HEALTH ASPECTS OF ECOLOGICAL SANITATION

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1. INTRODUCTION

Ecological sanitation (eco-san) regards human excreta as a resource to be recycled rather than as a waste to be disposed of. Recycling returns nutrients to soils and plants, reduces the need for chemical fertilisers and restores good soil organisms to protect plants (Esrey et al 1998).

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 (Wolgast 1993). However, 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). Assertions have been made that *human* fertilisers should be harvested and used to feed the following year's crops (Wolgast 1993).

Notwithstanding its merits, the reuse of human excreta for agricultural purposes should, 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 develop technologies that will not pose unacceptable risks to public health.

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 (Esrey et al 1998). Humans excrete approximately 7,5 kg of fertiliser each year, mainly nitrogen, phosphorus and potassium, which are sufficient to grow 230 kg of cereal (Wolgast 1993). Between 65 and 90% of these elements are found in the urine, and the fertilising effect of urine should thus be comparable to the application of the same amount of plant nutrients in the form of chemical fertilisers (Jönsson 1997).

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).

3. HEALTH ASPECTS OF EXCRETA REUSE: BRIEF LITERATURE OVERVIEW

3.1 Transmission routes of pathogens

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). 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 1. It should be noted that poor domestic and personal hygiene, indicated by routes involving food and hands, often diminishes or even negates any positive impact of improved excreta disposal on community health. Technology by itself cannot break the cycle of disease transmission and accompanying ill health if hygiene awareness in a community is at a low level.

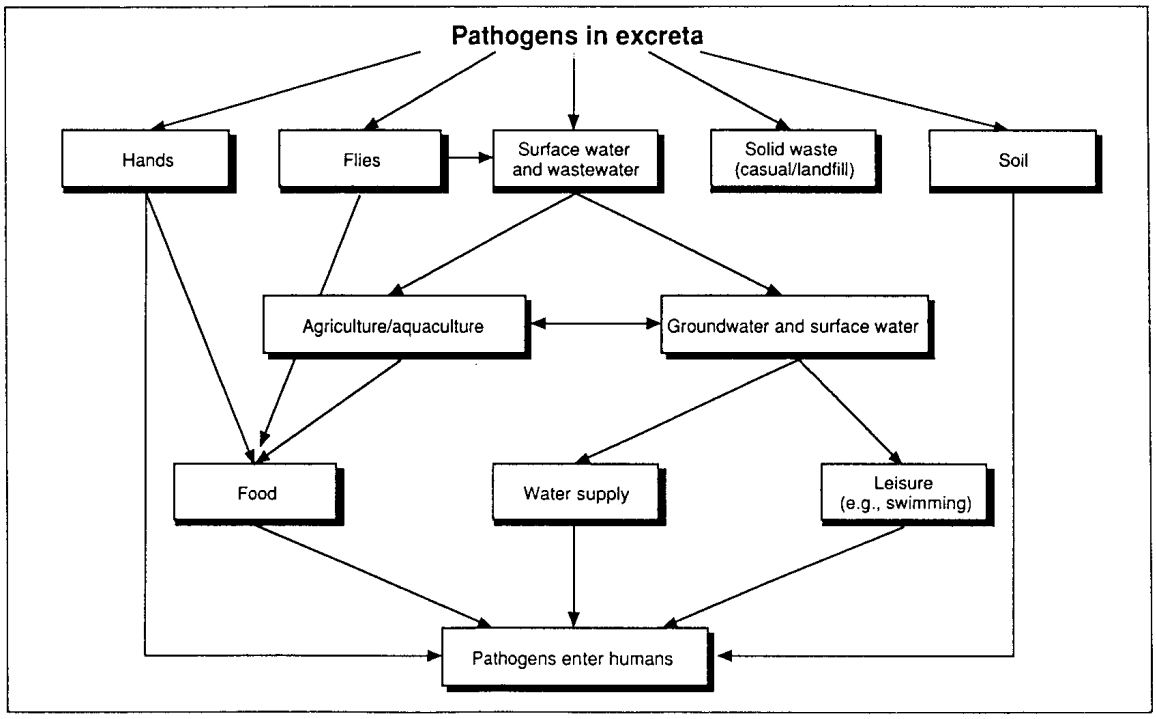

Figure 1: Transmission routes for pathogens found in excreta
(Franceys, Pickford and Reed 1992)

3.2 Destruction of pathogens

3.2.1 General

As the death or survival of excreted pathogens is an important factor influencing transmission, these organisms should be 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* (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^{o}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 ($\pm 10^4$) to high ($>10^6$).

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. 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).

3.2.2 Urinary pathogens

Urinary excreted pathogens are of less concern for environmental transmission than are faecal pathogens. Experiments in Sweden have established that, should faecal contamination of source-diverted urine occur, six months of storage time is probably 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).

3.2.3 Faecal pathogens

According to Wheeler and Carroll (1989), desiccation of faeces maximises the destruction of enteric microorganisms and reduces health hazards associated with handling. The authors further state that, according to experimental data, dry storage of faeces for a minimum period of one year usually results in a product of substantially improved microbiological quality.

The main factors influencing die-off over time are temperature, dryness and UV light (Strauss and Blumenthal 1994; Feachem et al 1983). Figure 2 shows the average survival periods of pathogens in untreated faecal sludges applied to fields in warm climates.

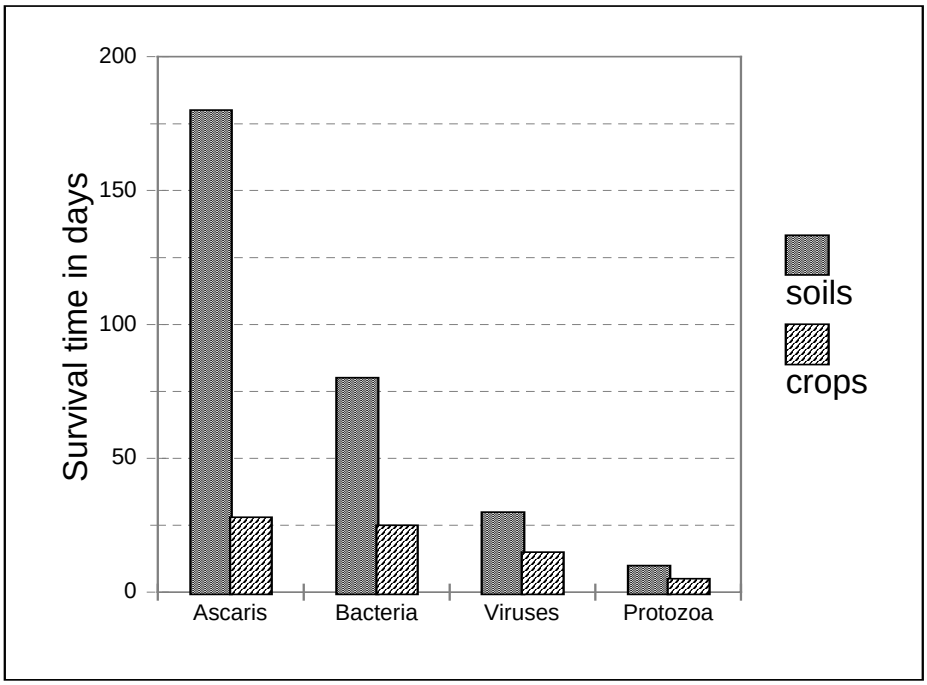

Figure 2: Survival times of pathogens in untreated faecal sludges applied to fields in warm climates (Strauss and Blumenthal 1994)

Helminth ova are the most hardy of the pathogens of interest in faecal matter intended for handling and reuse. However, according to Wheeler and Carroll (1989), provided storage exceeds one year, the number of even these pathogens is likely to be very low. The authors assert that 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^{o}C.

3.3 Current guidelines for wastewater and human excreta reuse

While extensive research has been carried out on reuse of faeces and faecally contaminated wastewater, and various guidelines developed over the years, reuse of dehydrated faeces has not been investigated to the same extent. Various rules of thumb regarding storage periods do exist, but there is a paucity of detailed scientific information on the subject. The following brief outline of existing guidelines serves as a background to the investigation carried out by the author.

3.3.1 Wastewater and sludge reuse

In 1989, the World Health Organization published guidelines for the use of treated wastewater in agriculture (WHO 1989). For unrestricted irrigation, the recommendations were as follows:

Intestinal nematode, e.g. *Ascaris* and *Trichuris* species and hookworms (arithmetic mean no. eggs per litre):	# 1
Faecal coliforms (geometric mean no. per 100 ml):	# 10^3

These recommendations were also supported at the time by an IRCWD report (Strauss and

Blumenthal 1990). The authors additionally interpreted these guidelines as including wastewater sludges, i.e:

Intestinal nematode
(arithmetic mean no. eggs per kg (1000 g) wet weight): # 1

Faecal coliforms
(geometric mean no. per 100 g wet weight): # 10^3

Heinss, Larmie and Strauss (1998) suggested that wet weight was not a good basis of measurement due to the varying quantities of solids present in sludges and slurries, and stated that permissible solids loading rates should be used instead. Consequently, these authors recommended that the guideline for nematode eggs should be

3 – 8 eggs per gram total solids (TS), based on a solids loading rate of 2 – 3 t/ha/yr.

A more recent study published by WELL (Blumenthal et al 2000) suggested that the WHO faecal coliform (FC) value of #10^3 per 100 ml was applicable to both unrestricted and restricted irrigation, and could be relaxed to #10^4 per 100 ml where insufficient resources existed to achieve this, as long as additional protective measures were taken. The WELL study further suggested that the nematode egg guideline of #1 egg per litre was still adequate to protect consumers of cultivated vegetables spray-irrigated with effluent of consistent quality and at high temperatures, but not necessarily consumers of vegetables surface-irrigated with effluent at lower temperatures. It was concluded that a guideline of #1 nematode egg per litre may be adequate where crops with a short shelf life are grown (e.g. salad crops), but that a stricter guideline of #0,1 eggs per litre should be adopted to prevent transmission of *Ascaris* infection.

In South Africa, guidelines for unrestricted use of sewage sludge are as follows (Water Research Commission 1997):

Viable *Ascaris* ova (per 10 g dry sludge): 0

Salmonella organisms (per 10 g dry sludge): 0

Faecal coliforms (per 10 g dry sludge): 10^3

Further restrictions are that the maximum application rate should not exceed 8 t/ha/yr (0,8 kg/m^2/yr), and that the soil pH should preferably be higher than 6,5.

3.3.2 Dehydrated faeces reuse

Strauss and Blumenthal (1990) report some observations made from limited data obtained from double vault urine diversion toilets in Guatemala. While die-off of bacterial pathogens was found to be high at elevated pH, it was seen that *Ascaris* eggs were very resistant - even after

storage for one year at temperatures of 17-20°C they were still found to average about 300 eggs per gram. The authors inferred that a one-year storage period is not enough to achieve low or zero egg viability within the vault at temperatures of 17-20°C, even though the toilet contents are dry and pH is high relative to the contents in other types of toilets.

In contrast to minimum storage periods of as little as six months that are actually implemented in some countries, Strauss and Blumenthal (1990) suggested the following:

	Storage condition	Vault storage period required	
		Without subsequent sun-drying	With subsequent sun-drying
X	at 17-20°C average (highland, subtropical):	18 months	12 months
X	at 28-30°C average (lowland, tropical):	10-12 months	8-10 months

The authors further concluded that there is no single best strategy for health protection and that each situation requires its own specific approach. Other health protection measures, e.g. crop restriction or human exposure control, should also be considered.

4. SPECIFIC ASPECTS INVESTIGATED

During 1998, the author conducted experiments on faecal matter extracted from various urine diversion toilets at an existing project in Eastern Cape province, South Africa. Toilet users sprinkled wood ash over the faeces after each defecation and, with a few exceptions, operated and maintained the toilets well. Faeces were deposited and stored in plastic containers inside the vault. After 10 months separate storage, samples of faeces were extracted and tested. Thereafter one of these samples was sun-dried for three weeks and re-tested. It was then stored at room temperature for a further period of twelve months and tested again, following which it was mixed with topsoil in a pot and re-hydrated with sterile water for six days, then tested once more. Climatic conditions varied from hot to cold over the period.

Table 1 shows the results (note: *Ascaris* was generally absent and is therefore not listed):

Table 1: Faeces from various urine diversion toilets

(Note: + indicates “present”)

Total coliforms (per gram)	Faecal coliforms (per gram)	Faecal streptococci (per gram)	Sal-monella	Clos-tridia	Coliphages (per gram)	% moist	pH

Set 1: Faeces after 10 months storage

10^2 - 10^6	10^2 - 10^6	10^2 - 10^5	+	+	0 - 10^3	4 - 40	8,6 - 9,4

Set 2: Faeces after further sun-drying for 3 weeks

3,8 x 10^5	3,1 x 10^2	1,1 x 10^6	+	+	5	1,4	

Set 3: After additional storage at room temperature for a further 12 months

0	0	5,4 x 10^4	-	1,0 x 10^3	5	0,8	

Set 4: Garden soil

1,9 x 10^2	1,4 x 10^2	5,5 x 10^3	+	0	5	18,4	

Set 5: Mix of sets 3 and 4; re-hydrated for 6 days

3,1 x 10^6	9,9 x 10^4	1,3 x 10^5	+	85	-	100	

During 2001, in an attempt to obtain more clarity on pathogen die-off in urine diversion toilets operating under different conditions, the author conducted further experimentation. Four well-maintained urine diversion toilets were selected for this purpose. Two of the families continued using plastic containers to collect the faeces, while the other two deposited them on the concrete floor of the vault and turned the heap over once a week to aerate it. After only two months of mild to cold conditions, the toilets with heaps showed markedly better results in all parameters:

Table 2: Faeces from selected urine diversion toilets; faeces heap - turned weekly

Total coliforms (per gram)	Faecal coliforms (per gram)	Faecal streptococci (per gram)	Sal-monella	Clos-tridia	Coliphages (per gram)	% moist	pH
5,8 – 6,6 x 10^2	5,1 – 5,9 x 10^2	1,0 – 5,8 x 10^2	-	1,1-1,7 x 10^2	0	4,1 - 8,9	8,4 - 8,6

In a further attempt to establish the resistance of certain organisms, some samples were subjected to a temperature of 50°C for 48 hours, while keeping the moisture content

approximately the same as before.

Table 3: Faeces subjected to 50°C for 48 hours at original moisture content

Total coliforms (per gram)	Faecal coliforms (per gram)	Faecal streptococci (per gram)	Sal-monella	Clos-tridia	Coliphages (per gram)
0	0	50	-	$2,3 \times 10^2$	0

5. CONCLUSIONS

The experimental programme described above revealed that it is inappropriate to generalise matters such as storage periods required to ensure sufficient pathogen die-off. These will differ with users' health status, climate, operational factors, etc. However, the following remarks can be regarded as being applicable to most urine diversion systems and reuse of their faecal products.

1. Wood ash is a good additive due to its relatively high pH, which assists pathogen die-off. It also virtually eliminates odour and flies, and the toilet is therefore more hygienic.

2. Faeces are likely to dehydrate better, thus assisting pathogen die-off, if they are collected and stored in a heap and turned occasionally, rather than in a closed container or compartment. This has construction as well as operational implications.

3. Faecal coliforms, which include pathogenic bacteria, may be present in large numbers (orders of magnitude in excess of current guidelines) up to a year after defecation, and possibly longer, even with low moisture contents.

4. The vast resistance of faecal streptococci towards unfavourable environmental conditions is evident. These organisms are indicative of decaying faecal matter.

5. Salmonella, a bacterium present in faecal matter, can result in severe gastro-enteritis. These organisms are seen to be relatively hardy; however, they can also be found in bird droppings, and are therefore often present in ordinary soil.

6. Sunlight (UV radiation) is a good destroyer of pathogens.

7. Re-hydration of dry faecal matter can result in many organisms becoming viable again.

It is widely accepted among agricultural and sanitation planners that reuse of human wastes is a desirable objective if it can be hygienically achieved. 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 (Feachem et al 1983).

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