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Possibilities for closing the urban-rural nutrient cycles

Karen Refsgaard, Petter D. Jenssen and Jakob Magid*

Summary

This chapter discusses the potential of organic farming for contributing to sustainable development, mainly in low-income countries, by integrating urban settlements with rural communities, through the recycling of domestic and household waste.

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* Corresponding author: Norwegian Agricultural Economics Research Institute, P.O. Box 8024 Dep., N-0030 Oslo, Norway. E-mail: Karen.Refsgaard@nilf.no

©CAB International 2005. *Global Development of Organic Agriculture: Challenges and Promises* (eds N. Halberg, H.F. Alrøe, M.T. Knudsen and E.S. Kristensen)

The chapter links the thermodynamic laws for the transport of matter with economics, institutional and technological structures and the views of the stakeholders. The quantities of nutrients and organic matter in the production and consumption cycle under different conditions around the world are discussed. The amounts of plant nutrients and organic matter present in sewage, household waste and waste from food processing industries, are almost sufficient to fertilize the crops needed to feed the world's population. Conventional wastewater systems have been developed to ensure high local hygienic standard and to address some problems in the aquatic environment. However sewage sludge is an unattractive fertilizer source, containing quantities of xenobiotic compounds and heavy metals. In agriculture in developing countries there is often a lack of nutrients due to limited capital, and a lack of organic matter on weathered soils. Due to limited availability and transport, urban organic wastes are predominantly used in urban and peri-urban agriculture. In dry parts of the world where water is highly valued (and may even be desalinised) use of wastewater for agriculture has been/is being developed. Ecological sanitation systems, based on biological (and technical) treatment in terrestrial systems are able recycle nutrients and organic matter from urine, faeces, greywater and organic waste. This chapter describes and evaluates the costs and benefits of such systems. It also discusses the moral and cultural challenges raised through the different ways in which science and religion deal with human behaviour when recycling urban waste. Combining these solutions with organic agriculture can contribute to improved recycling and sustainability. They imply institutional and economic challenges, but can contribute to improved health, agricultural production and social benefits, especially in low-income developing countries. While there are advantages in integrating urban settlements with rural ones through recycling human waste, it is paramount that health aspects of forming barriers against diseases are considered. The chapter ends with a presentation of examples of integrated recycling systems from urban to rural communities.

Introduction

The aim of this chapter is to look at the challenges and opportunities for organic farming to help integrate urban and rural settlements through utilizing flows of human waste and domestic waste: from the kitchen and toilet and from washing.

A basic principle in organic farming is the recycling of nutrients in order to reduce the use of non-renewable resources and the exploitation of fragile resources on a local scale. A central current focus of organic farming is on the recycling of nutrients at the farm scale. It is often a challenge for organic farmers to maintain nutrients levels within their production, the more so in plant production systems lacking access to animal manure, as there are fewer possibilities for substitution with input factors like mineral fertilizer, soil conditioner etc.

In Western societies the use of mineral fertilizer and imports of fodder results in a surplus of nutrients in certain regions. There is a flow of resources such as food, water, energy and minerals from rural regions and farms to urban regions, which also function as a sink for waste and emissions. In Denmark (5.5 million people) the nutrient turnover corresponds to the secretion from 120 million people (Magid, 2002), while in Norway (4.3 million people) it corresponds to 25 million people. This is due to a surplus of imports of farm products and agricultural inputs over exports. As such the nutrients from urban areas in countries like Denmark may only be of minor importance for conventional agriculture, but they may still be important for organic agriculture, if acceptable ways of recycling them can be achieved in practice.

Urban waste creates problems on a global scale; more than half of the world's population is city-dwellers and the proportion is increasing, implying that a major and growing proportion of waste is produced in urban agglomerations. Substantial amounts of plant nutrients and organic matter are present in sewage, household waste and waste from food processing industries (Skjelhaugen, 1999). Theoretically, the nutrients in domestic wastewater and organic waste are almost sufficient to fertilize the crops needed to feed the world population (Wolgast, 1993). However, conventional wastewater management systems have historically been developed with a view to sanitation standards and with little concern for recycling. As a result nutrients and organic matter are emitted to rivers, precipitated in sludge or, even incinerated and used as road material. More recently, environmental concerns have been the driving forces behind the technological development of sewage treatments that can biological remove N, P and organic matter. This technology addresses some immediate problems in the aquatic environment, but the sewage sludge from the treatment plants contains xenobiotic compounds and heavy metals, and only a fraction of the nutrients that entered the urban areas, thus making the sludge an unattractive fertiliser source. In recent years there has been concern about the sustainability of this approach to wastewater handling, as well as concern about the fate of the final waste deposits in the environment. (Magid et al., 2001).

Agriculture in developing countries often faces a lack of nutrients. This is due to a range of reasons, including limited capital resources, limited access to organic matter and, in some regions, also because of highly weathered soils. Soils in the South are low in organic matter, implying that compost may be an appropriate alternative to artificial fertilisers. However, due to limited availability and transport, urban organic wastes are predominantly only used in urban and peri-urban agriculture. Given the one way flow of nutrients and organic matter from soils in, already nutrient-depleted, rural areas to urban centres, the use of wastewater treatment solutions does not seem sustainable or sensible. In dry parts of the world where water is a scarce and highly valued resource, and may have to be desalinised, the use of wastewater for agriculture has already been developed (Cross and Strauss 1985).

The principles of ecological engineering offer a wide range of solutions for recycling nutrients and organic matter from different waste fractions: urine, faeces, greywater and organic household waste (Mitsch & Jørgensen, 1989). The combination of these ecological solutions and organic agriculture can contribute to improved recycling and sustainability. Yet they also raise institutional and economic challenges, which if successfully met may bring about improved health, agricultural production and other social benefits all of which are important in developing countries.

The chapter starts with a presentation of basic institutional and technological issues as well as the importance of integrating the views of the stakeholders. Then follows an overview of quantities of nutrients and organic matter involved in production and consumption cycles under different conditions around the world. A section presents ecological sanitation concepts or systems for managing wastewater from households in urban, as well as more rural, areas. Followed by evalutation of the benefits and costs involved and a discussion of the health aspects related to recycling urban waste The last section of the chapter presents a few selected examples of recycling systems based on ecological sanitation.

Recycling nutrients in society – an ecological economics perspective

The term "waste" in a society is a relative concept. The way we perceive the environment and the interactions between the environment and the economy, influence the way we view it, treat it and which solutions we choose to implement. Ecological economics views the economy as an integrated part of the biosphere – as an open subsystem of the environment. The focus is on the flow of matter and energy through the system, and the thermodynamic laws governing these processes; questions about the regulation of pollution might focus on the input, as well as the emissions, side of the economy (Vatn, forthcoming). See also chapter 4.

When considering the recycling of nutrients it is essential to look at the total production and consumption processes in society and the material flows of matter and energy. The challenge is to find a "proper" level of recycling nutrients and organic matter. From the thermodynamic interpretation, wastes are undesired joint products of the manufacturing process however, from the economic interpretation, manufacturing is directed to satisfy consumption. Because wastes are undesired joint products, and (according to neo-classical economic theory) humans want to minimise costs then no rational individual will want to pay for the waste. This implies that "they are left where they fall" and may, according to their nature and location, cause pollution. There is also the problem of a response of inaction because, although the damaging effect on nature or society as a whole may be considerable, the direct effect on any individual will be quite small. To sum up, then from a thermodynamic point of view the ideal is not to produce any material waste, while from an economic point of view it is necessary to evaluate the costs for containing the spread or preventing the creation of waste against the costs of so doing. (For further elaborations on how the thermodynamic laws govern the production and consumption processes and how this interfere with microeconomics see chapter 4.) It is necessary to include the social and behavioural aspects in these evaluations, because the costs are also related to production and consumption patterns. Questions of personal and social responsibility play a role. For example are people prepared to take individual responsibility to separate, sort or otherwise deal with waste? Alternatively what are the costs of controlling or otherwise regulation waste production and disposal? (Vatn & Bromley, 1997).

Today, organic waste is not easily recycled back into to food production systems in Western societies. Within most institutional regimes, waste is an externality, meaning that those responsible for creating the activity behind the waste affect the utility of those suffering from the problems of waste emission without compensating this decrease in utility, by for example lowering the quality of bathing water to unacceptable standards, or smell from a disposal site etc. (Baumgärtner, 2002). But this perception of waste differs, between individuals, and particularly, between different societies.

Bisson and Proops (2002:42) illustrate this by comparing different perceptions of waste in Europe from about sixteenth century, where it was seen as a problem due to the relative abundance of animal manure as opposed to Asia, where it was seen as a resource.

> "Agriculture in Europe was dominated by a mixed farming regime, with arable, pasture and grazing animals that served not only as a source of milk, meat and wool, but also as a nutrient pump from grazing ranges to the arable fields. The dung they produced was as valuable a resource as the other products that could be extracted from them. In such circumstances, human excrement from the cities was not considered a prime resource for agriculture. Japanese and Chinese towns, in contrast, relied on the supply of human excrement. Therefore, collection and transportation of nutrients from the cities back to the agricultural areas is economically feasible. Due to the very limited supply of animal manure in their agricultural systems, the rice-growing Asian agriculturalists needed not only to collect human excrement, but also to recycle such materials as oil-cake residues and ashes to fill the nutrient gap. The European solution came at a cost, because the production of manure via animals is an expensive solution in energetic terms. In solar based societies, energy means area, so the area needed to feed one person in Europe was much higher than in Asia, due to the extra area needed to produce animal fodder…. Another benefit was that cities in Asia were far more hygienic places than most European ones and water pollution due to faecal matter, one of the recurrent European problems, was almost unknown….".

This illustrates how the utilization of resources differs according to the natural conditions thereby creating different cultural practices, in this case about perceptions for use of human waste. These issues are further elaborated below. In the next section we take, as a starting point, a model that considers both the scientific as well as the social and cultural aspects in the evaluation of systems for handling human waste.

Basic economic, institutional and social aspects of waste handling

In this section we consider the basic economic, institutional and social constraints and challenges waste handling. A waste handling system is defined as comprising three different sub-systems (Figure 7.1), the users, the organisation managing the system and the technological structure in itself.

The social understanding of waste, which means how waste is defined in terms of behaviour and perceptions and the role of it in the "lived life", depends on the interplay of cultural concepts and material objects. Decisions about disposal, sewage, incineration and recycling of waste in different social contexts cannot be understood without considering both the material and the cultural contexts of waste. Firstly, stakeholders directly involved in the waste stream, in handling the products, through transportation, treatment and end disposal or use, have a central role. Waste can only become a resource if use of that resource is socially acceptable. There may be moral or cultural barriers against the use of, for example, human faeces; however these aspects are discussed more in detail later. Anthroposophy, for example, does not accept the use of human waste in agriculture, thus precluding its use in biodynamic systems. This is also the case for organic farming where the regulations prohibit use of human faeces and urine as fertilizer in agriculture. However in a survey among organic farmers in Norway about 40 % were positive to utilization of human urine and 24 % were positive to utilization of human faeces still it is not allowed (Lystad et al., 2002). These attitudes are mainly due to the nutrient recycling effect. On the other hand these organic farmers are reluctant to use because of a perceived bad quality with risk for environment and health. Prices have to be comparable to competing products, but here the State can legitimately play a role in subsidising such reuse by offsetting the saved cost of environmental externalities, such as water pollution. Also the responsibility for quality control and liability need to be clearly defined and here the State also can contribute facilitating for contracts and collective agreements among the actors and with information and general knowledge. Thus both the organisational structures and the technological structures must function.

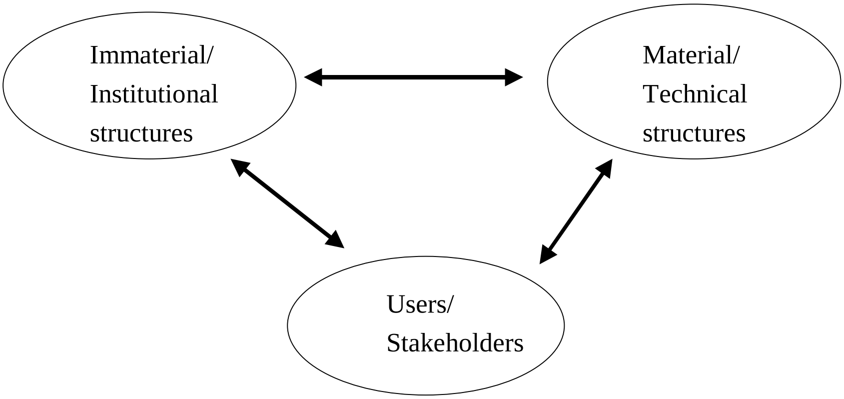

Figure 7.1. Institutional, technical and social components of waste systems. Source: Söderberg and Kärrman 2003 (eds.).

From a societal viewpoint it is important to ensure that controls are imposed on the recycling process, in order to eliminate the risk of disease vector transmission, and transmission of other substances that may compromise food safety. This principle of control is in accordance with existing practice in organic farming– whereby certification of products is often formalized in order to justify marginally higher economic returns. At present there are few examples of modern marketed organic agriculture based on urban fertilisers. The quality control aspect that would be necessary in developing such systems could be based on contract farming or long-term agreements on the management and use of urban fertilisers. This also applies to poor countries where urban agriculture plays an important role in sustaining food security.

As any input will cause emissions (see chapter 4), the focus needs to be on both the input and the emission side of the economy. This means that our evaluations and decisions over waste handling systems need to look at how waste is created as well as how it is disposed (Vatn, forthcoming). Calculations of the marginal costs for treatment, compared to the marginal costs for emission, have to include the costs of the whole process from production to recycling back to agriculture. That means not only the treatment and handling costs but also the transaction and administrative costs involved in changing peoples' minds and behaviour. The costs are not only related to technical options for controlling and managing emissions, or whether to opt for fees or quotas, but are also related to consumption structures and behaviour. For example costs may increase greatly if households only make poor efforts at recycling. Yet, controlling households to improve the recycling rate may be very costly, due to their great number and limited size. From society's point of view it is essential to evaluate the costs related to the disposal or containment waste material against the costs of prevention (Vatn & Bromley, 1997).

Nutrient recycling is not the only aspect of organic waste (water) handling. It is equally important to look at the total waste generation cycle from the consumption of food, creation, handling and emission of waste and attempt to reach a socially and economically optimal system. Considerable environmental benefits can be achieved by reducing nutrient emissions to water resources by removing urine from wastewater. This can be achieved by using source separating systems where the urine is collected separately and recycled to agriculture. Thus the benefits of implementing new waste management systems can counterbalance the costs incurred in so doing.

Quantities of nutrients and organic resources - from households to agricultural systems

In this section we give an overview of the production and consumption cycle for nutrients and organic matter. We show the composition of the nutrients and organic matter in the organic waste fractions from households and compare this with agricultural needs for nutrients and organic material.

The present day food production system is, to a great extent, a one-way nutrient flow powered by fossil energy input. Nutrients are purchased in the form of chemical fertilizer, applied to the (best) land, replacing those lost to the environment or removed in the crop which are sent to the city, passing through humans and are lost to wastewater and organic waste. However, there are several ways in which these cycles can be closed, at least to some extent (Hall et al., 1992). Firstly the nutrients could be recycled from urban areas back to areas of agricultural production. Secondly, the nutrients could be more efficiently recycled between crop and animal production systems, which already occurs to some extent in organic (and mixed farming) systems. Thirdly, marginal lands could be brought into production through the design of integrated systems that promote solar-powered energy flows (i.e. photosynthesis) and nutrient cycles.

In the Western societies the growing use of imported fodder and fertilizer in agriculture implies a build up of excessive[1] nutrients on the farm. Only a small proportion of imported nutrients leave the farm in agricultural products. Bøckman et al. (1991) provide several examples showing that only 10-30 % of the total nitrogen input into agriculture is recovered in the products used for human consumption. From 18-30 % on dairy farms and 30-40 on pig farms of the nitrogen from plant production is converted into consumable protein in the form of dairy or meat products, but the numbers seldom reaches 50 (Halberg et al., 1995; Kristensen et al., 2005). The remaining nutrients are recycled back into plant production or, to some extent, lost in "leaky" systems. The main input of

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[1] It is appropriate that there is some additional nutrient input to provide a safety net for recovery, as there is always a risk of some loss. However, within more intensive production systems these losses are excessive, to the point that in some countries they now have to be strictly controlled.

nitrogen in conventional agricultural systems comes from atmospheric nitrogen, made available to farmers through industrial processes (Bøckman et al., 1991). For phosphorus the situation is different as the major phosphorus loss in agricultural production is related to erosion. Secondly phosphorus is a non-renewable resource and in the long run we are forced to find solutions for recycling it.

The energy required for the processing, transportation and use of mineral fertilizer is about 38 MJ or 10.5 kWh per kg nitrogen (Refsgaard et al., 1998). This implies that agricultural production systems relying on mineral fertilizer use a great amount of low entropy fossil fuel to produce food. In organic agriculture the fossil fuel used for nitrogen production, producing about the same amounts of food is substituted with solar energy although this requires a larger acreage. However, today's organic production of nitrogen is mainly generated by animal husbandry production which, as discussed above, has a low level of energy efficiency. Still the process is changed from use of fossil fuels (social metabolism) to use of solar fuels (natural metabolism).

Table 7.1 shows where the nutrients in the household waste stream are concentrated.

Table 7.1. Resources from households in kg per person and year. Sources: Wolgast 1993; Jenssen & Skjelhaugen 1994; Polprasert 1995 & Mosevoll et al. 1996.

	Blackwater[1]		**Greywater**[2]			**Organic household waste**
	Urine	Faeces	Kitchen	Laundry	Shower/ bathtub	
Nitrogen	3.57	0.49	0.18	0.15	0.11	0.73
Phosphorus	0.32	0.16	0.07	0.03	0.01	0.12
Potassium	0.26	0.11				
BOD[3]			5.11	2.92	2.19	12.41
COD[4]			12.41	5.11	2.56	
Quantity	< 500 l	50-180 kg (wet weight)				35 kg

[1] Blackwater is wastewater from the toilet

[2] Greywater is wastewater from kitchen, laundry, shower and bathtub

[3] Refers to Biological Oxygen Demand

[4] Refers to Chemical Oxygen Demand

It is relevant to consider how much grain can be grown with the nutrients present in human waste. Urine accounts for 88 % of the nitrogen and 67 % of the phosphorus produced by humans. In addition it is virtually sterile and easy to spread. This ease of handling and spreading combined with high nutrient content (which is higher than animal urine) make human urine the most favourable fraction of the waste stream for recycling. By contrast, the benefits of using human faeces in agricultural production are more related to its organic matter content. Use of blackwater, which contains a mixture of urine, faeces and some flush water, is another possibility for reutilizing human nutrients and organic matter.

Using human excreta as fertilizer in organic production systems increases the possibility for plant production without animal husbandry. Assuming a need for about 150 kg nitrogen per hectare per year, the excreta from one individual can theoretically fertilize 372 m^2, this not taking into account other nutrients from kitchen waste.

However, there are losses of nutrients during the recycling process back to agriculture. Wrisberg et al. (2001) report that composting etc. significantly reduces the nutrient content, especially for nitrogen (43-86 %), diminishing the fertilizer value of the product. These losses depend on how they are treated and distributed. Given that the great majority of nutrients are found in urine, and bearing in mind the cost of composting direct separation would seem a preferable and more cost effective approach from the viewpoint of nutrient recycling. However, where increasing soil organic content is an issue, as it is in many developing countries, composting, in order to maintain this resource, becomes relatively more attractive.

Nitrogen is, however, perhaps not the most critical nutrient to be considered. Nitrogen losses and shortages may be offset by judicious cropping system including nitrogen fixing plants, as currently used in many organic systems. The return of phosphorus, potassium and micronutrients to agriculture is, however, essential for sustaining plant production.

There are vast differences between developed and developing countries in the levels of consumption and production of household waste. The volumes and mass increases the more industrialised the countries are. For example the production of waste in India is about 0.25 kg per person per day, while in USA it is 1.25 kg per person per day. The composition of this waste also differs between developing and developed countries. Most of the waste stream in developing countries is organic, whereas in (for example) North-European cities glass, metals and dust account for a much higher proportion (see table 7.2) which have important implications for recycling.

Table 7.2. Composition of waste in percent. Sources: Dalzell et al. 1987, Deelstra 1989.

% composition

Waste type	Accra	Indian city	South America	Middle East	North European city
Organic	87.1	75.0	55.0	50.0	3.0 -16.0
Paper	5.7	2.0	15.0	20.0	2.7 - 4.3
Metals	2.6	0.1	6.0	10.0	7.0 -10.0
Glass	0.7	0.2	4.0	2.0	10.0 -11.0
Textiles	1.2	3.0	10.0	10.0	3.0 - 7.0
Synthetics	1.3	1.0	*	*	3.0
Various	1.4	7.0	10.0	0.0	1.0 - 3.0
Dust		12.0	0.0	8.0	13.0 -16.0

* Textiles and Synthetics are listed together under the same category

Ecological handling systems for organic waste and wastewater

As shown in the last section, the composition of organic waste sources clearly indicates that the major part of the nutrients within household waste is contained in the urine and only a minor part in the faeces. These fractions constitute approximately 1 % of total household waste volume, but contain around 82-87 % of the nutrients (Magid, 2002).

This section presents sanitation systems designed to manage this waste in urban, as well as more rural, areas. Most of the systems are based on biological (and technical) treatment. To different degrees they offer opportunities for water saving, recycling nutrients and organic matter and, in some cases, for energy recovery. The systems have different specific effects, on, for example, the amount of phosphorus removed, or the emissions of nitrogen to water resources. The different systems also have different implications and requirements for people's behaviour responsibility and control.

Experience from Norway shows that almost complete recycling and zero emissions can be achieved by separating the treatment of blackwater and greywater. Organic household (kitchen) waste can be treated jointly with the blackwater and, thus, increase the yield of the produced fertilizer, soil amendment and energy recovery (Jenssen et al., 2003). Water consumption can be reduced by almost 50 %, without any reduction in the standard of living. Compact and technically simple solutions for greywater treatment can allow decentralised treatment facilities, even in urban areas (Jenssen & Vråle, 2004). This further reduces the need for a secondary piping and pumping system for transporting untreated wastewater. The treated blackwater can be injected directly into the ground and fertilise the soil with little, or no, odour (Morken, 1998). This substantially contributes to reducing air pollution in comparison with traditional surface spreading.

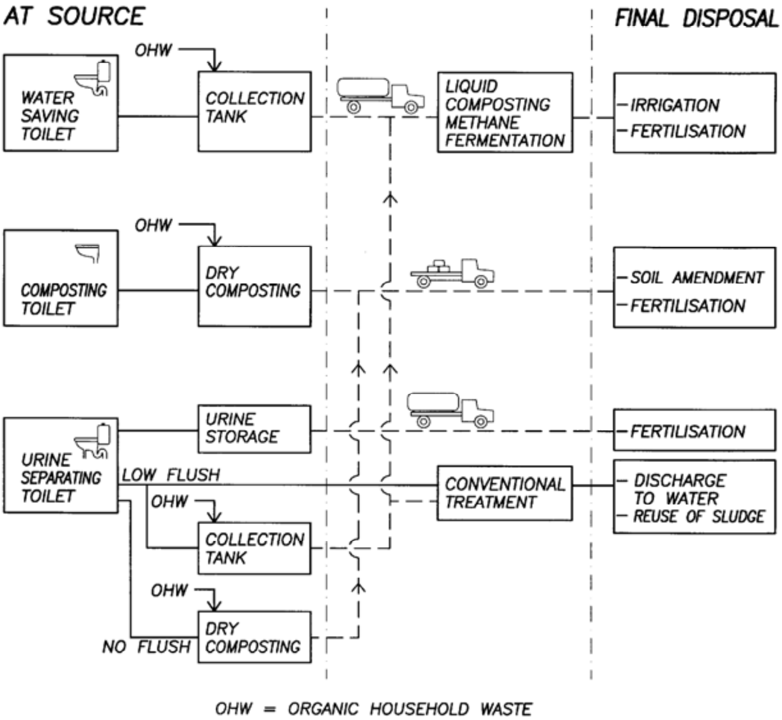
Blackwater and urine diverting systems

As illustrated in table 7.1 blackwater contains some 90 % of the nitrogen, 80 % of the phosphorus (when only phosphate-free detergents are used), and 30-75 % of the organic matter associated with wastewater. New toilet technologies like urine separating, composting, or extreme water-saving toilets, facilitate nutrient collection and recycling (Jenssen, 1999). This concentrated toilet and organic household waste can be used for energy recovery through aerobic or anaerobic processes. At the same time source separation eliminates the major sources (industry and road runoff) of micro pollutants, thereby facilitating source control, which is crucial when using waste as a source for plant fertilizer.

Source separation and collection is possible with toilets based on vacuum and gravity, that use only 0.5-1.5 litres per flush. This means that an average (Norwegian) family may reduce its volume of blackwater to 6-9 m^3 per year, whereas conventional toilets produce 6-15 times more. Such volumes can be handled and treated locally. However, even when the amount of flush water is reduced to only 1 litre, the mix will still contain less than 1 % dry matter. Organic household waste, animal manure or residues from food processing can all be used as additives to increase the dry matter content to a level required for successful composting (Jenssen & Skjelhaugen, 1994).

The blackwater can be treated aerobically in a liquid composting unit, which leaves only sanitized and odourless effluents (Jenssen & Skjelhaugen, 1994). By recovering heat generated by the composting process the unit delivers surplus, usable, energy. Anaerobic treatment is another attractive treatment possibility, due to the high methane content of the biogas produced and because this process requires only small amounts of energy. Efforts are being made to develop small-scale anaerobic digesters for use in cold climates.

In countries such as China and Malaysia both the capital and technology are available for development of such systems. They are also relevant in other developed countries, as some of the examples in the end of the chapter show.



Figur 7.2. Infrastructure of blackwater/urine handling. Source: Jenssen & Etnier, 1997.

The processed blackwater can be applied and used in agriculture. A mobile direct ground injection system (DGI) has been designed for the purpose of injecting liquid organic fertilizers directly into the ground (Morken, 1998). One characteristic of this equipment is that penetration of the ground is not necessary, rather high-pressure injections shoot the fertilizer directly into the ground. This creates immediate contact with the soil, securing the absorption of ammonia and, ensuring improved accessibility of the nitrogen content. The effect is to reduce ammonia losses by 15 % - 20 % compared to traditional surface spreading methods (where the losses typically amount to 70 % - 80 %). The equipment also makes it possible to combine sowing and fertilizing in one operation and can be used for any type of liquid organic fertilizer, including urine. The yields using the DGI method compare well to conventional methods using mineral fertilizer (Jenssen et al., 2003). However this system is only appropriate in countries where agriculture is relatively highly mechanised and plots are sufficiently large to accommodate this kind of machinery.

Urine diverting toilets come in two versions - single or dual flush. With a dual flush, urine diverting, toilet the faecal fraction may either be collected separately or discharged with the greywater. The greywater may be either discharged to a secondary collecting sewer or treated on site. However, if it also contains the faecal fraction the treatment requirements increase, due to larger loads of nutrients, organic matter and, especially, pathogens. This increases the area of land required for nature based systems, like wetlands, sandfilters etc. and decreases the possibility of finding the available space to install such systems in urban settings.

While it is possible to collect the faecal part within a dual flush urine diverting toilet this gives excessive amounts of dilute blackwater. The flush for faecal matter uses between 2 and 4 litres of water, reducing the dry matter content to << 1 %. This creates treatment problems for liquid composting and anaerobic digestion, making this option relatively expensive.

With a single flush, urine diverting, toilet the faecal fraction is collected dry. This is normally stored in a removable chamber. Since no urine, is present the collected faecal matter has much less odour than, the combined urine/faecal mixture in e.g. a composting toilet. The experience with the present single flush urine diverting toilet systems is that the faecal fraction is too dry or desiccate when stored under the toilet so that a composting process does not start. In order to achieve composting the faecal matter should be removed from the collection point under the toilet and then composted.

Greywater

Greywater includes wastewater from bath, washing machine and kitchen, and includes that part of kitchen waste, which is not collected in solid form. Greywater treatment constitutes an important aspect of ecological sanitation. Systems for greywater treatment have been successfully demonstrated with simple light-weight aggregate biofilter systems, in combination with man made wetlands (Jenssen & Vråle, 2004). A source-separating-complete-recycling system is conceptually shown in Figure 7.3.

Greywater usually contains only minor amounts of nitrogen and phosphorus, but rather substantial amounts of organic matter (Rasmussen et al. 1996). The extent of treatment depends on the final discharge standards required and use of the water. In Norway for example discharges to the sea require only a simple (or no) treatment, while a more efficient treatment is recommended for discharges to lakes or rivers. It is necessary to improve the hygienic parameters (i.e. reduce bacteria levels) prior to discharge to small streams or for use in irrigation or groundwater recharge. This can be achieved by means of sand filters or by combining a biofilter and a subsurface flow constructed wetland using light-weight aggregates or similar porous media (Jenssen and Vråle, 2004).

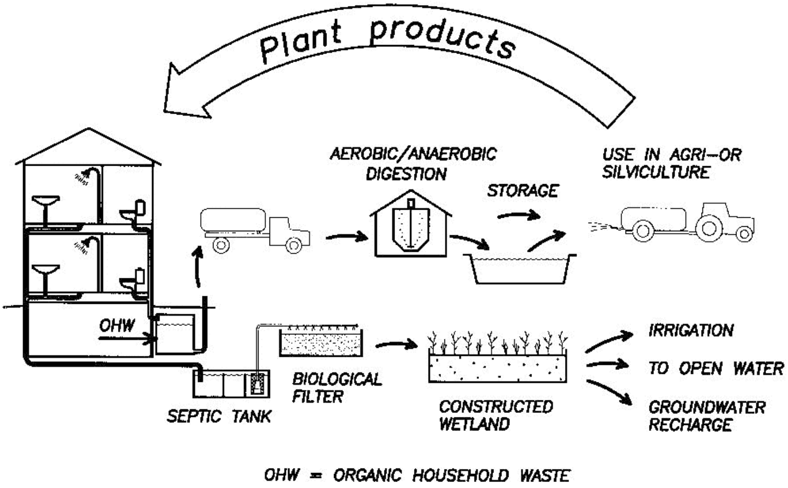


Figure 7.3. A complete recycling system based on separate treatment loops for blackwater and greywater. Source: Jenssen et al., 2003.

A single-pass biofilter aerates the wastewater and reduces the biological organic degradation and the bacteria. Tests show that a biofilter of 1 m^2 surface area is capable of treating greywater from about 10 persons (assuming a greywater production of 100 litres per person per day). It does so with a 70-90 % reduction in biochemical oxygen demand (BOD) and 2-5 log reduction of the indicator bacteria, depending on the loading rate (Jenssen & Vråle, 2004). This implies that very compact biofilters can be made. The key to their successful operation, however, is a uniform distribution of the liquid over the filter media and intermittent dosing with the greywater (Heistad et al., 2001).

Such treatment facilities can be compact enough to be located in urban settings. With an integrated biofilter, as in Figure 7.4 the total surface area required is about 2 m^2/person, with the wetland having a depth of a minimum of 1 metre and the biofilter of 0.6 metres. Typical effluent values from such a configuration are BOD< 10 mg/l, suspended solids (SS) < 5 mg/l, total nitrogen < 5 mg/l and faecal coliforms (FC) < 1000/100 ml. This last figure conforms to the European standard for bathing water quality, which requires FC values of < 1000. Thus, treated water can be discharged directly into local streams or water bodies, or used for irrigation or groundwater recharge, thereby eliminating the need for connections to the subsurface sewer system.

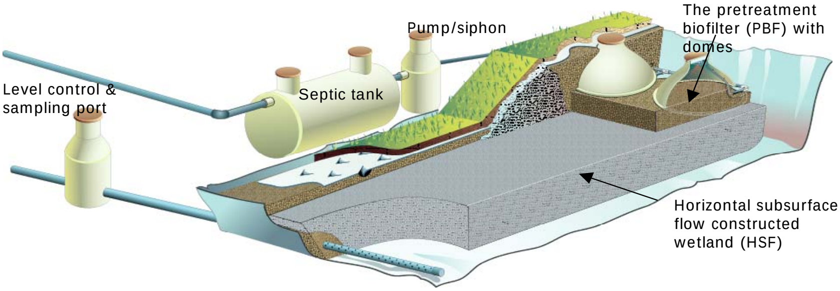


Figure 7.4. The last generation constructed wetlands for cold climates with integrated pre-treatment biofilter in Norway. Source: Jenssen & Vråle, 2004.

The cost of the handling system

Technical aspects of nutrient recycling are not the only issues that need to be considered with respect to wastewater handling. Considerable environmental benefits can be had from reducing nutrient emissions to aquatic environment, but the costs of installing the infrastructure of, for example, urine separating systems are considerable. In a social economic evaluation the benefits of implementing new waste management systems must balance the costs.

Sewerage systems are one of the most capital-intensive infrastructures in both developed and developing countries (Gupta et al., 2001), demanding construction, operation, maintenance and rehabilitation. According to Otis (1996) 80-90 % of the total capital cost of sewage treatment systems is due to these pipelines. In Norway numbers reported for investments in the sewage system due to pipeline construction are from 69 % to 87 % (Mork et al., 2000; Finsrud, 2003). These figures do not include the operational and maintenance costs which are also high, as it difficult to identify and rectify problems in the performance of submerged (and therefore invisible and inaccessible) pipelines in efficiently transferring wastewater to the treatment facility (Gupta et al., 2001; Tafuri & Selvakumar, 2002)). Recent calculations by the sector itself in Norway show that the investments necessary to rehabilitate the existing conventional sewage systems in Norway were in the region of EUR 26 billion (Finsrud, 2003), corresponding to approximately EUR 1.330 per household. Further the report stressed the urgency of carrying out such work as the pipelines are in critical condition, with a daily loss of 225 litres per person per day from water and wastewater pipelines (30 to 50 % of the water supplied is leaking out either through the water or the wastewater pipelines). Finsrud (2003) estimates equivalent figures of 7 % and 14 % for Denmark and Sweden respectively. This shows the extent of capital investment required in existing systems, and the potential for investing in more sustainable solutions.

Refsgaard and Etnier (1998) have compared the economic and environmental implications of nature-based and decentralised wastewater treatment systems with conventional treatment systems in Norway. To secure a proper comparison, all stages of the handling process were considered where changes would occur if nature-based and decentralised systems were introduced. This includes collection at the household level, transport, treatment and disposal or spreading in agriculture. For investment in solutions for single households in new development areas the costs ranged from EUR 730 to EUR 2,430. These calculations include costs for investment and operation of the total system, taking into considerations lower costs for organic waste handling and lower costs for drinking water pipes. By using joint solutions for several households the costs decrease although the economy of scale differs according to the type of system employed. Variables in the calculations include the natural conditions for nature-based systems and, in conventional systems, the cost of expanding the sewer network vary in relation the length of the pipes. Today, in densely populated areas, these costs can be reduced through use of pressure-systems that use thinner pipes. The comparisons also include figures for cost-effectiveness, recycling and emission quantities for nutrients and organic matter that reflect the better performance of the source separation solutions in meeting environmental standards and helping offset other defensive expenditure.

On an institutional level, the involvement of the (organic) agricultural sector as a "customer" of the end products of decentralised sewage solutions means that the sector would wish, or need to, take over part of the "responsibility" for treating wastewater and organic waste, so as to gain more control over the quality of the organic fertilizer produced.

Moral and cultural aspects related to recycling urban waste

Despite the strength of scientific and economic arguments for linking the rural-urban nutrient cycle, the implementation of such systems can give rise to conflicts. This is partly due to more informal institutional aspects of how science and religion view human behaviour in relation to wastewater treatment. Just as science introduces new concepts and modifies behaviour, so religion generally preserves old beliefs and maintains traditions (Warner 2000). Science emphasises dispassionate reasoning while religion demands blind obedience to ritual.

The influence of religion on such patterns of behaviour varies between different cultures and places. Unlike Western societies, the Far East evolved cultures that accepted and indeed required the reuse of excreta. More than twothirds of farmed fish come from Asia, where ponds are fertilised with excreta (Mara & Cairncross, 1986). Necessity, and the pragmatic nature of Buddhism both probably played contributory roles (Cross & Strauss, 1985). Warner (2000) argues that there are differences in the way in which Judeo-Christian and Buddhist doctrines evolved and influence wastewater practices, compared to Islamic and Hindu edicts. Moslem doctrine prescribes strict procedures to limit contact with faecal material as it is considered impure. Moreover, scientific evidence may have far less influence in theocratic societies (notably Moslem ones) where "religion is the law" than in secular societies, where law is "the religion" and is much more influenced by scientific evidence. Therefore one especially must consider and work with the established religious doctrines when trying to modify behaviour and attitudes (Warner, 2000). The agronomic, social, environmental and economic arguments need to be couched within, and compatible with, the prevailing religious orthodoxy, in order for farmers to benefit of adopting such practices and thereby create a demand for such products.

Health aspects related to recycling urban waste

The most important function of sanitation systems is that they form a barrier against the spread of diseases caused by pathogens in human excreta (Jenssen et al., 2004). In the short run, one of the greatest challenges to recycling human organic waste will be the awareness of health aspects for consumers (and animals) that the managers of the system must become. In the long run the challenges will include monitoring for any unknown, and unexpected, negative effects on soil quality and on the integrity of agricultural production systems.

Ecological sanitation implies separate, often dry, handling of faecal matter with the objective of recycling the resources contained therein back to agriculture. Keeping human waste separate from the water cycle, helps avoid contamination of surface and ground water, which is important from a public health point. Sanitation systems also face specific challenges in counteracting pathogen transmission in the handling of material and its use on agricultural land. Farmers today in Western societies are reluctant to use sludge from conventional treatment systems, mainly because of the risk of contamination by organic pollutants, pathogens and industrial residues (Jenssen et al., 2003; Magid, 2004; Refsgaard et al., 2004). However, wastewater recycling to agricultural land (for example through irrigation) is widely practiced in many developing regions and carries potential health threats (Ensink et al., 2002; IWMI 2003).

In many ecological sanitation systems, the primary treatment is done at the household level instead of at professionally run, centralised, treatment plants. This implies the challenge of establishing simple systems, which are easy to handle and manage and, at the same time, do not increase the risk of disease transferral. Stenström (2001) reports that dry sanitation systems may be as, or more, effective as conventional systems in reducing the risk of exposure to pathogens. Based on current knowledge the WHO is preparing new guidelines for excreta and greywater reuse that will be available in 2006.

Larger systems, with urine separation give a high level of protection prior to agricultural application on crops (Höglund, 2001). Treatment of the faecal fraction, using either dry, anaerobic or aerobic systems, can provide pathogen reduction that is in compliance with existing regulations for application to agricultural land (Jenssen et al., 2004). Further the biological processes that occur in the soil further serve to reduce pathogen levels.

The recent SARS and Avian Flu epidemics are dramatic examples of zoonotic (transferred from animals to humans and back) diseases that can arise in highly intensive animal husbandry in urban areas of the developing world. Another disease (Neurocysticercosis) that is less dramatic but never the less causing substantial human and animal health impact is presently spreading inexorably across the African continent, due to the increasing production of pigs in urban areas. Cholera, diarrhoea and other faecal-oral diseases are closely related to poor sanitation. Diversion of wastewater from open sewers for use on leafy vegetables and other crops in urban agriculture is frequently observed in developing countries (Magid, 2004). Scavenging poultry and other small domestic animals that are allowed to roam outside and subsequently enter the living quarters can transfer parasites as well. Thus, disease vectors thrive due to inadequate management of waste and mismanaged urban agriculture.

Antibiotics, other medicinal residues and hormones (especially from industrialized animal production) entering the water bodies through sewage are known to modify the characteristics of aquatic micro-organisms, flora and fauna, although little is actually known about the nature of these changes (see Vaarst et al, this volume). In the industrialized world we are increasingly facing ubiquitous multi-resistant E. coli as well as other bacteria previously susceptible to antibiotics. Fish and other seafood organisms take up resistant organisms, hormones and toxic substances and relay them back into the human food chain. Resistant bacteria and parasites pose an increasing challenge to the industrialized world to both in human and animal health. Some medical doctors believe that human and animal natural immunization may be able to provide a solution, but if not appropriate solutions for recycling human and animal excreta to peri-urban agriculture may provide the best form of prevention.

Recycling nutrients from urban waste – global examples

While in theory there are many advantages of recycling and, many problems due to lack of proper sanitation, real life examples of such systems in developing countries are still few and far between.

It has been suggested that urban wastes are most readily utilised in agriculture where alternatives are not available or are too expensive. Farmers may be prepared to buy bulk compost but, due to availability and transport, urban organic wastes are predominantly used in urban and peri-urban agriculture.

"Getting rid of the shit" is what matters to most people – and they are even willing to pay for it, or given a certain level of community cohesion, spend some of their own time on waste management. A few people take pride in composting organic waste to use it in their home gardening, but this practice normally requires a considerable effort to work as a feasible community solution in continuously changing urban settlements. In many urban environments informal recycling is practised by scavengers who corner a market by picking through the dumping grounds and, in some places, this is the basis of a substantial economy. Provided that such solutions can be practiced or developed while avoiding communication of disease vectors, they can be seen as environmentally beneficial. However, in the most rapidly developing urban environments (even in China and Vietnam these days) human and animal excreta often pose insurmountable management challenges. Sanitation systems are often either non-existent or inadequate. In so far as economics do allow new sanitation systems to be developed, the systems that are promoted collect rainwater, greywater and blackwater, ensuring that all urban water is mixed and thus contaminated with high loadings of nutrients, organic matter and disease vectors. In most cases the costs of sanitation, storage and transportation of waste for productive and appropriate use in agriculture are perceived as prohibitive, and even in capital intensive animal production systems situated in the urban fringe, waste management is minimal due to a lack of an appropriate physical and administrative infrastructure.

Costs of managing waste and wastewater should be balanced against the costs of mismanagement, in terms of the longer-term impacts on human health and the total environment. Many interesting cases can be found where community organizations or private enterprises play a crucial role in local waste management, financed by local dwellers. However, in most cases that we know of in developing countries the local management schemes cannot carry more than the costs of transporting the waste away from the local area. Paying for further treatment and the additional costs that would be involved in recycling is not seen as an immediate necessity, and therefore not given priority. Strategies for financing such activities are critical for achieving sustainable urban waste management. The cases given below provide some indication of what can be achieved. Yet, it is difficult to provide detailed cost figures for ecological sanitary systems because the local conditions, which they rely on, vary greatly. In general, figures from UNEP (2004) show that the annual costs for ecological sanitation options are lower than most conventional options, see Figure 7.5.

Not all the impacts of a change to a new sanitary solution can be expressed in monetary terms. Aside from the costs of toilets and treatment facilities, etc., there are many other important effects. These include environmental benefits, such as of reduced pollution of nearby rivers, improved health and increased availability of drinking water for the local population. They also include social aspects, like local employment from handling organic waste and increased food production through increased access to organic fertilizer resources for local farmers.

In this chapter a few selected examples of recycling systems based on ecological sanitation are presented. These examples are either drawn from the authors' direct experience or systems that the authors have secondary knowledge about through their academic networks.

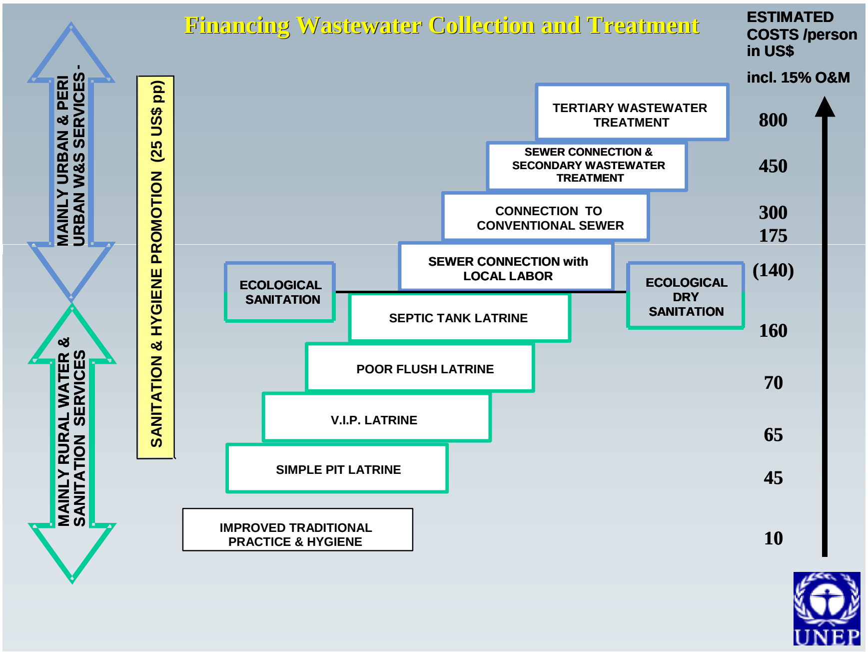


Figure 7.5. A ladder of sanitation options. Source: UNEP 2004.

China

China has a long tradition of effective management of natural resources. This includes reuse of garbage and human excreta in agriculture and aquaculture. The classical night soil system was reported to reuse as much as 90 % in agriculture (Edwards, 1992). Tradition therefore facilitates implementation of modern ecological sanitation in China. In 1998 70 households in the rural areas of Guangxi installed new urine-diverting toilets and by the end of 2002 more than 100,000 households had similar toilets (EcoSanRes, 2003). This has paved the way for urban implementation in China (Black, 2002). The reuse in aquaculture of wastewater from large cities started in 1951 in Wuhan, reaching about 20,000 ha by the 1980's (Edwards, 2000). The reuse of wastewater in aquaculture systems has been linked to traditional concepts of integrated farming and fish poly-cultures, which are seen as effective solutions for meeting a growing pollution problem in watercourses (Li, 1997). Irrigation with municipal wastewater reached about 1.5 million ha of land in 1995 covering around 1 % of the total cultivated land of China (Ou & Sun, 1996). However wastewater irrigation poses potential health problems that are not always properly dealt with.

India

A toilet centre provides sanitary facilities for 600 – 800 slum dwellers in Bangalore (Heeb, 2004). After storage, the urine is used as fertiliser and the faecal matter is composted with paper waste and garden waste and used for soil amendment. In addition to improving public health the toilet centre enhances the dignity of women through eliminating sexual harassment associated with the traditional practices of defecating in the open. The toilet centre, which generates 200 tonnes of urine and 100 tonnes of faeces per year, produces 50 tonnes of compost, which in turns yields 50 tonnes of bananas per year. The project has created 8 new full-time jobs. The annual cost of the existing systems is approximately 10 USD per user.

Wastewater aquaculture in Calcutta

The main sewers of Calcutta began functioning in 1875. In the 1930s sewage-fed fish farming started in the extensive pond system used for wastewater treatment. The fisheries developed into the largest single excreta-reuse aquaculture system in the world with around 7,000 ha in the 1940s, supplying the city markets with 10-12 tons of fish per day (EcoSanRes, 2003; Ghosh, 1997). Today the Calcutta Wetlands, using wastewater both in agriculture and in aquaculture covers an area of about 12,000 ha, known as the Waste Recycling Region (Ghosh, 1996). Wastewater-fed aquaculture systems like the Calcutta Wetlands represent controllable public health risks (Strauss, 1996). This is due to a combination of long retention times, high temperatures, high solar irradiance and natural microbiological activity and adequate personal hygiene and food handling. Lessons learned from Calcutta are that a wastewater reuse system can meet modern criteria of sustainable development and hygiene, even for a mega-city. It does so through:

- providing low-cost wastewater treatment, storm-water drainage and a green area as a lung for the city
- providing employment for about 17,000 poor people and production of about 20 tonnes of fish per day for the urban poor (Edwards, 2000) and
- reducing environmental impacts of contamination from heavy metals from major industries, e.g. chromium from the tanneries in Calcutta (Biswas & Santra, 2000).

As such the system serves as model that could be replicated elsewhere in India and other countries

Botswana

The villages of East and West Hanahai are located in Botswana's Kalahari Desert. On-site sanitation facilities allow families to produce their own soil conditioner and fertiliser for their vegetable gardens (Werner et al., 2004). The toilet systems collect urine and faeces separately. After a period of awareness raising, information sharing and mobilisation, which included meetings with the community chiefs and other events targeting all women and men in the villages, 20 families volunteered to pilot the concept of ecological sanitation. All of them selected urine diverting dry toilets, to provide privacy and comfort.

South Africa

After a successful pilot project involving 12 families, a new medium-income housing area for 3000 inhabitants in Kimberly will be equipped with ecological sanitation systems (SIPU International, 2002). The system include the following features:

- Separation and collection of urine, which will be used by the forestry department as fertiliser for silviculture.
- Regular collection of faecal matter for composting.
- Treatment of greywater in soak pits and subsequent drainage to a wetland.

Malaysia, Kuching

The city of Kuching, capital of the state of Sarawak, Malaysian Borneo, has prepared a strategy for sewage management in the city, which combines conventional and ecological sanitation. A solution for the sewage is urgent needed. Currently the blackwater is discharged to the storm water drains through septic tanks, that are emptied, at most, every 4 years, and the greywater, is discharged directly to the storm water drains. The result is a very high level of bacteria in drains and river tributaries (> 16.000 counts/ml) and high organic and nutrient load and a critical oxygen deficit. Outbreaks of cholera occur every year.

A proposal for a centralized sewage treatment system has been prepared. However, due to high costs and local physical conditions centralized sewage will only be suitable for the central business area of the town. The town is generally flat, with many low-lying areas, and only limited possibilities for gravity piping. In addition large part of the area is deep peat, which may decompose due to the draining effect of the sewers and thus lead to breaking sewers and rising mains due to subsidence.

The city has therefore prepared a framework plan for integrated sewage management, implementing *ecological* sanitation for large parts of the city. The ecological sanitation will be based on local treatment of greywater and collection of the blackwater for centralized biogas and fertilizer production. Greywater pilot facilities were established in late 2003. The design of the biogas plant has commenced. Collection of blackwater has commenced for selected housing areas and institutions (pilot project) when septic tanks have been cut off from the storm drains and emptied on a regular basis. After hygienic treatment in the centralized biogas facility, the blackwater will be used as fertilizer in oil-palm plantations. A number of problems will have to be solved along the way, including mechanisms for cost recovery, traceability of waste products and a number of technical and biological problems that may arise when implementing this type of approach in a tropical environment.

According to the government plan, successful implementation of the pilot project will lead to an eventual extension of the ecological sanitation scheme to around 250,000 households.

Australia

In Melbourne, the Werribee wastewater system was opened in 1897. Half of the wastewater from the 4 million citizens is used for irrigating pastures for cattle and sheep. The public water company Melbourne Water manages 54 % of its wastewater in 11,000 ha of ponds, wetlands and meadows, i.e., 500,000 cubic metres of wastewater per day. At present livestock grazes on 3 700 ha of pastures irrigated with raw or sedimented sewage and 3,500 ha non-irrigated pastures. The livestock yield a substantial return of about 3 million Australian dollars per year, which significantly offsets the cost of sewage treatment (Melbourne Water, 2001).

Sweden

In the Swedish capital of Stockholm, urine diversion is used in several urban housing areas, e.g. Palsternackan (50 apartments), Understenshöjden, (44 apartments), Gebers (30 apartments) and the newest Kullan (250 apartments). These are all family homes and show that people easily adapt to the new system (Johansson et al., 2001). On the Swedish west coast Volvo has established a new conference centre (Bokenäs) for 500 people where blackwater and organic household waste are used for biogas production and the greywater is treated in a natural system. In several Swedish cities nitrogen reducing wetlands have been shown to be cost efficient ways to meet increased water quality demands and some urine is utilised in agriculture.

Norway

Kaja - A complete recycling system at student dormitories in Norway

The Agricultural University of Norway is pioneering environmentally safe solutions to organic waste and wastewater treatment. In 1997, a first generation recycling system based on ecological engineering principles was built serving 48 students (Jenssen, 2005b). The system reduces water consumption by 30 %, almost completely eliminates pollution, and produces a valuable plant fertilizer and soil amendment product from the waste material. The concept is based on:

- Separate treatment of toilet wastewater and water from kitchen and shower.
- Modern and reliable vacuum toilet technology with high comfort levels (see Figure 7.6a).
- Liquid composting of toilet waste and organic household waste for sanitation, stabilization, removal of odours and production of high quality liquid fertilizer (see Figure 7.6b). Liquid composting can be substituted for, or combined with, biogas production.
- Simple and reliable filtration of greywater for producing water of a suitable quality for irrigation, groundwater recharges or discharge to a nearby stream.
- A patented machine for fertilizer distribution that hydraulically "shoots" liquid bio-fertilizer into the ground, resulting in higher yields and less pollution from run-off (see Figure 7.6c).
- Water-saving devices for showers, characterized by high comfort.

Liquid composting provides a sanitised mixture of organic household waste and blackwater. The liquid fertiliser is hydraulically injected into the soil and provides equivalent yields to mineral fertilisers. When the blackwater is removed, the remaining greywater meets drinking water standards with respect to nitrogen levels and bathing water quality standards with respect to bacteria. The greywater treatment systems are compact (1-2 sq. m per person) and can be landscaped.

Overall this system:

- Recycles 80-90 % of the nitrogen and phosphorus in the wastewater.
- Reduces nutrients and organic matter (BOD) by >95 %, hence; near zero emissions.
- Reduces the need for pipelines - the most expensive part of a traditional sewage network.
- Replaces expensive chemical fertilizer.
- Makes it possible to recycle nutrients locally, decreasing the need to transport fertilizer.
- Makes energy production from waste resources possible.
- Saves 30 % of the domestic water consumption. Adding more water saving devices makes it possible to save up to 50 % or more.
- It is possible to use the separated greywater for irrigation or groundwater recharge after filtration, thus saving even more water.
- Greywater treatment facilities can easily be adapted to the terrain.
- Facilitates development of real estate in areas with no existing sewage network.

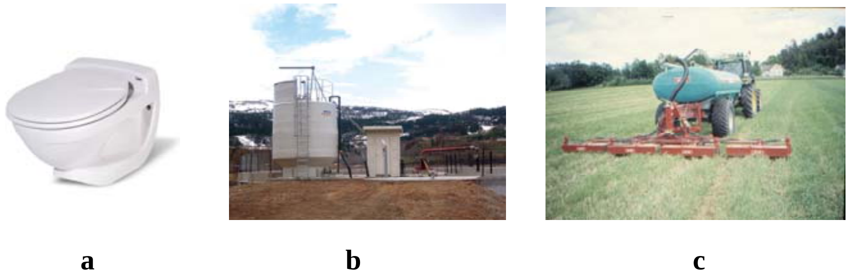


Figure 7.6. a) wall mounted vacuum toilet, b) the liquid composting reactor, c) direct ground injection. Source: Jenssen 2005b

Decentralized urban greywater treatment at Klosterenga

At Klosterenga, in the capital of Norway, Oslo, the greywater is treated in an advanced naturebased greywater treatment system in the courtyard of the building, see Figure 7.7 (Jenssen, 2005a). The system consists of a septic tank, pumping to a vertical down-flow single pass aerobic biofilter followed by a subsurface horizontal-flow porous media filter. The Klosterenga system was built in 2000 and has consistently produced an effluent quality averaging to:

- COD 19 mg/l
- Total nitrogen 2.5 mg/l
- Total phosphorus 0.03 mg/l
- Faecal coliforms 0

For nitrogen the effluent has consistently been below the WHO drinking water requirement of 10 mg/l and for bacteria no faecal coliforms have been detected. The space required for this experimental system is about 1 m^2/person, and part of the treatment area is also used as a playground, see Figure 7.7. Such high qualities of effluent water reduce the need for a secondary sewer collection system, because local streams or water bodies safely be used for receiving the treated water, even in urban areas. The low area requirement of the system and the high effluent quality facilitates use in urban settings, discharge to small streams, open waterways or irrigation or groundwater recharge.

Figure 7.7. The Klosterenga greywater treatment system. Upper left; Flowforms. Upper right; the wetland in the foreground the biofilter is underneath the playground behind the stonewall. Lower left, the treated effluent is exposed in a shallow pond. Discharge to a local stream is possible as the stream was reopened. Source: Jenssen, 2005a.

Conclusions

There are both possibilities and challenges for recycling urban waste to agriculture. From an urban viewpoint the primary goal for waste and wastewater management is attaining a healthy local environment. Thus "getting rid of the shit" is the main priority and people are willing to pay a certain amount of their income to attain this, or to organize themselves in ways that allow the disposal of waste from the surroundings. This implies the need to organise waste management schemes that are environmentally benign, and extend beyond the immediate local surrounding. This is particular problematic, yet also urgently required, especially in poor countries with weak institutions and weak environmental controls. Ecological sanitation systems can be combined with (organic) farming systems and contribute to sustainable development in such countries for the following reasons:

- There is a lack of established infrastructure for wastewater handling and scarce resources like water, capital, and fertilisers.
- Labour is cheap and available, whereas capital and water resources are often in short supply. Thus conditions in developing countries are more appropriate for developing ecological treatment systems rather than conventional ones are both capital and water intensive.
- Ecological sanitation systems have advantages like low transport costs, lower requirements for water, and reuse of nutrients. Ecological sanitation saves at least 20–40 % of domestic water consumption. After filtration, greywater can be used for irrigation, groundwater recharge or potable water. This is of key importance since water scarcity is a major limiting factor for development in many countries. Further, it is possible to recycle 80 % to 90 % of the nitrogen, phosphorus and potassium contained in excreta and wastewater from urban settlements into inexpensive local fertilisers for use in organic agriculture.

The thermodynamic principles analysis can be used to identify sustainable social modes of metabolism figuring out the material and energetic efficiencies for different systems as for example use of urban organic waste in organic agriculture. However these efficiencies also need to be evaluated and valued by the humans involved and the challenge is to find a "proper" level of recycling nutrients and organic matter. From a thermodynamic point of view the ideal is not to produce any material waste, while from an economic point of view it is necessary to evaluate the costs for containing the spread or preventing the creation of waste against the costs of so doing. And questions of personal and social responsibility matter. For example analysing if people are prepared to take individual responsibility to separate, sort or otherwise deal with waste, and considering what are the costs of informing, regulating and controlling waste production and use? Today, organic waste is not easily recycled back into to food production systems in Western societies. Within most institutional regimes, waste is an externality, meaning that those responsible for creating the activity behind the waste affect the utility of those suffering from the problems of waste emission without compensating this decrease in utility, by for example lowering the quality of bathing water to unacceptable standards, or smell from a disposal site etc.

By sustaining peri-urban and urban agricultural production ecological sanitation can play a multiple role in achieving development policy goals through enhanced food production thereby improving food security and reducing malnutrition, generating local business and job opportunities and thereby alleviating poverty. Organic agriculture is interesting in this perspective because of the focus on resource recycling in their aims. But it is also a real need for secure access to nutrients especially in systems with mainly crop production. However there are great challenges for the farms by enlarging the nutrient cycle with the cities related to dependency, soil health and human health.

Already proven technologies can be adapted and improved in new management systems, through collaborative schemes between stakeholders including: CBOs, SMEs, municipalities and peri-urban farmers. Our case studies show that this can best be done by thinking big, but starting small. Research is needed to document, monitor and improve development of such systems and their environmental and health impacts (adverse as well as beneficial).

A more fundamental research need is that of addressing the question of risk management. Whether we choose to dispose of our waste (or resource) in the aquatic system (as we do for the time being in the industrialized world) or through the terrestrial system there are risks involved. We are currently not able to foresee the consequences of these in the longer term. There is much evidence that disposal through the terrestrial systems can make these risks more manageable and, in some cases, involves lower costs than conventional centralized sewage treatment.

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