kg	7.0	18.6[a]	14.6	16.5
BOD_7	g	1829	1223	7700	1051
COD	g	3720	1668	17500	2931
N	g	3830	710	510	324
P	g	250	250	220	57
K	g	820	280	350	182
S	g	230	78	584	33
Cu	mg	17.2	635	2370	162
Cr	mg	0.16	49	149	182
Ni	mg	4.2	82	241	89
Zn	mg	107	16940[b]	2255	675
Pb	mg	4.2	13.5	88	40
Cd	mg	0.08	5.7	5.5	2.5
Hg	mg	0.16	3.2	1.1	2.7

a) The use of toilet paper was: 8.5 kg TS per person and year

b) This value is probably partly due to corrosion from the galvanised pipes which were a part of the system

Table 1: Results from measurements of source separated wastewater fractions at Gebers. The results are given as a *mass flow per person and year*. Urine mixture means urine with flush water included. The faeces measurements are presented with toilet paper included.

	Urine mixture		Faeces + TP		Greywater		Biodegr. solid waste	
Unit	µg l^{-1}	Std dev.	mg (kg TS)$^{-1}$	Std. dev.	µg l^{-1}	Std. dev.	mg (kg TS)$^{-1}$	Std. dev.
Ag	0.03	0.01	0.64	0.40	0.265	0.007	0.022	0.011
B	969	9	7.8	0.7	49.7	11.7	10.6	2.2
Bi	<0.050	-	0.014	0.004	<0.050	-	0.017	0.010
Co	0.25	0.04	0.518	0.005	0.394	0.009	0.58	0.49
Mn	1.5[a]	-	100	3	33	3	63.4	24.1
Mo	44.4	1.4	2.24	0.04	1.10	0.03	0.83	0.18
Pd	<0.020	-	<0.020	-	<0.020	-	<0.020	-
Pt	<0.003	-	0.003	0.002	0.014	0.002	<0.020	-
Rh	<0.010	-	<0.020	-	<0.010	-	<0.020	-
Sb	0.17	0.05	0.060	0.002	0.189	0.025	0.045	0.025
Se	<20	-	0.60	0.03	0.177	0.011	<0.40	-
Sn	0.917	0.138	16	6	1.65	0.31	1.33	1.44
Sr	42.7	1.1	33.6	1.9	60.3	2.0	40.0	14.4
Te	0.02	0.01	<0.005	-	0.019	0.003	<0.09	-
W	0.099	0.012	0.062	0.017	0.079	0.002	0.005	0.000

[a] Based on two values only

Table 2: Rare elements in source separated wastewater fractions and biodegradable solid waste at Gebers. The results originate from the average values from the three (weekly mixed) samples for each fraction.

Additional metals, many of them considered as hazardous, were analysed in source separated

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wastewater fractions and biodegradable solid waste at Gebers (see Table 2).

Samples of urine were analysed for antibiotics resulting in concentrations below the detection limit 0.25 µg per litre (Johansson, 2002). 43 out of the 80 investigated organic substances were detected in the greywater. Substances from all the seven groups were found. Significant variations in the presence and concentrations of the investigated substances were observed over the three sampling weeks. These results are presented in greater detail in Andersson & Jenssen (2002).

Discussion

Ratios between hazardous substances and plant nutrients

For some of the substances, the relation between hazardous elements and the plant nutrients phosphorus and nitrogen were studied in the four fractions (Tables 3a and 3b). A ratio of hazardous substances contra nutrients is one way of evaluating the potential for nutrient recycling. The lower the quotient, the better quality of the fertiliser. Obtained ratios for the waste and wastewater fractions were compared to the analogous ratios for sludge from municipal wastewater treatment plants (WWTP) and a chemical fertiliser (Eriksson, 2001). The sludge ratios were calculated from the median values of selected metals vs. phosphorus and nitrogen from 32 Swedish WWTPs with less than 20,000 people connected (Eriksson, 2001). The reason for selecting these WWTPs was that mainly households are connected to those small WWTPs, making the comparison between the sludge ratios and the ratios for waste and wastewater fractions more adequate.

[mg / kg P]	Urine	Faeces	Greywater	Biodegr. solid waste	WW sludge[a]	Chemical fertiliser
Ag	0.08	48	52	6.2	141	<
Cd	0.31	23	27	44	37	0.24
Co	0.64	39	77	158	144	4.5
Cr	0.66	196	739	3220	926	37
Cu	68.6	2530	11550	2865	11520	6.9
Hg	0.65	13	5.3	4.2	29	0.04
Ni	16.6	330	1170	1581	480	22
Pb	16.9	54	425	710	963	2
Pt	<	0.2	2.8	<	5	0.03
Sb	0.45	4.5	37	12.4	48	0.2
Sn	2.4	1200	324	386	593	0.4
Sr	110	2520	11820	11090	3500	270
Te	0.05	<	3.7	<	5	<
W	0.26	4.7	15.5	25.4	89	0.2
Zn	426	67700[b]	12370	11940	16440	76

a) Values from Eriksson (2001). WW sludge refers to median values for WWTP with less than 20,000 persons connected. The chemical fertiliser refers to NPK-S 21-4-7

b) This high value was probably partly due to corrosion from the galvanised pipes, which were a part of the system

Table 3a: The flow of metals per kg phosphorus in the wastewater fractions urine, faeces, greywater, and biodegradable solid waste at Gebers compared to analogous ratios of WW sludge and a chemical fertiliser.

The total uptake of macronutrients of the crop is approximately 100 times larger than the total uptake of micronutrients (Hammar et al., 1993). The macronutrients are nitrogen, phosphorus, potassium, sulphur, magnesium and calcium. Of these, yearly additions are normally not needed of calcium and magnesium, since soils with acceptable pH values normally contain enough calcium and magnesium. When the pH value of the soil is too low, it is raised by additions of lime, which often also contains magnesium (Hammar et al., 1993).

In most cultivation areas yearly additions are needed of nitrogen, phosphorus, potassium and sulphur. Thus, these four elements are of high significance when waste and wastewater products are discussed as potential fertilisers. The mass ratios between the four elements are also of importance, since different kinds of crops have different uptake of these substances. Compared to phosphorus, most crops take up 4-10 times as much nitrogen, 1-8 times as much potassium while the uptake of sulphur is 0.3-1 times the phosphorus (Hammar et al., 1993).

The composition of the waste and wastewater fractions, which are derived from food, matches these ratios well. Compared to phosphorus, the N:P:K:S relationships of urine mixture, faeces, greywater, and biodegradable solid waste at Gebers were 15:1:3:1, 3:1:1:0.3, 2:1:2:3 and 6:1:3:0.6. These ratios show that the urine mixture is a very nitrogen rich fraction, which makes it a potential fertiliser. It is also seen that the sulphur/phosphorus ratio falls within the range, 0.3-1, for urine, faeces and biodegradable solid waste, which correspond to the plant uptake of the S:P ratio (Hammar et al., 1993). For greywater though the S:P ratio is 3, which means that sulphur would be added in excess if greywater would be used for P-fertilising purposes. Surplus amounts of sulphur may have acidifying effects in the soil.

[mg / kg N]	Urine	Faeces	Greywater	Biodegr. solid waste	WW sludge[a]	Chemical fertiliser[a]
Ag	0.01	16.7	20.5	1.1	100	<
Cd	0.02	8.1	10.6	7.7	27	0.08
Co	0.04	13.7	30.5	27.6	103	1.5
Cr	0.04	69	292	562	658	12
Cu	4.5	889	4566	500	8184	2.3
Hg	0.04	4.6	2.1	0.74	20	0.01
Ni	1.1	117	462	276	342	7
Pb	1.1	19	168	124	684	0.7
Pt	<	0.08	1.1	<	4	0.01
Sb	0.03	1.6	14.6	2.2	34	0.07
Sn	0.16	417	128	67	421	0.13
Sr	7.2	892	4674	1936	2487	90
Te	0.003	<	1.5	<	3	<
W	0.02	1.6	6.1	4.4	63	0.07
Zn	28	24[b]	4891	2083	11684	25

a) Values from Eriksson (2001). WW sludge refers to median values for WWTP with less than 20,000 persons connected. The chemical fertiliser refers to NPK-S 21-4-7

b) This high value was probably partly due to corrosion from the galvanised pipes, which were a part of the system

Table 3b: The flow of metals per kg nitrogen in the wastewater fractions urine, faeces, greywater, and biodegradable solid waste at Gebers compared to analogous ratios of WW sludge and a chemical fertiliser.

The plants also require micronutrients such as boron, cobalt, copper, iron, manganese and zi nc (Hammar et al., 1993). Ratios for cobalt, copper and zinc in the waste and wastewater fractions are given in the Tables 3a and 3b. The mass flows of micronutrients in the urine and the faeces are likely to correspond to the mass flows of these substances in the food, due to the mass balance of the human body. Increased zinc values in the faeces indicate that they might have been contaminated by zinc from the galvanised pipes in the collecting system. The copper/phosphorus ratios for greywater and sludge, show that contamination of copper probably occur due to e.g. corrosion of the copper pipes for drinking water.

The other 12 elements in the Tables 3a and 3b are not needed by the plants and most of them can be toxic to soil microbes, plants, and animals including humans. Therefore, accumulation of these elements in the soil might be harmful in a long term perspective. Furthermore, the natural concentration of some of these substances, e.g. Ag, in the soil is very low, which means that also small additions rapidly increase the concentration in the soil. Table 3a and 3b show that the ratios were lower for urine than in the other waste and wastewater fractions. Several studies have furthermore shown that the fertilising effect of human urine is good (Kirchmann & Pettersson, 1995; Kvarmo, 1998; Richert-Stintzing, et al., 2001).

The ratios of the 12 non-essential elements to phosphorus and nitrogen are higher in the faeces than in the urine (Table 3a and 3b). If bound to particles or low solubility in the intestines liquids the elements, taken via the food, goes directly into the faeces, while the nutrients are metabolised and excreted via the urine (Birgersson et al.,1983). Normally the pollution level of the food equals the pollution that is removed from the fields, and to reach a mass balance on the field of these substances the fertiliser should not contain higher ratios than the food. Since the food is the main source of the discussed metals in urine and faeces these fractions could be potential fertilisers, provided that external sources of hazardous elements can be restricted.

According to the Tables 3a and 3b the ratios of WW sludge in general are higher than for urine and faeces. The same applies for the greywater, which makes them to difficult fractions when it comes to their fertilising potentials. Receiving a lot of chemicals and residues from our daily activities e.g. personal care products, washing powders etc. makes them doubtful from a chemical risk point of view. The ratios for the solid biodegradable waste were also generally higher than for urine and faeces, which partly might be due to pollution from peels and contamination form surfaces e.g. some chromium might come from stainless steel surfaces. All in all the potential as fertiliser for food production for the fractions WW sludge, greywater and biodegradable solid waste must be questioned in the long term perspective due to higher ratios of hazardous elements contra nutrients than what the plant uptake can counter balance.

Conclusions

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The flows of source separated urine, faeces, greywater, and biodegradable solid waste from the households at Gebers were 1.77; 0.22; 110 and 0.18 kg per person and day during the three weeks of measurements. The chemical compositions were reported for the following compounds: TS, COD, BOD_7, N-tot, P-tot, K, S, Ag, B, Bi, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Pd, Pt, Rh, Sb, Se, Sn, Sr, Te, W, and Zn in the Tables 1 and 2.

The NPKS relationships of urine mixture, faeces, greywater, and biodegradable solid waste at Gebers were 15:1:3:1, 3:1:1:0.3, 2:1:2:3 and 6:1:3:0.6. Except for greywater this corresponded well to the crop uptake of macronutrients, which make them to potential fertilisers from a plant nutrients point of view.

The ratios of the 12 non-essential elements to phosphorus and nitrogen were lower in the urine than in all of the other waste and wastewater fractions. To reach a mass balance on the field of these substances the fertiliser should not contain higher ratios than the food. Since the food is the main source of the discussed metals in urine and faeces these fractions could be potential fertilisers, provided that external sources can be restricted. The fertilising potential for the fractions WW sludge, greywater and biodegradable solid waste must be questioned in the long term perspective due to higher ratios of hazardous elements contra nutrients than what the plant uptake can counter balance, which implies that an accumulation of these metals may occur in the fields.

The content of both inorganic and organic hazardous substances in wastewater fractions is difficult to relate to a comprehensible reference frame due to the lack of knowledge. Even in such a small and well-defined wastewater system as Gebers, the diffuse sources to the chemical flow are difficult to keep track of, which also show how difficult it is to keep fractions unpolluted in our chemical society. The obtained results, for both the more well-known and the *new* compounds, are important pieces for accomplishment of substances flow analyses for the material flows within different types of wastewater systems.

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References

Andersson, Å. and Jenssen, A. (2002). Flows and composition of greywater, urine, faeces and solid biodegradable waste in Gebers. Uppsala: Department of Agricultural Engineering, Swedish University of Agricultural Sciences. Master thesis 2002:05. ISSN 1101-0843 (In Swedish)

Birgersson, B.; Sterner, O. and Zimerson, E. (1983). Kemiska Hälsorisker. Toxikologi i kemiskt perspektiv. Malmö: Liber Hermods. ISBN: 91-23-92593-0 (In Swedish)

Eriksson , Auffarth , Henze & Ledin (2002). Characteristics of grey wastewater. *Urban Water* 4, 85-04.

Eriksson, J. (2001). Concentrations of 61 trace elements in sewage sludge, farmyard manure, mineral fertiliser, precipitation and in oil and crops. Stockholm: Swedish EPA. S-EPA report 5159. ISSN: 0282-7298

Hammar, O., Emmerman, A., Eriksson, J., Hårsmar, P.-O., Jansson, S. L., Ledin, S., Linnér, H. & Nilsson, I. (1993). Växtodling 1 – marken (Crop production 1 – the soil). Stockholm: LTs förlag, Sweden

Jefferson, B.; Laine, A.; Parsons, S.; Stephenson, T. and Judd, S. (1999) Technologies for domestic wastewater recycling. *Urban Water* 1(1), 285-292.

Johansson, M. (2002). *Personal communication*. Contact: Environmental Chemistry, Umeå University, SE-901 87 UMEÅ, Sweden.

Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G. & Kirchmann, H. (2000). Källsorterad humanurin i kretslopp (Recycling source separated human urine). Stockholm: VA-FORSK/VAV. VA-Forsk Report 2000•1, Sweden. (In Swedish, English summary)

Kirchmann, H., Pettersson, S. (1995). Human urine – chemical composition and fertilizer efficiency. *Fertilizer Research* 40, 149-154.

Kvarmo, P. (1998). Humanurin som kvävegödselmedel till stråsäd. Uppsala: Dept. of Soil Sciences, Swedish University of Agricultural Sciences. Master thesis No. 107 (In Swedish)

Palmquist, H. (2001). Hazardous Substances in Wastewater Systems – a delicate issue for wastewater management. Luleå: Div. of Sanitary Engineering, Luleå University of Technology. Licentiate Thesis 2001:65

Richert-Stintzing, A., Rodhe, L. & Åkerhjelm, H. (2001). Humanurin som gödselmedel – växtnäring, spridingsteknik och miljöeffekter. Uppsala: Institutet för jordbruks- och miljöteknik. JTI-rapport Lantbruk & Industri 278. (In Swedish)

SGAB Analytica (2002). URL: www.sgab.com

Swedish EPA (2002). Aktionsplan för återföring av fosfor ur avlopp (Action plan for recycling of sewage phosphorus). Stockholm: Swedish Environment Protection Agency, Report 5214. (In Swedish – English summary and conclusions)

Vinnerås, B. (2002). Possibilities for Sustainable Nutrient Recycling by Faecal Separation Combined with Urine Diversion. Uppsala: Department of Agricultural Engineering, Swedish University of Agricultural Sciences. Doctoral thesis Agraria 353. ISSN: 1404-6249

The use of separated human urine as mineral fertilizer*

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Keywords

Fertilizer, field experiments, urine

Abstract

Human Urine contains most of the macro nutrients e.g. nitrogen humans excrete. Thus, separated human urine may be used as mineral fertilizer. In two field and one greenhouse experiments we compared the nitrogen availability of urine with mineral and/or organic fertilizers. On grassland we applied urine, slurry and a slurry urine mixture in two dosages (sum: 110 NH_4-N ha^{-1}). On arable land we applied to winter barley mineral fertilizer, urine and a slurry urine mixture in three dosages (sum: 170 NH_4-N ha^{-1}). On grassland and arable land, the urine plots tended to remove higher N amounts from the soil. However there were no significant differences between different treatments. In the greenhouse experiment we applied acidified urine with pH 4, urine with pH 8 and mineral fertilizer to Lolium multiflorum/italicum. The plots treated with urine showed higher N removals compared to the mineral fertilizer plots. Urine N may substitute N from mineral fertilizer. Due to the low N content in the urine we suggest to apply the urine with slurry. Treatments like acidification of urine could be buffered in a slurry with a high alkalinity.

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Introduction

Urine has a high content of nitrogen, phosphorus and potassium. Thus urine has the potential to be used as a mineral fertilizer. Only few studies have been performed with urine as fertilizer such as (Johannson, 2000), (Fittschen & Hahn, 1998), (Kirchmann & Pettersson, 1995). Comparative studies with one substrate in different management systems are missing so far. We compared yields and N availability from separated urine with other organic and/or mineral fertilizers on grassland and arable land. We did not focus on antibiotics or endocrine disruptors that may prohibit urine spreading in agriculture.

Materials and methods

Urine: From the experimental site „Lambertsmühle“ in Germany separated human urine was used. The macro nutrients and pH of the urine are listed in table 1. In the storage tank the urine was acidified with sulfuric acid to reduce microbial contamination and ammonia emissions. Compared to undiluted human urine the urine in the separation tank showed lower N concentrations that are similar to animal slurry.

*This paper has been peer reviewed by the symposium scientific committee

	N_{tot}	NH_4^+	P_{tot}	K^+	pH
Urine "Lambertsmühle"	1.4	1.2	0.15	0.5	1.8*
Undiluted urine	6.7	0.4	0.5	1.8	8.1

Table 1: Chemical composition of human urine from the "Lambertsmühle" used in the field experiments. The composition is compared to undiluted human urine [g l^{-1}], *: the urine was acidified with sulfuric acid.

Sites: The two sites (sandy loam) were next to the Lambertsmühle. Physico chemical parameters of the arable land are listed in table 2.

	texture	pH	P_2O_5 (mg/100g soil)	K_2O (mg/100g soil)	MgO (mg/100g soil)
arable land	sandy loam	6.5	17	19	15

Table 2: Soil parameters of arable land

On grassland we applied urine (pH 4.8), cattle slurry and a mixture of urine/ cattle slurry (50% NH_4^+ from each substrate). The plots were fertilized twice (first application: 60 kg NH_4^+-N ha^{-1}, second application: 50 kg NH_4^+-N ha^{-1}) and harvested thrice. Arable land with winter barely was fertilized in three dosages (first application: 60 kg NH_4^+-N ha^{-1}, second application: 60 kg NH_4^+-N ha^{-1}, third application: 50 kg NH_4^+-N ha^{-1}). We used urine (pH 4.8), mineral fertilizer (CAN) and a mixture of urine/cattle slurry (50% NH_4-N from each substrate). On both sites control plots received no fertilizer.

At each site we used a randomized block design with four treatments and four replicates. We compared the yield and N-removal.

To calculate the N-availability of the fertilizer N uptake of control plot were subtracted from the fertilized plots. Statistical analysis was performed with SPSS10.

In a greenhouse experiment the plant availability of urine-N was tested with Lolium multiflorum/italicum on a silty soil (table 3). Acidified urine (pH 4) and urine with a pH similar to untreated urine (pH 8) were compared with mineral fertilizers (CAN) at two dosages (1 and 2 g mineral N per pot with 9 kg soil).

texture	pH	N_{tot} (%)	P_2O_5 (mg/100g soil)	K_2O (mg/100g soil)
silt	6.3	0.08	6.7	4.8

Table 3: Soil parameters of the greenhouse soil

Results

Grassland: There were no significant differences in the yield from fertilized plots (figure 1). The urine used was acidified and thus no damages due to high pH on plant surfaces occurred.

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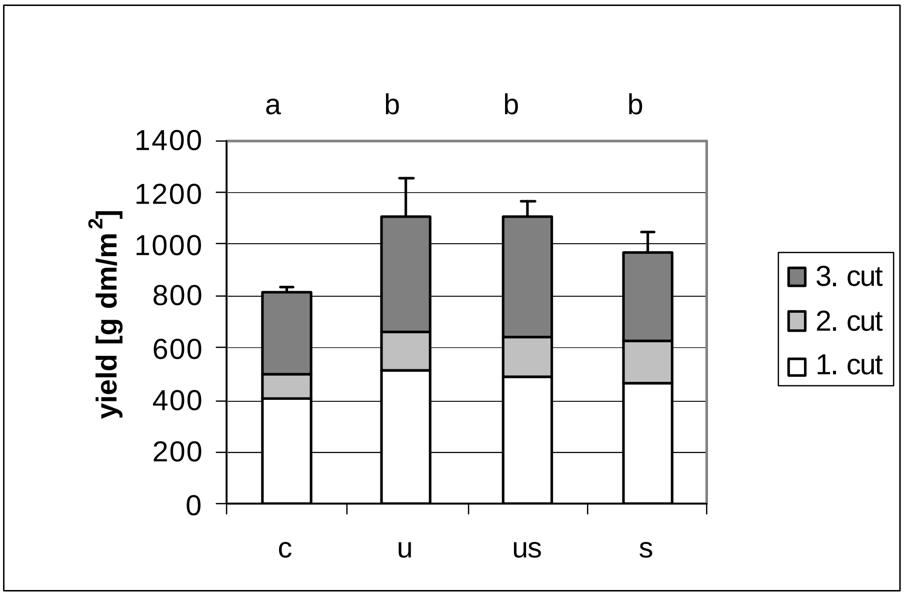

Figure 1: Yields from grassland, 1., 2. and 3. cut [g m^{-2}]; c: control; u: urine, s: slurry; u/s: mixture of urine and slurry.

The N removal was highest from plots that received either urine or a mixture of urine and slurry (figure 2), probably due to the acidified urine or mixture. N availability from urine was higher compared to slurry but again there were no significant differences (figure 3).

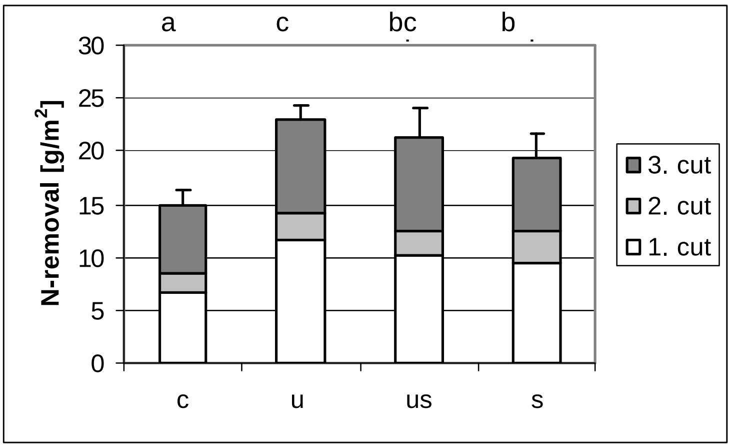

Figure 2: N-removal from the different plots (grassland); c: control; u: urine, s: slurry; u/s: mixture of urine and slurry.

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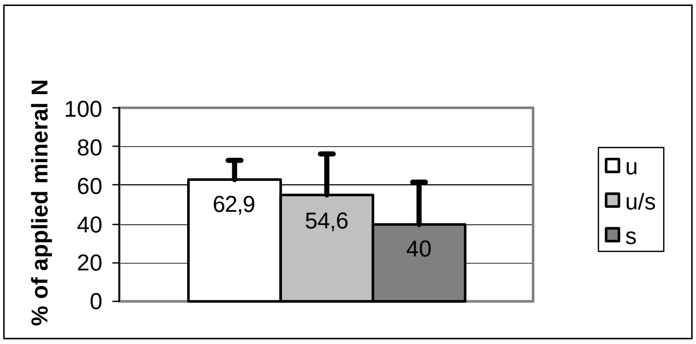

Figure 3: N-availability of the fertilizer used (% of the applied amount of mineral N) in a plot experiment (grassland); u: urine, s: slurry; u/s: mixture of urine and slurry.

Arable land: The barley yields from plots fertilized with urine or urine/slurry were higher compared to plots fertilized with mineral fertilizer (figure 4).

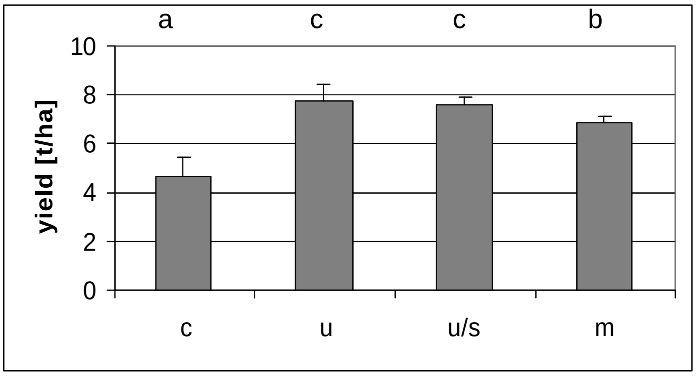

Figure 4: Yields from arable land (barley), yield [t/ha]; c: control; u: urine; u/s: mixture of urine and slurry; m: mineral fertilizer (CAN).

The N availability from the urine was higher compared to the other treat ments (figure 5). The application of urine went along with an "irrigation" of the plots because of the low N concentration of the urine. Probably the higher yields were induced by this additional application of water on the urine plots since the soil was quite dry when we fertilized the plots.

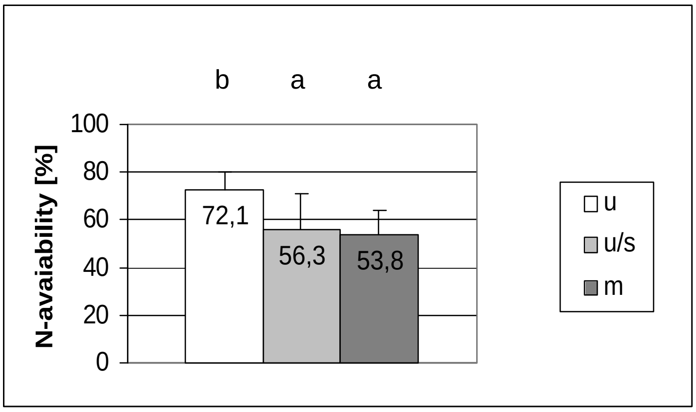

Figure 5: N-availability of the fertilizer used (% of the applied amount of mineral N) in a plot experiment (arable land; barley); u: urine; u/s: mixture of urine and slurry; m: mineral fertilizer (CAN).

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Greenhouse study: After the first cut the yields from untreated urine (U_8) tended to be lower compared to those from the other fertilizers (figure 6). This may be due to losses of ammonia (high pH of the urine). Also the yields from pots that received high urine amounts (U_4II and U_8II) were lower compared to those with low urine dosage (U_4I and U_8I), probably due to a higher input of sodium chloride. At the end of the experiment there were no significant differences within the groups with low and high N gifts.

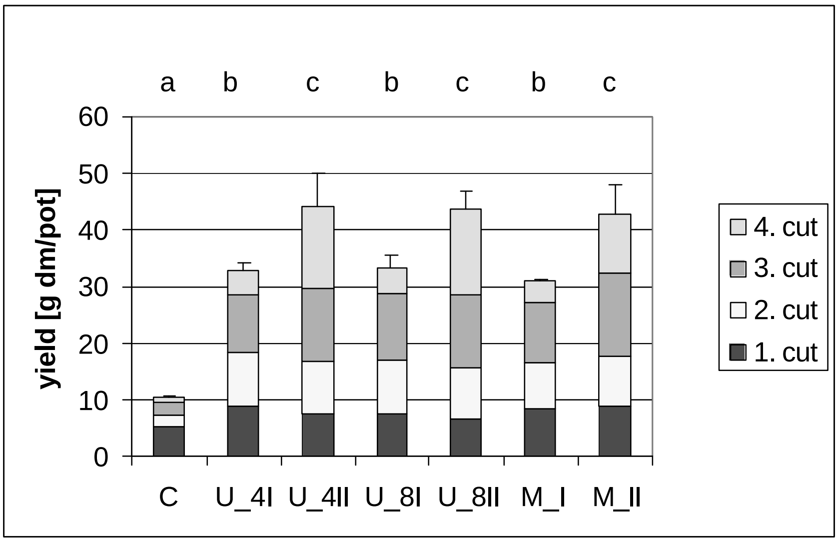

Figure 6: Yields from the greenhouse pot experiment (Lolium multiflorum/italicum)[g dm/pot]; c: control; u_4I: urine with pH 4 and 1 g NH_4^+-N; II: 2 g NH_4^+-N; _8: pH 8; m: mineral fertilizer (CAN).

The N availability from the fertilizers were in a range of 71.9 to 90.1 % of the applied mineral N (figure 7).

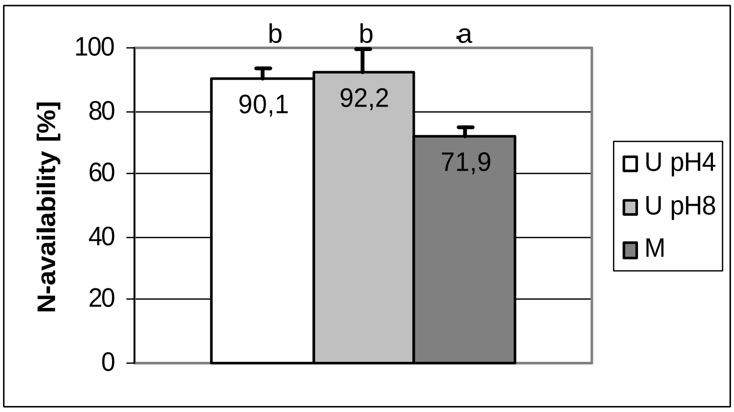

Figure 7: N-availability of the fertilizer used (% of the applied amount of mineral N) in a pot experiment (Lolium multiflorum/italicum); u: urine, m: mineral fertilizer (CAN).

Conclusions

Urine seems to be a suitable mineral fertilizer if the urine is acidified (pH<5) in order to reduce ammonia losses and plant damage. It should not be use in excess to avoid yield losses due to high inputs of sodium chloride.

We suggest to mix urine with animal slurry since application technologies for animal slurries are suitable for urine application, too. In such a case, urine acidification even to a very low ph (as in our field experiments) does not lead to plant damage because slurry has a high buffer capacity due to its high alkalinity.

References

Fittschen, I. & Hahn, H. H.: Characterization of the municipal wastewater part human urine and a preliminary comparison with liquid cattle excretion, Water Science Technology, 38, No. 6, 1998, pp. 9-16

Johannson, M.: Urine Separation - closing the nutrient cycle; final report on the R&D project Source-Separated Human Urine - A future source of fertilizer for agriculture in the Stockholm region? Stockholm Water Company, 2000

Kirchmann, H. & Pettersson, S.: Human urine - Chemical composition and fertilizer use efficiency, Fertilizer Research, 40, 1995, 149-154

Integrated systems on biogas production, non-polluted agricultural production and sanitation in rural China

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Keywords

Agricultural production, biogas, integrated system, sanitation

Abstract

This paper introduces three typical biogas systems that take anaerobic fermentation of human and animal "wastes" as the key technology and integrate biogas production with agricultural use of digested effluent and sludge, and sanitation. These popularly disseminated systems in China practice the theory of "closing the loop" and achieve great significant benefits on promotion of renewable energy utilization, improvement of farmers' living environment, increase of farmers' revenue from saving their expenditure on commodity fuels by biogas, and improvement of agricultural products by using organic fertilizer instead of chemical fertilizer.

Regarding with the population who are engaged in agricultural production, China is surely named as the biggest agricultural country in the world. The 2002' statistical yearbook[1] states that by the end of year 2000, there were 853.7 million rural populations, 66.57% of the total national population, much higher than 42.38% of the global average. On the other hand, the animal husbandry in either intensive farm or domestic scale, the animal husbandry is developed rapidly. However, contradicted with the increase of rural population and animal husbandry, the human urine and excreta and animal manure trend to be less and less effectively used, which worsens the rural opening environment and the quality of surface and underground water. Consequently it results in the spreading of infectious diseases. In year 2000 the chemical fertilizer application was 327.0 kg/hectare as a national average and to achieve a near-term high productivity, farmers shift to apply more and more chemical fertilizer, even traditionally, Chinese farmers used to apply human urine and excreta and animal manure for agricultural production. It was estimated that only 35% of the total fertilizer input was from organic fertilizer (Li Qingkui, 1998) and the utilization rate of human urine and excreta was less than 30% (Li Qingkui, 1998).

To solve the contradiction between more output of human and animal "wastes" from increasing population and expanding animal breeding and their less agricultural use is a systematic subject which concerns with multiple factors such as theoretical research on ecological circulation of matters, technical solution, financial feasibility, and social acceptance, etc.. Likely, there are some existing activities happening in China to take care of the treatment and re-use of the "wastes" in terms of improvement of toilet structure, handling approaches of "wastes", as well as from the point of end use or disposal. Currently, wide-spreading systems integrating "wastes" from toilet and animal houses with their agricultural use after appropriate treatment and taking the anaerobic fermentation as the key linkage in China sound prospective as a model of "closing the loop".

[1] 2002 Statistical Yearbook issued by the Chinese Ministry of Agriculture

Household biogas-integrated systems were originally developed and used mainly for energy production (biogas) in early 80's when the whole state faced a strong competitive demand on energy sources with the dramatic economic development after opening to the outside world and reform. Then the systems are improved gradually to be an integrated system with multiple functions along with the change on energy, agricultural production, rural development, as well as macro economic development. Consequently according to the statistics from the Ministry of Agriculture, the systems had been extended to over 9.57 million households accumulatively by the end of 2002 and 857.4 in operation in that year.

The experience shows that the systems are with multiple functions including clean energy production, sanitation, as well as green farming:

- Biogas - clean and renewable energy to replace coal, LPG, as well as firewood;
- Green farming - use of digested organic effluent and sludge;
- Sanitation - Improvement of living environment by avoiding open disposal of the wastes, elimination of flies production etc.

The systems experience the theory of "closing the loop". Urine and excreta from human beings, animal dung, and sometimes organic garbage from farm households are flowed to a biogas digester which produces biogas for both domestic use as household cooking and lighting and production use like biogas lamps in greenhouses as carbon fertilizer. The digested effluent and sludge then are used for agricultural plantation such as vegetable, cereal, and orchards. All the agricultural products are consumed by human beings and animals.

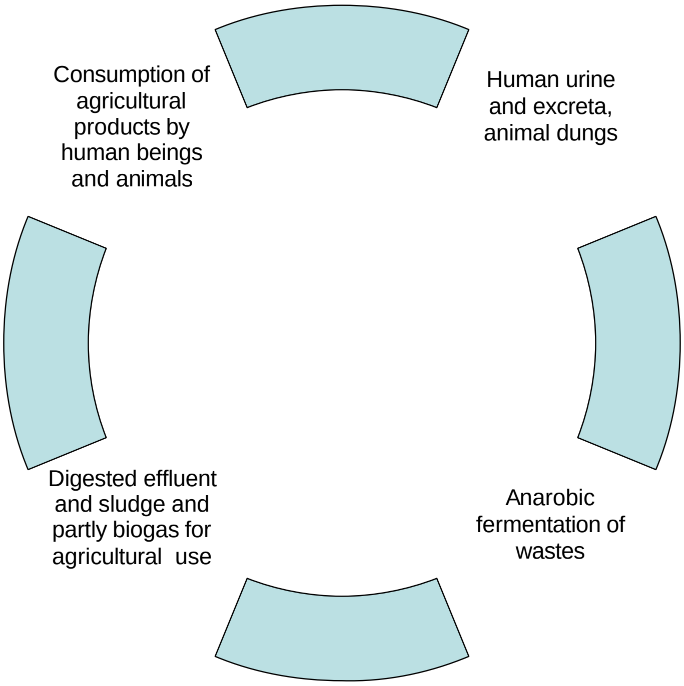

Figure 1: "Closing-Loop" of the integrated biogas system

Varying on various features of climate, agricultural production structure, availability of resources, as well as social behaviors in different regions in China, there are three major typical models in China. Shortly, there are named as "four-in-one" in cold Northern China, "pig-biogas digester-orchards" in southern China with more tropical climate, and "five components integration" in Northwestern China with dry climate.

I. "Four-in-one" model in cold Northern China

The system is consisted of the following essential components: a solar greenhouse facing the south with a area of around 200 – 600 m², a 20 m² animal house at its western or eastern side of the greenhouse, a 1 m² toilet, and a biogas digester with a volume of 6 m³ underground the animal house.

The northern model integrates the biogas digester, animal house, toilet, and the agricultural plantation in a closed solar greenhouse which keeps the digester, animal house, and plantation with an appropriate temperature and humidity to make the biogas production, animal raising, and plant growth possible in cold winter in Northern China. The greenhouse is constructed with a well-insulated wall as the framework at the northern side and usually adopts plastic film for sunshine transfer at the side facing south. The test done by Liaoning Rural Energy Office shows that even when the outside temperature is minus 20 °C, the inner temperature can reach over 10 °C, which enables the biogas production and agricultural plantation. Meanwhile, the animal breeding also helps to raise the greenhouse temperature. Measured by Liaoning Rural Energy Office, ten pigs weighing over 50 kg in pigpen inner a 100 m² enables the greenhouse temperature raise 1°C, and ten pigs weighing over 100 kg 1.5 °C. Carbon dioxide produced from exhale of pigs and combustion of biogas inner greenhouse increases the temperature of greenhouse and provides the plants as carbon fertilizer. On the other hand, the photosynthesis of plants provides sufficient oxygen for animal breath. The digested effluent and sludge from biogas digester is used as fertilizer for plants, which replace the application of chemical fertilizer and enable the vegetables and fruits certificated as non-polluted products.

All the system components form a well-circulated loop of energy and material flows (Fig 1).

A integrated system with a greenhouse covering 667 m², in which 494 m² of agricultural plantation land, a 8 m² biogas digester, a 20 m² pigpen, and a 15 m² room for farmers' stay, costs around US$ 1,840 as primary investment. With a yearly incremental revenue of around US$ 635 from sale of plants and pigs and save of chemical fuels and fertilizer, the dynamic investment recovery period is less than three years when taking 10% as the discount rate.

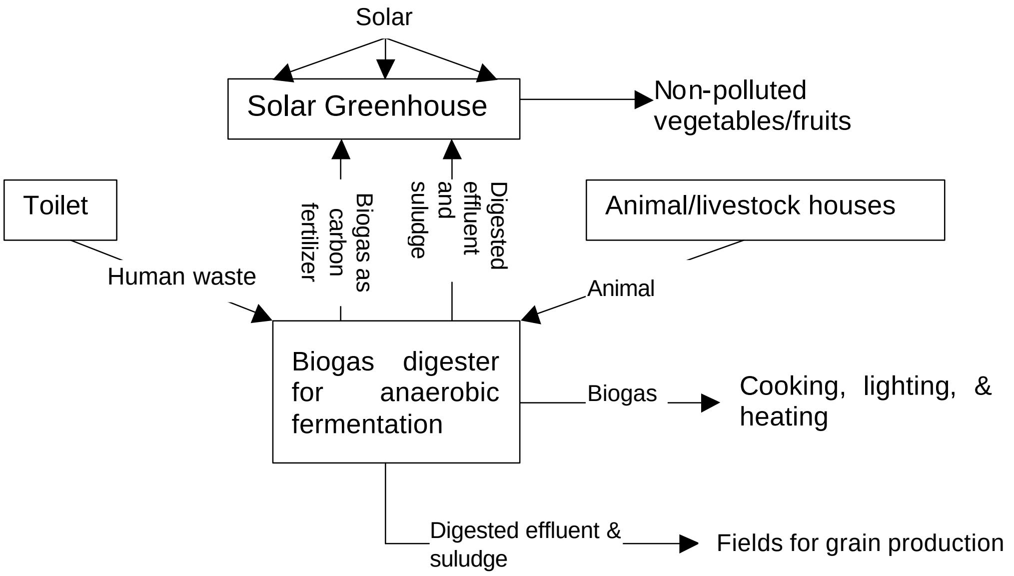

Figure 2: Sketch of "four-in-one" model in Northern China

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II. Pig-biogas digester-orchards"model in Southern China

The typical model on integrated biogas system for tropical southern China is normally consisted of the following essential components: an animal house (pigpen) covering 20 m^2 with 4-5 pigs in stock normally, a 8 m^3 biogas digester, and 0.33 hectare of orchard land or vegetable land. Similarly with the northern model, the digested effluent and sludge are applied for fruit or/and vegetable production, and the biogas for household cooking and lighting. Additional to that the toilet is connected with the inlet of digester, in some modern styles, the digested effluent can even be used to flash the toilet, which saves the water consumption. The improved orchard land, reconstructed pigpens, nearly built digester, and reformed sanitation toilet costs around US$ 585. With direct saving of cooking fuels and electricity by biogas, saving of chemical fertilizer by organic fertilizer, and incremental income from more and better quality fruits (vegetables, etc.) and pigs, the total revenue from the biogas integrated system is estimated as US$ 280, which makes the invested recovered in about two years.

More importantly, the replacement of firewood by biogas in southern China has a significant role on local ecological improvement. It is estimated that one biogas integrated system with a warm climate in Southern China can produce 450 m^3 of biogas. It is equivalent to the yearly growth of 0.35 hectare of firewood forestry.

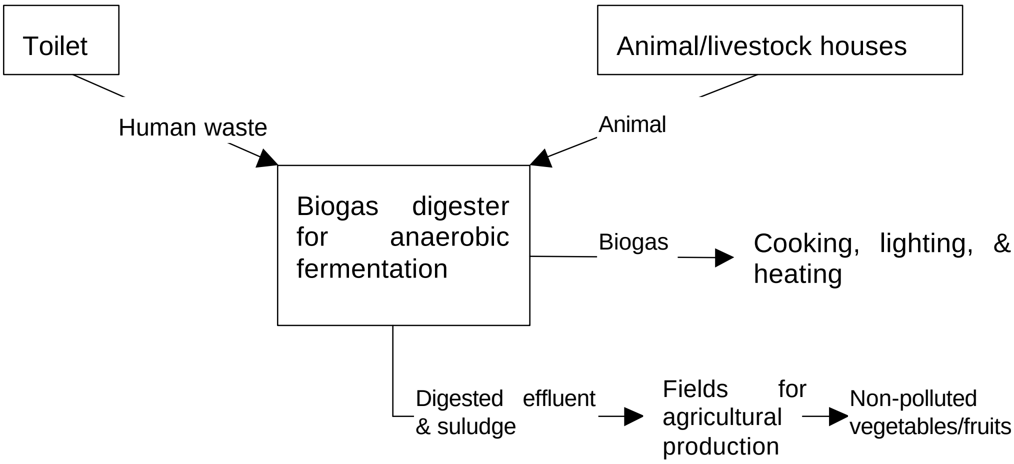

Figure 3: Sketch of "pig-biogas digester-orchards"model in Southern China

III. "Five components integration" model in Northwestern China

Considering the dry climate in North-western China, based on the availability of arable land, the system integrates 0.33 hectare of orchard land, a stay room for orchard care persons, 8 – 10 m^3 covered water tank, a 10 – 20 m^2 pigpen covered with plastic film in winters for 4 – 6 pigs in stock or sheep house, a 8m^3 biogas digester under the pigpen, and a toilet into one system. The biogas digester is the core which combines the plantation with the animal breeding, and the domestic life with the production. The water tank for saving rainfall in rainy seasons for the whole-year-around consumption provides water for not only human beings, animal or/and livestock, and biogas digester, but also production use of plantations.

The whole system including the improvement of orchard land and construction of a orchard care room, a 20 m^2 solar pigpen, a water tank, and a 8 8m^3 biogas digester costs US$ 646 in local price level. A yearly saving of fuels by biogas use and of chemical fertilizer by organic fertilizer application and a yearly incremental income from fruits or/and vegetable production and pig breeding account for US$ 256 in average. Consequently, the primary investment can be recovered in three years.

IV. Comprehensive utilization of products from the systems

Biogas for carbon dioxide in greenhouses

The content of carbon dioxide in atmosphere is around 0.03%. While biogas combustion in greenhouses can increase its content to over 0.1%, which accelerates the photosynthesis of plants, then their yields. Table 1 shows the impact of different contents of carbon dioxide to plants in greenhouses.

Content of CO_2 (%)	Celery		Cucumber yield (kg/m^2)
	Height of plant (cm)	Weight of single plant (g)	
0.02 – 0.03	44.9	7.8	7.8
0.08 – 0.11	66.8	12.5	10.3

Table 1: Impact of carbon dioxide increase by biogas combustion in greenhouses (Source: Zhou, 1999)

Fertility of digested effluent

For the anaerobic fermentation is a complex biochemical process, the contents of digested effluent vary with the differences of raw materials, rotation time, fermentation technique, etc.. Table 2 shows a test on its fertility.

Digested effluent	Whole C (mg/ml)	Whole N (mg/ml)	Whole P (mg/ml)	Whole K (mg/ml)	NH_3-N (mg/l)	Rapid effective P (mg/l)	Rapid effective K (mg/l)
Number of samples	135	133	74	75	74	78	78
Maximum content	4.82	0.99	0.98	3.90	971	315	3,900
Minimum content	0.42	0.09	0.10	0.38	24	4.95	375
average	2.03	0.39	0.37	2.06	295.5	73.32	1,758.3

Table 2: Fertility contents of digested effluent (Source: Yuan, 2001)

Conclusions and recommendations

The experience on integrated biogas system application in China shows that the different models designed on various local natural and economic conditions fit the local demands. They practice the theory of closing the loop by integrating biogas production by anaerobic fermentation with "wastes" treatment and agricultural utilization, by taking the "wastes" as valuable resources for agricultural use, and contributing to the improvement of sanitation condition in rural China.

However, in the current systems, there is no separation between urine and excrete in human wastes, and the animal waste is mixed with all the human waste from toilets. After anaerobic fermentation with normal-temperature (without any external heating input and the fermentation temperature varies upon the surrounding environment), the digested matter is applied for agricultural use without any further hygienic treatment. Therefore, it is recommended that there is urgent need on systematic studies on pathogen killness effectiveness in normal-temperature anaerobic fermentation and on safeness of agricultural use of digested effluent and sludge, such as their application on plantation. Specially, there is a use of digested effluent and sludge for animal breeding like pigs or/and fish. In this issue, a joint work between international and national efforts and a joint team composing expertises from different sectors including resource management, energy, health, sanitation, etc. should be fully encouraged.

References

Li Qingkui, et al.: Fertilizer Problem in Sustained Agricultural Development in China, Chemical Industry Press, 2000, P 13, P114

Zhou Mengjin, et al.: Biogas Production and Utilization Technologies, Press of China Agriculture University, 1999, P322

Yuan Ruihua, et al.: Biogas Eco-Agriculture Technologies, China Agriculture Press, 2001, P129

Composting with human urine: plant fertilizer approach*

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Keywords

Composting, fertiliser, human urine, plants, nutrients, temperature

Abstract

The purpose of this study was to collect the nutrients contained in human urine (nitrogen, phosphorous and potassium) by composting with grass leaves and fruit peel and to increase the compost activity by decreasing the C:N ratio. Compost temperature was used as an indicator of compost activity.

The tests demonstrated the importance of the structure in the material for good aeration of the compost, as ground raw material maintained lower temperatures than non-ground. Adding urine increased the nutrient content of the compost. Some of the nitrogen was lost as ammonia emissions but there was still more nitrogen and presumably more other macro- and micro-nutrients in the compost after urine addition. Addition of approximately 10-15% urine to the wet weight of the compost material increased the compost reaction and rendered a higher top temperature of the treatment. Thus, adding urine to the compost process can render better sanitised and stable mature compost in a shorter time period compared to when no urine is added.

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Introduction

Most of the nutrients in household wastewater come from human urine, approximately 80% of nitrogen and more than 50% of phosphorous and potassium (Vinnerås, 2002). However, urine only contributes 1% of the volume of household wastewater (Figure 1).

The nitrogen and the phosphorus are potential pollutants that have to be removed in the wastewater treatment plant. Most toilets in Thailand are water closets. The household wastewater is normally treated in septic tanks, located underground at each house, and discharged to the closest water recipient, groundwater or surface water.

In this kind of water-borne system, there are mainly two preferable solutions: 1) Large sewage treatment plants; and 2) Decentralised, source separating systems that recycle the nutrients and keep the pathogens out of the water.

In this region, large-scale wastewater treatment is not an economical option, except for the central parts of larger cities.

The overflow of these septic tanks finds its way to the nearest canal or possibly seeps and contaminates the underground water. This results in contamination by chemicals and microorganisms, leading to disease transmission and difficulty in locating clean drinking water.

*This paper has been peer reviewed by the symposium scientific committee

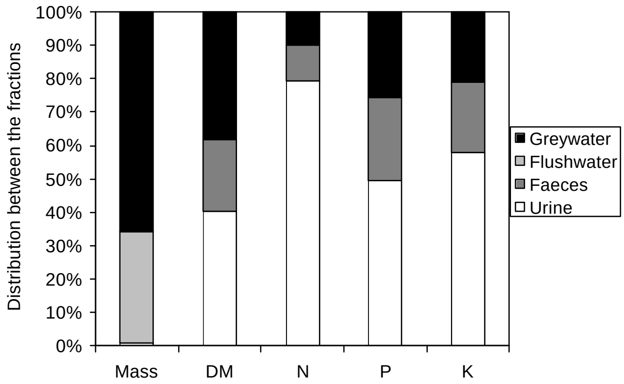

Figure 1: The amount of mass, dry matter, nitrogen, phosphorus and potassium in the different household wastewater fractions. The flushwater included represent the water usage of an average Swedish single flushed toilet (6l/flush). (Vinnerås, 2002).

In the near future, the cost of clean drinking water production will increase to levels not affordable for increasing parts of the community.

Separating urine right from the source and treating it in a small volume would be an easier option but in view of its nutrient value, it is even wiser to use this urine as plant fertiliser and gain the extra benefits to the economy and the environment. Taking the proposed new Swedish norm (Table 1), the amount of urine produced per person and year is 550kg, which in terms of nutrients represents 4.0kg N, 0.365kg P and 1.0kg K (Vinnerås, 2002).

		Urine	Faeces	Toilet paper	Greywater	Biodegradable waste
WM	Kg	550	51.5	8.9	36500	80.3
DM	Kg	21	11	8.5	20	27.5
BOD_7	g	-	-	-	9500	-
COD	g	-	-	-	19000	-
N	g	4000	550		500	550
P	g	365	183		190	104
K	g	1000	365		365	82
Cu	mg	37	400		2900	549
Cr	mg	3.7	7.3		365	137
Ni	mg	2.6	27		450	82.3
Zn	mg	16.4	3900		3650	700
Pb	mg	0.73	7.3		350	275
Cd	mg	0.25	3.7		15	2.7
Hg	mg	0.30	3.3		1.5	0.25

Table 1: The proposed norm for composition of the different fractions of household wastewater and biodegradable solid waste per person and year

The urine from the 14.000 students at King Mongkut's Institute of Technology, North Bangkok, corresponds to 56 tons of nitrogen, 5.1 tons of phosphorous and 14 tons of potassium per year. This urine is enough to fertilise 400-500 hectares.

Getting people in Thailand to accept application of human urine as a fertiliser is not easy. The main issue is the sociological difficulty, as the common belief is that human excreta are dirty and a disease transmission pathway. Approved sanitisation methodology by storage at temperatures above 20°C for six months is one of the keys to this barrier (Höglund et al., 1999, 2000, 2002). Other difficulties in implementing these systems are of a more practical nature: 1) There is no urine source separating toilet seat available in the sanitary products market in Thailand. 2) Urine is liquid and to transport this volume to the farm or application site is costly. Evaluating the energy consumption for transport compared to wastewater treatment and production of mineral fertilisers, it is still economical to transport the urine 200km (Jönsson et al., 2000).

One way to tackle the transport of these large volumes could be to trap the nutrients of the urine in a biological process by composting with carbon-rich organic waste. The nitrogen in the urine would increase the biological processes as the energy production increases, which would increase the temperature of the compost. The higher temperature achieved would make the compost safer, as pathogens and weed seeds would be killed by the treatment (Vinnerås et al., 2003). It would also be possible to capture some of the nutrients chemically by precipitation, e.g. adding Mg^{2+} to the urine precipitates struvite (NH_4MgPO_4). However, this kind of chemical treatment would only make it possible to capture the phosphorus and some of the nitrogen, while the major proportion of the other nutrients would still remain in the liquids. When using the urine in the compost, some of the nitrogen would be lost while the major proportion of the other nutrients, both macro- and micro-, would remain in the compost.

Composting

Composting is a biological decomposition of organic biodegradable material. As a result of the compost process a dark, soil-like material is formed. The degradation mainly occurs by the enzymatic digestion of material by soil microorganisms. Composting can be both aerobic and anaerobic, depending on the local conditions. Different conditions such as temperature and oxygen content lead to different microorganism concentrations, but the end product from the treatment is more or less the same. However, aerobic treatment can give rise to higher temperatures, due to more exothermic reactions. Anaerobic treatment gives a smaller final volume, as less organic material is used for construction of cell matter compared to in aerobic treatment.

The composting of organic matter can occur in different temperature ranges. Psychrophilic bacteria work in the lowest temperature range -18 to +13°C. Psychrophiles give off a small amount of heat as a by-product of their work, and this causes a rise in the ambient air temperature in the pile. Mesophilic bacteria act in a mid temperature range 21-32°C. Above that temperature, between 40°C and 93°C, the thermophilic bacteria are active.

In a normal aerobic composting process, the temperature first rises to about 35 °C, during which time the pH drops to approximately 4. After a few days with a temperature of about 35 °C, the pH increases and as a result of that the thermophilic bacteria increase their activity, which results in a rapid rise in temperature (Smårs et al, 2003). This high activity, optimal activity, occurs at approximately 55°C (Haug, 1995), and if it can proceed for a few days, much of the available organic material is degraded. This degradation leads to poor structure and a decrease in the temperature. Turning the compost material constructs new pores for the aeration and creates new contact areas for the microorganisms to find more easily degradable carbon. These two factors produce another increase in the temperature of the compost.

Diversity of composting materials

The diversity of the raw materials used is the key factor to good compost. In addition to major plant nutrients such as nitrogen, phosphorous and potassium, plants need several trace elements too. The more diverse the material composted, the more likely it is that these elements can be returned to the plants. Using a diversity of materials also increases the chances of having a suitable carbon-nitrogen ratio in the compost material. The C-N ratio in the compost directly affects how well the materials are composted. It is the term used to describe how much carbon a material contains relative to nitrogen. Microorganisms metabolise carbon for energy, and nitrogen for reproduction. The microorganisms use these two elements in the proportions of about 25-30 parts carbon to one part nitrogen. With this ratio in the substrate, the microorganisms can work and reproduce quickly if other factors such as aeration and moisture also are adequate. However, most materials available for composting do not have this ratio. Therefore, different materials need to be mixed into the compost to get a good mixture and C:N ratio. For example, mixing 50% by weight of brown tree leaves (C:N=40:1) with 50% grass clippings (20:1) results in a fast decomposing blend, with a 30:1 ratio. The C-N ratio of matured compost should not exceed 20, as a lot of carbon is lost during respiration by the microorganisms (Haug, 1995). During this process, a considerable amount of nitrogen, 40-60%, is also lost due to gaseous emissions.

Objectives

The main objective of this study was to determine the effects on the compost process of biodegradable household waste when the nitrogen content was changed, both on a small scale (1 litre) and pilot scale (200 litre).

Another objective was to see the dependence of the compost temperature when using different turning intervals. The final objective was to monitor and evaluate the effect of the nitrogen content in the matured compost using the different mixes and turning strategies.

Materials and methods

Materials

The urine was collected in a urinal installed at the Department of Industrial Chemistry. The urinal was connected via a plastic pipe to a small collection tank that was emptied every second day into a larger storage tank.

Two different sets of composters were used in the tests. Initially, small scale composting was

a b c

Figure 2: a) the urinal for collection of urine, b) the 1 litre urethane foam compost reactors, c) the 200 litre plastic compost reactor.

carried out in approximately 1 litre urethane foam compost reactors (Figure 2). For the larger scale tests, 200 litre compost reactors were used, one of plastic (Figure 2) and one of iron.

The composting material used in the tests consisted of grass, leaves and fruit peel as the carbon source. To get a good structure in the compost, chopped coconut husk and coconut fibre was used as an amendment. The collected human urine was used as the nitrogen source. To get a good initial microbiological population in the compost material, old, mature, compost was also added.

Eight sets of experiments were performed in the small compost reactors. The material composted was a mixture of 500g fruit peel, 50g coconut husk amendment, 130g old compost and varying amounts of urine (0, 50 ,100 ,150g). When different amounts of urine were added, the moisture content was adjusted by water addition to a level corresponding to the highest urine addition (150g). Two different sets of fruit peel were used, one where the peel was ground into small pieces and one where it was added as it was, in larger pieces. The composts were tuned/mixed every day and the temperature was monitored during the tests.

During the pilot scale composting in the 200 litre reactors, a mixture of 14 kg fresh grass, leaves and fruit peel was mixed with 2kg coconut amendment, 10kg old compost and different amounts of urine (0, 1, 3, 6kg). When different amounts of urine were added, the moisture content was adjusted by water addition to a level corresponding to the highest urine addition (6kg). Two different turning regimes was tested for the compost reactor, one reactor was turned every day and the other every third day. During this experiment, the temperature and the difference in nitrogen content in the final product was tested.

The nutrient content in the matured compost was analysed for its content of nitrogen, phosphorous, potassium and organic carbon. The nitrogen was analysed using the Kjeldahl method. Phosphorus was analysed by spectrophotometer (420 nm). Potassium was analysed using ICP-EAS. The total organic carbon was analysed using the Walkley-Black method (oxidation with $K_2Cr_2O_7$ in conc. H_2SO_4 followed by titration with $FeNH_4SO_4$ using o-phenolphthalein ferrous sulphate as indicator).

The buffering capacity of the matured compost was investigated as the pH of the mixture of 90% distilled water and 10% compost was monitored when 0.5M HCl was added. The buffering capacity of the compost was compared to the capacity of distilled water, and presented as the difference in HCl consumption for decreasing the pH from 7 down to 4.

During the 3 weeks of composting, the leachate was collected and the pH was monitored every second day.

Results and discussion

In the small sale composting reactors, two different structures of the material were tested; ground and non-ground fruit peel and different amounts of added urine. A tendency towards a higher temperature was found in the tests with non-ground material (Figure 3). The main reason for this was probably an effect from the better structure attained in the reactors with non-ground fruit peel. The higher structure resulted in better aeration of the material and thereby higher activity.

The different addition regimes of urine indicated that addition of 14% urine by wet weight to the mixture gave the best effect. This clear tendency was evident in reactors with both ground material and non-ground material.

Initially, the two pilot scale reactors were compared for their heat loss; both reactors had only small amounts of insulation. The results showed that there were high losses of heat from the reactors, even when the surrounding air temperature was between 25 and 30°C. No significant difference was found between the two construction materials, plastic or iron, of the reactors

(Figure 4). However, there was a tendency to be colder in the iron reactor, probably due to less insulation.

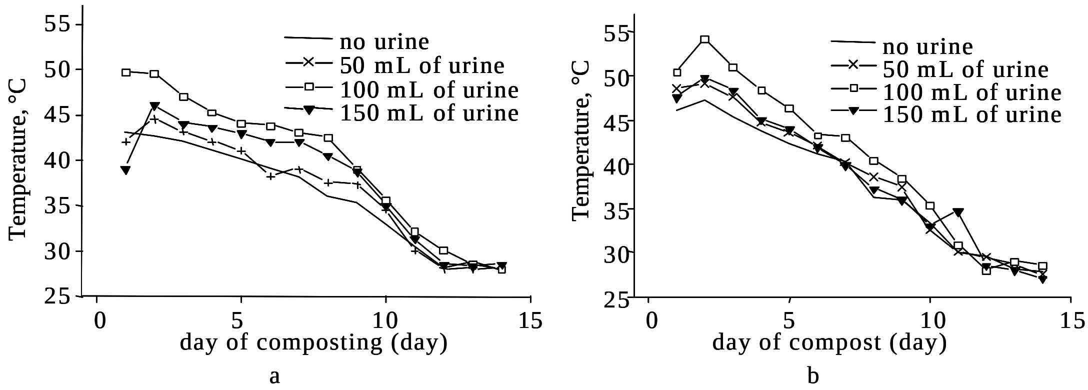

Figure 3: Temperature over time with different urine additions to pilot-scale compost reactors with a) ground and b) non-ground fruit peel.

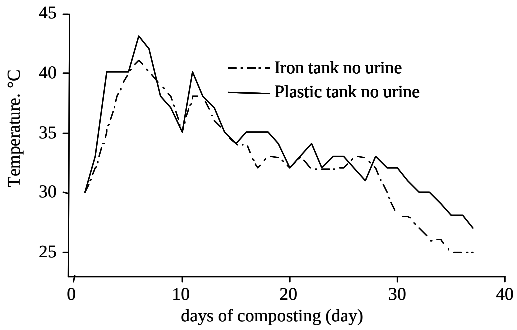

Figure 4: Effect of composting reactor construction material (iron or plastic) on compost temperature

Adding urine to the compost material gave a higher increase in temperature and a higher final temperature compared to the material to which no urine was added (Figure 5), although there were no significant differences in temperature of the compost between 1 litre and 3 litre addition of urine. The addition of urine also resulted in a more rapid process, so the urine composts were faster to reach the ambient temperature (Figure 5).

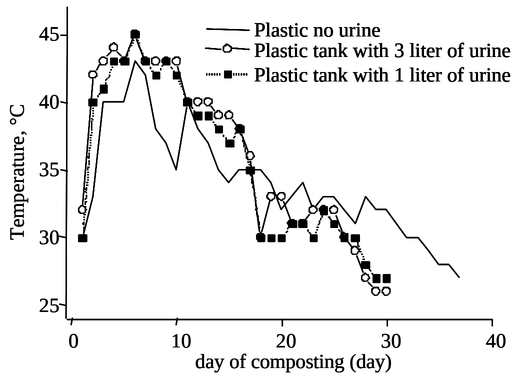

Figure 5: Effect of addition of 1 or 3 litres of urine to compost on temperature in the compost reactor.

Comparing the two different turning regimes for the compost every day to turning every third day, both the treatment temperature and the duration of treatment differed (Figure 6).

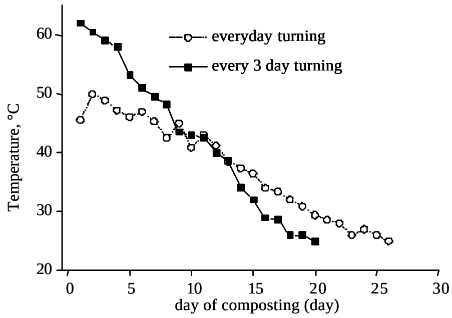

Figure 6: Effect of turning frequency on compost temperature.

When compost is turned every day, the material is cooled down to such extent that it is not possible for it to reach as high temperatures as a compost turned every third day. On the other hand, frequent turning of the compost material is important in maintaining a good structure for aeration and in creating new contact surfaces between the material and the microorganisms. Therefore during high activity phases, the compost should be turned more often than during low activity phases.

The total amount of nitrogen in the compost when greater amounts of urine were added increased somewhat (Fig. 7). The different turning regimes (1 day per turn and 3 days per turn) gave a significant difference in the amount of available nitrogen in the mature compost. The lower turning rate resulted in a significantly higher amount of nitrogen remaining in the compost.

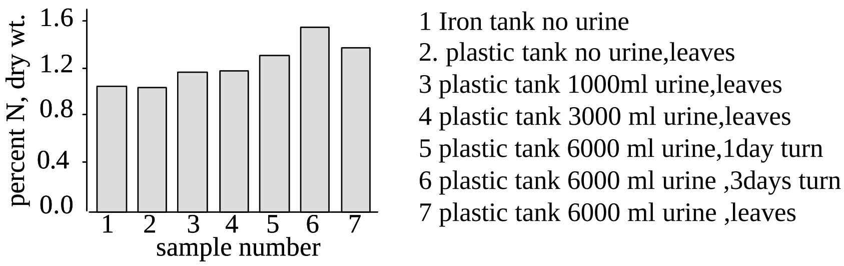

Figure 7: Nitrogen concentration in the matured composts with different urine additions and turning regimes.

In the compost mixes to which urine was added, the C/N ratio decreased compared to the no urine mixtures. This was mainly due to higher nitrogen content (Figure 7) combined with higher degradation of the organic material. Looking more closely at the different dosages of nitrogen in the compost process, the addition of 3 kg urine to the reactor had a major effect on the degradation of organic matter (Figure 8), especially since the concentration of nitrogen in the matured compost was similar to that in the compost that received only 1 kg (Figure 7). However, this indicates that the high degradation of organic matter was accompanied by a major loss of nitrogen, probably as ammonia emissions that can affect the environment in terms of eutrophication or acidification.

The highest addition of urine (6kg) with the lower turning frequency resulted in a higher amount of nitrogen in the end product, but a comparison of Figs. 7 and 8 shows that the lower turning rate tended to give a higher degradation, probably due to the higher activity in the material as indicated by the higher treatment temperature.

The pH in the compost leachate remained quite stable during the whole composting process within the range 7.96 - 8.03.

The buffering capacity of the compost material was significantly higher compared to that of the distilled water, so adding the compost to soil as a fertiliser would improve both the fertility of the soil and its buffering capacity.

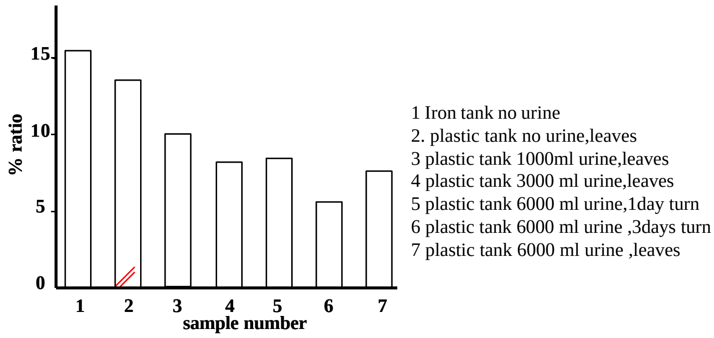

Figure 8: Carbon/nitrogen ration of the matured composts with different urine additions.

Conclusion

The small-scale treatments showed the importance of the structure in the material for composting, as the ground material did not reach as high temperatures as the non-ground one.

Addition of urine increases the nutrient content of compost. Even though some of the nitrogen may be lost as ammonia emissions, the compost still contains more nitrogen and presumably more other macro- and micronutrients too.

The addition of approximately 10-15% urine to the wet weight of the compost material increased the compost reaction and produced a higher top temperature of the treatment. Thus, adding urine to the compost process renders better sanitised and more stable mature compost in a shorter time period compared to when no urine is added.

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Acknowledgement

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References

Haug R.T. (1995). *The Practical Handbook of Compost Engineering*. Boca Raton, Florida, USA: LEWIS

Höglund C., Vinnerås B., Jönsson H. & Stenström T.A. (1999). Chemical and microbial composition of source separated human urine. *Proceedings "Civil and Environmental Engineering – New Frontiers and Challenges"* November 8-12, 1999, Bangkok, Thailand. Bangkok: AIT

Höglund C., Vinnerås B., Stenström T.A. & Jönsson H. (2000). Variation of chemical and microbial parameters in collection and storage tanks for source separated human urine. *Journal of Environmental Science and Health Part A: Environmental Science and Engineering* 35, pp. 1463-1475.

Höglund C., Ashbolt N., Stenström T.A. & Svensson L. (2002). Viral persistence in source-separated human urine. *Canadian Journal of Microbiology in press*

Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G. och Kirchmann, H. 2000. *Recycling of Source Separated Human Urine.* Rapport 2000•1, VA-FORSK (In Swedish)

Smårs, S., Gustafsson, L., Beek-Friis, B. & Jönsson, H. 2002. Improvement of the composting time for household waste during an initial low pH phase by mesophilic temperature control, *Bioresource Technology* 84:3, 237-241

Vinnerås B. 2002. *Possibilities for Sustainable Nutrient Recycling by Faecal Separation Combined with Urine Diversion*. PhD thesis Agraria 353. Swedish University of Agricultural Sciences, Uppsala

Vinnerås, B. Björklund, A. & Jönsson, H. 2003. Disinfection of faecal matter by thermal composting – laboratory scale and pilot scale studies. *Bioresource Technology* 88:1, 47-54

Sewage sludge humification in a sequential conversion procedure

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Keywords

Conversion, fertilising, sewage-sludge, soil-conditioning

Introduction

The reuse and disposal of sewage sludge has become of great interest all over the world. Intending to improve the acceptance ipp-consult has developed a system to convert sewage sludge to a substrate similar to humus (humification or conversion of sewage sludge). In a PPP-measure ipp-Consult has been contracted by GTZ to introduce this process in Egypt, where it had to be adjusted to the Egyptian climatic, social and economic conditions.

Project background

The drying of the sewage sludge in drying beds is the most common method in Egypt and also appears as the most efficient technique due to the normally short drying intervals. However the morphological, chemical and hygienic quality of the dried product is insufficient.

The content of nutrients in the sewage sludge is high, 1 kg of dry matter in Egypt contains for example an average of 17 g of nitrogen, 10 g of phosphorus, and many other micronutrients. These nutrients get lost from the nutrient cycle, if sewage sludge is simply disposed, i.e. dumped or burned, and not re-used. Therefore, sewage sludge should be regarded as a resource of nutrients and soil conditioner which can be used as a high-quality organic fertiliser in agriculture. Fresh sludge contains, besides harmless germs of the intestinal flora, also pathogens.

In Egypt the use of sewage sludge is legally restricted (Egyptian Sludge Regulations; Decree 214/1997), and these regulations are difficult to be complied with. Quality characteristics, which are important and indispensable, were taken from the American guidelines (Clean Water Act, Part 503, 1993), but their realisation was not sufficiently considered. According to these guidelines, sewage sludge can only be applied on arable land, if its hygienic qualities are proved by a corresponding analysis. Expensive analyses of the microbiological parameters have to be effected on a regular basis at the expense of the plant user and/or of the purchaser. Furthermore, a number of bureaucratic obstacles make the legal sale and the re-use of sewage sludge more difficult.

Project targets

Primary target of the project „Sewage sludge conversion in Egypt“ is the long-term improvement of the environmental situation with respect to sewage sludge and to establish an effective and sustainable method to gain a product of high quality from sewage sludge in the project locations El Minia and Nawag. The training of local experts shall provide a multiplication effect, which enables operators of waste water treatment plants of other communities to apply and integrate the method in their sludge treatment system. Furthermore, the product shall be used in agriculture as a fertiliser and soil conditioner.

Aimed results

After completing the project, technically and socio-economically acceptable solutions should be elaborated, tested and applied, which are transferable to other climatic regions in Egypt.

The method of sewage sludge conversion should known by other treatment plant operators as well as authorities of other regions within Egypt.

The correct application of converted sewage sludge as a high quality fertiliser should be known by farmers in the region of the project locations El Minia and Nawag. The awareness among the farmers, participating experts and treatment plant operators with respect to the interrelations between agriculture, environmental protection and soil protection should increase.

Course of the study

The project, which was initiated in March 2001, was executed during a period of 17 months. The study was divided into phases. Phase I (3,5 months) mainly served for organisatory tasks (selection of locations, permissions) and for first large scale experiments at the locations Tanta and El Minia. After some dissatisfying results, the experiments were continued in a bigger programme on a small scale in Nawag (Phase II: 3,5 months). Here, it was possible to determine the plant species to be used as well as the methods of operation. In Phase III (6 months) the results of the previous phase were tested with respect to their transferability on large scale in Nawag and El Minia. The fourth and last phase (4 months) of the project served for the execution of several agricultural experiments and field tests and the presentation of the project. The presentation of the project and information of the farmers was based on the execution of a socio-economic field study. The information campaign covered the local region as well as the governmental basis.

Present situation – problems of the dried sludge

The fast drying of sewage sludge in hot and dry climate has the disadvantage that the hydrolytic and microbiological decomposition as well as the microbiological conversion of organic and inorganic substances is minimized. After a few days, the humidity is not sufficient for the survival or the reproduction of microorganisms. If the dried product is applied in agriculture offensive odours may occur.

Disadvantages are often the big size and hardness of the lumps, the low water storage capacity, the low hygienisation rate and the low microbiological conversion of the organic substances during the short drying period.

The agricultural experiments with dried sludge in El Minia and Nawag showed that the product has high contents of substances which have harmful effects on plants. This substances lead to lower germination rates and to a slower development of the plants. The hygienic analysis showed a general decrease of pathogenic germs, but after a drying period of some months the product still contains, a high risk potential with respect to salmonellae and Helminths. All these disadvantages can be avoided with a well operated conversion system.

Basic knowledge about sewage sludge conversion

Sewage sludge conversion with grass

The principle of the conversion of sewage sludge is based essentially on the development of an environment in the sludge which differs considerably form the environment which appears in the drying sludge. The development of leaves and roots support the reproduction and development of micro-organisms which can also be found in natural soils. This mainly happens because of the dying and of the regeneration of root-cells, the aeration and the chemical compounds (root-exudates), which are emitted by the roots of the plants.

Sewage sludge is filled in layers of 30 – 40 kg TS/m² into so-called conversion polders. These polders usually have a usable depth of 1 m. A minimum filter layer of 20 cm of sand above 20 cm of gravel should be provided. Between the filling of each layer the sludge should dewater through air-drying and drainage.

After the completing of the fillings, the sludge dewaters until first cracks appear on the surface. The establishment of an environment similar to soil provides different decomposition processes in the sludge, which are comparable to the generation of humus or the composting of sewage sludge. Apart from the additional aeration, the penetration of roots has the effect of loosening up the sludge which is preventing the creation of large lumps during further drying.

After the complete development of the grass and the conversion of the first layer, the next layer of sludge can be filled in. With each further layer, the above described process will be repeated until the polder is filled (40 – 50 cm). The already developed environment in the lower layers probably plays an important role in the conversion of the next layer. Also the grass, which is not harvested, has an important influence by providing a structure and additional aeration of the fresh sludge after the filling. After the completing of 4 – 5 cycles, the product can be used.

Sewage sludge conversion with reed

In contrast to the conversion with grass, the reed species "Phragmites australis" is planted in polders with depths of 1 m – 1.5 m. For a better development, the filter layer (comparable with the filter layer of the grass conversion polders) is covered with a layer of soil (20 cm). At first, the reed develops a complex root system, after that, with the increasing height of the sludge, a rhizome system is developing.

The rhizomes begin to grow at the vegetation points when they are covered with sludge. This development provides the additional aeration of the sludge and supports the development of an environment which is similar to a natural reed location. Through the metabolism of the reed, the organic substance in the sludge is mineralised. The processes are comparable to the conversion with grass. The difference is that reed can grow also in anaerobic environments. The reason for this is that reed can transport oxygen from the green parts of the plant to the root zone.

The filling can be carried out in relatively short intervals. Normally the polders are used for 5 up to 10 years without emptying. Therefore, the method is continuously in contrary to the discontinuous conversion with grass, however the product contains a lot of reed roots and straw is only partly decayed.

Operational differences of sludge conversion compared to Germany

Conversion with grass

The most important difference to the operation of sludge conversion polders in Germany is the necessity of irrigation and the application of other grass species. Already the experiments in Nawag during the second phase have shown, that the regular irrigation of the sludge is indispensable for the germination and development of the grasses especially during the first

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weeks of growth. Especially in the germination phase the process is very sensitive. The use of pre-germinated seeds as well as the covering of the surface with straw is recommendable to support the germination.

The operation of a conversion facility in Egypt requires more attention than a comparable plant in Europe. Another difference is the use of tropical grasses for the process.

For the safe and functional operation of a sewage sludge conversion plant (SSCP) it is necessary to fulfil the following requirements:

- Existence / Installation of an irrigation system or irrigation facility. This can be treated waste water or liquid sludge in limited charges.
- Detailed schedule for the operation and maintenance of the polders
- Homogenous quality and sufficient biological stability of the sludge
- Sufficiently trained and motivated personnel

Experiences in El Minia and Nawag have shown that the process of conversion is sensitive especially in the first 2 weeks after seeding. The germination of the grass seeds on sludge of low biological stability need regular irrigation. A necessary post-stabilisation of the sludge leads to delays in the process and more space required.

Conversion with reed

The experiences in Nawag have shown, that the reed is less affected by the stabilisation grade of the liquid sewage sludge. For this reason, the required stabilisation is minor in comparison to the conversion with grass. Nevertheless, it is necessary to work with lower loads in the case of a low biological stability, which results in a reduction of the possible annual load.

The necessary and strict fulfilment of the loadings is a disadvantage of this method because it is not possible to react flexibly to high overloads and plant damages. Another disadvantage of the method is the necessity to chop up the final product to prevent the development of reed plants after the application on the field. This is dangerous, especially in Egypt, because the agricultural field are mostly irrigated by flooding which is an optimum condition for reed to sprout again.

For the operation of the sewage sludge conversion with reed, the following requirements must be fulfilled:

- The upper filter layer (sand) in the polder should contain sand of the quality 0/2. Coarse sand leads to negative results
- The outlets of the polder drainage should be equipped with valves to provide the possibility to inundate the polder for some days during the growth of the reed
- A detailed schedule for the operation and maintenance is indispensable
- A homogenous sludge quality and a sufficient grade of biological stabilisation of the liquid sludge are desirable.

Results of investigation - quality of the products

Morphological and aesthetic quality of the products

For the evaluation of the results a comparison between the products of the well-known and practiced drying of sludge and the conversion of sludge was made:

Dried product	Converted sludge
The structure shows large lumps	The structure is crumbly and looks like soil penetrated with roots
The colour is black-grey	The colour is mainly brown
Faecal odour develops after moistening	Only the odour of soil can be noticed
The sludge attracts flies, larvaes and ants	

Table 1: Average morphological and aesthetical appearance

pH-value, content of salt, organic substance

Parameter	Dried product	Converted sludge
PH-Value	6 - 7	5,8 – 7,18
Chloride	1,94 %	0,435 %
Sulphate	2,09 %	0,378 %
Electrical Conductivity	9,15 mS/cm	0,99 mS/cm
Volatile Solids	52 % - 75 %	36 % - 46 %

Table 2: Average pH-value, content of salt, organic substance (Nawag)

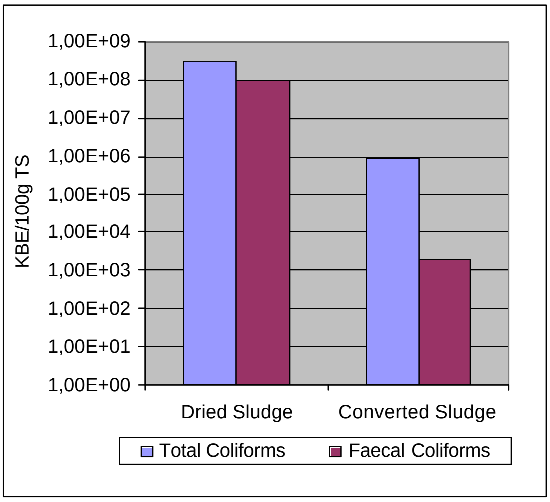
Plant nutrients

Parameter	Dried product	Converted sludge
Total Nitrogen	2,4 %	2,9 %
Total Phosphorous	0,5 %	0,6 %
Potassium	0,2 %	0,4 %
Magnesium	0,3 %	0,8 %

Table 3: Average concentrations of plant nutrients

Hygienic and microbiological qualities of the product

The efficiency of the reduction of coliform germs, faecal coliforms, salmonellae and helminth eggs is very different. The method of sludge conversion has evidently a strong hygienisation effect whereas the majority of the germs survive during the simple air drying of sludge.



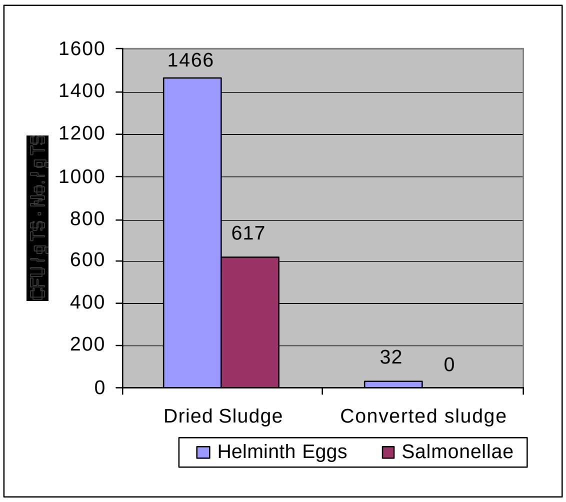


Figure 1 (left): Contents of Total Coliforms and Faecal Coliforms (Nawag)

Figure 2: (right): Contents of Salmonella and Helminth Eggs (Nawag)

Indicator for the contents and formation of humin-nutrient complexes is the micro organism Actinomycetis. Also here notable differences are observable.

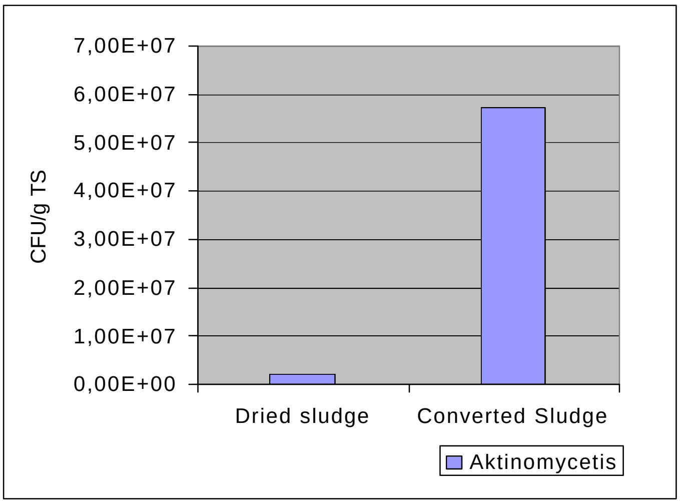


Figure 3: Contents of Salmonella and Helminth Eggs (Nawag)

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Agricultural experiments

The agricultural experiments in Nawag and El Minia were initiated to examine the quality of the converted sludge. At the same time, the suitability of the dried sludge was examined under the same conditions to give hints referring to its characteristics as fertiliser and soil-conditioner. The experiments showed evidently that with respect to both objectives of examination (germination rate and yield) the application of converted sludge is preferable compared to the use of air dried sludge. The germination rates in the sand were so low, that the aimed minimum number of plants per plot often was not achieved.

Especially the results on pure sand in Nawag obviously indicate that the availability of nutrients in converted sludge is adapted to the demand of the plants compared to the instantly available nutrients in dried sludge is potentially dangerous for the cultivated plants (Over-fertilization). The figure below shows the development of the plant Ladyfinger (Okra) in sand with different additions of dried and converted sludge.

Figure 4: Development of Ladyfinger on sand (f. l. t. r.: with 30l dried sludge, 10l dried sludge, 30l converted sludge, 10l converted sludge and without any soil conditioners)

Field study: agricultural application of sewage sludge

The results of the study show that the application of sewage sludge is known by the majority of the farmers. Furthermore, the study reveals that dried sludge is applied in Egypt and that the demand is increasing. Concerning the application of the converted sewage sludge product, the study draws the conclusion that the use can be supported by information and advisory campaigns, above all because the time needed from the first perception to the adoption of a method is up to 4 years. Most of the interviewed farmers prefer the application of sewage sludge products for the cultivation of crops and are interested in expanding the use of these products. Main limits are the high prices and the lack of supply. The majority of the farmers is willing to visit and participate in campaigns and experiments according the topic and to transfer their knowledge. With respect to the product “converted sludge”, the majority of the farmers is willing to use “converted sludge” immediately.

Conclusion

The aim of the project, the introduction of an effective and lasting method to produce high-quality sewage sludge in El Minia and Nawag, has been achieved. In Nawag, the treatment methods “sewage sludge conversion with grass” and “sewage sludge conversion with reed” were tested and applied for a period of 9 months.

The sewage sludge conversion with reed is assessed as less suitable since operational errors may quickly cause a failure in the process which cannot easily be corrected. Furthermore the reed roots within the product are feared by the farmers.

Regarding the morphological, aesthetic and hygienic characteristics, the generated sludge product, has significant advantages after a conversion period of only 2.5 months compared to the comparable dried substrates. If this technique is operated correctly, all hygienic risks, which may be caused by sewage sludge, can be reduced to a minimum.

The chemical-physical qualities of the dried sewage sludge and of the converted product could not only be determined by the analyses effected but also by the comparison of the two substrates for the agricultural use. The results indicated that the use of converted sewage sludge, even in high concentrations, has nearly no negative impact on the vegetation. Therefore, the use of converted sewage sludge might be very successful, particularly on sand, to improve the soil. Continuous applications of converted sewage sludge would also cause an accumulation of organic substances and therefore an improvement of the physical qualities of the soil of which, consequently, a lower demand of irrigation water will be the result.

Besides the quality of the crop products, there are also direct financial benefits due to an improved plant health and therefore lower expenses for fertilisers and plant protectives.

The socio-agricultural field study, carried out in July 2002, showed that the majority of the Egyptian farmers know about the possibility of using dried sewage sludge. The dried sewage sludge is used in Egyptian agriculture, however, the demand is much higher than the supply. The problems mentioned by farmers and transport companies may be solved or reduced by using the sewage sludge conversion method. Moreover, there is a considerable interest in the converted product among the interviewed farmers. The converted sludge may be successfully brought to market by means of corresponding advertising during information campaigns or by individual consulting.

Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish data*

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Keywords

Plant nutrients, excreta, urine, faeces, composition, diet, countries, regions

Abstract

In a sustainable society, the plant nutrients in excreta need to be recycled to arable land as fertiliser. New source separating sewage systems are promising in this respect. To evaluate these and further develop them, their nutrient recycling should be quantified. To do this, default values on the plant nutrient content of urine and faeces are needed. This paper presents a method for calculation of such default values from easily available statistics on the food supply and default values were estimated for five countries. The estimated values were compared with those reported for one country. The agreement was good for nitrogen and phosphorus. Values of the total nutrient excretion were calculated and apportioned between urine and faeces. Urine contained most of the nutrients, but its proportion of the total nutrients varies due to varying digestibility of the diet, making precise estimation hard.

Introduction

Since the nutrients in excreta originate from arable land, recycling of them as a fertiliser is an important task for the sustainable sewage systems of the future. To evaluate the nutrient recycling potential of different source separating sewage systems, the composition of the different incoming sewage fractions needs to be known. The nutrient content of urine and faeces, which contain most of the plant nutrients in sewage, essentially equals that of the food consumed. Therefore, the default values for the composition of urine and faeces differ in different countries, due to differing food consumption. The objective of this study was to develop a method to estimate default values for the nutrient content of excreta in different countries and regions of the world.

Methods

A proposal for new Swedish default values (Vinnerås et al., Submitted) has been developed. The proposal is based on the average Swedish food consumption combined with several studies of the amount and composition of urine and faeces produced. As an example, the amounts and composition of all urine, faeces, greywater and biodegradable waste produced at Gebers, a house with 80 inhabitants, were measured during three consecutive one-week periods (Palmquist & Jönsson, 2003). The proposal for the new default values (Table 1) is based on measurements of the excreta produced during more than 3500 person days in different residential areas in Sweden.

*This paper has been peer reviewed by the symposium scientific committee

Based on these values, default values were calculated for other countries. The calculations were based on the mass balance for the human body and on readily available statistical data on the food supply (FAO, 2003). The mass and composition of the adult body is fairly constant. In the human body, nitrogen mainly accumulates in proteins, i.e. in muscles, phosphorus in bones and muscles, and potassium in nerves and muscles (Nationalencyklopedin, 1993). Thus, adults do not accumulate any new plant nutrients in their bodies. Our calculations on the average weight gain and the average diet of children between 3 and 13 years of age show that children accumulate only a few percent of the nutrients consumed.

Parameter	Unit	Urine	Faeces	Toilet paper	Blackwater (urine+faeces)
Wet mass	kg/yr	550	51	8.9	610
Dry mass	kg/yr	21	11	8.5	40.5
Nitrogen	g/yr	4000	550		4550
Phosphorus	g/yr	365	183		548
Potassium	g/yr	1000	365		1365

Table 1: Proposed new Swedish default values (Vinnerås et al., submitted)

The amount of nitrogen in food is linearly correlated with its protein content. In fact, generally the amount of protein in food is calculated from analyses of its nitrogen content. Therefore, the nitrogen content of the excreta was calculated from the protein content of the food supply. Statistical analysis of the composition (LV, 2003) of 180 food stuffs (staple foods, vegetables, meats and fishes) showed that the contents of phosphorus and potassium are better correlated with the content of protein than with the origin (animal or vegetal) or the energy content. The analysis also showed that vegetal food stuffs on average contained approximately twice as much phosphorus and 5.6 times as much potassium per gram of protein as animal ones. Therefore, the amount of phosphorus in the excreta was calculated according to the sum of the animal and two times the vegetal protein supplied and the amount of potassium according to the sum of the animal protein and 5.6 times the vegetal protein supplied. Table 2 gives both the input and the results of these calculations performed for China. In the Swedish measurements, the nutrient excretion was measured both for urine and faeces and approximately 88% of the nitrogen, 67% of the phosphorus and 73% of the potassium was excreted via the urine (Table 2). In the calculations we assumed that the urine in all the different countries has the same proportions of the nutrients as in Sweden.

Country, year, type	Energy cal/cap day	Protein g/cap day	N kg/cap, yr	Pkg/cap, yr	K kg/cap, yr
Sweden, 1992,total	3052	98	4.6	0.5	1.4
Vegetal	2026	34			
Urine			4.0	0.4	1.0
Faeces			0.5	0.2	0.4
China, 2000, total	3029	86	4.0	0.6	1.8
Vegetal	2446	56			
Urine			3.5	0.4	1.3
Faeces			0.5	0.2	0.5

Table 2: Example showing the input and results when the proposed Swedish default values were recalculated for China

Results

To adapt the proposed Swedish default values to other countries, the FAO (2003) food supply statistics for Sweden were compared with the corresponding food statistics of the other countries (Table 3) and the relevant values for the total excretion and its distribution between urine and faeces were calculated using the method described above. The results of these calculations are presented in Table 4.

The most recent available statistics, those for the year 2000, were used for all the countries except Sweden. For Sweden, statistics for 1992 were used, since measurements and calculations on the Swedish diet in 1992 are important inputs to the proposed new default values (Vinnerås et al., Submitted).

Country	Tot energy cal/cap, day	Vegetal energy cal/cap, day	Tot protein g/cap, day	Vegetal protein g/cap, day
Sweden[a]	3052	2026	98	34
China, Asia	3029	2446	86	56
Haiti, West Indies	2056	1923	45	37
India, Asia	2428	2234	57	47
South Africa, Africa	2886	2516	74	48
Uganda, East Africa	2359	2218	55	45

[a]The data for Sweden are for 1992, since the default excretion values were developed for this year.

Table 3: Food supply (crops primary equivalent) in the different countries in the year 2000 (FAO, 2003)

Country	Nitrogen kg/cap, yr	Phosphorus kg/cap, yr	Potassium kg/cap, yr
China, total	4.0	0.6	1.8
Urine	3.5	0.4	1.3
Faeces	0.5	0.2	0.5
Haiti, total	2.1	0.3	1.2
Urine	1.9	0.2	0.9
Faeces	0.3	0.1	0.3
India, total	2.7	0.4	1.5
Urine	2.3	0.3	1.1
Faeces	0.3	0.1	0.4
South Africa, total	3.4	0.5	1.6
Urine	3.0	0.3	1.2
Faeces	0.4	0.2	0.4
Uganda, total	2.5	0.4	1.4
Urine	2.2	0.3	1.0
Faeces	0.3	0.1	0.4

[a]The data for Sweden are for 1992, since the default excretion data were developed for this year.

Table 4: Calculated estimation of the excretion in the different countries

Discussion

It is important to remember that the calculated estimation of the excretion was based on national statistics, while the excretion from an individual, a family or a block of houses depends on the actual diet of the persons involved. In many countries, differences in diet are very large between different population strata and this is reflected in the excretion.

From experience, we know (Vinnerås et al, submitted) that there are large uncertainties involved when measuring urine and faecal excretion. Many measurements of excreta have been carried out at large institutions and have only involved a limited number of persons, often only one fraction, one sex and persons with a limited age variation. Therefore, the value of these measurements is limited for determining reasonable default values. This is the reason why we based the proposed Swedish default values for excreta both on large studies of the diet and on several large measurements of the urine and faeces excreted by people at home. By measuring in apartment houses, men, women and children were included in the measurements.

The human metabolism is similar all over the globe and comparable statistics on food supply are, via FAO available for most countries. Therefore, reasonable default values can be calculated for the average excretion in different countries. To arrive at better default values, large measurements of the excretion from representative population groups are needed. This is shown for example by Ago et al. (2002), who report the average yearly total excretion of nitrogen, phosphorus and potassium in China as 4.4 kg of nitrogen, 0.5 kg of phosphorus and 0.8 kg of potassium. Comparing this with the calculated values in Table 4, the nitrogen and phosphorus values agree well, considering the difficulty in getting representative population samples and good statistics on the food supply in such a large country. For potassium the difference is quite large, 56%. One possible reason for this is that all vegetable foods have been lumped together in our calculation, even though the potassium content per gram of protein is about ten times higher in potatoes (staple food in Sweden) than in rice (staple food in China). Luckily, potassium is rarely the most limiting nutrient.

The distribution of nutrients between urine and faeces depends on the digestibility of the food. Digested nutrients leave the body via urine, while undigested matter leaves via faeces. Highly processed vegetal foods and animal foods are generally easy to digest and the proportion of such foods is higher in Sweden than in the other countries in Table 4. Therefore, higher proportions of the nutrients are to be expected in the faeces in those countries. This difference in digestibility is reflected in the amount of faecal matter produced, about 50 kg per person and year in Sweden (Table 1) and about 115 kg in China (Gao et al, 2002). Therefore, it is not surprising that Gao et al. (2002) also report a larger proportion of nitrogen (30%) and phosphorus (56%) in the faeces than the Swedish default values. However, the proportion measured in the faeces also depends on how successful the urine diversion system is. If a small proportion of the urine is mixed with the faeces instead of being diverted, then the amount of nitrogen, and also phosphorus, found in the faeces increases drastically. The proportion of urine not diverted depends very much on the toilet and on the dedication of the users. In our measurements, the proportion of misdiverted urine has varied between 5% and 50%.

Conclusions

The method presented enables the calculation of reasonable estimations of the plant nutrient excretion from the human body, just by use of easily available statistics on food supply. The uncertainty of the estimation seems small for nitrogen and phosphorus and large for potassium. The estimated excretion is the average value and the actual excretion can, depending on diet, vary very widely between individuals, families and population strata. Of the excreted totals, urine contains by far the largest proportion of nitrogen (70-90%), phosphorus (45-80%) and potassium (75-95%). The actual proportions measured depend on the digestibility of the diet and on successful diversion of all urine (100%) from faecal matter.

References

FAO (2003). FAOSTAT Nutrition data – Food Supply – Crops Primary Equivalent. http://apps.fao.org/page/collections?subset=nutrition visited 2003-02-28.

Gao XZh., Shen T., Zheng Y., Sun X., Huang S., Ren Q., Zhang X., Tian Y., Luan G. 2002. Practical Manure Handbook. (In Chinese). Chinese Agriculture Publishing House. Beijing, China.

LV (2003). Livsmedelsdatabasen (The food stuff data base). National Food Administration. Sweden. http://www.slv.se.

Nationalencyklopedin (1993). Nationalencyklopedin (The National Encyclopaedia of Sweden). Bokförlaget Bra Böcker. Sweden.

Palmquist H. and Jönsson H. (2003) Urine, faeces, greywater and biodegradable solid waste as potential fertilisers. Paper at the 2nd International Symposium on ecological sanitation. Germany.

Vinnerås B., Palmquist H., Balmér P., Weglin J., Jensen A., Andersson Å. and Jönsson H. The characteristics of household wastewater and biodegradable solid waste - a proposal for new Swedish norms. *Submitted to Urban Water*

Safe nutrient-removal from urban sewage

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Keywords

Crystallisation, endocrine substances, heavy metals, P-removal

Abstract

Different P-recovery-technologies for sewage are more and more discussed, while the use of sewage sludge on farmland is more and more criticised due to heavy metal and organic pollutants in the sludge. Three kind of technologies are described. Only the recovery from sewage sludge ash seems to be safe by now. Especially concerning the precipitation with lime and the crystallisation processes no data is available concerning the transformation of endocrine substances into the crystals and the tertiary sludge. Although the crystallisation-process is e.g. very promising concerning running costs further research is necessary on these basics.

Introduction

A lot of waste water treatment plants were built up in the last decades. E.g. in Germany and other EU-countries they are nearly all run with mechanical and biological treatment technology, most of them also with P-elimination. Due to sewage sludge decrees and waste water control the content of pollutants in sewage and sludge was reduced drastically. But there are still heavy metals left and especially organic pollutants and the endocrine substances are causing trouble. Therefore new approaches are necessary to remove nutrients like phosphates from sewage for using it as a fertiliser on farmland in order to close the nutrient-loop.

In industrialised countries, but also in developing countries, more and more people are living in urban areas. Their sewage is entering into waste water treatment plants by being mixed with waste water from the commercial sector, which is in most cases responsible for the pollutant-input. But this input can in most cases not be avoided during the next years. But nevertheless it is important to find solutions for saving also these nutrients instead of wasting this resource. But it must be done in a safe way.

Methods

Three major methods of separate P-recovery from waste water do exist.

- P-precipipation with lime by producing a tertiary sludge at the end of the waste water treatment process
- Recovery from ash, by burning sewage sludge first in a mono-incinerator
- P-crystallisation

First of all soluble phosphates can be removed by precipitating them not into the sewage sludge, but into a saleable tertiary sludge, which must be stored and treated separately from the primary and excess sludge. Especially in case lime is used for transforming the phosphates into calcium-phosphates, they can be used without further treatment in the agricultural sector. This technology is not a new approach at all, but it was not often installed at waste water treatment plants in the past.

Another technology is the removal from sewage incineration ash. A mono-burning plant is necessary, because in case of co-burning, e.g. with brown-coal, P-content in the ash is too low for the removal. A lot of chemical substances are necessary to dissolve the P afterwards, especially in case it has been eliminated by iron or aluminium instead of using a Bio-P-technology. Although most of the chemical substances can be removed during an ion-exchange-process, the process-water contains in most cases a lot of salt.

Last not least there is the so called crystallisation-technology. By adding magnesium-precipitants, struvite (MAP = magnesium-ammonium-phosphate) is produced in a crystallisator, a fluidised bed-reactor (Gaastra et al., 1998). This procedure can run in a side-stream- or full-stream-process. Side stream includes some advantages. For example only 60 % of the precipitants are needed to safe 90 % of the phosphate, that are removed during a full-stream process. PH, Mg/P-ratio, MAP-concentration in the reactor and the hydraulic retention time of the reactor are important operational factors of the MAP system. Due to the fact, that magnesium-precipitants are quite expansive, attempts with sea water (Kumashiro et. al., 2001) have been made, because sea-water contains magnesium and also sodium. The latter is stabilising the pH in the crystallisator.

Economical aspects

Besides technical aspects, first economical estimations have been made for full scaled operation plants. P from phosphate rock cost in Europe at about 0,40 €/kg (cif-price harbour Europe). Costs for recovering phosphates from the ash of former sewage sludge are at about ten times higher. But concerning the side-steam- crystallisation-process the costs are only 0,5 – 0,8 €/kg P (Buer et. al., 2002). Especially taking the economical situation in developing countries into account one has to add, that these cost will in most cases not lead to a further increase of imports whereas, imported phosphate or phosphor-rock has negative effect concerning the im- and export-balance sheet.

Concentrations of nutrient and pollutants in the recovered products

First of all it need to be mentioned that a very low concentrations of polluting substances is an essential demand on the produced products. Burning sewage sludge and recovering P from its ash is quite safe concerning organic pollutants which are destroyed during the burning process (in case of a modern emission-control-technology), but it is still an end-of-pipe-technology. And, last not least, it is very expensive.

Basically, the mentioned technologies offer the possibility to recover phosphate even from such kind of waste water, where a use of sewage sludge e.g. for agricultural purposes is impossible due to high pollutant concentration in the waste water. Especially the crystallisation-process does not allow a crystallisation if there is a high concentration of non-typical elements in the surrounding of the seeding material. Table 1 shows data concerning the heavy metal contents of struvit from Japan. Unfortunately the pollutant concentrations in the waste water were not mentioned.

d.m.-content (%)	N (%)	P (%)	K (mg/kg)	As (mg/kg)	Hg (mg/kg)	Cd (mg/kg)
41,8	5,5	12,5	565	0,7	<0,003	not detectable

Table 1: Concentration of MAP-granulats from Kitakyushu/ Japan Source: Kumashiro et al., 2001

Especially if one takes the results from phosphate rock into account this a good result, showing that contamination can be avoided with this technology. But further research is necessary to find out, whether it is possible for example for endocrine substances to find a place in these crystals, because they might not be excluded during the crystallisation-process, like for example cadmium or other “macro”-pollutants.

Conclusions

Table 2 is characterising the P-recovery-technologies by comparing them concerning their important „benchmarks“.

	Precipitation with lime	Crystallisation main-stream	Crystallisation side-stream	Recovery from ash
P-recovery-rate	40 - 65 %	65 - 70 % %	60 – 65 %	90 %
Running costs	middle	middle	low	High
Technical effort for installation	low - middle	high	high	extremely high (if no incinerator yet exists)
Final product	Calcium-phosphate	Struvit	Struvit	Depending on the technology Thermphos: P_4
Possibility of trans-formation of organic pollutants into re-covered P-product	Maybe possible, further research necessary	Maybe possible, further research necessary	Maybe possible, further research necessary	Not possible

Table 2: Characterisation of different P-recovery-technologies

On the one hand, the actual contamination of sewage in nearly every urban area of developing countries is too bad for using that sewage sludge for agricultural purposes. But besides that, there is even a discussion in developed countries like German, whether there should be a ban of sewage sludge from urban areas on farmland, due to hazard pollutants like endocrine substances.

On the other hand it is necessary to close the nutrient-loop. And due to the high percentage of urban sewage on the total amount, it is necessary to find ways, how the nutrients can be removed from urban sewage without transferring the polluting substances. Some very promising attempts have yet been made, but a future-target must include series of analytic tests especially on organic pollutants and the endocrine substances in special in order to find out, whether they are able to make their way into the crystals (and the tertiary sludge). In case this happens in serious concentrations, this would maybe even go against the initiation of these new technologies on waste water treatment plants. Research on especially this item is necessary.

References

Buer, T.; Montag, D.; Seyfried, A. (2002): Gewinnung von Phosphat und anderen Nährstoffen aus Klärschlamm (Recovery of phosphate and other nutrients from sewage sludge): Techniken und Wirtschaftlichkeit, in: Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL) (ed.): Landwirtschaftliche Verwertung von Klärschlamm, Gülle und anderen Düngern unter Berücksichtigung des Umwelt- und Verbraucherschutzes; BMU / BMVEL - Wissenschaftliche Anhörung, 25.-26.10.2001 in Bonn, Darmstadt/Germany.

Gaastra, S. et al. (1998): Full scale phosphate recovery at sewage treatment plant Geestmerambacht; Proceedings of the International Conference on the recovery of phosphorus from sewage and animal waste, Warwick University / Netherlands, 6. – 7. 05.1998; published on the CD-ROM (Ed.: CEFIC & CEEP) of the 2nd (!) International Conference on the recovery of phosphorus from sewage and animal waste, held in Noordwijkerhout / Netherlands, 12. – 13. 03.2001.

Kumashiro, K.; Ishiwatari, H.; Nawamura, Y. (2001): A pilot plant study on using seawater as a magnesium source for struvite precipitation, CD-ROM with the proceedings (Ed.: CEFIC & CEEP) of the 2nd International Conference on the recovery of phosphorus from sewage and animal waste, held in Noordwijkerhout / Netherlands, 12. – 13. 03.2001.

Nutrient uptake by different vegetable plants from source separated human urine*

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Keywords

Nutrient uptake, plant bio-mass growth rate, source separated human urine, vegetable plants

Abstract

In this paper nutrient uptake efficiency of different plants were studied. For this purpose source separated human urine in varying dilution was treated with different species of vegetable seeds. The growth of the plants was observed for 15 to 20 days experiment cycle. Five experiments were conducted in batch basis. Results showed that plants such as Green Pea, Black gram, Broad bean had high nutrient uptake efficiency**.** As media solution and effluent still contained traces of nutrients (NPK). Source-separated human urine can be further diluted for total nutrient recovery.

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Introduction

Human urine contributes large amount of nutrients to the household wastewater (Esrey et al., 1998; Jönsson et al., 1999; Larsen et al. 1999; Otterpohl, 2001). High levels of these nutrients uptake are possible with separate collection of human urine at source. Human urine is relatively sterile and can be reused without further treatment (Wolgast, 1993). However, due to faecal contamination, pathogens have been found in human urine-collected separately with means of separating toilet; but in low concentration, which will pose low hygienic risk of using human urine as a fertilizer, if it is stored at least for 6 months before being used in agriculture (Jönsson et al., 1999, Hellstroem and Johansson, 1999). Moreover, human urine has low concentration of heavy metal. Therefore, separately collected human urine can be used as fertilizer for growing vegetables. The main objective of this paper is to study feasibility of nutrients uptake by vegetable plants from source separated human urine. This will help to develop a sustainable treatment process for household wastewater as well as reducing the dependence on chemical fertilizers. In this paper, nutrient uptake efficiency of different plants is presented.

Methods and materials

For the experiment a temporary urinal was constructed, the outlet of which was connected to a collection tank whose outlet was again connected to a mixing tank. The outlet of the mixing tank was connected to culture chambers of 90*60*45 cm size. All the outlet points were installed with valves to control the flow. The chamber was filled with approximately 60 liters of gravel and

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pebble media of 5-10 mm size and coarse sand to cover up to 11 centimeters of the chamber. Prior to commencement of the experiment, the medias were washed thoroughly. After the completion of every experiment, the media was washed continuously stirring the media 3-4 times and water drained in each wash. New media was introduced only in the fifth experiment.

Different species of vegetable seeds of cress, spinach, tintel, mustard, 2 varieties of Rayo (rape), green pea (Botanical name Pisum Sativum), black gram (Botanical name Cicer Arietinum) and broad bean (Botanical name Vicia Faba) were allowed to germinate in the laboratory for two days and placed on the plant culture chamber. The seeds, which germinated were only taken and rest excluded. The germinated seedlings were planted on the chamber. The growth of the plant was observed for 15 to 20 days experiment cycle. Five experiments were conducted. The plant species taken for different experiments and climatic condition during the experiment is as shown in the Table 1.

Experiment No.	Vegetable Plant Type	Climatic Condition
1	Cress, Spinach, Tintel, Mustard, Rape, Green Pea, Black Gram, Broad Bean	Direct sunlight available maximum of 2 hours a day
2	Cress, Spinach, Tintel, Mustard, Rape, Green Pea, Black Gram, Broad Bean	Same as in exp. 1
3	Green Pea, Black Gram, Broad Bean	Same as in exp. 1 and 2
4	Black Gram, Broad Bean	No Direct sunlight available at all
5	Broad Bean	Same as in exp. 4

Table 1: Plant species and climatic condition

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The source-separated human urine was collected in the collection tank a day before the experiment and is diluted to required concentration in the mixing chamber. The dilution of human urine and nutrient loading were done as shown in Table 2.

Experiment No.	Human Urine Volume Loaded (Litre)	Dilution Ratio	Nitrogen Loading Rate (g/m^2)	Phosphorous Loading Rate (g/m^2)	Potassium Loading Rate (g/m^2)
1	12.0	1:10	10.7	2.4	3.7
2	12.0	1: 6	4.2	0.1	3.5
3	14.2	1:15	7.7	0.5	13.7
4	18.0	1:15	6.2	0.3	6.4
5	15.0	1:10	6.2	0.2	1.6

Table 2: Dilution and nutrient loading rate

The influent and effluent were analyzed for Nitrogen (N), phosphorous (P) and potassium (K). The effluent sample was drawn in every 5th day-except for experiment 2- for which only final effluent was drawn. At the end of the experiment, the plants were weighed, dried and analyzed for NPK. The process was conducted on batch basis i.e. human urine was loaded for one time just before planting of the seedlings.

Results and discussion

The uptake efficiencies of different plants are as shown in Table 3. Nitrogen uptake was in the range of 68 - 91%. Highest uptakeefficiency was achieved in experiment 3 for broad bean, black gram and green pea with 1:15 dilution. Phosphorous uptakewas in the range of 63 - 96%. Highest uptake efficiency was achieved in experiment 1 for Cress, Spinach, Tintel, Mustard, Rape, Green Pea, Black gram, Broad bean with 1:10 dilution. Also in experiment 3 phosphorous uptake was about 92%. Potassium uptake was in the range of 59 - 85%. Highest potassium uptake was in experiment 3 for broad bean, black gram and green pea with 1:15 dilution.

Experiment No.	Influent Characteristic (mg/L)			Effluent Characteristic (mg/L)			Uptake Efficiency (%)		
	N	P	K	N	P	K	N	P	K
1	479.6	108.8	165	57.3	3.4	n.a	88.1	96.9	n.a
2	197.6	4.6	155.3	59.7	1.7	n.a	68.2	63.0	n.a
3	291.4	19.7	521.2	26.0	1.6	75.0	91.1	91.9	85.6
4	184.8	9.4	191.0	33.5	0.9	72.9	81.9	90.4	61.8
5	222.1	7.1	59.3	61.8	0.9	24	72.2	87.3	59.5

Note: The uptake efficiency is based upon initial volume. n.a. means not available.

Table 3: Characteristics of influent and effluent

The NPK content of the dehydrated plant bio-mass is shown in Table 4. Maximum nitrogen recovery was made in 33.3% of loading value in the fourth experiment with broad bead and black gram, Maximum Phosphorous recovery was made in 50.0% of loading value in the third experiment with broad bead, black gram and green pea. Maximum Potassium recovery was made in 45.2% of loading value in the fifth experiment with broad bead.

	Nitrogen		Phosphorous		Potassium	
Experiment No.	Uptake By Plants (mg)	% Of N Loading	Uptake By Plants (mg)	% Of P Loading	Uptake By Plants (mg)	% Of K Loading
1	57.6	1.0	11.1	0.9	77.0	3.9
2	332.8	14.8	15.9	28.8	261.0	14.0
3	192.8	4.7	139.8	50.0	509.9	6.9
4	1107.9	33.3	55.3	32.7	1000.5	29.1
5	991.2	29.8	7.1	6.7	402.1	45.2

Table 4: Plant uptake of nutrient and percentage of loading rate

In the successive experiments, the plant species were selected depending upon mass of plant growth. Higher growth varieties were retained and low yielding plant in terms of plant bio-mass growth were excluded in the later experiments. In the fifth experiment only one species i.e. Broad bean (Botanical name Vicia Faba) was planted. Maximum plant bio-mass growth was achieved in experiment 4 with broad bean and black gram with 1:15 dilution (Table 5)

Experiment No.	Duration of Experiment (days)	Mass Of Plant Growth (g)	Mass Of Plant Growth Per Unit Area (g./m^2)	Mass Of Plant Growth Per Unit Area Per Day (g/m^2/day)
1	15	12.1	22.3	1.5
2	15	65.2	120.7	8.0
3	15	185.6	343.7	22.9
4	20	234.2	433.7	21.7
5	20	108.2	200.4	10.0

Table 5: Plant bio-mass growth rate

From the results it showed that plants Green Pea, Black gram, Broad bean had high uptake efficiency. Results also showed that up to 33 % of Nitrogen, 50% of phosphorous and 45% of potassium were utilized by vegetable plant.

In all experiments, influent pH, which was at stronger alkaline state had been changed to lower values (Table 6). Electrical conductivity also changed from higher to lower values, signifying low ion concentration in effluent (table 6).

Experiment No.	Influent pH	Effluent pH	Influential EC (mS/cm*)	Effluent EC (mS/cm)
1	12.4	9.2	2.9	1.9
2	8.6	8.3	2.4	1.5
3	9.0	8.1	3.5	0.3
4	8.7	7.9	0.8	0.2
5	9.3	8.5	1.2	0.6

** Electrical Conductivity (mS/cm) – millie-Siemens per centimetre*

Table 6: Change in pH and EC in wastewater

Conclusions

The source-separated human urine can be used for the vegetable plants particularly broad bean, black gram and Green Pea. There was still unutilised NPK found in the media solution. With the applied dilution, effluent still contains traces of NPK. Therefore, further dilution of source-separated human urine can be applied for total nutrient recovery. In future studies, actual nutrient uptake by vegetable plants from source separated human urine and chemical fertilizers in soil media with different dilution or loading rate in the same condition can be investigated in terms of bio-mass growth.

The system is based on reuse of valuable nutrients, giving rise to a sustainable treatment process with vegetable plants. It can reduce the dependence on chemical fertilizers, which will save foreign currency needed to import the fertilizers in the developing countries like Nepal.

References

Esrey, S.A., Gough, J., Rapaport, D., Sawyer. R., Simpson-Hébert, M., Vargas. J., and

Hellström, D. and Johansson, E. (1999). Swedish experiences with urine separating systems. *Wasser & Boden 51(11), 21-25.,* Blackwell Wissenschafts-Verlag, Berlin

Jönsson, H., Vinnerås, B., Höglund, C. and Stenström, T.-A. (1999) Source separation of urine. *Wasser & Boden 51(11). 21-25*, Blackwell Wissenschafts-Verlag, Berlin

Larsen, T. A. and Udert, K.M. (1999): Urinseparierung- ein Konzept zur Schließung der Nährstoffkreisläufe. *Wasser & Boden 51(11), 21-25*, Blackwell Wissenschafts-Verlag, Berlin

Otterpohl, R. (2001) Design of highly efficient Source Control Sanitation and practical Experiences. in: Decentralised Sanitation and Reuse (Lens, P.; Zeemann, G. and G, Lettinga. Eds*). IWA Publications*. LondonWinblad, U. (1998). *Ecological sanitatio*n. Swedish International Development Cooperation Agency. Stockholm.

Sanitation of blackwater and organic material*

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Keywords

Batchwise aerobic thermophilic treatment, blackwater system, hygienisation, organic waste, small scale treatment plant, wet composting

Abstract

The municipality of Sund in Åland (Finland) is a rural area with small villages surrounded by the sensitive Baltic Sea, where an EU-Life demonstration project is being carried out. The overall objective is to move the most concentrated fraction of wastewater from the coastal area to batch-wise treatment, followed by agricultural use as an organic fertiliser. The aim of the treatment is to stabilise and sanitise the material. Treatment of two batches has been monitored. The maximum temperature in treatment of the first batch (A) was 55°C, and in the second batch (B) a temperature of 62°C was reached. Microbial analyses have been carried out. The results indicate that the wet composting process reduce indicator bacteria sufficiently, but additional batches have to be evaluated before conclusions can be drawn.

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System description and methods

Blackwater together with grey-water septic sludge from about thirty households and two tourist camping areas is treated together with food waste from the camping areas and energy-rich organic material from a nearby potato-chip factory. The collection concept is based on the use of extremely efficient water-saving toilets, with separate systems for the blackwater and greywater in the households. Greywater from the households and camping areas is infiltrated in soil filter beds (Malmén et al, 2002).

The treatment consists of a batch-wise aerobic thermophilic process (wet composting process), where the materials reach at least 55°C during a minimum of 10 hours. Aeration is supplied by an immersed ejective aerator. The maximum batch volume is 290 m^3. After sanitation and stabilisation by the treatment, the slurry is used in agriculture as an organic fertiliser.

Aerobic thermophilic treatment (wet composting) has traditionally been used for treatment of sewage sludge and liquid manure. Nowadays the method has also become interesting for treatment of organic waste and blackwater, and development in this field has mainly taken place in Norway and Sweden (Skjelhaugen, 1999; Skjelhaugen and Sæther, 1994; Norin et al, 2000, Norin, 1996). The main advantages with the wet composting process are that a sanitation and stabilization of the material is reached, while there is hardly any losses of plant nutrients during treatment. The treatment process takes place in a closed reactor and the outgoing air is cooled,

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resulting in NH_3 from the air returning to the reactor with the condensation. Aerobic conditions are maintained by active supply of oxygen. Generally, the material for treatment should have a dry matter content of between 3-10 % (Skjelhaugen and Sæther, 1994).

To reach a sanitation, it is recommended that the material shall remain at a temperature of at least 55°C for at least 10 hours, in a reactor where all of the material is being totally mixed (Lundeberg et al, 1999). The reactors of the treatment plant contain equipment for continuous measurement of the temperature in the material during treatment. This has enabled an evaluation of whether the hygienic demands regarding time and temperature in the treatment process have been reached. The material in the two batches was sampled before, during and after treatment using a sterile sampler. Sampling was done while stirring equipment was operating in order to have a homogenous batch. The samples were transported in a cooled box to laboratory within 24 hours. The selection of analyses to be carried out was decided in accordance to recommendations from the Swedish National Veterinary Institute, SVA.

Results and discussion

Temperature graphs from the treatment of two batches can be seen in Figure 1 and Figure 2 respectively.

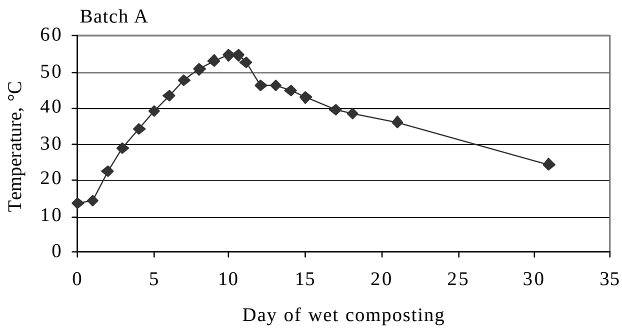

Figure 1: Temperatures during the wet composting process of Batch A in October 2001. The aerator and the stirring device were turned off on day 21.

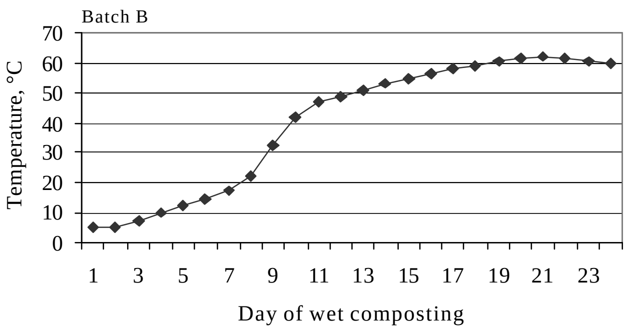

Figure 2: Temperatures during the initial phase of the wet composting process of Batch B, April 2002. The aerator and the stirring device were turned off on day 23.

The first batch to be treated in October 2001 (Batch A), consisted of approximately 120m^3 blackwater and greywater sludge (DM 0,4%) and 12m^3 of potato peelings (DM 32%). By starting the aerator and stirring device, the aerobic thermophilic treatment (wet composting) of the batch was started. The temperature of the material in the reactor was about 14 °C at the start. The heat developed by the aerobic bacteria and frictional heat from the machines in the reactor made the temperature of the material rise to 55°C after 10 days. The temperature remained at 55°C for 10 hours, before it started to get lower again (Figure 1). The pH-value in Batch A was 7,2 before treatment; 8,7 after 10 hours treatment at 55°C and 8,9 after six months storage following the treatment.

During ten weeks, from February to April 2002, 130 m^3 of blackwater and 22m^3 of potato peelings were pre-storaged, without any further addition of material to the reactor. The process of wet composting Batch 2 was started in April 2002, when the temperature of the material in the reactor was about 5°C. During treatment the temperature rose to 55°C after 14 days. It increased further, and reached a maximum of about 62°C after another six days. In total, the temperature in the treated material remained at more than 55 °C for about two weeks, before it dropped (Figure 2). The pH-value in Batch B was 5,5 before treatment after ten weeks of pre-storage, and after 24 hours treatment at > 55°C it was 6,2.

The difference between Batch A and B regarding the reached maximum temperature, is most likely explained by the larger amount of potato peelings in Batch B, and hence a larger amount of BOD. Since the blackwater does not contain much energy, it is important to ensure a sufficient load of BOD by adding the potato peelings.

The results from the microbial analyses can be seen in table 1.

	Coliform bacteria (37°C)	Thermotolerant coliform bacteria (44°C)	*E. coli*	*Enterococcus* spp.	*Clostridium* spp.	*Campylobacter jejuni* and *coli*	EHEC	*Salmonella* spp.
Unit	CFU/g					Affirmative/non affirmative		
Batch 1								
Rawmaterial before treatment								
2001-10-09	3 500 000	200	200	7 300	5 600	non aff.	non aff.	non aff.
Treated material (wet composted), after 10 hours at >55 degrees Celcius								
2001-10-18	< 10	< 10	< 10	< 100	400	non aff.	non aff.	non aff.
Treated material, stored 2 months after treatment								
2001-12-13	< 10	< 10	< 10	< 100	420	non aff.	non aff.	non aff.
2001-12-13	< 10	< 10	< 10	< 100	390	non aff.	non aff.	non aff.
Treated material, stored 6 months after treatment								
2002-04-29	< 10	< 10	< 10	< 100	360	non aff.	non aff.	non aff.
2002-04-29	< 10	< 10	< 10	< 100	500	non aff.	non aff.	non aff.
Batch 2								
Rawmaterial before pre-storage								
2002-02-10	1 300	< 10	< 10	3 000	6 500	non aff.	non aff.	non aff.
Rawmaterial after 10 weeks of pre-storage and just before treatment								
2002-04-21	<10	<10	<10	470	150 000	non aff.	non aff.	non aff.
2002-04-21	<10	<10	<10	450	140 000	non aff.	non aff.	non aff.
Treated material (wet composted), after 24 hours at >55 degrees Celcius								
2002-05-05	<10	<10	<10	< 100	100	non aff.	non aff.	non aff.
2002-05-05	<10	<10	<10	< 100	<10	non aff.	non aff.	non aff.
Treated material, stored 4 months after treatment								
2002-09-08	< 10	< 10	< 10	< 100	50	non aff.	non aff.	non aff.
2002-09-08	< 10	< 10	< 10	< 100	100	non aff.	non aff.	non aff.

Table 1: Microbial analyses of two treated batches (1 and 2) of collected rawmaterial (blackwater, potato peelings and greywater septic sludge).

All of the examined micro-organisms in the rawmaterial was almost completely reduced by the treatment, with exception of the spor forming bacteria *Clostridium* in the first batch. This is expected, since reduction of spor forming micro-organisms requires a higher temperature. According to previous studies at SVA (the Swedish National Veterinary Institute), spor forming bacteria have been found after pasteurization (Bagge et al, 2003). This has not given rise to any further investigation or demands for measures to be taken. Spores from *Clostridium* exists in the ground. Some of the spor forming bacteria are pathogenic, which makes the sanitary risk difficult to estimate, since there is a lack of knowledge in the area. The experiences from a Norwegian aerobic thermophilic treatment unit, treating sludge from a wastewater treatment plant, show that Salmonella and thermotolerant coliform bacterias are reduced if the amount of organic material is sufficient (Nybruket et al, 2003).

From studies of other treatment processes it is known that there is an obvious risk for re-contamination and re-growth of both indicator bacteria and pathogens during handling and storage of the processed material. However, no re-growth was observed for any of the two batches, during the storage after treatment. Neither did the pH-value in the material change much during storage after treatment. This indicates that the main part of the easily degradable organic material was consumed during the composting process, which makes a re-growth of micro-organisms more difficult.

Conclusions

The results indicate that the wet composting process reduce indicator bacteria sufficiently. Normally, this also means that conventional pathogens are reduced sufficiently. But, since treatment of only two batches has been monitored additional batches has to be evaluated before conclusions can be drawn.

From a hygienic safety point of view, a batch treatment is preferable to a semi-continuous process, which is often selected. In a batch process the treated material will be exposed to higher temperatures over considerably longer times than in a semi-continuous process.

From a technical point of view the system is a success. The project has faced no major technical problems. As a result the Government of Åland is discussing the introduction of the system in other places.

References

Bagge, E., Sahlström, L. and Albihn, A.(2003). The Effect of Hygienic Treatment on the Microbial Flora of Biowaste at Biogas Plants. In manuscripte.

Lundeberg, S., Johansson, C., Kron, E., Sandström, M., Klingstedt, E., Brohede, L., Norin, E., Carlsbæk, M, Palm, O. and Brunes, L. (1999). Sjösättning av certifieringssytem för kompost och rötrest, slutrapport. AFR-Report 257, Naturvårdsverket. RVF Utveckling, Rapport 99:2, Stockholm.

Malmén, L., Palm, O. and Norin, E. (2002). A collection and treatment system for organic waste and wastewater in a sensitive rural area. In Ozturk, I. & Tanik, A. (Eds.) Proceedings from "The 5th Specialised Conference on Small Water and Wastewater Treatment Systems", September 2002, Istanbul.

Norin, E. (1996). Liquid composting for the stabilisation and hygienisation of organic waste (in Swedish with an English summary). JTI-rapport, Kretslopp och avfall nr 3, Uppsala.

Norin, E., Gruvberger, C and Nilsson P-O. (2000). Handling of blackwater from the school of Tegelviken – recycling system with liquid composting (in Swedish with an English summary). VA-Forsk Rapport 2000:3, Stockholm.

Nybruket, S, Paulsrud, B and Nedland, K.T., 2003. Experiences with sewage sludge disinfection in Norway (In Norwegian with an English summary). VA-Forsk Rapport 2003:32, Stockholm

Skjelhaugen, O.J. and Sæther, T. (1994). Local ecological waste water solution for rural areas. Report N. 94-B-039, AgEng –94, Milano.

Skjelhaugen, O.J. (1999). A Farm-operated System for Recycling Organic Waste. Journal of Agricultural Engineering Research. Vol. 73, No. 4, August 1999.

Ecological sanitation: valorisation of waste sludge by composting for agricultural production

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Keywords

Composting, fertiliser, reuse, sanitation, waste sludge, yield

Abstract

Pit latrine sludge endangers health and environment if not treated. Nevertheless, even when this is the case, treated pit latrine sludge is seldom reused. Physical and chemical and bacteriological analyses of stabilised and dehydrated pit latrine sludge from SIBEAU lagoon treatment plant in Benin shows a high content of nutrients, such as nitrogen and phosphorus in stabilised sludge; which are indispensable for agricultural production. A one-year field experiment investigated the effect of stabilised pit latrine sludge on biomass production. It came out that stabilised pit latrine sludge had a positive effect on biomass production of e.g. tomatoes, when compared to chemical fertiliser and control. Dehydrated pit latrine sludge is usable, without any further treatment, as a fertilising agent or after its composting. The interest of composting is two-fold; 1. Increase the availability of nutrients in sludge; 2. Reduce the pathogen content in sludge. This is attained when temperature during composting is raised to 60°C.

Introduction

In both West and Central Africa, sludge coming from latrine pits is handled in a rather chaotic manner. This often endangers the lives of humans and environment. Because of this situation, CREPA (the Regional Centre for Water Supply and Sanitation) instigated a research programme to explore for possible solutions to handle this sludge. The results of this work illustrated that in order to ensure a sustainable management within urban, peri-urban and rural environments, a strategy is required. Such strategy must integrate latrine sludge as a resource to improve people living conditions, for example, by increasing agricultural production. This study presents the current state of valorising dehydrated latrine sludge from the treatment lagoon of the Benin's Industrial Company for Water and Urban Sanitation (SIBEAU) in Cotonou, Benin.

[1] *Centre régional pour l'Eau potable et l'Assainissement à faible coût*

Method

Methodology used in this study based on a participatory approach (questionnaire, focus groups, interviews, and meetings), to inform and take into consideration the opinion of all stakeholders in the research project. Different stakeholders involved in the research made decisions concerning the experimental site, the installation of composting units by consensus.

A physical, chemical, bacteriological, and parasitological characterisation of different fertilising agents, soil, and water was made.

The effect of the different fertilising agents on the biomass production of different fruits and vegetables was tested by evaluating the mass, quality, and quantity of fruits and vegetables produced either per plant or per square meter.

Fertilising agents used were 1. Dried sludge, 2. Dried sludge mixed with solid waste, and 3. Chemical fertiliser. Yields were compared to a control where no fertilising agent was used.

Results

Soil, fertilising agent, and water characteristics

Soil in the experimental site in Benin offers an example of typical poor soil found in the littoral zone in West Africa. It has a high content of sand, with a high infiltration rate and an acid pH (5.5). The organic matter, carbon, and nitrogen content were low in the soil, and the C/N ratio was 10. This indicated that the soil was highly mineralised and weathered.

Dehydrated sludge had a pH close to 7 with humidity content of 10.3% and a dry matter content of 89.7%. The C/N ratio showed that the organic matter in the sludge was in an advanced state of decomposition, which indicated that the nutrients in the sludge were more or less available to the plants.

Water used for watering during the experiment came from well and contained faecal contamination indicator organisms.

Effect of fertilising agent on plants: dehydrated sludge and chemical fertiliser.

Plants	Performance indicator (weight in gramme)	Type of substrate		
		Dehydrated sludge	Chemica fertiliser	control
Célosie (25 plants/m^2)	Biomass / m^2	925	575	567
Lettuce (25 plants/m^2)	Biomass/ m^2	650	591,5	567
Amaranth (25 plants/m^2)	Biomass / m^2	866,5	741,5	508, 25
Grande morelle (25 plants/m^2)	Biomass / m^2	2032, 5	3174,5	1360,25
Tomatoe (04 plants/m^2)	fruits / m^2	104	100	20

Table 1: Agronomic performance of fertilisers on plants

Table 1 indicates that yield obtained with dehydrated sludge was higher than yield obtained with a control (fig. 1, fig. 2, fig. 3 and fig. 4). This is also the case when we compare yield obtained with dehydrated sludge to the results obtained with chemical fertilisers, except for “grande morelle”, where chemical fertilisers gave a higher yield than dehydrated sludge. For tomatoes, similar results were obtained with both dehydrated sludge and chemical fertiliser, whereas we noticed less leaves and fruits on the control plant.

Figure 1: célosie (dehydrated sludge as fertiliser)

Figure 2 : célosie (control: without fertil.)

Figure 3: papaya (control: without fertiliser)

Figure 4: papaya (dehydrated sludge as fertil.)

Residual toxicity

Metal contamination was identified on the plant fertilised with sludge mixed with solid waste. However, the level of contamination was lower than the thresholds for toxicity.

Compost experiment

Three different types of composts were produced: sludge + solid waste, sludge + wood shavings, sludge + leaves from the acacia tree). The swath have a size of 6m×2m×1.5m. The choice of carbon source for compost was made basing on composting techniques used in the region.

Composting maturation results

Maturation process was followed for 60 days. Parameters investigated during compost maturation were pH, humidity, organic matter content, and the C/N ratio. Composting took place during the rainy season. A heavy precipitation was noted in October 2002; and this did not allow for humidity control. Moreover, temperature did not reach above 55°C.

Compost characteristics

Compost	pH	Humidity (%)	Organic mat er	C/N
sludge + solid waste	6,93<pH<7,25	45,52	31,72	12
Sludge + wood shavings	6,69<pH<7,20	31,48	9,92	13
sludge+ acacia leaves	6,34<pH<7,15	28,32	11,24	18

Table 2: Compost characteristics after maturation

Compost maturation was achieved after approximately 60 days. A progressive decrease in the C/N ratio was noted during the composting process. The final C/N ratio for the sludge + solid waste, sludge + wood shavings, and sludge + acacia tree leaves were 12, 13, and 18 respectively. A high C/N value was observed for sludge + solid waste; but the trend reversed towards the end of the process for Sludge + Wood sawing and Sludge + Acacia Tree leaves. The presence of lignite in the two last composts whose biodegradation kinetics is relatively slow may explain this situation.

Ongoing experiments on cultures

Ongoing experiments to test the comportment of some speculation vis-à-vis the compost amendments and to compare their performance with those of other substrates and chemical fertilisers, agronomic values, residual toxicity, parasitological and bacteriological data.

Conclusion

Yields revealed interesting agronomic qualities concerning residual sludge. Improvements with a supplementation in structuring matters (solid waste, wood sawing, Acacia leaves) enable a further enrichment of soils both for vegetables and fruit cultures.

Not only does soil amendment with sludge enable an increase of their productivity, but it also contributes in accelerating plant vegetative cycles. For a better valorisation of sludge in agriculture or gardening, it must be sufficient to control the toxicity factor of sludge and agricultural products from a chemical, bacteriological, and parasitological viewpoint. An estimate of the gross product per hectare of gardening operations is needed for each type of culture.

Sustainable utilisation of human urine in urban areas – practical experiences*

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Keywords

Aquaculture, ecological engineering, struvite, urine, zeolite, urine separation

Abstract

After several years of research on utilisation of nutrients in human urine an opportunity to build and use a greenhouse aquaculture demonstration plant appeared in the new science centre Universeum, in Göteborg, Sweden. The challenge for this project is to recycle all the nutrients in urine collected from the staff and the visiting public (about 500 000 visitors during the first year) and to demonstrate its value as nutrient with different eco-sanitation technologies on site. The nutrients are collected by the use of 26 urine-sorting toilets (estimated 100-300L urine per day, 50% diluted). Part of the urine is treated directly by the aquaculture food chain (algae-zooplankton-fish). Another part will be concentrated by chemical precipitation (struvite) and adsorption to minerals (zeolite). The main part of the urine is to be spread in agriculture. This multiple use of the source-separated urine favours a sustainable recycling of nutrients in urban areas, and it also demonstrates the usefulness of human urine as a nutrient source for the visitors. Furthermore, any eco-toxicological concern by its use can be directly investigated in the aquaculture food chain on site, opening possibilities for interesting research projects in the future. This paper will present a brief description of the site, the ongoing projects, and some practical experiences.

Session F

Introduction

The Universeum science centre

Universeum science centre located at Korsvägen in Göteborg, Sweden, was inaugurated in 2001 (Wallin, 2002). The science centre is an educational platform and an excellent forum to tempt youngsters (in ages between 7-19 years old) to develop a better understanding and a direct experiment of sciences by visiting this building (Ervik, 2003).

In the business plan for Universeum, demonstrations of science and technology from an ecological perspective was emphasised and the building was identified as a resource for communicating this perspective. Environmental ambitions were developed into system requirements. During the design process, a reference group of researchers gave advice on goal settings, system design and specific details (Wallin, 2002).

Ecological engineering and the wastewater system

Ecological engineering was defined in 1971 by Howard T. Odum as the management of nature for human use (Odum, 1971). The synthesis between ecology and technology (eco-technology) requires a combination of basic and applied research as well as interdisciplinary teams for its

*This paper has been peer reviewed by the symposium scientific committee

proper application (Jensen et al, 1992; Mitch, 1991). Because of the complexity of nature a broad professional knowledge is required when creating ecological engineering systems .

After the Brundtland convention (1987), and environmental meetings (e.g. Rio, 1992) fundamental terms as "Agenda 21 ", "life cycle assessment" and "recycling", are stated and widely acknowledged, which has focused the practical local action on new technical developments towards local system for wastewater treatment. This has lifted environmental issues to a higher priority in decision-making processes, and also brought fundamental thinking on local scales to all levels in the society, people are involved. The future work with sustainable development in Sweden is following 15 environmental goals (http://www.environ.se). Two of these goals are “No eutrophication” and "A sea in balance with living coast and archipelago". These goals are especially important for urban areas producing enormous amounts of wastewater and discharging large amounts of nutrients to water recipients through agricultural runoff and wastewater treatment plants.

Figure 1: The Universeum exterior autumn 2001, view from the main entrance. Photo Zsofia Ban.

The discovery of nitrogen as a major cause of eutrophication, especially in the marine environment, has intensified the research on nitrogen removal from sewage water. Further demands on nutrient removal cause treatment plants to be rebuilt or extended (Mattsson, 1997). More than eighty percent of the nitrogen in sewage water from households originates from human urine (Adamsson, 1999). Therefore, source separating of urine could be a complement to decrease nitrogen discharge to estuaries.

Four aspects need to be considered for wastewater treatment methods (Jenssen et al 1992; Jonasson 1993):

- health aspects,
- recipient aspects,
- cost efficiency aspects and
- recycling aspects.

By using separating systems, the nutrients could be used as a resource directly after toilet disposal and appropriate hygienic stabilisation (i.e. storage) and thereby reduce the nitrogen load in incoming water to coastal sewage plants. The value of human urine as fertilizer or soil conditioner in agriculture is well known in Sweden (Jönsson et al., 2000; Johansson, 2000). However, its use can be controversial regarding different stages of urine management (storage, transports, spreading and overall aspects of hygiene). In recent years, research made at Göteborg University have shown that nutrient recovery in crystalline form to obtain a slow-release soil conditioner known as struvite [Mg (K, NH4)(PO_4) •6H2O] can be an ecologically and environmentally desirable way (Ban, 1998; Lind, *et al*.,2000). Human urine could also be used in an aquaculture approach (Adamsson, 2000). After several years of research on utilisation of the nutrients in human urine in a constructed food chain (Adamsson, 1999), the possibilities for demonstrating this technique became a reality at Universeum science centre.

The objectives of this paper are (1) to describe the technique of aquaculture and the initial research on crystallisation based on sorted human urine from Universeum, (2) to share some practical experiences from the operating toilet system at Universeum and (3) to discuss if new techniques like collecting of urine and crystallisation (struvite) could be a solution for sustainable utilisation of human urine in urban areas.

Methods

Collecting urine

The majority of the nutrients (N and P) are collected by the use of 26 urine-sorting toilets (system called "Dubletten", developed by Bibbi Innovation & Co AB). The front bowl is connected to a separated pipe, which collects urine into two storage tanks (volume of 6m^3 each). The back bowl is flushed to ordinary sewage system and the sewage plant for Göteborg city, with exception of 7 toilets on the personal floors. The faeces from these 7 toilets are connected to a sludge separator (3 chambers with a total volume of 12m^3) and this effluent could be used in the aquaculture or be transported to the ordinary sewage system.

The total urine volume collected per year is estimated by number of visitors and a dilution factor of 50% (about 1.2-1.5dl flushing volume according to the manufacturer of the toilet, see http://www.dubbletten.nu/english-presentation/WCdubbletteneng.htm).

Chemical and microbiological analysis have been made on the urine from the storage tanks by using a water-lifter (small plastic container on a wooden stick) directly placed into the manhole of the tanks, filling a glass bottle (1L), which were transported in a cool box (+4°C) directly to an accredited laboratory.

The aquaculture-principles (Figure 2)

The diluted urine is pumped [1] from storage tanks to a blender [2] (about 50L) in the water treatment centre (aquaculture). From this blender the solution flows by gravity to four cylinders (1m^3 each) which contain microscopic algae [3] (i.e. *Scenedesmus acuminatus*). Using photosynthesis, these algae assimilate the nutrients from the urine. The overflow of algae runs to each of four separated 1m^3 large concrete aquaria (replicates), were the algae are eaten by zooplankton, water fleas (*Daphnia magna*) [4]. The aquaria also contain a plastic foam (1m * 0,7m * 0.1m) with a pore size of about 0.1-10mm, which is aerated. The function of this is to act as a biofilter with an attached nitrification bacterial community. The water containing water fleas flows by gravity down to a 6 m^3 (water volume) large tank with small tropical fish (Guppy) [5]. These fishes fed on *Daphnia* sp. and are in turn harvested to become food for larger fish in some of the other aquaria in the building. The water runs down to a series of small pools [6] were water plants are cultivated. Not only these plants, but the roots of the rainforest trees are able to take up nutrients which still remain in the water. Then the water is

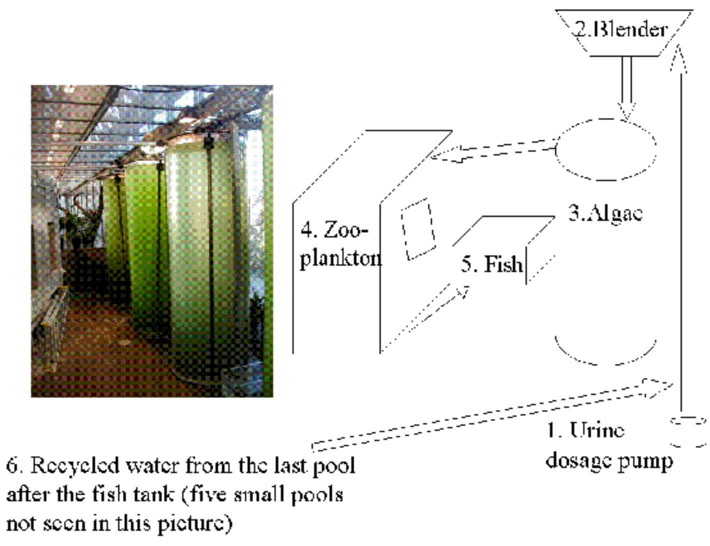

Figure 2: The aquaculture system at Universeum.

returned to the blender by a pump. In the blender, new urine is added. The water flows in a closed loop system, which is technically operated only by a dosage station for urine and the pump station in the final pool [6]. Biomass production of zooplankton has been recorded as well as pH, dissolved oxygen, total nitrogen, ammonia, nitrate and nitrite in order to monitor the nutrient flow and locate functional problems within the system during one month the first year (Barone, 2002). Urine from the storage tank in the aquaculture has also been sent for chemical and microbiological analyses.

The struvite process and mineral adsorption

Lind *et al*. (2000) showed that by addition of small amounts of magnesium oxide (MgO) to human urine most of the phosphorous (95-99%) and part of the nitrogen (20-50%) can be recovered as a precipitate. Crystalline struvite [Mg (K, NH4)(PO_4) •6H2O] was the major component of the precipitate, which also contained montgomeryite [$Ca_4MgAl_4(PO)_4(OH)_4$ *$12H_2O$], brucite [$Mg(OH)_2$] and epsonite [$MgSO_4$ *$7H_2O$]. In this way also 22-64% of K and 2-5.6% of Ca was recovered. Additional mineral adsorption steps improved the nitrogen recovery. Natural zeolites and wollastonite showed excellent adsorbent qualities in contact with ammonia solutions as well as in tests with human urine (Ban, 1998). When struvite crystallisation and mineral adsorption was combined 64-80% of the nitrogen (as ammonia) was recovered together with 95-99% phosphorus, (Lind *et al*., 2000).

The experiments with Universeum urine were based on the combination of two steps:

a) *dephosphatisation* using different amounts of MgO for struvite crystallisation

b) *mineral adsorption* using different amounts of zeolite for improved nitrogen removal.

Human urine was collected from the urine tanks at Universeum and transported immediately in closed plastic cans to the laboratory for testing. The urine was directly used for the experiment, without freezing or further storage.

The mineral zeolite (with high clinoptilolite content originating from Mad, Hungary, and a grain size of 1,2-2mm) was used in its natural form. MgO and zeolite was added to the urine in a series of batch tests.

The contact time of the experiment was 72 h at room temperature (20°C), which is more than enough for both struvite formation and ammonium adsorption processes (Lind, 2000). A short, manual stirring was made once daily. After 72 hours the supernatant was decanted and analysed for total-P and total-N (Spectrophotometer DR 4000, Hach-methods 3036 and 2558). Figures 3 and 4 show the results of the experiments.

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Results and discussion

Sorted human urine at Universeum

Collecting system

Since these systems are new, some technical problems were expected. Most of them were related to pipe dimensions and slopes and the design of the toilet seat. This has caused some additional work for the maintainers and cleaning staff at Universeum during the first year. Due to educated and interested staff at Universeum, these toilets have, in spite of their non-optimal design, been well maintained and are, in most cases, accepted and appreciated by the visitors. There are areas in the building that are more critical than others (i.e. more visited) like the entrance hall, where in high seasons, very frequent cleaning by staff is necessary. This was not always possible, which has lead to some complains from visitors of odours and blockages of the front bowl used for urine (paper jam, etc.).

Nutrients in collected urine:

Total N varied between 2 and 6g/L in collected urine (see Table 1 and Figure 3) and total P varied between 0.13 and 0.85g/L (see Table 1 and Figure 4).The reduction of *E.coli* in stored human urine occurs within a few days. Therefore, also other indicator organism should be used when evaluating hygienic risks from sorted human urine prior to its use as nutrient source (Jönsson, 2000; Höglund, 2001).

Table 1. Chemical and microbiological data for two samples of sorted human urine (about 50% diluted by flush water) at Universeum, Göteborg Sweden. Sample 1 was taken directly from the incoming water to the storage tanks. Sample 2 was taken when the urine enters the blending tank in the aquaculture. This means that the urine in sample 2 has been stored further for at least 1 week at 26 ± 2ºC.

Parameters	Method	Unit	1	2
pH	SS 028122-2.Titro		9.2	8.7
BOD (7)	SS 029143-2	mg/l	1200	290
COD (Cr)	Hach	mg/l	2100	1200
Total Nitrogen	TRAACS	mg/l	2200	2700
Ammonium-N	TRAACS	mg/l	2300	2700
Total Phosphorous	TRAACS	mg/l	130	150
Potassium	ICP-AES	mg/l	840	930
Cadmium	ICP-MS	mg/l	< 0.0004	<0.0004
E. coli	SS 028166-1	cfu/100ml	>160000	<2
Heterotrophic bacteria, 20 C, 2d	SS 028171-1	cfu/ml	>300000	>300000
Coliform bacteria, 35 C	SS 028166-1	cfu/100ml	>160000	<2

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The aquaculture

Research at a laboratory scale and in a small greenhouse system (Adamsson, 1999; Adamsson, 2000) showed that *Scenedesmus acuminatus* and *Daphnia magna* can grow and reproduce with human urine as nutrient source. Then the reduction of nutrients through the aquaculture system ranged 36-97% for nitrogen and 67-98% for phosphorous. The results from the first 18 months of operation of the aquaculture system at Universeum have shown that the critical step is the zooplankton production. This is mainly due to high temperature, low food quantity (lack of light for photosynthesis) and ammonia toxicity (Adamsson, not published; Barone, 2002). One aim is to increase the urine concentration (more nutrients) in the blender to produce more algae to improve *Daphnia* production. This must, however, be combined with acceptable pH value in the system to decrease the risk for ammonia toxicity to *Daphnia* (Adamsson, 1999). A complete evaluation of the production and reduction efficiency of this pilot scale system is so far unknown, although, a study based on one month performance of the plant (Barone,2002), indicated that the nitrogen concentration was reduced after the aquaculture steps, and the major part of nitrogen was in form of nitrate, indicating that both nitrification and nitrogen reduction was efficient.

The struvite process and mineral adsorption

The addition of MgO increased the initial pH value from 8.9 to 9.3 (data not presented here). Total-N and total-P reduction after addition of small amounts of MgO respective zeolite to human urine collected from the urine tanks is shown in Figure 3 and 4.

Nitrogen reduction:

a) The tot-N reduction from human urine is highly dependent of the amount of MgO added and of the stoichiometric conditions for *struvite* precipitation (molar ratio of 1:1:1 and weight ratio N:Mg:P of 1:1.7:2.2). Human urine contains an excess of ammonium relative to phosphate and with Mg added and a phosphate recovery of nearly 100% just a part of ammonia is recovered as struvite. Theoretically, the maximum part of the total N that can be captured in the struvite structure is 38% from Universeum urine.

b) The further nitrogen uptake by *zeolites* depends on the ion exchange property of the mineral, the amount used, the grain size and contact time (Lind, *et al.,*2000). The clinoptilolite type of zeolite used here has good ammonium absorbent capacity (Lind, *et al.,* 2000) but the struvite precipitation itself slightly reduces the end-pH of the urine tested and during the adsorption process to the zeolite a competition may occur between H-ions and NH_4-ions for the exchange sites in the mineral structure. The simultaneous precipitation and mineral adsorption processes are complex processes and a clear picture of the tot-N uptake due only to the zeolite was investigated earlier (Lind, *et al.,* 2000). A deeper discussion about the processes using concentrated urine is under publication elsewhere. However, an additional of 30-85% total N reduction (from remaining amounts after struvite precipitation) due to zeolite adsorption was found in this study (Figure 3).

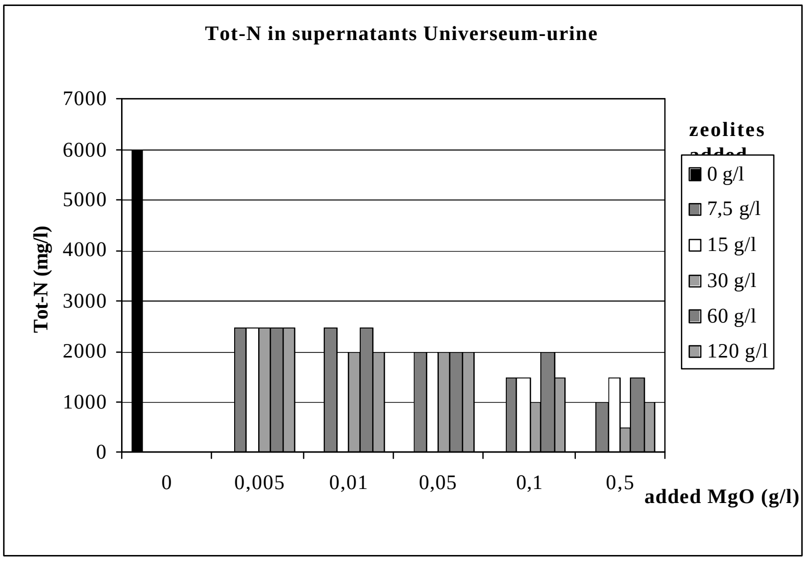

Figure 3: Total-N reduction in urine from Universeum by addition of MgO and zeolite.

Phosphorus reduction:

a) The stoichiometric ratio (molar weight based) Mg:P is 1.71: 2.21 for *struvite* precipitation for urine containing 0.85 g P/l. According to our experiments 0.5 g MgO per litre urine is sufficient to get a tot-P reduction of 95-98% in combination with zeolite, because the zeolite is a good phosphorus adsorbent.

b) The natural *clinoptilolite type of zeolite* has also a good tot-P adsorption capacity. When tested with human urine. This process is mainly due to the possibilities for chemisorption on the Ca-, Fe- or Al-oxide sites in the zeolite structure (under publication elsewhere).

Previous test results with combination of struvite precipitation and further ammonium uptake by

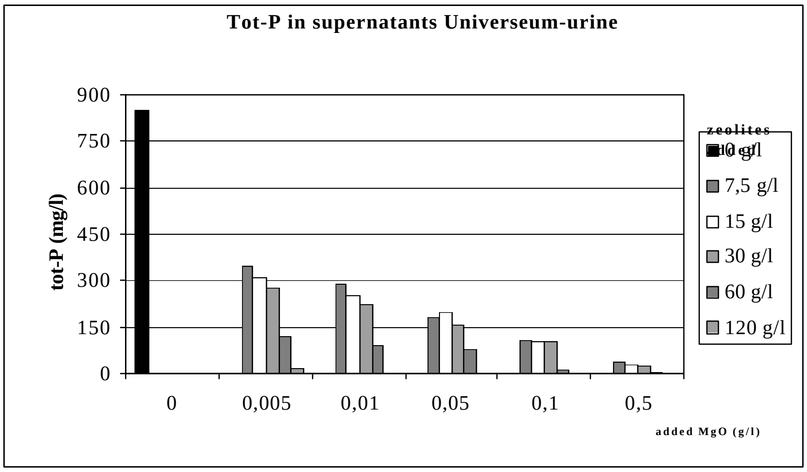

Figure 4: Total-P reduction in urine from Universeum by addition of MgO and zeolite.

zeolites have also demonstrated a 64-80% ammonium uptake together with a 98-100 % phosphorus uptake from human urine (Lind *et al*., 2000). Process optimisation at Universeum is in progress.

Sustainability and future work

Wastewater is a resource and should, therefore, be treated as such. However, its use has important hygienic aspects that has to be considered. The aquaculture technique is perfect as a demonstration pilot plant and for educational purposes regarding understanding the scientific background behind eutrophication, and could also be used for research on bioaccumulation and biomagnification of different elements in the organisms living in aquatic environments. But the aquaculture technique as such has only a limited potential as a commonly used wastewater treatment technique, even if it can be used in combination with other techniques. The most realistic and interesting approach on utilising the nutrients in human urine in urban areas is, therefore, simple collection in storage tanks. The urine fraction must then be transported to farmers to close the loop between urban and rural areas for further use in agriculture. This transport could be environmentally improved by using the struvite process, and in this way decreasing the transport of water. Therefore we are looking forward to construct a pilot plant for mineralization of N and P from human urine at Universeum in the near future. The research is at experimental level, mostly at laboratory scale, and a holistic approach including a system evaluation is necessary.

Modern society will probably continue to have some large-scale wastewater plants that were constructed during the 70ths and forward for many years to come. This is not a question of either having large and efficient conventional systems or small scale, expensive, low functioning systems, to meet the future demand on sewage systems. This is about how to use the best technologies in combination to meet the areal restrains of large cities and to recycle materials in an as environmentally friendly way as possible to reach a sustainable society for coming generations, and also considering aspects of what is acceptable from the users point of view.

This multiple use of the source-separated urine from one facility demonstrates a possibility for a sustainable recycling of nutrients between urban and rural areas and it also demonstrates the usefulness of human urine as a nutrient source for the exhibition visitors. Furthermore, any eco-toxicological concern including endocrine disruption, can be investigated in the aquaculture food chain, opening possibilities for interesting research projects in the future.

The Universeum ecological wastewater system is a demonstrating plant and a research site in an educational environment that is visited by people of all ages and professions. It is a good starting point for discussions and debates on future sustainable utilisation of human urine and wastes in general in urban areas.

Conclusions

- Urine collection and the utilisation of its main nutrients (N and P) have been practiced for two years (2002-2003) at a science centre (Universeum) in Göteborg, Sweden.
- Problems relating to the function of urine-separating toilets and mineralization of the nutrients have been addressed and partly solved.
- Ecological recycling is demonstrated in an aqua cultural food chain (algae-zooplankton-fish).
- Mineralisation of N and P by precipitation as struvite and adsorption to zeolite have been tested at a laboratory scale with recoveries of 30-85% of the total nitrogen and 95-98% of the total phosphorous in the collected urine.

References

Adamsson, M.: Treatment of domestic wastewater by Aquaculture. Doctoral thesis. Department of applied environmental science, Göteborg University, 1999, pp.106

Adamsson, M.: Potential use of human urine by greenhouse culturing of microalgae (*Scenedesmus acuminatus*), zooplankton (*Daphnia magna*) and tomatoes (*Lycopersicon*). Ecological Engineering, 2000, Vol. 16, pp. 243-254

Adamsson, M. and Dave, G.: Toxicity of human urine and its main nitrogen excretory and degradation products to *Daphnia magna*. Environmental Research Forum, Vols. 5-6, 1996, pp.137-144

Adamsson, M., Dave, G., Forsberg, L., Guterstam, B.: Toxicity Identification Evaluation of ammonia, nitrite and heavy metals at the Stensund Wastewater Aquaculture plant, Sweden. Water Science and Technology,Vol. 38, No. 3, 1998, pp.151-157

Ban, Z.: Nutrient recovery from human urine – a concentration and crystallization process. Honour Thesis, Göteborg Univ./ Dept. of Applied Environmental science and Dept. of Geology. 1998, pp 60

Barone, K.: Universeum´s Ecological wastewater system-a study of an alternative wastewater system. Honour Thesis, Göteborg Univ./ Dept. of Applied Environmental science. 2002, pp 31.

Ervik, F.: Asking questions is good science. Reflektioner. Faglig og visual revy. Number 1 winter 2002/2003. In Scandinavian and English p 48-55 and p 149-151

Höglund, C.: Evaluation of microbial health risks associated with the reuse of source-separated human urine, Doctoral Thesis, Royal Inst. of Technology, Dept. of Biotechnology, 2001, pp78

Jensen, P.D., Maehlum, T. and Wetlesen, M.: Økologisk renseteknologi- Oversikt over ulike naturbaserte behandlingsmetoder for kommunalt avløpsvann. Statens forurensningstilsyn, Oslo. In Norwegian, 1992, pp. 72

Johansson, M.: Urine separation –closing the nutrient cycle. Final report on the R&D project: Source-separated human urine –a future source of fertilizer for agriculture in Stockholm region?, Stockholm Water, 2000, pp 40.

Jonasson, S.A.: Lokal avloppshantering. Del 1. Möjlig tillämpning i Västsverige med exempel. Report 1993:13. Göteborgs stad - Miljö - och hälsoskydd/VA-verket, Göteborg. In Swedish, 1993, pp. 29

Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G., Kirchmann, H.: Källsorterad humanurin i kretslopp. VA-FORSK Rapport 2000 (1), in Swedish, 2000, pp 105

Lind B.B., Ban Z., Bydén S.: Nutrient recovery from human urine by struvite crystallization, with ammonia adsorption on zeolite and wollastonite. Bioresource Technology 73, 2000, pp.169-174

Mattsson, A.: Denitrification in a Non-nitrifying activated sludge system employing recirculation from a tertiary nitrification unit. Doctoral thesis. Department of Sanitary Engineering. Chalmers University of Technology, Göteborg, Sweden, 1997, pp. 240

Mitsch, W.J.: Ecological engineering: The roots and rationale of a new ecological paradigm. In: Ecological Engineering for wastewater treatment. Etnier, C and Guterstam, B (Eds.). Bokskogen, Limmared, Sweden, 1991, pp. 19-37

Odum, H.T.: Environment, power and society. Wiley-Interscience, John Wiley & sons, Inc., New York, 1971, pp. 331

Pettersson, A., Adamsson, M. and Dave, G.: Toxicity and detoxification of Swedish detergents and softener products. Chemosphere, Vol. 41, 2000, pp.1611-1620

Wallin, B.: Design with Environmental adaption- The Universeum Example. On integration of environmental aspects in the architectural design process. Licentiate thesis (in Swedish) Department of built environment and sustainable development, school of architecture, Chalmers Univeristy of technology, Sweden, 2002, pp 155.

Session F

The effects of sewage sludge application on the yields of berseem and forage maize in newly reclaimed soil

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Key words

Egypt, nutrients, reclaimed soil, sewage sludge, trace elements, yields

Abstract

Two large-scale field trials with fodder crops (berseem and maize) were established under centre pivot irrigation on a reclaimed desert soil in the Western Desert, near Sadaat City, Egypt, comparing the use of air-dried raw sewage sludge with normal farmer practice. The application of sludge improved crop yields and strong residual benefits were observed in subsequent years. The nutritional quality of these animal fodders was also improved by sludge applied to this deficient soil, with useful increases in nutrient and trace element concentrations. There were no increases in heavy metal concentrations.

Introduction

The newly reclaimed soils in Egypt are characterised by low fertility and poor moisture retention. Since animal manure is no longer readily available, other materials such as sewage sludge should be tested and used to meet soil nutrient and organic matter requirements. Sludge use in agriculture is widely regarded as the best practicable environmental option but is untested under Egyptian conditions (Smith *et al*., 1995).

Cairo produces large quantities of sludge (0.4 million t dry solids y^{-1}), and the preferred management option is beneficial use in agriculture. The Cairo Sludge Disposal Study (1995-99) was a 4 year demonstration programme, funded through the European Investment Bank, to evaluate how sludge can be reused practically and safely, particularly on newly reclaimed desert land.

This paper reports on one of the 30 arable and fruit field trials conducted during the study (Smith *et al*., 1999). The aim of this trial was to evaluate the effect of sludge on forage yield and quality in a fully mechanised large-scale field trial on calcareous sandy reclaimed desert soil.

Materials and methods

Two large-scale field trials were conducted under centre-pivot irrigation system on a private farm at km 100 on the Cairo-Alexandria Desert Road, under a rotation of fodder and cereal crops. Fertigation is normal farmer practice and large plots were established with and without sludge addition to assess direct, residual and cumulative effects. Only the fodder crops are considered in this paper. The first trial was carried out on berseem, while the second trial was with forage maize (*Zea mays* L.).

In 1995/96 winter season, berseem (Egyptian clover *Trifolium alexandrinum* L.) was grown on a centre pivot area of 30 ha. Half the area was treated with 24 m3 ha^{-1} of air-dried raw sludge prior to sowing and the rest untreated. Three cuts of berseem were made, yields assessed from 10 large randomly selected quadrats. Foliage was analysed for nutrients and trace elements.

In summer 1996, fodder maize was grown on a second pivot area (15 ha). The area was similarly divided and treated with 48 m^3 ha^{-1} of sludge. In summer 1998, maize was grown again and assessed for residual effects of the sludge applied two years previously.

Results and discussion

Soil and sludge quality

The soil type was a well-drained Typic Calciorthid (Aridisol), with contents of CaCO3 5%, gypsum 0.6%, organic matter <1%, with pH 7.5 and electrical conductivity of 3 dS $m^{-1.}$ The soil had only recently been brought under cultivation and previous crops had been poor due to the difficult soil conditions.

The chemical analysis of sludge from Abu Rawash WWTP used in the field trials is summarised in Table 1. The nutrient concentrations are typical for Egyptian sludges and heavy metal concentrations are well within prescribed quality limits (Decree 214, 1997).

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Units: nutrients %, other elements mg kg^{-1}		
Determinand	Mean	±95% confidence
N	1.61	0.49
P	0.57	0.28
K	0.23	0.07
Fe	1.90	0.40
Mn	286	145
Zn	656	301
Cu	168	51
Cr	36.6	30.6
Pb	102	62.3
Cd	2.57	0.70
Ni	51.3	32.3

Table 1: Chemical analysis of sludge

Crop yields

The mean yields of berseem at each cut are presented in Table 2. There was no significant effect of sludge on berseem yield at the first cut when mean yields were13.2 and 12.5t ha^{-1} for the untreated (normal farmer practice) and the treated areas respectively. However, in the subsequent cuts, the yields from the sludge-treated area were significantly greater than the yields from the untreated area: the latter declined with each harvest to 5.0t ha^{-1} at the third cut, compared to 10.1t ha^{-1} from the sludge treated area. The maintenance of yields in successive harvests in this way is of significant benefit of sludge for the farmer. Overall, the results show that sludge applied at 24 m3 ha^{-1} increased crop yields from 27.8 to 37.8t ha^{-1}, an increase of 25%.

Treatments: FP farmer practice; SS sludge 24 m^3 ha^{-}						
	Cut 1		Cut 2		Cut 3	
	FP	SS	FP	SS	FP	SS
Mean	13.2	12.5	9.6	12.2	5.0	10.1
p	>0.05		0.033*		<0.001***	
LSD	ns		2.4		2.6	

Table 2: Yields of berseem (t FW ha-1).

Treatments: FP farmer practice; SS sludge 48 m3 ha^{-1}		
	FP	SS
	First season (sludge applied)	
Mean	6.43	16.9
P	0.004**	
LSD	6.77	
	Fourth season (residual effect)	
Mean	12.7	17.0
P	0.008**	

Table 3: Yields of maize (t FW ha^{-1})

The yields of forage maize from the second trial in the first season are given in Table 3. The sludge-treated area produced a significantly higher yield (P < 0.004) than the untreated area; 16.9t ha^{-1} compared to 6.43t ha^{-1}, 160% increase. The yields generally were rather poor. The establishment of arable crops on newly reclaimed land can be variable due to the difficult soil conditions, particularly if seed is sown too shallow where it is more at risk of desiccation. The addition of the organic matter in the sludge may assist in moisture retention and improved seedling survival.

Maize was grown on the same area two years after sludge was applied. Yields were overall were much greater than for the first crop, presumably due to the intervening effects of cultivation and fertilisation. Nevertheless, significant residual effects on yield were observed on the sludge treated area (Table 3), presumably due to addition of organic matter and slow-release nutrients.

Crop quality

Table 4 summarises the nutrient content of the berseem (means of three cuts). The concentrations of the heavy metals Cr, Co, Cd, Pb, and Ni were below detection limits. There were only a few statistically significant beneficial effects due to the sludge application on N, P and K contents of berseem, bearing in mind that all of the crop received fertiliser by fertigation. However, the concentrations of Fe, Mn, Zn and Cu were generally significantly greater in the berseem grown on the sludge-treated area than the untreated area. Since the yields of the sludge-treated plot were also generally much greater, the total off-take of these nutrients would be substantial. Thus, in terms of plant and animal nutrition, sludge improved herbage quality since these elements are often deficient in such alkaline soils. Even so, Zn and Cu content of berseem on the sludge-treated plot only reached the adequacy levels for the ruminant nutrition.

It has been reported from similar trials through this study that frequent applications of sludge to reclaimed soil will increase soil fertility and can reduce inorganic N fertiliser requirements. Four to six consecutive applications at the suggested rates of addition (48m3 ha^{-1} for raw sludge and 24m3 ha^{-1} for digested sludge) can reduce inputs of inorganic N fertilisers by 50 %. Ameliorating the marginal physico-chemical properties of reclaimed soils for crop production demands large and frequent inputs of organic matter and plant nutrients. To satisfy this requirement, sludge can be applied regularly to reclaimed desert soils. All crops may be treated within a rotation provided that due diligence is given to balance K supply with inorganic fertilisers and that the sensitivity to N of certain crops, such as sesame and legumes, is considered. FYM can be used as an effective source of K and, if inorganic K fertilisers are not available, alternate dressings of sludge and FYM should be applied to balance NPK inputs to soil.

Units: nutrients % DM; trace elements mg DM kg^{-1}		
	Farme practic :	Sewage sludge
N	1.77	1.75
P	0.22	0.19
K	0.98	1.03
Fe	62.2	80.9
Mn	29.8	30.7
Zn	17.4	22.9
Cu	5.76	6.45

Table 4: Quality of berseem (means of 3 cuts)

Conclusion

Sewage sludge has important cumulative and residual value for field crop production on reclaimed desert soils. Yields of crops grown on land treated previously with sludge may be increased by 10 - 20% compared with normal farmer practice. The addition of heavy metals to the soil during the trial was very small from a single application of sludge and had minimal effect on crop and soil concentrations. The calcareous nature of most Egyptian soils and the relatively low concentrations of heavy metals in Cairo's sludges Smith et al., 1995; 1999) means that it is unlikely that heavy metals from sludge will pose a significant threat, even in the long-term.

References

Decree 214 (1997). Concerning Processing and Safe Use of Sludge. Min. of Housing, Utilities and Urban Com., Egypt.

Smith, S R, Abd El Lateef E M, Hall J E, and Rasheed A A (1995).The Agricultural Use of Sewage Sludge in Warm Climates, with Special Reference to Egypt. WRc Medmenham, UK

Effect of long-term application of wastewater on bioavailability of trace elements and soil contamination

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Key words

DTPA extraction, citrus, Cu, Cd, leaf concentration, soil concentration, toxicity, Zn

Abstract

As part of a four year study evaluating the practicability and value of sewage sludge use in Egypt, soil and plant surveys were carried out on a citrus plantation, irrigated with Cairo sewage since the 1920s, in order to evaluate the long-term accumulation of heavy metals and their bioavailability. While total and DTPA soil concentrations correlated well, no relationship could be found between soil and plant tissue concentrations, despite elevated levels of heavy metals in the soil.

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Introduction

Cairo is now served by six large wastewater treatment works which produce significant quantities of sludge. The preferred option is to use this in agriculture, particularly on reclaimed desert land which is inherently deficient in organic matter, nutrients and trace elements. However, there are concerns about the long-term accumulation and potential effects of heavy metals, and as part of the Cairo Sludge Disposal Study, a number of field trials and surveys have been carried out.

The Gabal El Asfar Farm is a fruit plantation on reclaimed desert land north of Cairo. It has been irrigated with sewage for over 80 years and there are concerns about the contamination of the site by potentially toxic heavy metals. The site provides a possible model of the potential long-term effects of heavy metals on crops for sewage sludge-treated soils in Egypt.

Materials and methods

The heavy metal contents of citrus leaves and fruit (orange and mandarin) and total and DTPA extractable concentrations in soils were measured in samples collected from different areas of Gabal El Asfar Farm during two surveys of the site in 1997.

Results and discussion

Total and DTPA concentrations of heavy metals in the surveyed soils showed significant enrichment by long-term irrigation with sewage effluent. For example, the maximum total concentrations of Zn and Cu were 530 and 366 mg kg^{-1}, respectively, representing a potential risk to crop yields (Table 1). The maximum Cd concentration detected was 9 mg kg^{-1} and Cd may be a potential risk to the human food chain from uptake into staple crops grown at the farm. The concentrations of DTPA extractable metals were also increased by sewage application and were significantly correlated ($P<0.001$) with the total contents of Zn ($r=0.81$), Cu ($r=0.89$), Ni ($r=0.88$), Cd ($r=0.73$) and Pb ($r=0.62$) (Figure 1a).

Element	Survey 1		
	Minimum	Maximum	Mean
Zn	180	530	331
Cu	50	117	84
Ni	1	51	22
Cd	1	9	3
Pb	5	70	23
Cr	80	230	154
	Survey 2		
Zn	32	143	95
Cu	7	366	67
Ni	10	92	45
Cd	0.2	4.6	1.6
Pb	16	290	70
Cr	2	376	89

Table 1: Total heavy metal content (mg kg^{-1}) of soil at Gabal El Asfar Farm

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However, crop analysis showed no relationships were apparent between tissue content (Table 2) and the corresponding total and DTPA extractable concentrations in soil for the elements determined (Table 3 and Figure 1b). Leaf Zn and Cu concentrations were in the low (16-24 and 3.6-4.9 mg kg^{-1}, respectively) to optimum (25-100 and 5-16 mg kg^{-1}, respectively) ranges for citrus. The other heavy metals were within normal ranges.

Whilst DTPA is widely used in nutrient diagnosis assessment, it has not provided a reliable indication of the bioavailability of potentially toxic elements to citrus in reclaimed desert soil.

	Fruit (Survey 1)			Leaves (Survey 2)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Zn	0.4	2.6	1.1	1.2	150	27.8
Cu	0.1	0.5	0.3	1.0	9.4	3.8
Ni	0.1	1.2	0.4	0.8	10.0	4.3
Cd	0.02	0.1	0.07	<0.1	0.2	0.1
Pb	0.2	2.1	1.0	0.5	30.0	12.4
Cr	0.4	3.6	2.0	0.2	4.1	2.0

Table 2: Heavy metal content (mg kg^{-1}) of citrus at Gabal El Asfar Farm

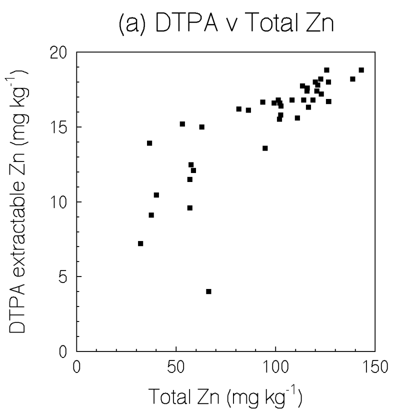

Figure 1a: Relationships between total and extractable Zn in soil at Gabal El Asfar Farm (Survey 2)

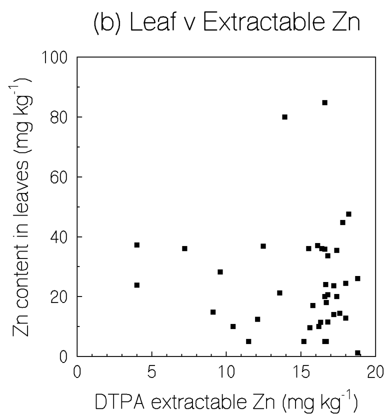

Figure 1b: Relationships between extractable Zn in soil and Zn content of citrus leaves at Gabal El Asfar Farm (Survey 2)

	Fruit		Leaves	
Zn	-0.11ns	0.03ns	-0.01ns	0.05ns
Cu	0.27ns	-0.03ns	0.36ns	0.24ns
Ni	0.06ns	-0.35ns	0.38ns	0.18ns
Cd	0.39ns	0.35ns	0.35ns	0.47ns
Pb	0.24ns	-0.24ns	-0.10ns	0.04ns
Cr	0.09ns	0.01ns	0.01ns	-0.05ns

ns: not significant at P=0.05

Table 3: Correlation coefficients (r) of relationships between metal concentrations in soil and citrus at Gabal El Asfar Farm

This study has contributed to a broader understanding of the behaviour of heavy metals in reclaimed sandy and calcareous desert soil which is the principal 'market' for sludge in Egypt. As part of the Cairo Sludge Disposal Study (Smith et al., 1995: 1999), funded through the European Investment Bank, this has contributed to the development of Egyptian standards for sludge use in agriculture (Decree 214, 1997).

References

Decree 214 1997 Concerning Processing and Safe Use of Sludge. Min. of Housing, Utilities and Urban Com., Egypt.

Smith, S R, Abd El Lateef E M, Hall J E, and Rasheed A A 1995 The Agricultural Use of Sewage Sludge in Warm Climates, with Special Reference to Egypt. WRc Medmenham, UK.

Smith, S R, Abd El Lateef E M, Hall J E, and Rasheed A A 1999 Scientific Justification for Agricultural Use of Sewage Sludge in Egypt. WRc Medmenham, UK.

Urine-separating toilet in popularising ecological sanitation in the peri-urban areas of Manipur, India

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Keywords

Eutrophication, Imphal, Loktak lake, urine-separating toilet

Abstract

To popularise the beneficial aspects of the fertilizing utility of human urine to the general public of Manipur state and also to make a step toward checking the deteriorating environment of Imphal city by protection of water bodies, a urine-separating toilet has been introduced and demonstrated at Kangla a locality of Imphal city. The harvest of potatoes and chilies when urine is used as fertilizer are very good and comparable to the harvest which are fertilized with chemical fertilizer.

Urine-separating toilet at large may be adopted by the general public of Manipur state with awareness programme through print and electronic media and active involvement of NGOs.

Introduction

Manipur is the north-easternmost state of India adjoining with Myanmar. It is a hilly state whereas the central part consisting 10% of the total area of 22,327 sq. km. is the Imphal valley where 70% of the state's population of two million plus are inhabited. Traditionally by and large Meitei the people of the valley are orthodox. They consider human excreta as untouchable in any form whether dry or wet; raw or composted. Even in recent times one should necessarily take bath after toilet.

The two main rivers viz, Imphal and Iril flowing through the capital city Imphal are the main source of water for half the inhabitants of the city. The two rivers and river Nambul also act as open drains to which all the used water of the city are merged. The polluted river water ultimately join the Loktak lake to the southwestern side of the valley. Loktak lake is the biggest fresh-water lake in the north-eastern India. The socio-cultural civilization of the valley of Manipur has been flourished around this lake in its pristine time. But because of unchecked end-point disposal of all human activities including heavy loading of nutrients to the lake, the quality of the lake and its surrounding area has been deteriorating. Eutrophication is going on in the lake resulting in excess growth of aquatic weeds and floating mass of vegetation.

Even though the people of Imphal look neat and clean the traditional method of disposal of human excreta has not been so hygienic. Septic tank without soak-pit and pit latrine are the usual disposal system of human excreta. In the periphery most of the latrines are open-pit type. Sewage from the septic tank without soak-pit are directly discharged to the open drains which again flows mainly to any of the three rivers. But with the recent introduction of training programmes for capacity and capability building to the users in the sector of water and sanitation conducted by Human Resource Development Cell, sanitary latrine like two-pit pour-flushed latrines are becoming popular in the peri-urban areas of Manipur. People started taking interest in disposal of human excreta in a safer way.

The concept of urine-separating toilet (Ecological Sanitation–ecosan) was introduced by the author to groups of knowledgeable persons of Imphal city sometimes in the month of October, November 2001. One of the group started a pilot project on urine-separating toilet at a place known as Kangla about 10 km northeast of Imphal. A liberal minded family has been selected to adopt urine-separating toilet. In the household of 7 member family, three members the husband, wife and daughter were fully convinced about the benefits of ecosan specially the fertilizing utility of urine.

Methods

The three member team of the household started collecting urine by squatting on a tray kept in the toilet specially in the evening time. The urine was immediately transferred into a 5-litre plastic jerkin. The jerkin was kept closed and stored for a minimum of 10 days without dilution. 2.5 to 3 litres of urine can be collected in a day. All the collected urine were stored to be used as fertilizer later.

150 potatoes plants of JYOTI variety were planted on an ordinarily prepared bed during the first week of November, 2001. When the plants were of about 15 cm height and four leaves were sprouted from the stem, soils were scooped by THANGJOU (local contrivance) about 5 cm away from each plant and 200 ml stored urine without dilution was administered in the depressed area near the stem. After urine was poured the soils were made again flat as before. During the same time another bed with sprinkled DPA (Diammonium phosphate) was also prepared for planting another 150 potato plants of the same variety. Urea and potash were used as fertilizer on these plants at the same time when urine was put on the other bed.

Figure 1: Administering store-urine to the potato plants

Again in the first week of Jan, 2002, 200 plants of Chillies of "MEITEI MOROK ASHAANGBI" variety were planted on an ordinarily prepared bed. When the plants were about 25 cm high 150 to 200 ml stored urine without dilution was administered in the same manner as in the case of potato plants. Chillies are usually planted without any additional fertilizer otherwise the stems are bent and most of the plants are spoiled. As the stems of the urine fertilized chilli plants are growing faster spikes are provided to support the bending stems. During the same time another 200 plants of the same variety were planted on another ordinarily prepared bed without any fertilizer.

Results

During the third and fourth week of Feb, 2002 the potatoes were harvested. It has been found that the urine-fertilized-plants have 10 days longer time with green leaves before the leaves were wilted than the ordinarily fertilized-plant with DPA, urea and potash.

In case of chillies also the urine fertilized-plants have10-15 days longer time with green leaves. Harvesting started from the first week of July to the middle of August. Results of the harvest of both potatoes and chillies are summarised in the following table.

Crops	Variety	One time undiluted store - urine dose on each plant	Harvest
Potato	Jyoti	200 ml	Very good, produce are as good as that of fertilized plants with DPA, urea and potash
Chilli	Meitei Morok Ashaangbi	150 – 200 ml	20% more than the ordinarily planted chillies without fertilizer

Table 1: Result of the harvest of potatoes and chillies fertilized with store–urine

Conclusions

No one in the neighbourhood was informed about the urine fertilization on the potato and chilli plants and no complaint of anything sort including smell had come up from the neighbourhood. Even the older members of the same family were not informed less they might object because of religious believes and other orthodox views. In the Meitei society the first harvest of any plant is offered to the Almighty God and it is unthinkable for an orthodox Hindu Meitei to offer urine-fertilized potatoes or chillies to the Almighty. Nevertheless the harvest of both potatoes and chillies were very good without any extra cost and the family members were very happy. One toilet model with separate arrangement for urine collection tray has already been started functioning in the same locality after the successful story.

Awareness programmes with practical demonstration to show the beneficial aspects are essential to take-up ECOSAN activities in the area. Government efforts like advertisement in the radio, T.V. and newspaper are important steps to overcome the orthodox believes of the society. Active involvement of NGOs working in the field of water supply and sanitation is also necessary for widespread popularisation of ecosan in Manipur.

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Reference:

Report–July 1999 –March 2001 Loktak Development Authority, Manipur. Wetlands International South Asia, New Delhi.

Sustainability and optimisation of treatments and use of wastewater for irrigation in mediterranean countries

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Keywords

Epuvalisation, nitrogen fertilization, wastewater reuse, wastewater storage, wastewater treatment, wetlands

Abstract

The aim is to find long term solutions to the general problem of wastewater reuse, in accordance with specific needs and environmental conditions in Mediterranean countries. Low cost technologies for wastewater treatment are investigated. Free Water Systems with and without recycling, mixing olive oil wastewater with municipal wastewater or fresh water, achieve good results especially for BOD removal. The maturation and seasonal storage of wastewater prove the positive effect on decontamination rate. The epuvalisation system tests the purification efficiency of different hydroponics plants and reveals that mentha and celery are among the most robust and best suited ones. Irrigation techniques compatible with sustainable agriculture are studied for what concerns their impact on the irrigation system itself, on the soil/plant complex, as well as complementation irrigation for cereal crops and optimization of nitrogen fertilization under irrigation with wastewater. The study of performances of irrigation equipment using wastewater demonstrates that the drip irrigation system with integer emitters gives the best yields and optimal hydraulic working. The need of controlling the leaching of nutrients and contamination of soils and water leads to several recommendations in order to reduce the risk of nitrogen pollution as well as the cost of supplied water.

Introduction

The two aspects experimented in the frame of the INternational COoperation project – INCO (FP4) - financed by the E.U., are wastewater treatment, to obtain a effluent which can be reused in agriculture, and irrigation techniques, which are compatible with sustainable agricultural practices. The goals are to produce, in a sustainable way, crops irrigated with wastewater treated by low cost technologies adapted to the Mediterranean environment and adequate for producing advanced treated effluent. The success of this initiative results from the collaboration of Mediterranean countries research teams and European Union laboratories.

New technologies are developed for the treatment of wastewater from small settlements, villages and towns, in order to produce water suitable for irrigation. Traditional wastewater treatments have not succeeded due to the high costs of both construction and maintenance as well as to the need of highly specialized personnel for their supervision.

The use of wastewater for irrigation may potentially have adverse impacts on both the environment and the public health, mainly depending on the wastewater characteristics, degree of purification, method and location of use and irrigated crops. Soil, groundwater and surface water pollutions are the most important disadvantages of wastewater use. However, sound scientific planning and effective management of the irrigation or fertilization regime according to water and nutrient requirement of selected crops can minimize these disadvantages to the level of environmental insignificance. Selection of crops is one of the most powerful means to protect public health. Flowers, particularly those which are dried, industrial crops or crops consumed after transformations open new perspectives on wastewater use since they can be used on profitable and sustainable bases.

Material and methods

The technology developed for wastewater treatment by the Free Water Systems (FWS) consists of parallel basins or channels with permeable bottoms soil, emergent vegetation and shallow water depth. Pretreated wastewater is applied continuously and a further treatment occurs as water flows slowly through the stems and roots of the emergent vegetation. Among all the aquatic systems, the FWS are considered the most appropriate to obtain reclaimed wastewater for irrigation (Tchobanoglous, 1987 and Angelakis and Tchobanoglous, 1996). Various ponds configurations, including recycling or not, with various BOD loading rate, and selected indigenous aquatic plant species tests the efficiency of FWS for treatment of municipal and olive oil wastewaters.

Epuvalisation, the biological treatment of wastewater based on the principle of hydroponic crops, is a system well in use in temperate countries as a tertiary treatment, producing an effluent available for unrestricted agricultural reuse, producing greenhouse or decoration flowers, seaside windbreak plants, etc. Thanks to the gravity flow of the liquid to be purified, and an abundant aeration, the microbial flora acts like a bacterial bed. It mineralizes matter in solution and the plants, by their root system, act as a filter which retains the matter in suspension and pathogen micro-organisms. (Xanthoulis, 1996, 1997, Dumont, 1999) The transposition of the technology to Mediterranean countries has to face the problem of the too high temperature, which is lethal for both the rooting system of the plants and the bacterial bed in the channels, and also induces a lack of dissolved oxygen. The efficiency of the regional plants species are tested; flowers produced under irrigation are compared for their quality between irrigated one with water produced by epuvalisation and four other sources of water, added or not with fertilizers.

One of the disadvantages of wastewater reuse for irrigation is its microbiological quality. To avoid contamination of the crops by irrigation, the most influential factors on bacterial indicators die-off, together with the practice of long term storage of wastewater before irrigation, are identified. The bacterial decontamination time needed under various climatic conditions and with different basin depths and capacities are determined. The maturation and the seasonal storage of effluent are evaluated by means of the wastewater characteristics, under different storage basin management modes (M.Raïs, D.Xanthoulis, 1999). The products obtained (eg citrus and olive trees, eggplants) from crops irrigated with clear water and with wastewater treated by storage are compared for their microbiological qualities. Irrigation with wastewater also encounters problems with the irrigation systems themselves. The behavior and performances of micro irrigation systems are modified when wastewater, instead of conventional water, is used. The impact of wastewater is tested on drip irrigation, sprinkling and modernized furrow irrigation systems; emitters and filtration performances in laboratory are compared with results obtained in the field (Chenini, 2000). The influence of nitrogen and salts contents in the recycled wastewater has a capital importance on the growth of plants and the yields they achieve. The response of chickpeas to water application and the response curve of the plant yield to water level is studied in Israel. Nutrient and water regime management, alternations between well water and treated wastewater, to optimize the use of nitrogen, are tested to find solutions to the Moroccan problems of high electrolytes concentration in the well water.

Results

Preliminary results of pre-treatment processes, before entering the Free Water System, show a removal efficiency of BOD of 90% and 40% for Olive Oil Wastewater (OWW) and Municipal Wastewater (MWW) respectively. In the unit mixing OWW with fresh water without recycling, the Total Suspended Solids (TSS) and BOD concentrations of the effluent range from 282 to 663mg/L and from 225 to 750mg/L, respectively. In the other units, including recycling and units mixing OWW with MWW, the TSS and BOD concentrations of the effluent range from 68 to 501mg/L and 95 to 365mg/L, respectively. Briefly, a BOD removal efficiency of 77% is obtained with recycling and 51% without.

Celery is grown in epuvalisation channels at water flow rates of 400 and 300L/hour. A decrease of 45% and 37.5% in suspended solids is observed (from 40ppm to 22 and 25ppm), one also observes a decrease in nitrates from 85ppm to 62 and 64ppm respectively but no effect on the BOD removal (from 97mg/l to 94 and 95mg/l). From the results of Gerbera flower production per plant it is shown that freshwater produces significantly more flowers per plant than the other water qualities; fertilization has a significant effect on flower production for both freshwater and borehole water but no significant effect on wastewater irrigated plants. In general freshwater produces better quality flowers in terms of flower height, weight and especially diameter, without the application of fertilizers. In the case of wastewater treatments, there is a significant difference in the quality of flowers with and without addition of fertilizer, whereas, in the case of freshwater, there is no significant difference between the two treatments. In the case of borehole water there is a significant increase only in flower weight with the application of fertilizer but no significant effect on flower height or diameter.

For the Long Term Storage, the trend curves of the microbiological decontamination rate, with respect to the evolution of the faecal coliform concentration in the water of basins with different depths, exhibit the same behaviour and are close to each other, illustrating a similar decontamination effect. Thus the volume of stored water has little influence on decontamination progress. The results for the bacteria indicators during a seasonal storage prove that long term storage improves the bacteriological quality of the water. The mean rate for the faecal germs tends to decrease till values undetectable with the analytical method being used. The comparison of results obtained from plots irrigated by means of reclaimed wastewater with and without storage basin has not shown a significant effect on bacterial quality of the yield. The study of performances of the irrigation equipment using wastewater shows that the drip irrigation system (integer emitters) is the system giving the best yield and the optimal hydraulic functionning.

The influence of nitrogen and salts in recycled water on the growth of chickpeas shows that increasing the application of nitrogen under form of fertilizer gives lower yields than those obtained in the control treatment. High salts content decreases the symbiosis and nodule formation on the roots of plants. Increasing nitrate concentration sharply reduces the uptake of molybdenum which, in turn, reduces nitrate assimilation by the plants. A few promising species, suitable for early and late planting, that respond to irrigation with yield increase, are identified. For wastewater management, one of the most important parameters to be carefully considered is the irrigation scheduling. When properly managed, treated wastewater has the benefit of reducing environmental degradation. Alternating saline well water with treated wastewater reduces the nitrogen leaching and increases the nitrogen efficiency. The results show that treated wastewater does not only supply major nutrients (N, P, K) but also contains micronutrients and soluble organic substances which stimulate growth and increase the total yield. Efficiency of water use on sweet pepper improves with increasing nitrogen application. Since treated wastewater is rich in nitrogen, it therefore increases total fruit yield and increases water use efficiency, as already reported by many investigators (Hussain Al-Jaloud.H, 1995). Increasing the water regime irrigation by 20% reduces the nitrogen efficiency for all treatments (Xanthoulis, 2001).

Conclusions

New alternative wastewater treatments are successfully investigated, producing water suitable for irrigation without restriction, opening new perspectives for wastewater reuse in Mediterranean countries.It is now proved that a proper irrigation management, with attention drawn to a good equipment, applications adapted to the plants growth stages, respecting quantities depending on the soil and wastewater characteristics, cultivating species more resistant, irrigating in alternation with fresh water, are new agricultural practices that may improve yields and products quality, without using conventional water, already in deficit for domestic and industrial uses in Mediterranean countries.

References

Tchobanoglous G. and A. N. Angelakis. (1996). Technologies for Wastewater Treatment Appropriate for Reuse: Potential for Applications in Greece. Water Sci. and Techn., 33(10-11): 17-26.

Angelakis, A.N. and G. Tchobanoglous. 1995. Municipal Wastewaters: Natural Treatment Systems, Reclamation and Reuse and Disposal of Effluents. Crete Univ. Press, pp. XII, 464 (in Greek).

Chenini F. (2000). Impact de l'utilisation des eaux usées traitées sur les systèmes d'irrigation localisée utilisés sur une culture de pomme de terre, Transfert de technologie and INCO reports - DGXII, Univ. Agron. Gembloux, Belgium.

Dumont Ph., Philippon p. (1999). Du céleri pour épurer les eaux. Biofutur n°188

Hussain,.Al-Jaloud.A.A. (1995). Effect of irrigation and nitrogen on water use efficiency of wheat in Saudi Arabia. Agriculture water management 27; 143-153. Master thesis, IAV Hassan II, Agadir, Morocco.

Raïs, M. and Xanthoulis, D. (1999). Amélioration de la qualité microbiologique des effluents secondaires par stockage en bassins. Biotechnol. Agron. Soc. Environ. 3 (3), 149-157.

Xanthoulis D. et Dumont Ph. (1996). L'épuvalisation : un système d'épuration et de valorisation écologique des eaux usées. International Workshop on sewage treatment and re-use for small communities : Mediterranean and European experience. Agadir - Maroc, nov 1996.

Xanthoulis D. (1997) Epuration et valorisation des eaux usées par épuvalisation. Rapport de synthèse, projet STD3 – DGXII, Univ. Agron. Gembloux, Belgium.

Xanthoulis D. (2001). Sustainability and optimization of treatment and use of wastewater in agriculture. Annual scientific report, INCO DC project, DG XII, nov.2001, Univ. Agron. Gembloux, Belgium.

Investigation of constructed wetland performance considering water reusing

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Introduction

With the development of economics, water needs rose rapidly. At the same time, water resource was destroyed because of serious water pollution along with economic development. Water shortage has become a worldwide crisis.

In China, more than 300 cities face the problem of water shortage, moreover, more than 50 cities with population higher than one million are in very serious water shortage now. It was estimated that total water shortage has reached 11 million cubic meters per day, and as a result more than 120 billion RMB of industrial production value was influenced. On the other hand, lack of efficient way for water treatment, only 70% of the industrial wastewater and less than 15% of the domestic wastewater is treated now. Low-level wastewater treatment deteriorates the water environment and sharp the water shortage crisis furthermore.

To be benefit to the whole environment and considering the concept of Ecological Sanitation, besides sanitation itself, disposal of wastewater and sewage before the water is discharged into environment or development the reuse technology are also important aspects.

Ideally, ecological sanitation systems enable the complete recovery of all nutrients from faeces, urine and greywater to the benefit of agriculture, and the minimisation of water pollution, while at the same time ensuring that water is used economically and is reused to the greatest possible extent, particularly for irrigation purposes.

Constructed wetland is just anticipated to be a potential ecological engineering act to ameliorate dispersed point source pollution and improve the environment. The most important, from one aspect, the effluent can be considered to be reused for irrigation, on the other side, the nutrient can be absorbed by aquatic plant and then recycled for paper making or recycled as fertilizer after they are composted.

To optimize the operation of constructed wetland, orthogonal designed experiment is introduced to investigate the influence of several key factors of constructed wetland to the performance of pollutants removal. The feasibility of application of constructed wetland to treat domestic wastewater directly, and the feasibility of using effluent for irrigation are discussed.

Method

Considering the variables those will influence the performance of constructed wetland and gas emission, four species of hydrophytes, two types of media, two values of water level and hydraulic loads were used. The designed mixed level orthogonal experiment arrangement was shown in Table 1 and the schematic figure of the experimental facility was shown in Figure 1.

Trail No.	Factors			
	Plant Species	Media Type	Water Level(cm)	Hydraulic Load (cm/d)
1	*Cyperus alternifolias*	Sand	10	10
2	*Cyperus alternifolias*	Gravel	-10	5
3	*Vetiveria zizanioides*	Sand	10	5
4	*Vetiveria zizanioides*	Gravel	-10	10
5	*Typha Orientalis*	Sand	-10	5
6	*Typha Orientalis*	Gravel	10	10
7	*Phragmites australis*	Sand	-10	10
8	*Phragmites australis*	Gravel	10	5

Table 1: Assignment of the factors in the orthogonal experiment

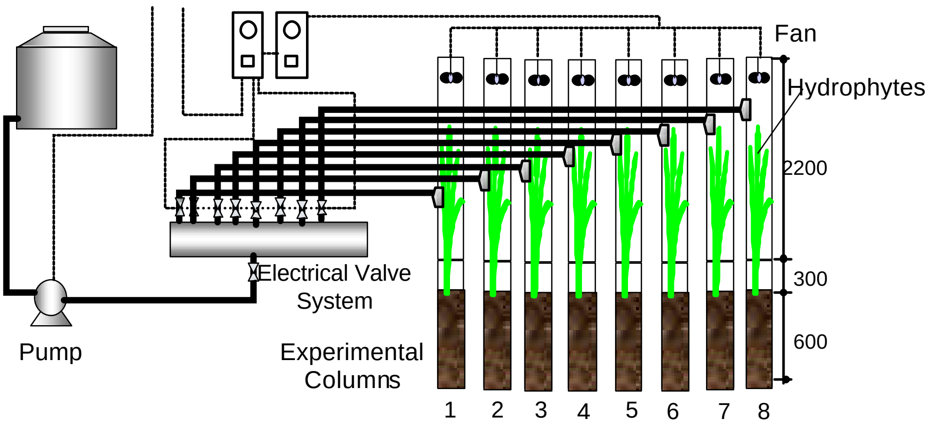

Figure 2: Schematic diagrams for orthogonal designed experiment facilities

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Results

For NH_3-N removal, all these four factors showed obvious influence on the results. Increase of hydraulic load decreases the removal rate of NH3-N. Sand media achieved higher NH_3-N removal than grave due to the higher specific surface area for microorganism's growth in it. Veteveria and Phragmites got better NH_3-N removal than the other two types of plant. Water level of 10cm lower than media surface achieves higher NH3-N removal.

The same tendency was found among the results for COD and T-N removal, but the difference that was found is not obvious. This is supposed to be due to the high ability of COD and T-N removal for these systems during the experiment period and the difference was not shown.

But if consider the potential influence of system effluent to result in algae bloom, Plant species seemed to be very significant to influence it. Plant Cyperus alternifolias and Phragmites australis were recognized to be good for Algae growth control.

Conclusions

Considering pollutants removal, the extreme deviation for hydraulic load is highest and it means it influence the performance the most. The next is water level. Influence of plant and media type is very closed to each other. But consider algae growth potential of effluent, plant species was recognized to be most important.

The use of sewage fertiliser products on arable land – requirements from the farmers' perspective

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Keywords

Farmers, fertilisers, on-site treatment, sewage products, source separation

Abstract

The aim of this paper was to discuss farmers' requirements for using sewage products as fertilisers on arable land. A questionnaire followed up with interviews was used in a watershed area close to Stockholm. The study also included calculations of the cost to farmers of handling different sewage products. Farmers were most interested in source-separated human urine and precipitated septic tank sludge originating from on-site treatment. A high concentration of plant nutrients was important for farmers, as well as good hygiene quality of the product and a low content of heavy metals. However, the most important factor for farmers was that the expenses for e.g. collection, transporting, storage and spreading were covered.

Introduction

In Sweden, interest is growing for small-scale and source-separating wastewater systems from which the sewage products can be recycled as fertilisers in agriculture. One reason for this is the recommendation from the Swedish Farmers' Organisation (LRF) not to use mixed sewage sludge from conventional wastewater treatment plants on arable land. The Swedish food industry is also very reluctant to buy agricultural products grown on fields fertilised with sewage sludge. Several environmental systems analyses have also found that source-separating systems are more environmentally friendly than conventional (e.g. Bengtsson *et al.,* 1997; Kärrman *et al.,* 1999; Jönsson *et al.,* 2000). Local recirculation systems also decrease the need for transportation, and thus air emissions. However, finding arable land on which to spread the products has been identified by urban authorities as a serious obstacle to the introduction of systems for recycling the sewage products from on-site treatments. This problem also remains for sewage fertiliser products acceptable to the food industry.

Why is there such a low demand from the agricultural sector for these sewage fertiliser products? What are the requirements of farmers as regards the systems and the sewage fertiliser products? How can systems, in which for example farmers act as entrepreneurs, be designed? In order to answer these questions, a study was performed in the watershed area of 'Oxundaån' close to Stockholm (Sjöberg, 2003). In this area, which includes five municipalities, different projects aimed at improving the water quality have been initiated. As 90% of current on-site treatment plants in this area are considered to be operating insufficiently, the urban authorities concerned have an interest in alternatives to the current wastewater systems.

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Methods

Initially, a questionnaire was sent out to all 180 farmers in the area, involving 6800 hectares of arable land. Answers were received from 50 of the farmers, corresponding to 70% of the arable land in question. Eleven of the farmers were further selected for interviews, based on their interest in taking part in future systems for recycling of sewage fertiliser products. These interviews were organised in a semi-structured way consisting of both quantitative and qualitative parts. In both the interviews and the questionnaire, questions were posed concerning farm production, as well as farmers' attitudes towards different sewage products originating from on-site treatment and their willingness to act as entrepreneurs within these systems. The on-site sewage systems considered were urine separation, blackwater separation, chemical precipitation in the septic tank, package treatment systems and filter beds. These products were selected as they give a high reduction in nitrogen and/or phosphorous and enable a high degree of recirculation. Information on the different systems was sent out to the farmers beforehand. The study also included calculations of the costs relating to the handling of different sewage products; i.e. transportation, storage and spreading operations.

Results and discussion

More than 50% of the farmers were positive towards the use of sewage products from the neighbourhood. Five of these, holders of 1100 hectares in total, were highly interested in starting a closer cooperation with the community by handling and using different sewage products as fertilisers. These 1100 hectares correspond to the area required for spreading urine from 16.000 individuals, precipitated septic tank sludge from 25.000 individuals or blackwater from 16.000 individuals. The most interesting fertiliser products from the farmers' perspective were source-separated human urine and precipitated sewage sludge from septic tanks originating from on-site treatment (Figure 1).

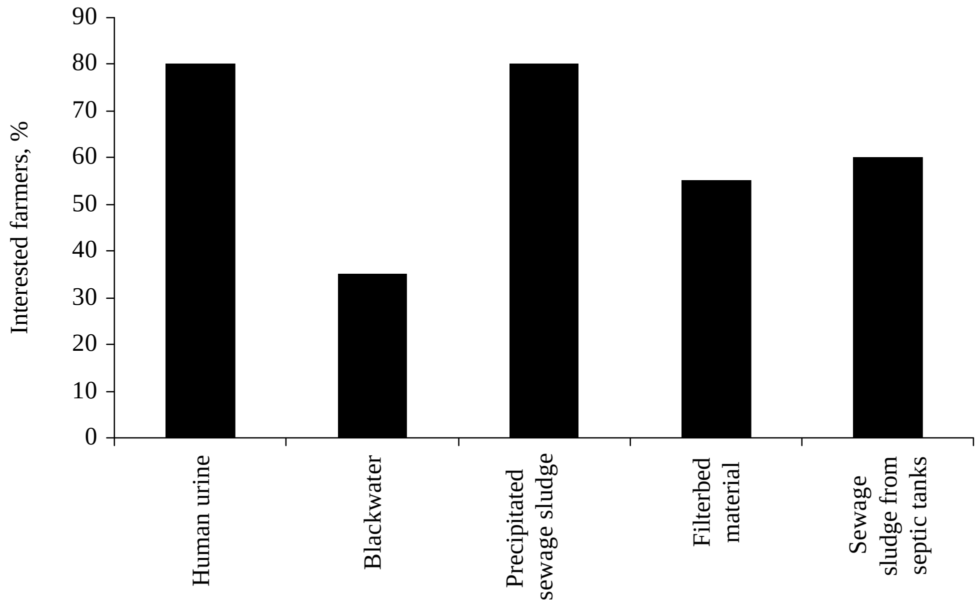

Figure1: Degree of interest of farmers in different fertiliser products from on-site sewage systems.

A high concentration of plant nutrients was a key issue for the farmers. The main advantages with source-separated human urine were its high content of available nitrogen and the fact that the spreading could be extended in time, since it can be spread both before sowing and in the growing crop. A phosphorus-rich product, such as precipitated sewage sludge from septic tanks, could on the other hand be spread during less busy seasons, e.g. the autumn, which can minimise the risk for soil compaction. Both source-separated human urine and sewage sludge from septic tanks involve relatively small volumes to handle, compared with e.g. blackwater, a fact that was also highlighted as important by the farmers. However, different machinery is required for handling different products depending on the characteristics of the products.

Good hygiene quality of the product was pointed out as important, as well as a low content of heavy metals (Fig. 2). According to the farmers surveyed, the amount of heavy metals in sewage products must be low enough not to give rise to an accumulation of these in the soil. In cases where the farms were situated close to residential areas, possible odour during the spreading operation could be another obstacle.

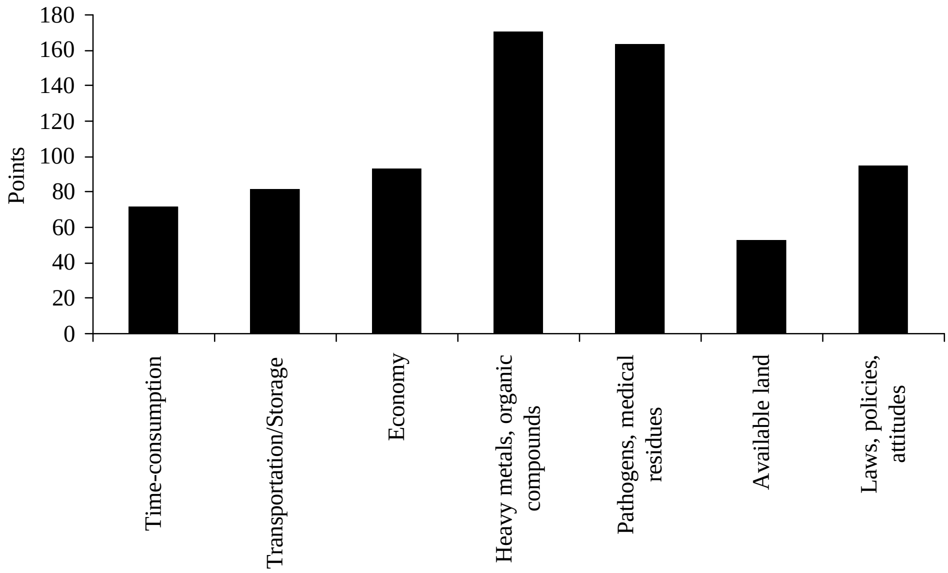

Figure 2: The evaluation of factors regarded as obstacles for using sewage products from on-site sewage systems among the farmers who responded to the questionnaire. The points came from a ranking system where the highest points were given to the alternative regarded as the most difficult obstacle.

Utilising plant nutrients in sewage products is more interesting for farmers specialising in crop production than for farmers specialising in milk and meat production, as those often already have a surplus of plant nutrients on their farms. Existing spreading equipment on farms handling manure might, however, be an economic and practical advantage for animal farms. From an environmental point of view, sewage products should be used on farms specialising in crop production, as the plant nutrients in sewage products can replace mineral fertilisers on such farms.

The farmers stressed the importance of acceptance for these sewage fertiliser products from the food industry as well as the authorities and neighbours. It is therefore an advantage if the farmers or the farmers' organisations become involved in an early stage of the planning of such systems. Some farmers wanted the responsibility for the whole chain, including collection, storage and spreading, while others only wanted to let their land for spreading the products.

However, an absolute prerequisite for the farmers' involvement was that the expenses for e.g. collection, transporting, storage and spreading should be covered. Today, it is not unlikely that the cost of the spreading operation will in itself exceed the value of plant nutrients in the sewage products. Spreading under poor soil conditions might also give severe soil compaction. For urine, the economic value of the plant nutrients corresponds approximately to the cost of spreading concentrated urine, without any flushwater mixed in. In this study the cost of collection, storage, sanitation and spreading of source-separated urine was 120 SEK per person and year. The corresponding cost was 1100 SEK for blackwater and 200 SEK for precipitated sludge. The value of the fertiliser products was between 5 and 22 SEK per person and year. Although the farmers surveyed said that lack of time was an obstacle today to becoming involved in sewage fertiliser recycling, they would consider making other priorities if the economic compensation was high enough.

Conclusions

- Farmers interested in using sewage products as fertilisers can easily be identified by strategic methods.
- Several different sewage fertiliser products might be of interest for agriculture. The machinery required for handling the different products differs depending on the characteristics of the product.
- Farmers seem to be most interested in source-separated human urine and precipitated septic tank sludge.
- The quality of the sewage product regarding e.g. hygiene and heavy metals must be high and guaranteed through continuous analyses.
- It is important to involve farmers and other actors, e.g. the food industry, at an early stage when planning new recycling wastewater systems in an area.
- The sewage products represent an economic value corresponding to their concentration of plant nutrients. However, in most cases the farmers must be compensated for the costs related to e.g. collection and transportation and even spreading.

References

Bengtsson M., Lundin M. & Molander S. 1997. Life Cycle Assessment of Wastewater Systems. Case Studies of Conventional Treatment, Urine Sorting and Liquid Composting in Three Swedish Municipalities. Report 1997:9. Chalmers University of Technology, Technical Environmental Planning. Sweden.

Jönsson H., Vinnerås B., Höglund C., Stenström T.A., Dalhammar G. & Kirchmann H. 2000. Källsorterad humanurin i kretslopp. VA-FORSK Report 2000-1. VAV. Sweden.

Kärrman E., Jönsson H., Gruvberger C., Dalemo M., Sonesson U. & Stenström, T.A. 1999. Miljösystemanalys av hushållens avlopp och organiska avfall – syntes av hanteringssystem undersökta inom FoU-programmet "Organiskt avfall som växtnäringsresurs". VA-FORSK Report 1999-15. VAV. Sweden.

Sjöberg C. 2003. Lokalt omhändertagande av restprodukter från enskilda avlopp I Oxundaåns avrinningsområde. Institutionsmeddelande 2003:01. Swedish University of Agricultural Sciences, Department of Aqricultural Engineering. Sweden.