CHAPTER 7

BACKGROUND TO URINE DIVERSION TECHNOLOGY

"The mundane act of defecation has wrought profound effects on every aspect of our social history."

Lewis, D (1996). *Kent Privies*. Countryside Books, Berkshire, UK.

CHAPTER 7: BACKGROUND TO URINE DIVERSION TECHNOLOGY

7.1 THE NEED FOR AN ALTERNATIVE TO VIP TOILETS

In chapters 1 and 2 the main construction and operational disadvantages of VIP toilets were described. These can be summarised as follows:

- Adverse geotechnical conditions, for example hard ground or non-cohesive soils, have a negative effect on the capital cost of constructing VIP toilets, while a shallow water table presents a danger of aquifer pollution;
- when pits become full, it is not always a feasible option, either physically or economically, to empty them or to build new toilets;
- a perception exists that this technology is a "poor man's solution" to the sanitation problem;
- various socio-cultural, educational and institutional issues associated with VIP toilets have not been adequately addressed;
- there exists a lack of innovation for people with differing needs and customs; and
- they are unsuitable for densely-populated urban or peri-urban areas.

To address these shortcomings, it has been necessary to think beyond the limitations imposed by traditional methods of providing dry sanitation. This need has been supported by increasing awareness worldwide of the environmental issues associated with sanitation. Furthermore, pressure on land to produce more food to feed the ever-growing populations of developing countries has made it imperative to utilise natural resources, including human excreta, wherever possible. The concept of ecological sanitation, or "eco-san" as it is also known, is seen as an alternative solution to some of the problems associated with pit toilets, environmental degradation and food shortages.

In chapters 2 and 3 the problems of conventional sanitation approaches were expounded upon at some length. These vary from the poor status of the sanitation sector, inadequate institutional capacity to deal with the sanitation process, the fixation with providing either a full waterborne system or a VIP toilet, the social acceptability of different systems, and the perception that dry, on-site sanitation systems are inherently inferior. It was also emphasised that the basic purpose of any sanitation system is to contain human excreta (chiefly faeces) and prevent the spread of infectious diseases, while at the same time avoiding damage to the environment. If an alternative sanitation technology can do all these things with fewer operational and maintenance problems than those associated with conventional VIP toilets, and also produce a free, easily accessible and valuable resource for agricultural use, then the implementation of such a technology should be actively encouraged.

Ecological sanitation systems are neither widely known nor well understood. They cannot be replicated without a clear understanding of how they function and how they can malfunction. They have some unfamiliar features such as urine diversion pedestals or squatting plates, which raise questions about their cultural acceptability. In addition, they require more promotion, support, education and training than ordinary pit or VIP toilets (Esrey et al 1998).

A concern is often expressed that some ecological sanitation systems are too expensive for low-income households in developing countries. Eco-san systems need not cost more than conventional systems. While some systems may be sophisticated and expensive, others are relatively simple and low-cost. There is often a trade-off between cost and operation: lower cost solutions mean more manipulation and care of the sanitation system, while with higher cost solutions manipulation and care can be reduced. Eco-san systems need not be expensive to build because:

- the entire structure is built above ground – there is thus no need for expensive digging and lining of pits;
- urine is diverted, no water is used for flushing and the volume of the processing vault is fairly small, as it is emptied periodically; and
- the contents of the processing vault are dry, which means that there is no need for expensive watertight constructions (Esrey et al 1998).

The introduction of eco-san systems is bound to lower the total costs of urban sanitation in particular. If a waterborne system is being considered, the sewers, treatment plants and sludge disposal arrangements will cost several times as much as an eco-san system, while for ordinary VIP toilets the institutional capacity required for desludging full pits may be nonexistent . These are important considerations for developing countries, where public institutions face stringent financial limits (Esrey et al 1998).

7.2 HUMAN EXCRETA – WASTE PRODUCT OR VALUABLE RESOURCE?

7.2.1 Biology of human excreta

For adult persons who maintain approximately the same mass during their lifetimes, the excreted amounts of plant nutrients are about the same as the amount eaten. The excreted amounts of plant nutrients depend on the diet and thus differ between different persons as well as between different societies (Jönsson 1997). A great deal of research on the subject has been carried out in Sweden and Table 7.1 is based on the average Swedish diet and Swedish circumstances. Although the comparative figures for other countries can be expected to be somewhat different, the overall picture will be essentially the same.

Table 7.1: Estimated Swedish averages for mass and distribution of plant nutrient content in urine and faeces (based on Jönsson 1997)

Parameter	Urine		Faeces		Total toilet waste	
	g/p/d	%	g/p/d	%	g/p/d	%
Wet mass	900 - 1200	90	70 - 140	10	970 - 1340	100
Dry substance	60	63	35	37	95	100
Nitrogen	11	88	1,5	12	12,5	100
Phosphorus	1,0	67	0,5	33	1,5	100
Potassium	2,5	71	1,9	29	3,5	100

Roughly 65 to 90 % of the excreted nitrogen, phosphorus and potassium are estimated to be found in the urine. Furthermore, plant nutrients excreted in urine are found in chemical compounds that are easily accessible for plants. Initially 80 - 90 % of the nitrogen is found as urea, which rapidly degrades to ammonium and carbon dioxide as follows:

$$CO(NH_2)_2 + 3H_2O \leftrightharpoons CO_2 + NH_4^+ + 2OH^-$$

The urea degradation increases the pH value of the urine from its normally slightly acidic state (pH ±6 when excreted) to a value of approximately 9. The phosphorus in the urine is in the form of phosphate, while the potassium is in the form of ions. Many chemical fertilisers contain, or dissolve to, nitrogen in the form of ammonium, phosphorus in the form of phosphate and potassium in the form of ions. Thus, the fertilising effect of urine ought to be comparable to the application of the same amount of plant nutrients in the form of chemical fertilisers (Jönsson 1997).

The faeces contain undigested fractions of food with plant nutrients. However, organically bound plant nutrients are not plant available. The undigested food residuals have to be degraded before their plant nutrients become available, therefore the plant availability of the nutrients in faeces is expected to be slower than the plant availability of the nutrients in urine (Jönsson 1997).

7.2.2 Potential for reuse of human excreta

Key features of eco-san are prevention of pollution and disease caused by human excreta, treatment of human excreta as a resource rather than waste, and recovery and recycling of the nutrients. In nature, excreta from humans and animals play an essential role in building healthy soils and providing valuable nutrients for plants. Products of living things are used as raw materials by others. Conventional approaches to sanitation misplace these nutrients, dispose of them and break this cycle (Esrey et al 1998).

The fertilisers excreted by humans are sufficient to grow the 230 kg of crops they need each year, as illustrated in Table 7.2 below. The table is based on an average human production of 500 litres of urine and 50 litres of faeces per year.

Table 7.2: Annual excretion of fertiliser by humans compared with fertiliser requirement of cereal (Wolgast 1993)

Fertiliser	**500 ℓ urine**	**50 ℓ faeces**	**Total**	**Fertiliser need for 230 kg cereal**
Nitrogen	5,6 kg	0,09 kg	5,7 kg	5,6 kg
Phosphorus	0,4 kg	0,19 kg	0,6 kg	0,7 kg
Potassium	1,0 kg	0,17 kg	1,2 kg	1,2 kg
Total N+P+K	**7,0 kg (94 %)**	**0,45 kg (6 %)**	**7,5 kg (100 %)**	**7,5 kg**

Obviously human urine is the largest contributor of nutrients to household wastewater. If no phosphate detergents are used, at least 60 % of the phosphorus and 80 % of the nitrogen in household wastewater comes from urine. The total quantities of nutrients in human urine are significant when compared with the quantities of nutrients in the mineral fertilisers used in agriculture. For example, it is estimated that in Sweden the total yearly production of human urine contains nitrogen, phosphorus and potassium equivalent to 15 - 20 % of the amounts of these nutrients used as mineral fertilisers in 1993. Thus, by source-separating human urine, the amounts of nutrients recycled to arable land can be significantly increased while at the same time the nutrient load of wastewater can be significantly decreased (Jönsson 1997).

The fertilising effect of source-separated urine has been tested in some experiments in Sweden and appears to be almost as good as that of the corresponding amount of chemical fertiliser, provided that ammonia emission from the urine is restricted. The uptake of urine nitrogen by barley harvested at flowering stage was found to be 42 % and 22 % at two application rates, while the uptake of ammonium nitrate nitrogen at the same application rates was 53 % and 28 % respectively. The lower uptake of urine nitrogen has been explained by higher gaseous losses of nitrogen (i.e. ammonia) from urine than from ammonium nitrate. The utilisation of urine phosphorus, however, was found to be 28 % better than that of chemical fertiliser. The barley fertilised with urine derived 12,2 % of the phosphorus, while that fertilised with dipotassium hydrogen-phosphate derived only 9,1 % from the fertiliser. In a field experiment, the nitrogen effect on oats of stored urine was compared to that of ammonium nitrate fertiliser at three different application rates. The human urine, which was surface spread and immediately harrowed into the ground, gave approximately the same yield as the corresponding amount of chemical fertiliser. Using the recycled toilet products as fertilisers will therefore save chemical fertilisers containing almost the same amount of nutrients and thus also the resources needed to produce and distribute them (Jönsson 1997).

A major advantage of using human urine instead of chemical fertilisers or sewage sludge is the very low concentrations of heavy metals found in urine (Jönsson et al 1997). This viewpoint is supported by Hanaeus et al (1997) who state that the quality of sewage sludge is not fully trusted by agriculturalists due to the risk of hazardous compounds being present. According to Höglund et al (1998), human urine in Sweden contains less than 3,6 mg Cd/kg P, while commercial chemical fertilisers contain approximately 26 mg Cd/kg P. Furthermore, the sludge from the 25 largest sewage plants in Sweden was found in 1993 to contain an average of 55 mg Cd/kg P.

Although faeces contain fewer nutrients than urine, they are a valuable soil conditioner. After pathogen destruction through dehydration and/or decomposition, the resulting inoffensive material may be applied to the soil to increase the organic matter content, improve water-holding capacity and increase the availability of nutrients. Humus from the decomposition process also helps to maintain a healthy population of beneficial soil organisms that actually protect plants from soil-borne diseases (Esrey et al 1998).

CHAPTER 8

REVIEW OF URINE DIVERSION EXPERIENCE AND APPLICATION

> "Science knows now that the most fertilising and effective manure is the human manure............ Do you know what these piles of ordure are, those carts of mud carried off at night from the streets, the frightful barrels of the nightman, and the fetid streams of subterranean mud which the pavement conceals from you? All this is a flowering field, it is green grass, it is the mint and thyme and sage, it is game, it is cattle, it is the satisfied lowing of heavy kine, it is perfumed hay, it is gilded wheat, it is bread on your table, it is warm blood in your veins".
>
> Victor Hugo, *Les Miserables*, 1862

CHAPTER 8: REVIEW OF URINE DIVERSION EXPERIENCE AND APPLICATION

8.1 URINE DIVERSION THEORY AND PRACTICE IN THE WORLD

8.1.1 Some examples of urine diversion sanitation technology

Sanitation using the technique of urine diversion is applied in many parts of the world and has been shown to be a feasible option that works. Some examples are described below (based mostly on Winblad 1996b, except where otherwise indicated).

The first example is from Sanaa, in Yemen (Figure 8.1). A single-chamber dehydrating toilet with urine diversion is placed in a bathroom several floors above street level. In a traditional Yemeni town house the upper floors have toilet-bathrooms next to a vertical shaft that runs from the top of the house down to the level of the street. The faeces drop through a hole in the squatting slab and down the shaft, while the urine drains away through an opening in the wall and down a vertical drainage surface on the outer face of the building. Personal cleansing with water takes place on a pair of stones next to the squatting slab. The water is drained off in the same way as the urine. As Sanaa has a hot, dry climate, the urine and water usually evaporate before reaching the ground, while the faeces dehydrate quickly. They are collected periodically and used as fuel.

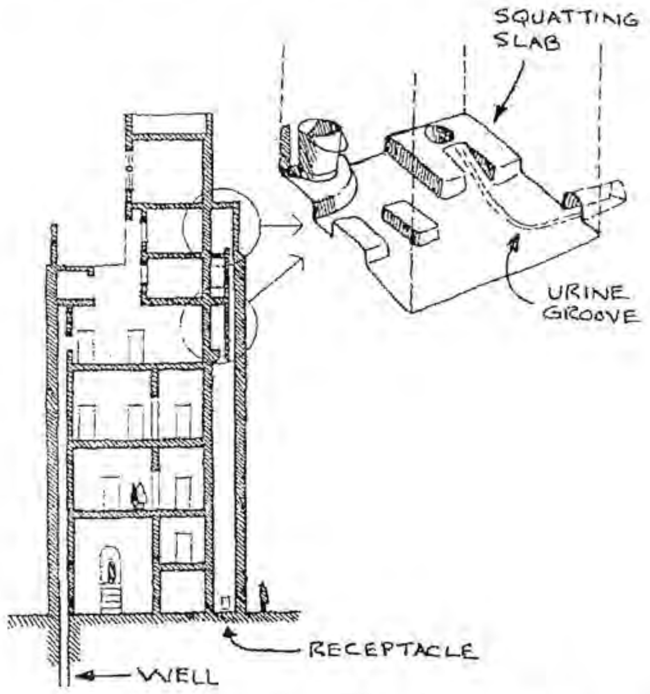

Figure 8.1: Section through a house in the old part of the town of Sanaa, Yemen
(Esrey et al 1998)

The second example is from Vietnam (Figure 8.2). It is a double chamber dehydrating toilet with urine diversion. The toilet chambers are built above ground. Urine is collected and piped to a container or soakpit. Faeces are dropped into one of the chambers while the other one is kept closed. Paper used for personal cleansing is put into a bucket and later burnt, while the dehydrated faecal material is used as a soil conditioner.

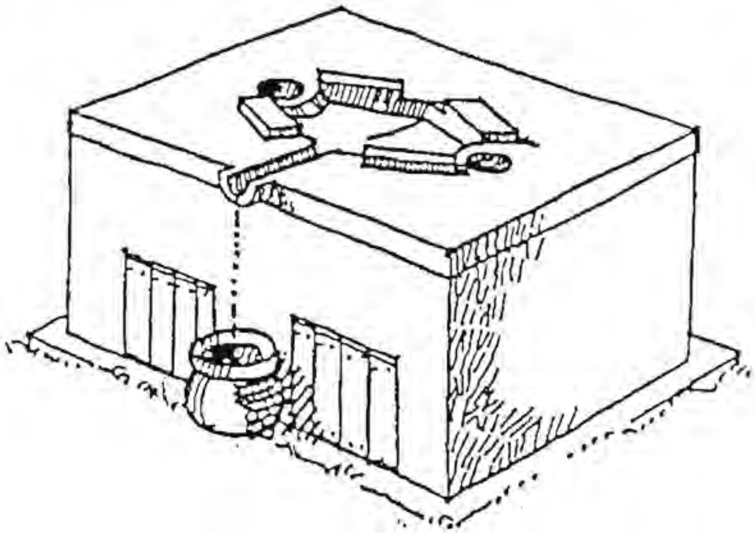

Figure 8.2: The Vietnamese double vault dehydrating toilet, shown here without the superstructure (Winblad 1996b)

Before a chamber is used, its bottom is covered with a layer of powdered earth. The faeces are covered with kitchen ashes, which absorb moisture and deodorise them. When the chamber is two-thirds filled its contents are levelled with a stick before it is filled to the brim with dried, powdered earth to create conditions conducive for anaerobic composting.

The Vietnamese double-vault originated in the 1950s when peasants who were using human excreta as manure found that composting reduced the smell and improved its fertiliser value. This became the key component of a rural sanitation programme for disease prevention and increased food production that began in North Vietnam in 1956. After much experimentation it was found that the addition of kitchen ashes effectively neutralised the bad odours normally associated with anaerobic composting, and also effected the destruction of intestinal worm ova – after a two-month composting period 85 % of the ova were found to have been destroyed. The anaerobic composting also played an important role in converting organic nitrogen to inorganic forms more readily available to plants (World Bank 1982). According to Van Buren et al (1984), these composting latrines produce more than 600 000 t of organic fertiliser each year and have also been responsible for a substantial reduction in intestinal diseases.

A toilet of similar type to the Vietnamese version is the Guatemalan LASF toilet (*Letrina Abonera Seca Familiar*), which is an adaption of the Vietnamese version and is provided with two pedestals rather than squatting holes. It is also used in high density urban squatter areas, for instance in the centre of San Salvador, the capital of El Salvador (Figure 8.3).

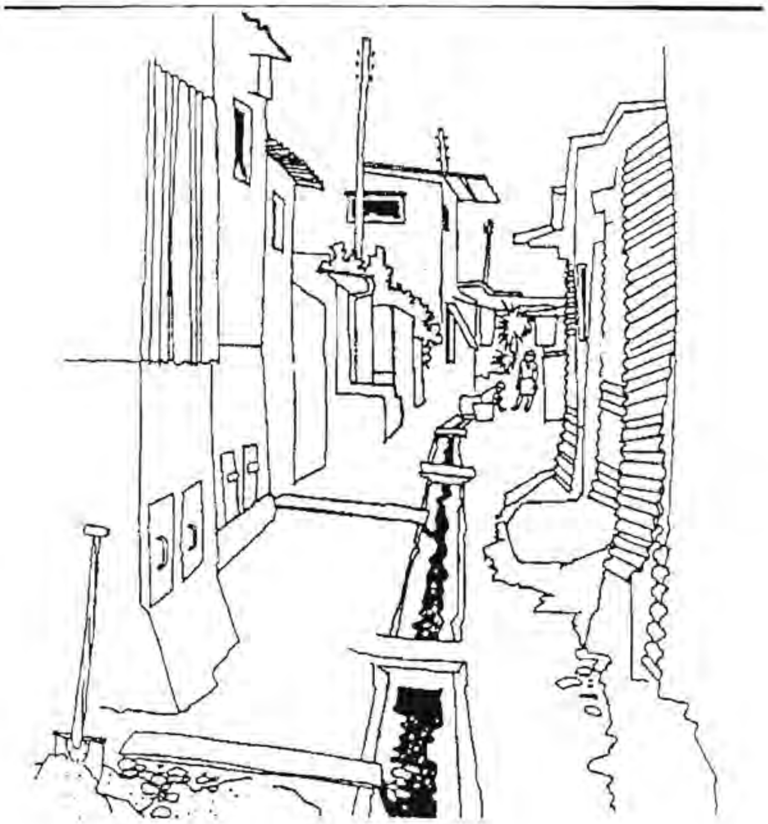

Figure 8.3: LASF toilets in a densely populated squatter area in central San Salvador. The open drain is carrying sullage (Winblad 1996b)

A further development of the LASF toilet has been equipped with a solar heater (Figure 8.4). The main purpose of the heater is to increase evaporation in the chamber. The example shown is from the community of Tecpan, near San Salvador. Figure 8.5 illustrates an example of a double chamber solar-heated composting toilet in Ecuador, high up in the Andes Mountains. At this altitude there is no need for urine diversion as the natural evaporation takes care of any excess liquid. Although termed a composting toilet, it is more likely to function as a dehydrating toilet.

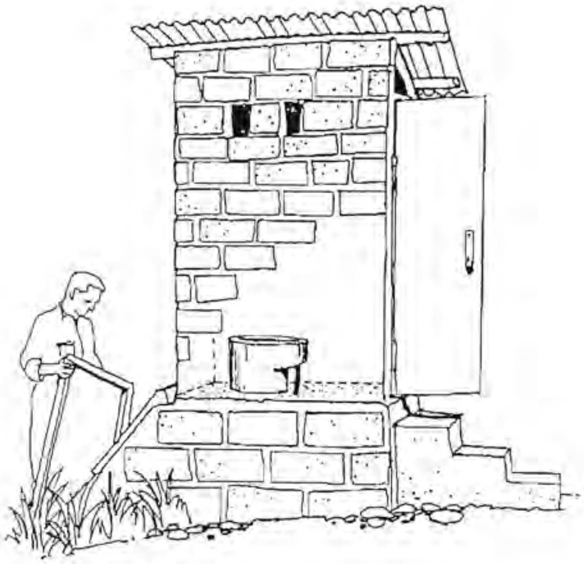

Figure 8.4: A dehydrating toilet with urine diversion and solar-heated vault, El Salvador (Winblad 1996b)

Figure 8.5: A solar-heated dehydrating toilet in Ecuador (Winblad 1996b)

8.1.2 Comparison: desiccation and composting

When something is dehydrated all the water is removed from it. In a *dehydrating toilet* the contents of the processing chamber are dried with the help of heat, ventilation and addition of dry material. The moisture content should be brought below 20%. At this level there is rapid pathogen destruction, no smell and no fly breeding. A requirement for dehydration is, except in very dry climates, the diversion and separate processing of urine (Winblad 1996b). The waste chamber is solar-heated by means of an inclined black-painted lid and small amounts of ash, sawdust or dry soil are added after each use. The faeces may be desiccated within a few weeks. The desiccation process, while not producing a material as rich as true compost, still acts to enrich soil to which it is added (Dudley 1996).

Composting is a biological process in which, under controlled conditions, various types of organisms break down organic substances to make a humus. In a *composting toilet*, human excreta is processed together with organic household residues. Optimal conditions for biological decomposition should be sought. This means that sufficient oxygen should be able to penetrate the compost heap to maintain aerobic conditions. The material should have a moisture content of 50 - 60% and the carbon : nitrogen balance (C:N ratio) should be within the range 15:1 to 30:1 (Winblad 1996b).

In order to function correctly, a composting toilet requires the addition of carbonaceous (organic) matter to maintain the correct C:N balance. In some cases it may also be desirable or necessary to add lime to maintain a more or less neutral pH, but this depends on the nature of the material entering the toilet. Further, in order to get true composting, air must be able to reach all parts of the toilet contents. The need to turn and ventilate the heap is not just to allow oxygen to play its part in the chemical process, but also to facilitate evaporation in the depths of the heap. The most common problem with composting toilets is an excess of moisture which slows or stops the aerobic decomposition process and leads to bad smells. A conceptual problem with the composting toilet is that to be successful at composting, it must create conditions which encourage bacteria to thrive. If part of the intention of a toilet is to kill harmful bacteria, this may be counter-productive. On the other hand, when a desiccating toilet is well managed, the contents of the processing chamber can be reduced to an apparently innocuous state very rapidly (Dudley 1996).

8.1.3 System hardware and operational requirements

The basic requirement of a urine diversion sanitation system is a toilet pedestal (or squatting plate) which prevents urine and faeces from being mixed together. Examples of pedestals for both the dry box and flushing systems found in Sweden are illustrated in Figure 8.6. Both are indoor toilets. In the dry-box version, small amounts of ash, dry soil or sawdust are sprinkled on the faeces after each bowel movement; this serves to absorb the moisture which is an inherent part of fresh faeces and thus also to prevent odours. It is essential that the excreta remains as dry as possible and that moisture is prevented from entering the waste compartment. Paper and other material used for personal cleansing is not deposited in the receptacle but is stored in a separate container and disposed of by burning. The urine can be collected in any suitable sealed container if its reuse for agricultural fertilizer is desired. Alternatively, it can be led into a soak pit. The urine bowl is washed with water periodically, while the rear chute may be cleaned with a damp toilet brush when necessary.

In the flushing version, the urine is collected and stored in underground vaults, from where it is collected by farmers for use as agricultural fertiliser. The faeces are in most cases flushed into a conventional sewer system for further treatment, and the reduced nutrient load due to the exclusion of nitrogen and phosphorus found in the urine results in lower treatment costs. The front compartment of the bowl, used for urine collection, is flushed with a spray of approximately 200 ml of water from a nozzle on the side of the bowl, while the rear compartment is flushed from a conventional toilet cistern.

(a) (b)

Figure 8.6: Urine diversion pedestals for (a) dry system and (b) flushing system. Photographed in Sweden.

In Mexico a pedestal cast in mortar, using a fibreglass mould, is used (Figure 8.7). This pedestal is usually painted and provided with a conventional seat and lid, after which it looks quite attractive.

(a)

(b)

Figure 8.7: Mexican urine diversion pedestal cast in mortar.
(a) The pedestal, which can be fitted with a conventional seat and lid.
(b) The pedestal shown together with its fibreglass mould.

The practice of covering fresh faeces with earth, ash, etc is not new. In England, Rev Henry Moule patented an earth closet in 1860 (Figure 8.8). This wooden structure had a seat and hopper. The hopper was filled with dry earth, charcoal or ash. A pull of the handle in the seat released the earth onto the contents of a bucket set below the seat.

Figure 8.8: Rev Henry Moule's earth closet patented in 1860. Found in the grounds of Cooling Castle, Kent, UK.
(Lewis 1996)

8.2 AGRICULTURAL PROSPECTS: SOME EXAMPLES

8.2.1 Introduction

The potential value of human excreta as fertiliser and soil conditioner was introduced in chapter 7.2, where the plant nutrient content of urine and faeces was described. In this section, some policies and examples of human excreta reuse for agricultural purposes in various countries are described.

In order to grow plants that supply our food, fertilisers such as nitrogen, phosphorus, potassium and about 25 other additional elements have to be supplied. Today, artificial fertilisers account for the largest share of these nutrients, but at the present rate of use the available resources will be rapidly depleted. Use of human excreta as fertiliser has been implemented only to a very limited extent. Rather, they have been flushed out into the rivers with consequent growth of algae, etc, resulting in a lack of oxygen in the aquatic resources. These resources have also been polluted with pathogenic micro-organisms to the extent that many large rivers have become virus infected more or less permanently. It is thus better to create a closed system, with no pollution from bacteria or viruses and where *human* fertilisers are harvested and used to feed the following year's crops (Wolgast 1993). Nutrients are removed from fields with the harvested crops; in sustainable agriculture therefore, the same amounts of nutrients that are removed from a field should be returned to it (Jönsson 1997).

8.2.2 Recycling: how nutrients are returned to the soil

Ecological sanitation regards human excreta as a resource to be recycled rather than as a waste to be disposed of. The very idea that excreta are waste with no useful purpose is a modern misconception. It is at the root of pollution problems that result from conventional approaches to sanitation. In nature there is no waste – all the products of living things are used as raw materials by others. Recycling sanitised human urine and faeces by returning them to the soil serves to restore the natural cycle of life-building materials that has been disrupted by our current sanitation practices (Esrey et al 1998).

There are many reasons for recycling the nutrients in excreta. Recycling prevents direct pollution caused by sewage being discharged or seeping into water resources and ecosystems. A secondary benefit is that recycling returns nutrients to soil and plants, and reduces the need for chemical fertilisers. It restores good soil organisms to protect plants, and it is always available locally, wherever people live (Esrey et al 1998).

8.2.3 Examples

Japan:

Japan has a unique practice of collection and treatment of nightsoil (human urine and faeces). This country introduced the practice of reusing human excreta for agriculture in the 12th century, possibly influenced by monks of Zen Buddhism who studied in China (the Chinese practice of reusing human excreta arose at a very early stage in the country's development). This practice continued in Japan until the middle of the 19th century. Cities were so clean that Portugese missionaries reported their astonishment to the Vatican during the 16th century. From the 17th to the middle of the 19th century Japan became a closed society, and the recycling of human excreta was encouraged. Farmers purchased human urine and faeces from customers in the urban areas, and, due to the country's closed policy, typhoid, cholera and other communicable diseases were virtually unknown. Farmers placed a bucket at street corners in the towns and villages, collecting free urine from pedestrians and providing a simple public toilet at the same time (Matsui 1997).

China:

In China's city of Shanghai, only 13 % of the population has waterborne sewerage facilities. The Shanghai Bureau of Environmental Sanitation (SBES) collects the major part of the city's human waste. The vacuum trucks of the SBES remove more than 8 000 t of nightsoil each day from public toilets, septic tanks and nightsoil dumping stations. During the night, the wastes are shipped by river and canal in sealed barges to depots on the outskirts of the city. There the waste is stored for between 10 and 30 days in covered tanks, after which it is sold to farmers who apply it to their fields as manure (Robson 1991).

Growing vegetables in Mexico City, Mexico:

In response to rapid inflation, high unemployment and inadequate nutrition in Mexico City, Anadeges (a network of NGOs) has perfected a method of growing vegetables in containers using human urine as fertiliser. The project was launched in 1988 and more than 1 200 urban households are currently participating.

The technology used was selected and adapted to fit the local circumstances, which include no land available for conventional kitchen gardens, participants unable to afford the required investment in containers and fertilisers, and the need for growing containers of lightweight material to allow rooftop cultivation.

Vegetables are grown in containers such as 20 ℓ plastic buckets or discarded car tyres filled with deciduous tree leaves or grass clippings and topped with a 30 - 50 mm layer of soil. The soil is made up of plant material from the previous year's containers that has composted into a rich humus, and household garbage that has been composted with worms. Urine, which has been stored in separate receptacles for 3 weeks, is applied to the vegetable containers after dilution with water on a 1:10 ratio.

After several years of study, certain observations were made, and it became clear that plants fertilised with urine grew more rapidly, and were larger and healthier than those grown with conventional agricultural techniques. Furthermore, less water was required (Esrey et al 1998).

Guatemala:

In Guatemala, deforestation and erosion are serious problems throughout the highland areas. This is the result of the high population density in these zones, together with inequitable land distribution and the use of the more gently sloping and flatter lands for the cultivation of cash crops, thereby forcing the subsistence crops to be cultivated on steep slopes. To counteract this situation of increased soil loss, the use of human faecal matter as soil conditioner by subsistence farmers is of particular value. While it is recognised that this practice may not solve the area-wide problems of deforestation and soil erosion, it is regarded as an appropriate and low-cost method for improving the fertility and productivity of the soil of the individual farming family and for the country as a whole. The farmers are aware that the application of chemical fertilisers to the fields without replenishing the organic fraction leads to an impoverishment of the soil (Strauss and Blumenthal 1990).

The LASF latrine described earlier was introduced here because it was regarded as the most suitable technology for the people of the area. Ash, or a mixture of ash and soil or of lime and soil, is added after each defecation. This, together with the separation of urine, renders the faecal material alkaline, with a pH of around 9. This enhances the die-off of bacterial pathogens. The mixture of decomposed, humus-like material of faecal origin and ash, called "abono", is dried in the sun and then stored in bags upon removal from the vault until the farmer uses it in his fields at the time of tilling. The potassium levels of the "abono" are much higher than ordinary excreta due to the addition of ash, which is very rich in potassium. On average, the application rate of "abono" amounts to the equivalent of about 2 500 to 3 000 kg/ha for each plant cycle. With the average "abono" production rate of about 425 kg per year per family, the family's fertilising potential for maize crops is approximately 1 900 m^2 on the basis of the phosphorus content of the "abono" and 2 580 m^2 on the basis of potassium, but only about 123 m^2 on the basis of the nitrogen content. The fertiliser from these latrines is therefore complemented by the collected urine, or else nitrogen-fixing crops such as legumes are planted in rotation with other crops (Strauss and Blumenthal 1990).

Zimbabwe:

A unique tree-panting method that is combined with a composting or dehydrating toilet, called the *arborloo*, is used in Zimbabwe. A small hole suitable for planting a tree is dug; the size is approximately 600 x 600 x 600 mm, thus forming a shallow pit for a toilet. A lightweight, removable slab is placed over the hole and a simple toilet structure, which is also able to be moved easily, is erected above it. The unit is fitted with a urine diversion pedestal or squat plate. The urine is thus diverted and reused as liquid fertiliser, while the shallow pit fills up relatively quickly with faeces. These are treated in the same way as in any other dehydrating toilet, by being covered with ash or dry soil. As soon as the hole is full, the superstructure is moved to another similar hole, while the first hole is topped up with soil and a fruit tree planted in it. In this way, whole orchards of productive fruit trees are grown. The most commonly planted trees are avocados, paw-paws, mulberries, mangoes and guavas.

Sweden:

Sweden is probably the country with the most advanced system of collection and reuse of human urine, where it is practised by farmers on a large, mechanised scale. There are a number of settlements, called *eco-villages*, in the country, where the residents have ecological sanitation systems with urine diversion toilets. The urine from all the houses is collected in large underground tanks, and what the residents do not use themselves is collected by farmers in road tankers and used for fertilising their crops. The usual practice is to spray it onto the lands while they are being prepared for planting, and then harrow it into the soil before sowing the seed.

The country also has an agricultural research farm a short distance from Stockholm, where the Department of Agricultural Engineering of the Swedish University of Agricultural Sciences, Uppsala, has for a number of years been actively researching the plant uptake of urine fertiliser compared with conventional chemical fertilisers. The fields are divided into lots where various dilutions of urine are applied (see Figure 8.9), and cuttings from the growing plants are analysed in the laboratories to determine the uptake and utilisation of the various fertiliser constituents in the urine.

Figure 8.9: Part of the agricultural research farm near Stockholm. The fields are divided into lots for experimentation with various dilutions of urine. The crop being tested here is barley.

8.3 HEALTH ASPECTS OF EXCRETA REUSE

8.3.1 Transmission routes of pathogens

The health hazards associated with excreta reuse are of two kinds: the occupational hazard to those who handle the excreta, and the risk that contaminated products from reuse may subsequently infect humans or animals through consumption or handling (Feachem et al 1983).

The main pathogenic organisms of interest in sanitation are viruses, bacteria, protozoa and helminths (worms). There are a number of different varieties of all these organisms. In developing countries especially, excreta-related diseases are very common, and the excreta thus contain high concentrations of pathogens that cause diseases in man. Pathogenic organisms can enter the human body by a number of routes, as illustrated in Figure 2.1, Chapter 2.

The most important property of any sanitation system is the ability to break the cycle of transmission of these diseases. Obviously this depends as much, if not more, on human factors as on purely technical issues. Proper operation and maintenance of a sanitation system, as well as observance of good personal hygiene habits, are essential components of a healthy lifestyle. The reuse of human excreta for agricultural purposes must therefore, as far as possible, not expose people to the risk of infection. Sanitation systems designed for reuse of the excreta thus pose a special challenge to the engineer to design and develop technologies that will not pose unacceptable risks to public health.

8.3.2 Destruction of pathogens

(a) General

As the death or survival of excreted pathogens is an important factor influencing transmission, these organisms need to be either destroyed or otherwise rendered harmless. In principle, pathogens die off upon excretion, as environmental conditions outside the human host are generally not conducive to their survival. Prominent exceptions are pathogens whose transitional stages multiply in intermediate hosts, such as *Schistosoma*, which multiply in aquatic snails and are later released into the water body (Strauss and Blumenthal 1994). Also some viruses, although they cannot multiply outside a suitable host cell, may survive for many weeks in certain environments, especially where temperatures are cool (<15°C) (Feachem et al 1983). Another important factor is the *infective dose* of a pathogen, i.e. the dose required to create disease in a human host. For helminths, protozoa and viruses, the infective dose is low ($<10^2$), while for bacteria it is medium ($\pm10^4$) to high ($>10^6$). The manifestation of a disease is different for the various pathogens: with viruses, protozoa and bacteria, an infected person may or may not become sick, while with helminths an infected person will exhibit various degrees of disease intensities depending on the number of worms he carries in his intestines (Strauss and Blumenthal 1994).

According to Golueke (1976), environmental factors of importance in the die-off rate of pathogens are high temperatures, low moisture contents and time. A high temperature, especially, is the most important consideration, as all living organisms, from the simplest to the most complex, can survive at temperatures only up to a certain level. Above that level, they perish. Regarding moisture content, all biological activity comes to a halt at moisture contents of 12 % or less, although the process would be disastrously slowed long before that level was reached. Generally, moisture content begins to be a severely limiting factor when it drops below 35 to 40 %. Also, time *per se* does not kill the microorganisms; rather, it is the *continued exposure to an unfavourable condition* that does the job.

A further important factor is pH. While microorganisms will often grow over wide ranges of pH, there are limits to their tolerance. Drastic variations in pH can harm microorganisms by disrupting the plasma membrane or inhibiting the activity of enzymes. External nutrient molecules may also be negatively affected, thus reducing their availability to the organisms. The pH limits for the survival of *E. coli*, for example, are between 4,4 and 9,0, with the optimum between 6,0 and 7,0. In general, pH values greater than about 9,0 are detrimental to all microbial growth (Prescott, Harley and Klein 1990). This was clearly illustrated in the Eastern Cape pilot project, described in Chapter 9, where ash was sprinkled over the faeces in the toilets. Ash from wood fires generally has a pH of 10 or above, and the microbiological tests carried out on the desiccated faeces samples bear testimony to the large reduction in pathogenic organisms which took place as a result of an elevated pH.

(b) Urinary pathogens

While urinary excreted pathogens are of less concern for environmental transmission than are faecal pathogens (see Table 2.1, Chapter 2), there remains a possibility that faecal contamination can still enter the urine bowl of the pedestal. This usually happens where users are suffering from stomach disorders, when the faeces are watery and tend to spray on emission. Experiments in Sweden have established that six months of storage time for source-diverted urine is usually sufficient for the destruction of pathogenic organisms. However, this is also dependent on the temperature and dilution of the mixture – lower temperatures and higher dilutions tend to increase the survival time of the pathogens (Olsson 1996; Höglund et al 1998).

(c) Faecal pathogens

Desiccation of faeces maximises the destruction of enteric microorganisms. This greatly increases their value and manageability as an agricultural resource, both as a fertiliser and soil conditioner, as well as reducing pollutant burdens on the aquatic environment and health hazards associated with handling. Experimental data has confirmed that dry storage of faeces for a minimum period of one year usually results in a product of substantially improved microbiological quality (Wheeler and Carroll 1989).

The main factors influencing die-off over time are temperature, dryness and UV light (Strauss and Blumenthal 1994; Feachem et al 1983). Figure 8.10 shows the average survival periods of pathogens in untreated faecal sludges applied to fields in warm climates.

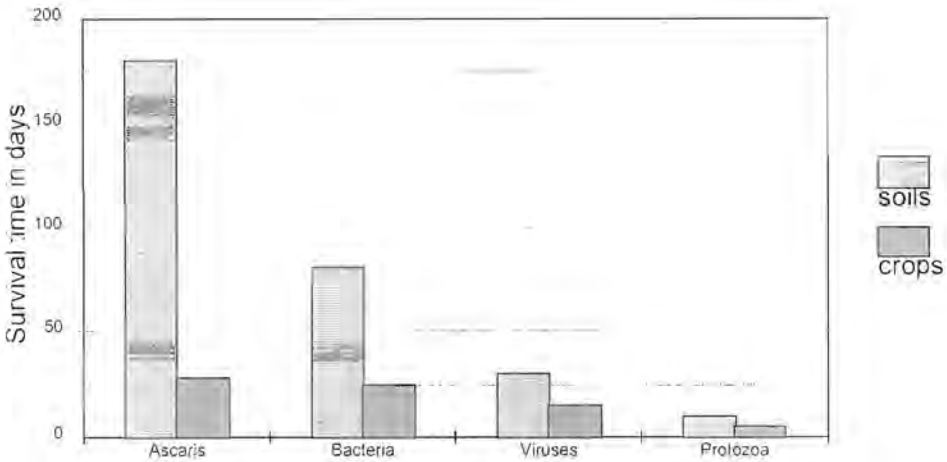

Figure 8.10: Survival times of pathogens in untreated faecal sludges applied to fields in warm climates (Strauss and Blumenthal 1994)

It is possible that the product from toilets with short retention times (less than one year) carries some potential risk. The risk in epidemiological terms would depend on the extent of exposure and susceptibility to the infection. If farmers handle the fertiliser with bare hands then, depending on hygiene practices, there is a potential for transmission of infection via the oral route. This could occur in the case of helminth infections, such as *Ascaris*. Where the fertiliser is used before or at the beginning of the growing cycle of an edible crop, and dug into the soil, there would be no risk to consumers of the crop. However, in cases where the fertiliser is used in a way that brings it into contact with the edible portion of the crop, then a risk of transmission of helminth infections could occur (Strauss and Blumenthal 1990).

Helminth ova are the most hardy of the pathogens of interest in faecal matter intended for handling and reuse. However, most evidence suggests that, provided storage exceeds one year, the number of even these pathogens is likely to be very low. Even the most persistent eggs, e.g. *Ascaris*, are usually rendered non-viable by storage after more than one year in sludge at moderate temperature, e.g. 25°C (Wheeler and Carroll 1989).

Feachem et al (1983) conducted an intensive investigation into the relationship between temperature and rate of die-off of various pathogenic organisms. According to this seminal study, there is a so-called "safe zone" which represents a combination of time and temperature above which no pathogens can survive (Figure 8.11). Various pathogens have different combinations of time and temperature which are destructive to them, the most hardy of all being *Ascaris*. These various combinations have been plotted on the figure, and the importance of the two parameters, namely time and temperature, is clear.

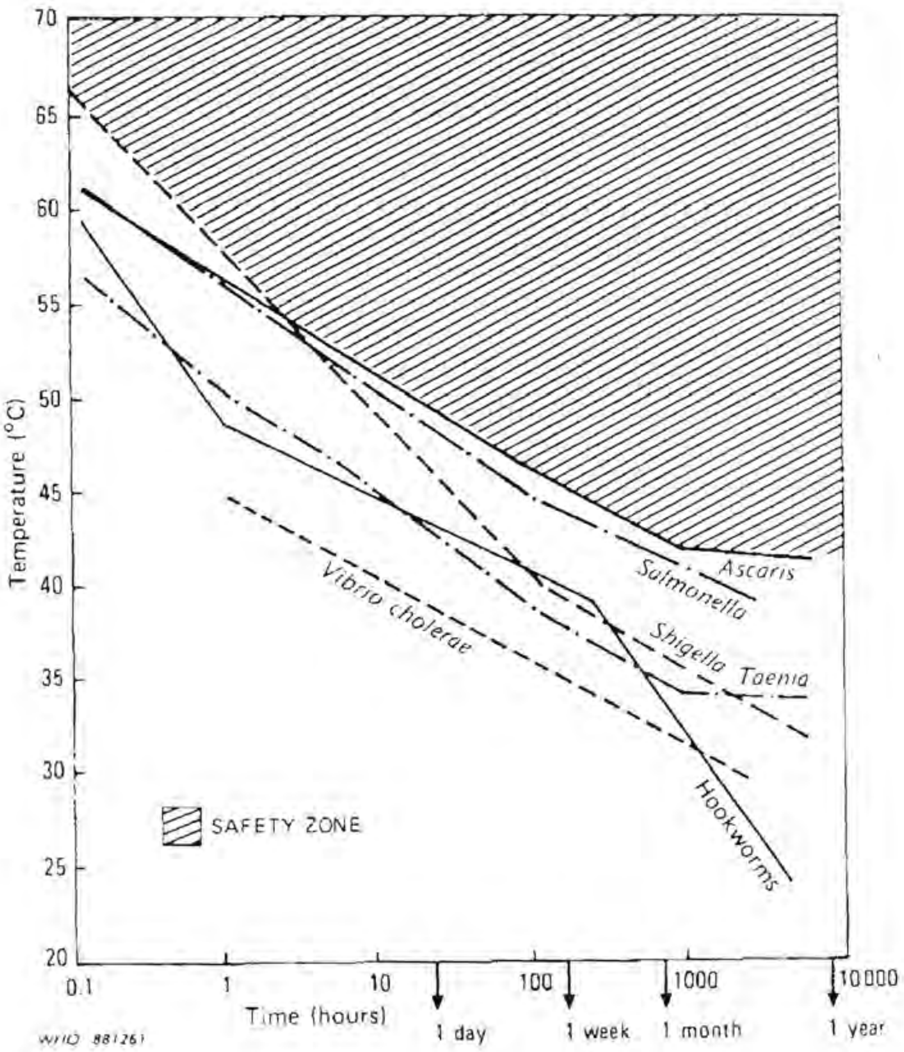

Figure 8.11: Survival times of various pathogens as a function of temperature
(Feachem et al 1983)

8.3.3 The human element (Feachem et al 1983)

It is difficult to predict how people will respond to technical innovations, because many factors enter into their choice. However, much can be gained by the planner's appreciation of the user's position and looking at innovations from the user's point of view. For the user, the toilet itself is a most important element in the excreta disposal system, and even a few minor disadvantages in its operation (for instance the need to physically remove the desiccated faeces from the waste compartment of a urine diversion toilet, no matter how simple the task) may be perceived reason enough to reject the proposed innovation. The willingness to reuse the excreta for agricultural purposes obviously plays an important role here.

It is widely accepted among agricultural and sanitation planners that reuse of human wastes is a desirable objective if it can be hygienically achieved. This conclusion brings experts into line with the large part of mankind that has always favoured reuse. In many parts of the world, however, the problem is not reuse, but how to persuade people that additional stages of treatment are sufficiently important for their health to warrant the increased time and expense that treatment requires. Proper education and hygiene awareness are thus essential parts of any strategy aimed at promoting excreta reuse.