Possibilities and impossibilities of the use of human excreta as fertilizer in agriculture in sub-Sahara Africa

A literature review

Draft, not to be quoted

Lies Timmer and Cinty Visker

February 1998

Collaborative study financed by the Royal Tropical Institute (KIT) and the University of Amsterdam (UvA)

Executive abstract

In sub-Sahara Africa, food security at household level is increasingly endangered as a result of decreasing soil fertility. The agricultural sector has to comply with intensifying demands for agricultural commodities by an ever-increasing population. In addition, to feed the growing urban population, and to comply with the increasing intercontinental trade, more agricultural produce is leaving the agricultural system. Nutrient cycles are becoming exceedingly unbalanced, and also change into nutrient flows. The use of mineral and organic fertilisers has been too low to close the nutrient gap. In the majority of Asian countries, the use of human excreta (faeces and urine) as fertiliser is a very ancient practice. The African history of land abundance, shifting cultivation and lack of population pressure have led to the development of agricultural practices in which nutrient re-usage is rarely maximised. However, in sub-Sahara Africa, human excreta have great potential to improve soil fertility levels: its production is about 27 million tonnes annually.

Human excreta are a rich organic fertiliser. Their fertilising potential is greater than animal wastes. Long-term benefits of the use of human faeces are improvement of the soil's organic and humus fraction, the maintenance of moisture and air regulation, and the increase in nutrient storage and release. The production and chemical composition of human compost are influenced by diet, activity, age, sexe, social status and anal cleansing methods. Faeces production ranges from 100-520 gr/day (wet weight) and urine production ranges from 1-1.5 l/day. Faeces consists of 4.8-7% N, 3.0-5.4 % P_2O_5 and 1.0-2.5 % K_2O. Urine consists of 15.0-19.2 % N, 2.5-5.0 % P_2O_5 and 3.0-4.5 % K_2O.

During the International Drinking Water Supply and Sanitation Decade (1981-1990), many sanitation facilities were built, often without paying much attention to their sustainability. Reduced possibilities to maintain and empty facilities are current problems faced by sanitation programs. At the same time, the waste management sector deals with ever-increasing amounts of waste, for which only few cities are prepared. The principal organic waste produced in urban areas is sewage.

In sub-Saharan Africa, the agricultural, sanitation and waste management sectors have been operating in isolation. Consequently, the sanitation and waste management sector form a permanent drain of nutrients from the agricultural systems. Integration of these sectors means that organic material, which is already available, can be used as fertiliser, providing an opportunity for the agricultural sector. Also the sanitation sector benefits, because excreta become a valuable source, and people will be motivated to empty, use, and maintain sanitary facilities. The waste management sector benefits, because a permanent solution for the human excreta is provided, reducing the quantities of waste.

Cultural values and beliefs concerning the collection, disposal and use of human faeces are very diverse and can crucially affect the acceptance of collection, disposal and use practices.

Hinduism and islam forbid contact with human excreta, but in practice, the interpretation of religious laws and the impact on disposal and use practices is highly variable. Chinese folk religion stresses that man communes with nature, and therefore encourages the use of human excreta as fertiliser. Muslims and hindus are less opposed to composted or diluted excreta than to fresh excreta.

In many societies, human excreta collection is seen as employment of low status. Collectors either belong to a low caste, or they become persons to be avoided because of their occupation. However, the profession may be in strong demand if alternative sources of employment for people of inferior status are unavailable. The status of excreta removers is higher in societies where human excreta are commonly used, or where much importance is attached to hygiene.

Gender issues should be considered in the planning of sanitation or composting programs, because women often are the controllers and purveyors in local learning systems related to water, health, and sanitation. Additionally, the location of compost pits and sanitary facilities should be in accordance with local customs. Women may be secluded in their compounds, while they often are expected to clean sanitary facilities and to carry refuse to compost pits. These activities may also be an uninvited aggravation of women's workload.

To achieve a high degree of use of sanitary facilities, location and privacy of facilities and access to facilities should meet local conventions. Comfort, e.g. washing facilities, appear to be an incentive to use, while bad maintenance and cleaning form a constraint. New conventions are created in crowded urban environments, where the bush becomes inaccessible and people are urged to use latrines.

The commercial value of excreta may be an incentive to private sector activities such as collecting and selling of excreta. In this setting, commercial organisations selling excreta can provide for public sanitary facilities, while these are often provided and subsidised by public authorities in societies where excreta have no commercial value. Financial benefits of use of human excreta in agriculture may form an incentive to its effective use as fertiliser.

Apart from subsidizing, authorities play a major role in promotion and control of sanitation programs and in the legislation of use of human excreta. However, authorities can not enforce the proper functioning of excreta disposal systems if these are not suited to the environmental conditions, or if the public is not behind the policies of the authorities. Authorities may have to assume didactic roles in situations in which traditional understanding and practice strongly contradicts modern interpretations of health and disease. They also play a role in creating equity, directing sanitation to the poor, and improving the status of people handling excreta.

Excreta carry many pathogenic microorganisms, among which viruses, bacteria, protozoa and helminths, depending on the diseases endemic in the society. Infection of human hosts takes place in various ways. Excreta related diseases account for 10-25 % of illnesses that reach the health care services in developing countries, and cause a vast amount of misery that goes unreported. Health risks from microorganisms are a function of hazard and exposure, and can best be determined by direct measurement or monitoring of ambient conditions. Faecal contamination is universally determined by the use of faecal indicator bacteria, but their usefulness is doubtful.

All pathogens will lose infectivity or eventually die after excretion and release into the extra-host environment, depending on particular environmental factors. Factors determining pathogen survival in excreta in disposal facilities differ per type of facility. In most facilities, retention time, temperature, and amount of water determine pathogen survival. Pathogen survival in soils depends on pathogen type, climate, soil environment, and plant cover. Pathogen survival on crops further depends on pathogen type, crop type and method of application. Crops can be protected by irrigation after waste application, by application of the waste before planting, or by discontinuing waste application before harvesting. However, these protection methods will not be sufficient, especially if raw waste, rich in pathogens, is used.

Safe use of human excreta, which means exclusion of disease transmission, requires that excreta are treated in a way that reduces the amount of pathogens to very low numbers. The feasibility of treatment methods depends on the type of community and institutional environment, cultural values regarding excreta, handling patterns of excreta, and economical and technical constraints to treatment. Treatment methods which are considered to have a reasonable good chance of success in tropical countries are thermophilic composting, in which high temperatures are the main factor contributing to pathogen inactivation, and stabilization ponds, in which long retention time is the main factor contributing to pathogen inactivation.
The composting of faeces additionally reduces its volume, facilitates handling and enhances nutrient concentration. During composting, the organic matter in excreta stabilises. When compared to fresh organic fertiliser, compost acts slower as fertiliser. The composting of faeces leads to the loss of considerable amounts of nitrogen, unless precautions are taken.

Urine needs not to be treated before agricultural use, as it is generally sterile. After excretion of urine from the human body, considerable amounts of nitrogen are lost, unless precautions are taken.

The soil can be choked and damaged if its capacity to absorb and retain water, its capacity to maintain water and air housekeeping balanced, and the needs and limitations of soil organisms are lost out of sight.
The proportion of waste discharge to waste application should be in balance with the soil's assimilation rate. Municipal sewage may contain high concentrations of heavy metals which prove toxic to plants, which makes it unsuitable for land application.

Human faeces produces very little humus and urine produces none. Therefore, they should not be used as a basal dressing or the main fertilizer, because the valuable nutrients would be wasted and the soil would become aggregated and compacted. Composted human faeces and urine contain a very high percentage of nitrogen. The application of large amounts can cause crops to overgrow and produce underdeveloped grains, and, moreover, the extra amounts are used by weeds or are washed away. Therefore, they should only be used for dressing application and on crops with high market value.

The use of human excreta in agriculture is influenced by institutional organisational, demographic, political, economical, financial, socio-cultural, technical, medical and environmental factors, which apply for the agricultural, sanitation and waste management sector. These factors from either constraints or opportunities to the use of human excreta.

Increased demands for agricultural products, decreasing soil fertility levels, increasing prices for mineral fertiliser and increased poverty are an incentive to use of human excreta a fertiliser in agriculture. Another incentive to the use of waste, among which human excreta, is the increased demand for employment in a situation of increasing poverty. New conventions to use and empty sanitary facilities are created in crowded urban environments, in which space is scarce and access to the bush is limited. Furthermore, new policies in the sanitation and the waste management sectors claim that sustainability of these sectors demands their being part of a lang term planning, including a.o. agriculture, opening possibilities for human excreta use.

Literature on sub-Sahara Africa is not complete and not current enough to make a definite statement on the possibilities for the use of human excreta as fertiliser. A diagnostic research, considering all factors and the opinions of all stakeholders in the agricultural, sanitation and waste management sector, is necessary to understand possibilities of the use of human excreta as fertiliser in agriculture in sub-Sahara Africa.

Acknowledgements
We are grateful to the Royal Tropical Institute (KIT) for financing our activities and for offering the facilities that enabled us to conduct the literature study. We would also like to thank the University of Amsterdam (UvA) for making available supplementary funding. We thank the Working Group, consisting of KIT, UvA, Waste, IRC and LEI-DLO for their support.

Contents

1 Introduction

Ever-creasing population pressure in sub-Saharan Africa are intensifying the demands for agricultural commodities. Recent studies have pointed out that, because of the higher demands, sub-Sahara Africa is mining its soil nutrient reserves. Nutrient output is increasingly exceeding nutrient input, apparently even in agricultural systems that aim at food self-sufficiency. The resulting negative nutrient balances are rendering agricultural systems unsustainable, lowering agricultural productivity and endangering food security (Pieri, 1983, Stoorvogel and Smaling, 1990, van Keulen and Breman, 1990, van der Pol, 1992).

Also natural nutrient cycles are becoming exceedingly unbalanced. Because rural agriculture is serving an increased and more urbanised population, more agricultural produce is leaving the rural agricultural system (Agboola and Kintomo, 1995). The movements of the agricultural commodities are further increased with improvements in transportation systems and increased demand for exotic products. Intercontinental trade of agricultural products leads to the loss of nutrients from the agricultural systems that exports them (Cooke, 1988). Nutrient cycles are changing into nutrient flows (Noordwijk and Nijsten, 1984), creating a different spatial nutrient distribution over an expanded geographical area.

During the past several years, much attention was given to understand and quantify the cycling of nutrients (Smaling et al, 1996; Smaling and Fresco, 1993).

The use of mineral fertilizers in sub-Sahara Africa has been too low to close the nutrient gap (Mokwunye et al, 1996). Attention has recently become focused on integrated nutrient management, in which the use of organic sources of nutrients to complement inorganic fertilizers is emphasized (Dudal and Roy, 1993).

There is considerable scope to improve the exploitation of crop residues, animal manures and organic wastes from other sources for the maintenance of soil fertility. In sub-Sahara Africa, about 102 million tonnes of refuse are generated annually. The human excreta potential is about 27 million tonnes annually. Large amounts of animal waste can be recycled. Presently, compost and farmyard manure are not being used widely and effectively (Agboola and Kintomo, 1995).

The extent to which a farm household adopts integrated nutrient management determines not just whether high farm output can be realised, but also whether production can remain high in the long run (Smaling et al, 1996).

Human excreta (faeces and urine) stands at the end of the human consumption chain of agricultural commodities. In nutrient cycling balances human wastes have often been a factor that has been ignored, if not systematically forgotten (Budelman, 1997).

Although the human body wastes have greater fertilising potential than animal wastes, this potential is tapped seriously in only a very few countries (Hesse, 1984).

Most practice and experience with the use of human excreta in agricultural systems in developing countries is found in the Far-East countries, e.g., India, China, Japan, Korea, Nepal, Vietnam and Thailand (Cross, 1985). Over 90% of the national night soil production in China is, after treatment, applied to the land and this represents fully one third of all nutrients actually used by the crops (Galle, 1979).

In Africa, a history of land abundance, shifting cultivation and lack of population pressure have led to the development of agricultural practices in much of Africa in which nutrient re-usage is rarely maximised. There is no tradition in the use of human excreta in agriculture or aquaculture in Africa. Many societies do practice agricultural composting and fertilising but there appears little evidence of faeces traditionally being added. Aquaculture practice is in itself limited, though reportedly growing in Africa, but again there is no record of use of human faeces in pond fertilisation (FAO, 1975, quoted in Cross, 1985). Domestic animal (principally pigs and dogs) commonly feed upon human excreta in many African cultures (see for example Ouma and Van Ginneken, 1980).

The use of human excreta in agriculture involves the sanitation and waste management sector as well. Since the launching of the Water and Sanitation Decade (1981-1990), the coverage of sanitation facilities has increased (WHO, 1989). Depending on, amongst others, the type of sanitation facilities, human excreta disappear into the waste management sector. Reuse of human excreta has never been part of the planning of the sanitation sector (Cairncross, 1992) or waste management sector (Lardinois and van de Klundert, 1993). This means that present waste management and sanitation practices form a permanent drain of nutrients from agricultural systems (WHO, 1994).

A working group was initiated in the Netherlands to explore possibilities and impossibilities of the use of human excreta as fertiliser in agricultural systems in sub-Sahara Africa. The working group consists of the following organisations: the Royal Tropical Institute (KIT), the University of Amsterdam (UvA), the International Water and Sanitation Centre (IRC), the consultancy bureau Waste and the Agricultural Economic Institute (LEI-DLO). The working group is preparing a research project that aims to contribute to understanding of actors and factors involved in the use of human excreta as a fertiliser in agricultural systems in sub-Sahara Africa. Furthermore, the project aims to contribute to increased sustainability and productivity of agricultural systems through the use of human excreta as fertiliser in agriculture. This literature study is a part of the preparation phase of the research project and aims to provide insight in constraining factors and incentives for the introduction of human excreta as a fertiliser in agricultural systems in sub-Sahara Africa.

Chapter 2 describes the potential of organic fertilisers in general, and human excreta in particular, as fertiliser. Chapter 3 describes mutual benefits of an integration of the agricultural, sanitation and waste sectors. Chapter 4 describes socio-cultural, economical and political factors influencing the use of human excreta. Chapter 5 describes pathogens present in human excreta. Chapter 6 describes the survival of pathogens.
Chapter 7 describes how to treat human excreta in order to make it safe to use. Chapter 8 describes how fertilizer quality can be influenced by storage and treatment methods. Chapter 9 describes how human excreta can be applied to the field. Chapter 10 is the conclusion and discussion.

2 Contribution of human excreta to soil fertility

Human excreta in nutrient cycles

From the total amount of nutrients that are taken up by cereals, 60% of the N and P, and 15% of the K can be found in the harvested (consumable) parts (Van der Pol, 1992). Relatively much of the N and P and practically all of the K is excreted by the human body (Cooke, 1988).

In India, the amount of human excreta is only 15% of the total amount of animal (cattle, sheep, goats, pigs, chicken) and human excreta. However, the nutrients in human excreta account for 50% of the total nitrogen, 39% of the total phosphorus and 27% of the total potassium. The percentages for cattle were respectively 32% for N, 40% for P and 50% for K. Average nutrient contents in human excreta are ten times higher than those in cattle excreta (Gaur et al, 1984).

The total amount of nutrients in annually produced human excreta in sub-Sahara Africa is estimated to be 2.2 million tons of N, 0.5 million ton of P_2O_5, and 0.4 million ton of K_2O. These amounts are comparable to the amount of mineral fertilisers used in 1983/1984 (Cooke, 1988).

Benefits of the use of human excreta to the soil

Nutrients in nightsoil are more easily available to plants than nutrients in cattle manure or composted plant residues. This is probably due to the relatively high content of mineralized nitrogen contained in nightsoil (Cross and Strauss, 1985).

The value of excreta as nitrogen supplier is reflected in the C:N ratio, which is low in nightsoil (≤ 2 if urine is stored together with faeces) and faeces (6-8), compared to low-urine cow manure (12-17) and plant residues (30-40) (Cross and Strauss, 1985).

The amounts of N, P and K in human excreta are illustrated by the following examples.
A family of 4-5 members can collect 180-220 kg excreta per year in which there are 3 kg N, 2 kg P and 0.8 kg K (these amount are equivalent to 15 kg ammonium sulphate, or 6 kg urea, 10 kg of superphosphate, and 1.6 kg of potassium (excluding fillers). Each family can collect nearly 1 tonne of urine, in which there are approximately 10 kg N, 1.2 kg P and 1.6 kg K-nutrient (these amounts are equivalent to 20 kg of urea, 6 kg of superphosphate, and 3.2 kg of potassium sulphate (Polprasert et al, 1981).
A family of 5 adults can provide sufficient nitrogen and phosphorus to cultivate a rice plot ranging in area from $1600m^2$ to $2000\ m^2$. For maize, the area would be 20-30% smaller, while for soya beans it would be 25-50% larger (Strauss, 1990).

Night soil, like other organic fertilizers, has also long-term beneficial effects on the soil: it amends the soil's organic and humus fraction, an advantage not offered by mineral fertilizers. Humus, in turn, helps to maintain soil characteristics as moisture and air regulation as well as nutrient storage and release (Strauss and Cross, 1985).

Besides N, P and K, organic manures supply the soil with micronutrients such as B, Zn, Cu, Mo, Ca, Si, thus preventing micronutrient deficiencies in spite of the long history of cultivation (Wen, 1984).

Production and chemical composition of human excreta
There are several factors that influence the production and chemical composition of human manure (excreta and urine), e.g., diet, activity, age, sexe, social status. The composition and quantities of the night soil are also influenced by anal cleansing methods. When solid material, such as grass, stones, clay balls, coconut husk, corn cobs etc, are used, the specific excreta volume is increased by some 50% over that obtained when using water for this purpose (Riedijk, 1982).

Vegetarians generally have higher faecal weights than other groups, and faecal weights in rural areas are higher than in towns. Children, adolescents an the elderly produce lower faecal weights than others (Feachem et al., 1983). Generally speaking men produce greater amounts of faeces and urine than women and the quantity of nutrients in adult faeces is greater than in the faeces of children. The contents of N-nutrient and P-nutrient in male faeces are lower than those in female faeces, but the contents of N- and P- nutrients are higher in male urine than in female urine (Polprasert et al, 1981). The water content of faeces varies with the faecal weight. As the faecal weight increases so does the water content (Feachem et al, 1983).

Appendix 1 presents detailed information on the daily production and composition of human excreta and urine per person according to several authors. Data on production of faeces range between 100 and 520 gr/day (wet weight). Data on production of urine range between 1.0 and 1.5 l/day.
The percentages of nutrients in faeces range between:

- 4.8 % and 7 % N
- 3.0 % and 5.4 % P_2O_5
- 1.0 % and 2.5 % K_2O.

The percentages of nutrients in urine range between:

- 15.0 % and 19.2 % N
- 2.5 % and 5.0 % P_2O_5
- 3.0 % and 4.5 % K_2O.

3 Interface between use of human excreta as fertiliser in the agricultural sector, the sanitation sector and the waste management sector

Challenges in the sanitation sector

In 1980, the United Nations launched the International Drinking Water Supply and Sanitation Decade (1981-1990). Improved health was the primary motivation herein. On the sanitation side, improved health could technically be achieved by isolating urine and faeces so that the infectious agents could not reach the new host (WHO, 1992). One of the main objectives of the Decade was to have adequate excreta disposal facilities available to everyone by the year 1990. A dramatic increase in the rate of construction of sanitation facilities, especially in rural areas, was needed to achieve the goal (WHO, 1989). For the disposal of human waste, different sanitation systems are in use, ranging from dry to waster-borne systems. The choice for a particular system is based on:

- environmental conditions
- socio-cultural aspects
- infrastructural aspects
- financial capabilities of target groups
- management requirements for operation and maintenance (Van Buuren et al, 1997)

A publication at the end of the Decade states that in Africa, 5% of the population is connected to a sewerage system. The coverage of pit latrines, which form the basis for the low cost sanitation in rural areas, is around 35% (WHO, 1989).

Sanitation facilities were built with a short term view, and little attention was paid to their sustainability (Pacey, 1978). Maintenance should be one of the fundamental considerations, when choosing sanitation technology, particularly for rural communities where technical and institutional resources are limited. But many sanitation planners embark on programs without a clear policy, or at least without a proven strategy, of what to do when pits need to be emptied or latrines replaced (Cairncross, 1992). Many systems which could serve the needs of the future rely on emptying as a regular, if not frequent, operation (Pacey, 1978). Without proper attention paid to cleaning and emptying provisions, the sanitation facilities are not sustainable, and more seriously, fouled, full and unused latrines become health hazards in themselves (Feachem et al, 1983). The necessity of emptying the facilities also grows when space for new facilities is becoming less available.

Health benefits from the sanitation facilities will not be fully realized unless sanitation programs achieve a high degree of coverage and a high degree of use. This demands a great commitment of households in all phases of the sanitation program: design, construction and use (Cairncross, 1992). Strategies for water supply and sanitation programs have been traditionally based on, among others, the ability and willingness of rural households to pay for services (Mancy, 1993). Willingness of people to pay for water and sanitation services seems a crucial factor in the adoption of different sanitation practices. Without their willing cooperation any program is doomed to fail (Cairncross, 1992). The willingness depends largely on the perception of the value and benefits of these services (Mancy, 1993).

The principal challenges for the 90's are not the technical know-how, which has improved substantially during the decade, but the organisation and financing of water and sanitation programs and the training, organisation and motivation of people to install, use and maintain sanitary facilities. Recently it has become recognised that the sustainability of sanitation programs demands their being part of a long term, overall health, community welfare, and socio-economic planning, including environment, agriculture and education (Cairncross, 1992).

Problems in the waste sector

Population growth, its concentration in towns and cities, and higher living standards have led to a substantial increase in the quantity and diversity of waste products, particularly municipal solid wastes and sewage sludges (Ayuso et al, 1996). The composition of waste differs considerably and is determined by social customs and living standards (Arinola and Arinola, 1995).

Urban waste can be divided in two major streams: sewage sludge and solid waste or garbage (Parr and Hornick, 1993). The principal organic waste produced in urban areas is sewage (Hesse, 1984). Literature data of urban solid waste in economically less developed countries state that 40-85% is organic (Lardinois and van de Klundert, 1993). Domestic and commercial sources (restaurants, hotels, markets, shops) are responsible for the major part of the urban waste, that originates from the consumption of agricultural commodities (Parr and Hornick, 1993).

Few cities are prepared for the increasing amounts of waste. They lack the facilities to handle the increasing volumes adequately. Waste and waste management are becoming one of the most serious and still growing environmental problems in the world (Conradi et al, 1996).

Waste is often disposed of without thinking of its inherent value (Lardinois and Van de Klundert, 1993). The major part is dumped in rivers and streams or on refuse dumps. Nutrient cycling in urban areas is very inefficient. Virtually nothing is recycled except in some compound farms and home gardens in the lower density areas of urban centers where domestic animals such as sheep, goats, donkeys, horses and poultry are kept (Agboola and Kintomo, 1995). The ideas concerning the value of wastes, however, are changing (Nagelhout et al, 1989). Factors, such as poverty, increasing prices for fertilisers and decreasing soil fertility level are changing the ideas about the value of waste (Owusu-Bennoah and Visker, 1993, Lardinois and van de Klundert, 1993).

Monitoring current practices in disposal provides insight into part of the system of nutrient cycles. Monitoring disposal practices also provides insight into factors determining the possibilities for recovery and re-use of the nutrients within the wastes. Disposal systems and consequently possibilities for the recovery of wastes are affected by:

- technical factors (e.g., ways of disposal, techniques of recovery);
- economical factors (e.g., costs of collection, costs of recovery, market possibilities);
- social factors (e.g., acceptability of recovery);
- political factors (e.g., involvement of informal sector, legislation in waste management, re-use of the product).

Integration of the agricultural sector, the sanitation sector and the waste management sector
So far, the sanitation sector and the waste management sector have been operating in isolation from the agricultural sector. Present sanitation practices, which often imply isolation of excreta, form a permanent drain of nutrients from agricultural systems (WHO, 1994). Integration of these sectors could give a new impetus to some of the challenges and problems faced in all sectors.

Agriculture takes advantage of the waste problems by efficiently recycling the nutrients in excreta from sanitary facilities and using it as a fertiliser in agricultural systems. The maximum reutilization of excreta is important to the maintenance and improvement of soil fertility and to the reduction of agricultural costs (Wen, 1984).

The sanitation sector will be given a new impetus if excreta are used in agriculture, because excreta will be no longer considered a cause of nuisance to be abated, but rather a valuable source (Mancy, 1993). Emptying of, investment in and willingness-to-pay for sanitary facilities will be seen in a different light. Selling of human compost can partly pay off investments in sanitary facilities (Mancy, 1993). Furthermore, the indiscriminate discharge of human waste into the environment causes disease (Edwards, 1992). Thus apart from supporting economic activities and food production, agriculture is also directing curative health care towards preventive health care.

The waste management sector benefits from an integration with the agricultural sector, because recycling of excreta effectively reduces waste management problems: agriculture has a great renewed opportunity in being not only the food supplier for the whole society, but also the waste collector and receiver (Berge, 1994).

However, a change from a state of ignorance about the value of faeces and urine to the habit of utilizing them is not easy to make. It has been observed that in regions where people are not in the habit of using septic bins, to persuade a family to build one is a very difficult task. After building the septic bins, to persuade them to use it and keep it clean is not easy. Above all, it is most difficult to persuade people to empty the bin and to carry the compost to the field (Polprasert et al, 1981). Furthermore, it is difficult to achieve changes in excreta disposal practices, because they are part of the basis behavioral pattern of a community, which people are accustomed to from a very early age (Zeitlyn and Islam, 1991, quoted in Boot and Cairncross, 1993; Mara and Cairncross, 1989; Feachem and Cairncross, 1978).

Also the type of sanitation facilities influence the recycling possibilities, because of technical constraints and the difference in appearance of the waste product from the different sanitation systems. For example, in China, Subba Roa et al (1993) noted that "Since domestic waste disposal methods have improved, most of the human waste is diluted and sent to a septic system and not collected for further use. In the near suburbs of cities, some diluted human wastes are transported to vegetable fields. However, this is rarely undertaken because of the labour-intensive and unpleasant nature of the work".

4 Social, cultural, economical and political factors influencing the use of excreta in agriculture and the use of sanitary facilities in Sub-Sahara Africa

4.1 Cultural values, religion, traditional practices and beliefs concerning the disposal of human faeces

In many societies, excreta are considered taboo. An explanation for the existence of taboos on excreta is that those things become taboo which are difficult to classify culturally. A corollary to this idea is that most societies prefer to maintain a clear distinction between man an animal. Defecation and excreta reveal to man an aspect of his animal existence that he would prefer to forget. This anthropological observation may have sufficiently widespread relevance to explain why man seeks privacy to defecate, defecation is confined to the bush, people are resistant to use latrines, and excreta are, if possible, avoided (Douglas, 1966, quoted in Feachem et al, 1983).

The management of human excreta and waste always raises sensitivities relating to traditions, accepted behaviour or inhibitions, as well as cultural or religious beliefs and practices (Eade and Williams, 1995).

Cultural interpretations of excreta and defecation underlie people's responses both to the deposition technologies and to removal and reuse processes (Curtis, 1978, quoted in Feachem et al, 1983).

Response to deposition technologies
Cultures are very diverse in beliefs and practices regarding water and sanitation (Simpson-Hebert, 1984). Cultural values, traditional practices and beliefs concerning the disposal of human faeces can crucially affect the acceptability and impact of excreta disposal methods (Feachem et al, 1983; Simpson-Hebert, 1984). These beliefs are as vital to consider and understand as the management and technical aspect of the proposed solutions (Simpson-Hebert, 1984). The social prerequisites for effective sanitation are seldom achieved in practice (Feachem et al, 1983). Culturally related interpretations of excreta are reflected in the principles and practices of personal hygiene found around the world (Feachem et al, 1983; Boot and Cairncross, 1993; Hall and Adams, 1991) and differ per family, local community, nation, or religious, socio-economic group (Boot and Cairncross, 1993). Many hygienic practices have little to do with pathogen avoidance (Feachem et al, 1983; Boot and Cairncross, 1993; Hall and Adams, 1991). Studies in India (Chandra, 1964, quoted in Simpson-Hebert, 1984) and in the Philippines (Feliciano and Flavier, 1969, quoted in Simpson-Hebert, 1984) revealed that objections to a latrine project included a belief that going to the open fields was more sanitary than using a latrine. In many societies, the excreta of babies and little children are often incorrectly considered to be harmless (Boot and Cairncross, 1993).

A number of universal and deeply felt human reactions to the phenomenon of defecation exist, all of which can be utilised to promote practices conductive to improved hygiene. Privacy and dirt avoidance are all values that lend themselves to the use of modern excreta disposal technologies. Beyond these, there are a range of widely shared values: smell avoidance, household cleaning, sweeping, clothes washing and so on, that contribute to a reliable common basis for domestic sanitation programs (Feachem et al, 1983).

Response to removal and reuse processes
Human society has evolved very different socio-cultural responses to the use of untreated excreta, ranging from abhorrence through disaffection and indifference to predilection. Products fertilised with raw excreta are often regarded as tainted of defiled. However, these views are not held so rigidly in relation to excreta derived composts or wastewater sludges (Feachem et al, 1983).

In many African countries, contact with and use of human excreta is regarded with disaffection (Feachem et al, 1983; Cross, 1979; IDS, 1978; Muhondwa, 1976; Adeniyi, 1973). How deeply this view prevails is highly variable; for some populations, excrement is simply dirty, for others it is dangerous, a matter for personal defilement or for evil uses, to be scrupulously avoided or carefully disposed of (Curtis, 1978, quoted in Feachem et al, 1983).

The response to the use of human excreta in agriculture and aquaculture in China, Japan and Java is completely different from most African societies. Excreta have been used for thousands of years. This practice is in social accord with the Japanese and Chinese traditions of frugality and reflects a deep ecological, as well as economic appreciation of the dependent relationship between soil fertility and human wastes (Mara and Cairncross, 1989).

Religion
Islam and Hinduism
Islam and Hinduism have concepts of what is clean and what is dirty, as part of their religious ideologies (Kochar, 1991, quoted in Boot and Cairncross, 1993; Simpson-Hebert, 1984; Khare, 1962, quoted in Simpson-Hebert, 1984). In Hindu villages in northern India, the purpose of maintaining a state of ritual purity in life is to create a condition favourable for upward spiral of the soul. These values form an important part of the *karma* (action) and *dharma* (religion) of an individual (Khare, 1962, quoted in Simpson-Hebert, 1984). If people lead a clean and pious life, the various gods and deities will be in good humour. Displeasure of the gods is regarded as one of the causes of death and illness (Chandra, 1964, and Dube, 1956, both quoted in Simpson-Hebert, 1984).

In Hindu and Islam societies, ritual impurity can, amongst others, be caused by natural happenings, such as coming into contact with impure substances. Excreta is one of the most polluting substances. Even when drains, sewage, contents of latrines or ditches are cleaned, they still remain ritually impure (Khare, 1962, quoted in Simpson-Hebert, 1984). In Islamic societies, excreta are regarded as containing impurities by Koranic edict. Therefore, the use of human excreta in agriculture and aquaculture and re-use of wastewater are not condoned (Mara and Cairncross, 1989; Cross, 1985).
When one becomes ritually impure, he or she undertakes actions that result in ritual purification, through cleaning and further avoidance of the polluting agents. One must be physically 'clean' to be ritually 'pure' (Khare, 1962, quoted in Simpson-Hebert, 1984). In Muslim and Hindu religion, concepts of clean and dirty, purity and pollution have a strong effect upon personal and household hygiene. Still, purity and pollution may refer to ritual states rather than physical ones (Kochar, 1991, quoted in Boot and Cairncross, 1993; Simpson-Hebert, 1984; Khare, 1962, quoted in Simpson-Hebert, 1984).

Excreta use in Islam societies after treatment would be acceptable if the treatment is such that the ritual impurities are removed, for example after thermophilic composting which produces a humus-like substance that has no visual or odorous connection with the original material. Use of human excreta are also religiously acceptable if they are diluted in fish-ponds and if the diluted excreta flow from one pond to another (Mara and Cairncross, 1989). A study on the acceptability and use of fertiliser from compost latrines in Tanzania revealed that there was no significant difference between Muslims and Christians. Muslims and Christians judged the compost to be sufficiently dissimilar from fresh human faeces and not to be regarded as a taboo resource (Killewo, 1980, quoted in Cross, 1985).

Despite the power, influence and clarity of Islamic law with regard to contact with human waste, in practice, resource constraints, and religious, ideological and cultural variations lead to different practices, not all of which are wholly in keeping with ideal Islamic hygiene behaviour (Cross, 1985).

In some cases, the proscriptions of Islamic law certainly do not succeed in limiting contact with human excreta. Roughly 95% of the rural population in Egypt have no access to sanitation facilities, which implies a high level of contact with faecal matter (Haedlee, 1933; Farooq and Mallah, 1966, both quoted in Cross, 1985). Despite the strictures against the use of faeces in agriculture, in practice much defecation occurs in fields (Cheesemond and Fenwick, 1981, quoted in Cross, 1985).

Studies in Muslim communities in Nigeria (Chen, 1969, quoted in Simpson-Hebert, 1984), Egypt, Iran (Adeniyi, 1973, quoted in Simpson-Hebert, 1984) and Malaysia (Chen, 1969, quoted in Simpson-Hebert, 1984) reveal that people customarily use their hands with water for anal cleansing, which results in directly touching faecal material, and say that this is in keeping with the Moslem religion (Mara and Cairncross, 1989).

Other reasons why Muslims sometimes use excreta against the Islamic rules regarding hygiene behaviour, is that Koranic edicts are variously interpreted among different Islamic movements. Furthermore, the Islam has various degrees of penetration into indigenous cultures. In Indonesia, for example, where Islamic culture is superimposed upon a strong indigenous culture, fertiliser is sold from nightsoil collection in Jakarta (Morrow, 1975, quoted in Cross, 1985). The direct application of nightsoil in freshwater fish culture in West Java is an ancient cultural practice which has altered little under Islamic rule (Djajadiredja et al, 1979, quoted in Cross, 1985).

Chinese folk religion

Chinese folk "religion" is an amalgam of Confucianist, Taoist and Buddhist thinking (Chan, 1953, quoted in Cross, 1985). Folk beliefs in China are less concerned with salvation or the supernatural, but are sustained by earthly fears and rewards. Man's one-ness with nature is stressed, rather than the sense of his supreme importance in the order of things. Ancestral cults existed in earlier days involving the worship of natural objects, such as the life-giving soil, water and so on. The relationship to the soil - "man belongs to the soil and not soil to man" -, remains a continuing theme in Chinese culture (Cressey, 1934, quoted in Cross, 1985).

Chinese acceptance of nightsoil re-use is in accordance with chinese folk religion. The great value attached to nightsoil is reflected in traditional excreta disposal practices. These are far from indiscriminate, and practically all human wastes together with organic agricultural wastes were, and still are, preserved. Actual practices in the conservation and use of human wastes vary traditionally across China. An initial distinction is between the direct and immediate use of raw excreta, and indirect methods which involve mixing excreta with organic material or storage prior to usage (Cross, 1985).

Significance of cultural barriers

There are several reasons why the cultural barriers to reuse is less than it might appear. Processing can transform something that is socially unacceptable into something that is much more easily accepted (Feachem et al, 1983). Furthermore, the distance between the producer and the consumer of food is becoming larger. Unlike the true subsistence farmer who experiences the whole cycle of agriculture from production to consumption and back to production, a commercial farmer produces for a distant and impersonal market and is better prepared to use any agricultural aid conductive to a good market return. The urban consumer knows little of the origins of the food he/she buys. The separation of producer and consumer is both geographical and institutional (Feachem et al, 1983).

4.2 Social structure of the community

In communities where people abhor the use of excreta, the task of collecting urban nightsoil is regarded as employment of very low status (Mara and Cairncross, 1989). In many towns throughout the world, sweepers and night soil removers are drawn from disadvantaged minority groups (strangers, refugees, or other disadvantaged minorities) living in segregated communities within the towns (Feachem et al, 1983; Curtis, 1978, quoted in Cross, 1985). In India, handling sanitation is thought to pollute the soul of a person and has hence traditionally been limited to castles groups (Khare, 1962, quoted in Van Hooff, 1994), which are indicated as sweeper caste by Feachem (1995). Other castes refuse to come into contact with other people's excreta, as it would harm their caste status (Khare, 1964, quoted in Simpson-Hebert, 1984).

In many African societies, people who come into regular contact with excreta, become themselves persons to be avoided (Feachem et al, 1983; Curtis, 1978, quoted in Cross, 1985).

Therefore, it is becoming increasingly difficult for urban authorities in many developing countries to recruit people for the collection of urban nightsoil. As a result, sanitation facilities that produce nightsoil, such as bucket latrines, are being replaced by those that do not, for example pour-flush latrines (Mara and Cairncross, 1989). However, the stigmatised occupation of collector of nightsoil may be in strong demand if alternative sources of employment for people of inferior status are unavailable (Feachem et al, 1983). If this is the case, operators in parts of cities covered by private cartage systems may have to purchase the rights to service a street (Streefland, 1978, quoted in Feachem et al, 1983).

In societies where reuse of excreta has always been practised, it is unlikely that the job of night soil removing has ever carried the stigma that it does in societies where the rituals of excreta avoidance are highly developed. (Feachem et al, 1983). The status of night soil removers in Chinese society is not low. It has improved since the revolution, because of the importance attached to health (Streefland, 1978, quoted in Feachem et al, 1983).

4.3 Gender issues

The power and financial means to change the existing sanitation situation often rest with the men. However, there are several reasons why women need special consideration in the planning of water and sanitation projects. Firstly, women are most often the controllers and purveyors in the local learning systems related to water, health, and sanitation. Therefore they can be regarded as legitimate mediators between existing community knowledge and new project-provided information (Roark, 1984). The hidden participant accepting or rejecting a new water supply or sanitation technology is most often a woman (Elmendorf and Isely, 1981, quoted in Roark, 1984). Secondly, some local customs demand seclusion of women in their compounds. This should be considered when choosing the location of sanitary facilities and compost pits. In India, a compost pit project failed because the pits were dug at the fringe of the village. It was unacceptable for women to be seen outside their compounds, carrying loads of refuse to the compost pits. Men could not do the job, as it was considered to be women's work (Simpson-Hebert, 1984).

Thirdly, sanitation programmes often have an impact on women's workload in the sense that an uninviting activity is added, such as the cleaning of sanitary facilities, and the carrying of refuse to compost pits (Borba, 1996; Boot and Cairncross, 1993).

4.4 Economic factors

Economic constraints or incentives to construct disposal systems

The existing distribution of sanitary facilities is heavily skewed towards the rich because of their cost. At some point down the scale of poverty it ceases to be reasonable to expect people to pay for their own installations (Feachem et al, 1983). A latrine project in the Philippines did not succeed because the costs of latrines would have amounted to one half the annual income of the average farmer (Feliciano and Flavier, 1969, quoted in Simpson-Hebert, 1984).

Costs of latrines may always remain a problem for tenants of land, who are reluctant to improve a property for which their landlord may increase the rent as a result of their efforts. Furthermore, in urban settings, squatters are not likely to invest in sanitary facilities if they are likely to be evicted (Cairncross, 1992).

Voluntary groups often have difficulty in collecting money (needed to pay a cleaner or to pay water and electricity bills) from their members on a routine basis, because defaulters encourage those who would otherwise be inclined to pay regularly to be similarly lax (Feachem et al, 1978, quoted in Feachem et al, 1983). Many consumers, even in rural communities, are willing to pay for individual connections, but are far less interested in paying for a public source such as a standpipe or communal handpump if alternative water sources are available and accessible (Briscoe and De Ferranti, 1988, quoted in Cairncross, 1992).

In most cases, public facilities are provided and subsidised either by public authorities alone or in conjunction with the users (Feachem et al, 1983). An exception is made for societies where night soil has a commercial value. In these societies, there may be potential for the commercial organisation responsible for reuse to provide the toilets themselves (Feachem et al, 1983). Individual Indonesian fishpond owners recognised the economic value of nightsoil in aquaculture, and provided latrines overhanging their ponds for the use of the neighbourhood (Djajadiredja et al, 1979, quoted in Cross, 1985).

Economic constraints or incentives to empty facilities
In many societies where night soil is valued as a fertiliser, cartage is a private sector activity. Cartage contractors make their money by selling the material to farmers, by being paid for the job of removal itself, or by a combination of both.

In some towns, different areas are serviced by small-contractors who make agreements with individual households for night soil removal. In others, larger-scale operatives undertake contracts with city corporation. Private contractors may be difficult to control, particularly where they are numerous and stand to gain from dumping their loads in the nearest watercourse instead of removing them from the city to agreed disposal points. A good price for the product, however, is an effective incentive to efficient night soil removal (Feachem et al, 1983).

In some societies, nigh soil collection is done by cooperatives. Vietnamese co-operatives have implemented systems for buying, collecting and processing human faeces and urine. Payments were done in the form of cash, unhulled rice or higher personnel grade, depending on the conditions in each region (Lohani and Chan, 1981). In other societies, night soil collection is institutionalised by municipal authorities. In pre-Revolutionary China, city nightsoil collection earned municipal authorities a considerable income. The collection was generally contracted out to entrepreneurs, who hired people for the actual collection (Streefland, 1978, quoted in Cross, 1985). Nightsoil was sold to rural areas (Cressey, 1934, quoted in Cross, 1985).

Economic constraints or incentives to use excreta in agriculture
The use of excreta is dictated by survival economies. It is used in societies, where intensive cultivation practices have evolved in response to the need to feed a large number of people living in an area of limited land availability. This has necessitated the careful use of all the resources available to the community, including excreta (Mara and Cairncross, 1989).
In Chinese conception and practice, nightsoil is a desirable, economically valuable natural source of nutrients. Its use exemplifies a tradition of frugality in Chinese peasant culture (McGarry, 1976, quoted in Cross, 1995).

Financial benefits of the use of human excreta as fertilizer may form an incentive to its use. Reuse of composted night soil as fertilizer is practised at household level in rural areas of Korea. The composting operation yielded the farmer an annual benefit of $37 on an annual cost of $34 (Kalbermatten et al, 1982).

4.5 Political factors

The government is often bound to be involved in sanitation programs for several reasons.

Subsidies
Government funds are necessary to ensure that sanitation programs take place, when individuals and groups cannot overcome the costs of latrines (Feachem et al, 1983).

Promotion and control
The success of sanitation programs hinges largely on the capability of the municipal governments or other public authorities who must promote, control, and service the schemes. These authorities must not only understand the nature of the task but must also be able to exercise their authority to enforce routines and ensure that the public plays its part. The need for administrative discipline extends beyond the supervision of routine operations to the collection of dues and the control of access to services. Experience past and present indicate that this management ability is often the chief limiting factor in sanitation programs (Rybczynski et al, 1978, quoted in Feachem et al, 1983).

Feachem et al(1983) states that the assumption that society is within governmental control and that authorities can enforce communities to use sanitary facilities is false. There are two reasons for this. Firstly, the proper functioning of excreta disposal systems demands that the system is suited to the environmental conditions such as the climate, endemic diseases, water availability or the civic wealth, many of which are beyond the control of public authorities. Secondly, no civic administration can maintain the integrity of sanitation programs for long without active public support. The public at large must be solidly behind the policies of their authorities and must be allowed to effectively exercise some influence upon the course of events. If this is not the case, a large range of difficulties (contractors dump night soil indiscriminately in rivers or drains, workers gain political protection when attempts are made to enforce work routines, members of the public get their houses preferentially connected to water supplies or sewer lines by paying "speed money" to minor officials, the poor pay their dues while the rich avoid payment) is likely to occur (Feachem et al, 1983).

There are some examples of political control, which has lead to the use of excreta for several purposes. In several parts of Africa, excreta use is fish farming in sewerage ponds is formally endorsed by several local authorities. The formal scale of sewage sludge by local authorities has long been established in many cities, most notably South Africa, where there is extensive public health legislation controlling the use and sale of sludge (Oberholster, 1983, quoted in Cross, 1985).
Although the compost privy is described in a number of standard monographs on rural sanitation, there are no reports of its application on a wide scale until 1956. At this time, the Democratic Republic of Vietnam initiated a Five Year Plan of rural hygiene, during which a very large number of anaerobic composting privies (an on the spot composting facility) were built (Rybczynski, 1978).
The government of India decided several years ago to gradually replace the urban bucket latrines or 'service privies' by pour-flush double-pit latrines, mainly to decrease handling and use of raw night soil by scavengers and farmers, and thus to reduce risks of disease transmission (Strauss and Blumenthal, 1990).

Authorities may have to assume didactic roles in situations in which traditional understanding and practice is strongly contraindicated by modern interpretations of health and disease. Effective excreta disposal may then require that people come to have some new understandings of the health hazards from excreta and of the measures that can be taken to avoid these hazards (Feachem et al, 1983). People may overcome their reluctance to use sanitary facilities or to handle fertiliser containing excreta through demonstrations and schooling (Bilqis et al, 1994; Peel, 1976, quoted in Cross, 1985; Feliciano and Flavier, 1969, quoted in Simpson-Hebert, 1984; Gillis, 1946, quoted in Cross, 1985).

In Vietnam, government cadres and officials are responsible for initiating changes to make people collect and utilise human faeces and urine. In regions where people are reluctant to use faeces and urine, due to ignorance about fertilisers and the nourishment of development of crops, or due to inexperience with fertilisers and their effects on crops, government cadres and officials are expected to influence these people through propaganda (Lohani and Chan, 1981).

Creating equity
An argument for the involvement of the government in sanitation programs derives from equity considerations. Sewerage projects, which rarely serve low-income communities, usually fail to recover their capital costs from the beneficiaries. Whether by design or by default, it is hardly equitable to oblige poorer residents who cannot afford a sewer connection to pay a greater share of the cost of their cheaper sanitation facilitates. In many urban environments, sanitation programs must be seen as attempts to overcome one of the effects of poverty. As such, they are bound to involve a degree of government intervention through subsidies (Feachem et al, 1983).

There are problems in securing political support for low-income schemes when upper-income groups, who better afford to pay and have more political weight, themselves clamour for higher standards of service. Politicians face the full brunt of deciding priorities in urban development and, if they have to recruit public support to keep themselves in office, they often face pressures to employ more sweepers or to favour particular parts of the community (Feachem et al, 1983).

The approach of involving the public in hygiene and sanitation improvement committees does not necessarily improve the status of people employed in night soil removal (Feachem et al, 1983). The Indian government has been endeavouring to overcome the untouchable status of the sweeper castes. It is promoting programmes to replace bucket latrines with pour-flush toilets not only for reasons of improved health, but also because of society's demand for doing away with the degrading practice of human beings carrying nightsoil loads (Venugopalan, 1984, quoted in Mara and Cairncross, 1989). In practice, this kind of social change has proved very difficult wherever there is continuing association of a caste or single group with occupations such as night soil removal, and eliminating a stigmatised occupation is a major additional incentive to changing an excreta disposal system (Feachem et al, 1983).

Legislation
In many countries it is illegal to apply fresh excreta, mixed with water, to the crops because of the accumulation and spreading of pathogenic germs and parasitic eggs to animals and humans (Polprasert et al, 1981). The government of India has decided to gradually replace the urban bucket latrines or service privies by pour-flush double-pit latrines, mainly because of a decrease in the handling and use of raw night soil by scavengers and farmers and thus contribute to reducing the risks of disease transmission (Strauss and Blumenthal, 1990).

4.6 Convenience of sanitary facilities

Location
Locations of sanitary facilities should be chosen according to the place where people are normally accustomed to defecate. Acceptable or preferred places of defecation vary widely (Davis and Lambert, 1995). Acceptable places differ according to culture, opportunity, personal preference (Boot and Cairncross, 1993) and physical setting of a village or city (Hall and Adams, 1991).
The following factors must be considered when choosing a location:

- In many societies, the taboo on excreta and defecation implies that people do not want others to know that they are using sanitary facilities. The journey to sanitary facilities, but also the view of toilets to visitors will be embarrassing (Faul-Doyle and Doyle, 1996; Feachem et al, 1983; Boot and Cairncross, 1993).
- In some societies (for example in India, the Middle East and Egypt), sanitary facilities are bound to be located inside the house, because women are not allowed to leave their houses (Simpson-Hebert, 1984).
- If the toilet is close to the house or even in the house, there may be a feeling that defecation is not adequately segregated from the rest of daily living (Feachem et al, 1983). For this reason, occupants of small apartments in Madras filled their toilets with sand and used the space for other purposes (Curtis, 1978, quoted in Feachem et al, 1983).
- If the latrine is sited at some distance from the living quarters, people may be discouraged from using it on dark nights or in inclement weather (Feachem et al, 1983; Cairncross, 1992; Hall and Adams, 1991). Furthermore, the old and infirm may have physical difficulties in moving far form a shelter or compound (Davis and Lambert, 1995; Cairncross, 1992).
- In many societies, women and men may not use the same place (Faul-Doyle and Doyle, 1996; Davis and Lambert, 1995; Eade and Williams, 1995; Boot and Cairncross, 1993; Hall and Adams, 1991). There may also be restrictions as to the use of the same place by certain family relations (e.g. father and daughter-in-law) (Almedom and Chatterjee, 1995; Boot and Cairncross, 1993). In some societies, communal defecation areas are unacceptable for this reason (Davis and Lambert, 1995).
- Children and adults may be afraid to fall through the hole in latrines (Davis and Lambert, 1995; Feachem et al, 1983; Boot and Cairncross, 1993; ; Adeniyi, 1973, quoted in Simpson-Hebert, 1984) or may be frightened to full through wooden slats covering the pit (Feliciano and Flavier, 1969, quoted in Simpson-Hebert, 1984).

Privacy
Toilets must be private (Almedom and Chatterjee, 1995; Mancy, 1993; Feachem et al, 1983). In urban environments, private locations for outside toilets may be hard to find. Constructors of outside toilets should pay attention that door catches are adequate Also, people might find it disconcerning that people can see their feet through the ventilation gap left at the bottom of doors to their outside toilets (Feachem et al, 1983).

Access to the right people at right time
The use of sanitary facilities is often constrained by the fact that these are not accessible to the right people at the right time (Feachem et al, 1983; Adeniyi, 1973, quoted in Simpson-Hebert, 1984). Householders may be inclined to keep outdoor latrines locked to prevent misuse by passers by, with the unfortunate consequence that they are not available for children during the day (Feachem et al, 1983).

Creating new conventions
Crowded urban environments present opportunities for creating new conventions, practices and concepts of comfort that program directors should seize upon. Private, domestic latrines have so many advantages to the user that they are always preferable wherever people can afford them and space is available. The problem that people prefer to go to the bush than to use a latrine decreases when the bush becomes inaccessible. At this point, the population presumably becomes susceptible to new interpretations of what constitutes an appropriate environment for defecation. Furthermore, latrines can be presented as answers to the problem of privacy, and an analogy with the bush may be maintained by siting the facility at a suitable distance from the house. Crowded urban environments present opportunities for creating new conventions, practices and concepts of comfort that program directors should seize upon (Feachem et al, 1983). Within Africa's sprawling peri-urban population there are reports of ingenious informal sector uses for a variety of waste products. Fishing (often illegally) in waste stabilisation ponds is reported from several cities. (Oberholster, 1983, quoted in Cross, 1985)

4.7 Comfort of sanitary facilities

Comfort has been found to be a great selling point for latrine programs, but the social requirements are difficult to predict.

Conventional expectations
There are cultural preferences for sitting or squatting and for anal cleansing procedures that must be accommodated by the new technology (Davis and Lambert, 1996; Feachem et al, 1983; Boot and Cairncross, 1993). Washing facilities for total body washing in privacy often are much appreciated (Feachem et al, 1983). Muslims demand the appropriate orientation of the facilities in relation to Mecca (Goyder, 1978, quoted in Feachem et al, 1983).

Cleaning of sanitary facilities
The degree to which certain individuals in a society are prepared to be involved in the cleaning of latrines is affected by cultural norms. Small coherent groups, such as families, are more likely to take responsibility for care and maintenance than large, disparate groups (Davis and Lambert, 1996; Feachem et al, 1983; Cairncross, 1992). In Nigeria, the indigenous social structure of family groups provide a framework for the social control of latrines (Pasteur, 1979, quoted in Feachem et al, 1983).

Public toilets have a poor record in the respect of maintenance and have inherent shortcomings (Feachem et al, 1983; Cairncross, 1992). It takes only one misuser, perhaps a child avoiding the frightening squatting hole, to establish a chain of subsequent misuse for which no one is willing to take responsibility. In most cases, cleaners can only be hired if the costs are covered by a small charge to the users. The arrangement most likely to ensure sustained cleanliness is to have one cleaner constantly stationed at each public toilet. A cheaper alternative is to have a cleaner responsible for several public toilets, which he continually travels among. In Beijing, China, cleaners are responsible for several public toilets, which they continually travel among on three-wheeled bicycles which are provided with cleaning equipment (Feachem et al, 1983).

If public sanitary facilities are not cleaned, and become malodorous and fly ridden, people may prefer to use the bush instead of a latrine (Feachem et al, 1983; Feachem and Cairncross, 1978; Adeniyi, 1973 and Feliciano and Flavier, 1969, last two quoted in Simpson-Hebert, 1984). In Tanzania, the introduction of composting latrines failed because people refused to use fouled latrines (Simbeye, 1981, quoted in Cross, 1985).

5 Pathogenic organisms

5.1 Presence of pathogenic organisms in human excreta

Pathogenic organisms present in faeces
Excreta can contain large numbers of pathogenic microorganisms: viruses, bacteria, protozoa, helminths. Unhygienical disposal of human waste can cause the transmission of diseases. The actual number of pathogenic organisms depends on a variety of factors, such as, country, prevalent infections among the human population, the season, and so on (Block, 1985).

Viruses
Numerous viruses may infect the intestinal tract and be passed in the faeces. Five groups of pathogenic excreted viruses are particularly important:
- Adenoviruses
- Enteroviruses (Polioviruses, Echoviruses, Coxsackie viruses)
- Hepatitis A virus
- Reoviruses
- Rotaviruses (Norwalk agent and other viruses) (Feachem et al, 1983).

Bacteria
The faeces of a healthy person contain large numbers of commensal bacteria of many species. The bacteria most commonly found are Enterobacteria, Enterococci, Lactobacilli, Clostridia, Bacteriodes, Bifidobacteria and Eubacteria (Feachem et al, 1983).

On occasion, some of bacteria listed of their particular strains, may give rise to disease, as may other groups of bacteria normally be absent from the healthy intestine. These pathogenic, or potentially pathogenic bacteria are:
- Campylobacter fetus ssp jejuni
- pathogenic Escherichia coli
- Salmonella (S. typhi, S. paratyphi, other salmmonellae)
- Shigella spp
- Vibrio (V. cholerae, other vibrios, Yersinia enterocolitica) (Feachem et al, 1983)

Protozoa
Only three species of human intestinal protozoa are considered to be frequently pathogenic:
- Balantidium coli
- Entamoeba histolytica
- Giardia Lamblia (Feachem et al, 1983).

Helminths
Many species of parasitic worms or helminths have human hosts. Some can cause serious illness, but a number generate few symptoms. Only those helminths whose eggs or larval forms that are passed in the excreta are mentioned. Helminths are classified in roundworms (nematodes) and flatworms (which are flat in cross-section). Flatworms are again classified in tapeworms (cestodes), which form chains of segments, and flukes (trematodes), which have a single flat unsegmented body (Feachem et al, 1983).

The following pathogenic helminths are considered:
- Ancylostoma duodenale
- Ascaris lumbricoides
- Clonorchis sinensis
- Diphyllobothrium latum
- Enterobius vermicularis
- Fasciola hepatica

- Fasciolopsis buski
- Gastrodiscoides hominis
- Heterophyes
- Hymenolepis nana
- Metagonimus yokagawai
- Nectorator americanus
- Opisthorchis felineus
- Opisthorchis viverrini
- Paragonimus westermani
- Schistosoma haematobium
- Schistosoma japonicum
- Schistosoma mansoni
- Strongyloides stercoralis
- Taenia saginata
- Taenia solium
- Trichuris trichiura (Feachem et al, 1983).

Pathogenic organisms present in urine
In general urine is a sterile and harmless substance. There are, however, occasions when host infections cause passage of pathogens in the urine. The three principal infections leading to the significant appearance of pathogens in the urine are urinary schistosomiasis, typhoid and leptospirosis.

People infected with urinary schistosomiasis (caused by Schistosoma heamatobium) will pass eggs chiefly in their urine. The worms will live for years and superinfection occurs, so that those affected may pass eggs for much of their lifetime (Feachem et al, 1983).

During the phase of typhoid and paratyphoid fevers when bacteria are disseminated in the blood, the organisms will usually be shed in the urine (Feachem et al, 1983).

An individual with leprospirosis will pass Leptospira intermittently in the urine for a period of about 4-6 weeks; chronic human carrier states are rare (Feachem et al, 1983).

Coliform and other bacteria may be numerous in the urine during cystitis and other urinary infections, but they constitute no public risk. In venereal infections the microbial agents will also reach the urine but they are so vulnerable to conditions outside the body that excreta are unimportant vehicle of transmission (Feachem et al, 1983).

5.2 Transmission of pathogenic organisms

Viruses
Viruses may infect new human hosts by ingestion or inhalation. One gram of human faeces may contain 10^9 infectious virus particles, regardless of whether the individual is experiencing any discernible illness. Although they can not multiply outside a suitable host cell, the excreted viruses may survive for many weeks in the environment, especially if temperatures are cool (< 15°C) (Feachem et al, 1983).

Viruses are immediately infective upon release into the environment (i.e., their latent period is zero). The minimal infective dose is usually low; it is believed that even a single virus may confer infection if circumstances are suitable (Cross and Strauss, 1985).

An individual who survives a viral disease will have acquired life-long immunity to the particular virus. He or she may, however, still be susceptible to other types of viruses (Cross and Strauss, 1985).

Bacteria
Bacteria most commonly enter a new host by ingestion (in water, on food, on fingers, in dirt) but some may enter through the lungs (after inhalation of aerosol particles) or through the eye (after rubbing the eye with faecally contaminated fingers). At some time during the course of an infection, large numbers of the bacteria will be passed in the faeces, thus allowing the spread of infection to new hosts (Feachem et al, 1983).

A carrier state exists in all the infections. Thus in communities where these infections are endemic, a proportion of perfectly healthy individuals will be excreting pathogenic bacteria. A carrier becomes especially dangerous when engaged in food preparation or handling or in water supply (Feachem et al, 1983)

Bacterial pathogens confer immunity to variable degrees, i.e., immunity may last for a limited period of time only or may depend on the doses and protect against a specific strain only (Cross and Strauss, 1985).

The sanitary disposal of all faeces (both human and animal) and perfect personal hygiene would largely eliminate all the viral and bacterial diseases (Feachem et al, 1983)

Leptospira have been excluded. Leptospira are excreted in urine of animal carriers and usually reach new animal and human hosts through skin abrasions or mucous membranes contaminated by infected urine. Man may be an intermittent carrier for a few weeks (rarely months) after an acute infection. Leptospirosis is considered here because of the risk to workers who handle excreta, which may contain leptospiras either from animal carriers (sewer rat) attracted to such environments or occasionally from infected people (Feachem et al, 1983)

Protozoa
Infective forms of protozoa are often passed as cysts in the faeces, and man is infected when he ingests them (Feachem et al, 1983). Infection which occurs through the hatching of the cysts in the new host's intestines is either directly via faecally-contaminated hands or through ingestion via contaminated food or water (Cross and Strauss, 1985). An asymptomic carrier state is common in all three pathogenic protozoa and in the case of Entamoeba histolytica, it is carriers who are primarily responsible for continued transmission (Feachem et al, 1983).

There is evidence that an immune response (formation of antibodies) does occur in persons who become infected with E. histolytica or G lambia. However, the acquired immunity appears to be neither fully protective nor lasting (Cross and Strauss, 1985).

Helminths
Helminths (except for Strongyloides) do not multiply within the human host, and this is of great importance in understanding their transmission, the ways they cause disease, and the effects of environmental changes on their control.

The development stages through which helminths pass before infecting man, their life cycles, are very complex. Most of the roundworms infecting man, and also the schistosome flukes, for example, have separate sexes, so that the transmission depends upon infection with both male and female worms and upon the meeting, mating, and egg production of these worms within the human body. A number of individuals may be infected with a single sex or with unmated worms. These cases are of no epidemiological significance because they do not transmit infection (Feachem et al, 1983). The other trematodes (flukes) and cestodes (tapeworms follow an asexual reproduction pattern (Cross and Strauss, 1985)

Helminthic disease is not an all-or-nothing phenomenon. In infections due to viruses, bacteria and protozoa, where massive asexual reproduction occurs within the host, once infection occurs its severity cannot be related easily to the infecting dose of organisms. With helminthic infection it is essential to think quantitatively. The question is not just whether or not someone has a hookworm infection but how many worms he has (how heavy or intense the infection is). The egg output is always a better measure of transmission and sometimes a better guide to pathology than the burden of adult worms. The number of heavy infection is not simply proportional to the prevalence of infection (Feachem et al, 1983).

It is generally thought that, apart from schistosomiasis, helminth infections do not produce host immunity. Therefore, persons suffering from helminthic infections have been repeatedly in contact with the infective larval forms of a particular helminthic pathogen. This leads to an increased burden of adult worms, which then causes damage and symptoms inside the host (Cross and Strauss, 1985).

5.3 Determination of risks of excreta use because of pathogenic organisms

Excreta related diseases account for 10-25 % of illnesses that reach the health care services in developing countries, and cause a vast amount of misery that goes unreported (Feachem et al, 1983). The most important factor in human excreta use, for any purpose, remains thus the continuation of the sanitation motive: preventing the transmission of diseases through the excreta. However, the fact that the pathogenic microorganisms in the excreta can be harmful to (public) health is not sufficient reason to declare that the sludge use or contact with it is unsafe. Only risk assessment can avoid two potential errors: first judging excreta application to be safe when in fact it is not and second to declare excreta application hazardous when it is not (Block, 1985). It is necessary to define the type of pathogen, its load, and its fate outside the human host (Cross and Strauss, 1985).

In the different application fields of human excreta the following health hazards can be distinguished

- *agriculture*: the occupational hazard to those employed to work on the land being fertilized; and the risk that contaminated products from reuse may subsequently infect human or animals through consumption or handling.
- *fish production*: fish may passively carry excreted pathogens in their intestines or on their body surfaces and subsequently infect people who may handle, prepare or eat the fish; transmission of helminths whose life cycles involve fish as intermediate host; transmission of other helminths with life cycles involving other pond fauna, such as the snail intermediate hosts of schistosomes.
- *algal culture*: high-rate ponds have a short retention time of about 1 day. Pathogen removal is therefore minimal and harvested algae will be rich in excreted viruses, bacteria, protozoa and helminth eggs.
- *macrophyte culture*: occupational risk to those who work in the water; the harvested plants may be heavily contaminated with pathogens and may infect those who harvest, handle, prepare or eat them.
- *biogas production*: health problems associated with biogas production come entirely from the reuse of the slurry (Feachem et al, 1983).

Risk assessment is, despite its uncertainties, the only tool available for discriminating between environmental health problems because of excreta use and for evaluating control decisions. In the simplest sense population risks from microorganisms are a function of two measurable factors: hazard and exposure. In a regulatory setting, risk assessment has one or more of the following steps: hazard identification, dose response assessment, exposure assessment, risk characterization, and economical/social evaluation (Block, 1985).

Hazard identification involves weighting the available evidence and deciding whether a microorganism is concerned with a particular adverse health effect. Once it is known that a microorganism is likely to cause a particular human effect, we determine its potency; how strongly it elicits that response at various levels of exposure (dose), (dose-response assessment) (Block, 1985). Data on basic epidemiological features of excreted pathogens by environmental category are provided in appendix 2.

Safe levels or thresholds exist for any pathogens, however, there are at least three problems concerned in determining the level:

- Infective doses may be smaller in infants or in adults suffering from malnutrition or immunologically compromised. Immunity is also an important factor in variation. The different populations exposed to microbial contamination from sludges and/or waste waters will not all have the same degree of susceptibility to pathogens.

- Detection of adverse health effects is dependent on the variables used in the study (from serum antibody changes to illness diaries, and so on).
- Most of the work on effective doses has been studied in controlled laboratory conditions with pure suspensions. It would therefore be unwise to extrapolate such results to sludges because we know little about the availability of bacteria and viruses embedded in and surrounded by sewage sludge. In these conditions, the infective dose of pathogens in sludges may be greater because of the protective effect of the organic colloidal matter (Block, 1985).

The best method in determining the health risks involved is direct measurement or monitoring of ambient conditions (exposure assessment). The degree of exposure may vary firstly with the population itself: from direct to indirect exposure[1]. Secondly, the degree of exposure will vary with different pathogens, their type and survival time (Block, 1985). Thirdly, disease transmission patterns are necessary to understand the actual (as opposed to potential) health risks (Cross and Strauss, 1985); to determine the significance of the infection route compared to other potential infection routes[2].

Assessment of exposure is usually limited because of resources or time required to do scientifically valid studies for all microorganisms. Even given average pathogen concentrations, local situations, climatic influences on the die-off of microorganisms, endemic levels of particular pathogens, etc., cause considerable variation from one region to another (Block, 1985)

The last step in the risk assessment is to estimate the health risk, it's socio-economic implications, associated with the known exposure in a particular situation or in the worst situation as possible (Block, 1985).

5.4 Detection of pathogenic organisms

In drinking water supply systems the use of faecal indicator bacteria for the detection of faecal contamination is universal (Cross and Strauss, 1985).
Faecal indicator bacteria are selected from among those commensal species that exclusively live in the intestinal tract of man and other warm-blooded animals without causing disease. Because they are always and naturally present in faeces and excreted in large numbers (10^9 or 10^{10} cells per gram of faeces), their presence in water indicates beyond doubt that the water has been contaminated with faecal material and possibly with excreted pathogens. Three main groups of bacteria are used as faecal indicators in conventional water bacteriology: the faecal coliforms, the faecal streptococci and the anaerobic bacterium Clostridium perfringes (Feachem et al, 1983).

The usefulness of indicator bacteria has been strongly questioned: (1) the faecal coliform enumeration procedures are extremely sensitive and difficult to control in simple infrastructured laboratories; (2) the ratios of indicator

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[1] If agricultural fieldworkers bring the infections back into their homes and subsequently infect their families, then a measurable difference in their health compared with that of nonagricultural workers and the whole community may not be apparent. Moreover, in many agricultural communities practically the whole population works in the fields at some time of the year, and so all may be exposed to the risk (although not equally) (Feachem et al, 1983).

[2] Epidemiological literature indicates that wherever an infection is highly endemic in a community wherein poverty and squalor are also found, the introduction of the particular pathogen into the home on contaminated vegetables or other crops may have a negligible effect on transmission. In contrast, wherever an infection is not widespread in a community that has improved its standards of hygiene and housing, the introduction of contaminated crops into the home may be the major transmission route of some excreted pathogens. Thus the significance of contaminated crops in disease transmission has mainly been emphasized in countries such as Japan, Israel, South Africa, or Germany in postwar periods, when the use of sewage or excreta on crops was combined with a relatively high level of hygiene and housing (Feachem et al, 1983).

organisms to bacterial and non-bacterial (viral, protozoal, helminthic) pathogens are either unpredictable or unknown[3]; (3) to differentiate human from non-human pollution poses a major difficulty (Cross and Strauss, 1985).

Faecal indicator bacteria are also of limited value in the context of excreta use in agriculture and aquaculture where faecal matter is the focus of activity. Occurrence of Ascaris eggs is proposed as the parameter of choice for a meaningful judgement of the quality and safety of waste products where Ascaris is endemic. Ascaris eggs are extremely resistant to environmental stress. Therefore, if viable Ascaris eggs are absent, one may conclude that all the other pathogens are also dead or have lost infectivity (Cross and Strauss, 1985).

6 Pathogen survival

All pathogens will eventually die or lose infectivity after excretion and release into the extra-host environment. In general, the reduction of viable pathogens is exponential. Variations of this die-off pattern are found with a few bacteria (e.g., Salmonella) which may temporarily multiply outside the host and with most helminths which have one or more non-infective intermediate development stages with typical die-off patterns. A further variation is found with trematodes (e.g., Schistosama, Chlonorchis sinensis) which have a multiplication phase in intermediate hosts (Strauss, 1985).

Pathogen die-off basically follows the same exponential-type independent of the kind of environment, such as soil, crops, sludge or excreta stored in latrine or leaching pits. Particular environmental factors, however, determine the actual die-off rate and the number of organisms surviving within a given time period (Strauss, 1985). The major environmental factors that influence pathogenic die-off are (Strauss, 1985):

Environmental factor	Effect on pathogen die-off or survival
Temperature	Accelerated die-off with increasing temperature, longer survival at low temperature
Moisture content (of foods, soils, in waste products), humidity	Generally longer survival in moist environment and under humid weather conditions, rapid die-off under conditions of desiccation
Nutrients	Nutrients accelerated die-off if essential nutrients are scarce or absent
Competition by other micro-organisms	Longer survival in an environment with few or no microorganisms competing for nutrients or acting a predators
Sunlight (ultra-violet radiation)	*Accelerated die-off if exposed to sunlight*
pH	Neutral to alkaline pH tends to prolong survival of bacteria; acid pH tends to prolong survival of viruses

[3]Fecal indicator bacteria only demonstrate fecal contamination. This fact is useful in assessing the safety of drinking water supplies, but when health aspects of sanitation systems, excreta and sewage treatments and reuse processes are considered, what is needed is not a fecal indicator bacterium but, rather, a pathogen indicator organism (Feachem et al., 1983)

6.1 Pathogen survival in soil or on crops

Whether or not the pathogens become attached to the surface of the crops depends upon the method of application and the crop. Crops grown on or near the ground are almost certain to become contaminated. Where wastes are sprayed or poured on the fields with growing crops, contamination is also certain. Crops may be protected by subsurface irrigation, by drip or trickle irrigation, where crops are not on the ground, by irrigation in furrows not immediately adjacent to the crops, or by similar techniques. Alternatively, wastes may only be applied prior to planting, or application may be discontinued one month before harvesting (with the hope that all pathogens will die before the harvest). All these methods may be effective in preventing crop contamination when the waste applied has been treated. When a waste rich in pathogens is used, however, pathogens are likely to reach the crops despite these protective strategies (Feachem et al, 1983)
Once pathogens are on the crop, survival rates are quite sufficient for viable pathogens (except perhaps protozoa) to be transported into markets, factories, homes and subsequently infect those who handle, process, prepare or eat the contaminated crops. A distinction is sometimes made between crops eaten raw (tomatoes, e.g.) and those normally cooked (such as cabbage). Conservative and appropriate public health policy regards these similarly because even if a food crop is eventually cooked, those who handle and prepare it are still at risk (Feachem et al, 1983).

For three pathogens the use of excreta on pastures or fodder crops may consist a significant factor in disease transmission: beef tapeworm infection, salmonellosis, and tuberculosis (Feachem et al, 1983).
The helminth of beef tapeworm infection (Taenia saginata) circulates between humans and cattle, but infection only continues when cattle eat Taenia eggs excreted by humans. Taenia eggs are hardy and are surpassed only by Ascaris eggs in their ability to survive outside the host. T saginata infection in humans, however, is not a major health problem in most countries (Feachem et al, 1983).
Salmonella may reach the pastures or fodder crops and may infect animals and animals may subsequently infect people. The infective dose required are high, however, and Salmonella infections are transmitted among cattle in many ways other than contaminated fodder. There is no clear evidence that cattle grazed in pastures fertilized with wastes are at more risk from salmonelloses than other cattle (Feachem et al, 1983).
Tubercle bacilli may be numerous in sewage, sludge and night soil infecting animals and subsequently humans (Feachem et al, 1983).

After disposal on land, the process of pathogen die-off continues, although at different rates for each type of pathogen, and influenced by a number of factors such as climate, soil environment, and type of plant cover, mainly. The relative importance of soil versus crops as pathogen transmission foci depends on numerous factors, including among others the soil-plant micro-climate, the type of crop (root crops vs. low-growing vs. high-growing crops), and the time and method of excreta application to the field (Strauss, 1985).

Virus

Survival in soils

Soil moisture, temperature, pH, ionic strength, organic substances, and indigenous soil microorganisms are important factors influencing the fate of viruses. All these factors are interdependent, and therefore prediction of virus survival in a soil on the basis of known soil properties is hardly possible. Nevertheless, based in the findings of several studies, a number of interferences regarding the fate of viruses in soil can be made (Strauss, 1985):

- Virus inactivation is strongly temperature dependent: survival times have been observed to vary between >180 days at 4°C, <150 days at <10°C, <50 days at 20°C and ,15 days at 25°C.
- Soil moisture is of great importance: virus survival tends to be shortened by decreasing soil moisture. Rather low moisture contents (<2%) are required to cause rapid (< 10 days at 22°C) virus die-off.
- Acid pH enhances virus survival, whereas alkaline pH leads to rapid die-off.
- Virus survival is prolonged under anaerobic as well as under sterile soil conditions. It is therefore generally inferred that aerobic soil microbial activities enhance loss of virus infectivity.
- Consequently, it may be concluded that from a hygienic point of view, drying periods of a few days should be allowed between repeated faecal waste application to the same plot. This will help to ensure soil aeration

and prevent accumulation of viable viruses.

- Virus adsorption to soil particles is an important phenomenon with a substantial impact on virus survival. Clays variably absorb viruses, which are then protected from antagonistic effects and tend to survive longer than in an unabsorbed state. Thus, viruses deposited on cultural land tend to survive longer in "heavy" (loamy, clayey) soils than in "light" (more sandy-silty) soils. While some viruses lose infectivity in an absorbed state, possibly due to key infecting sites of the virus being occupied by absorption, most of the others remain infective. Soils of high organic content (>4-6%) are bad virus absorbers. They leave the viruses exposed to adverse effects which enhance their die-off.

Data on survival times of excreted pathogens in soil at 20-30 degrees Celsius are provided in appendix 3.

<u>Survival on crops</u>
Similar to other pathogens, the risk of potential transmission of excreted viruses is mainly associated with root crops and crops with low-growing leaves or fruits. Although there is far less data available on virus survival on crops than on their fate in soil, the data indicate that the viruses die off faster and have shorter maximum survival periods on crops than in the soil (Strauss, 1985)

Data on survival times of excreted pathogens on crops at 20-30 degrees Celsius are provided in appendix 3.

Bacteria
<u>Survival in soils</u>
Conditions of relatively high soil moisture, protection from direct sunlight, and high contents of fine soil particles (loam, clay) and organic matter (nutrient supply) allow for extended survival, whereas bacterial survival is substantially shortened under direct sunlight, sandy soil and low moisture content. While the majority (90-99%) of pathogenic bacteria reaching the soil will die off relatively rapidly, i.e. within a few days or weeks, a small number of hardy organisms may survive for an extended period of time (Strauss, 1985).
Most bacterial pathogens, notably Salmonella species, have high ($>10^6$) median infective doses. The few surviving organisms which are analyzed as still viable after extended periods may therefore signify a reduced risk. It appears that in soils of warm climates most bacterial pathogens are reduced to below infective dose levels in periods shorter than vegetable growth periods. Exceptions may occur if moist, overcast weather prevails and the soil remains shaded for prolonged periods of time. Salmonella in particular appear to be good survivors under such conditions. To predict bacterial survival any closer than this is both impractical and impossible because numerous environmental factors interact with the pathogen. The most distinct lethal effects, however, comes from hot and dry conditions and solar radiation (Strauss, 1985).

<u>Survival on crops</u>
Survival on crops whose produce are in close contact with the soil, notably root crops, naturally tends to be associated with or resemble survival in or on the soil, where the soil acts as a reservoir of infection (Strauss, 1985).
Survival times of excreted pathogens on crops - with the possible exception of root crops - are shorter than in soils due to pathogens' greater exposure to climatic influences (sunshine, radiation, elevated temperatures, desiccation).
Survival periods of excreted bacterial pathogens on crops in tropical and subtropical climates also tend to be considerably shorter than the vegetation periods of some common vegetables except on root and possibly low-growing crops for which the soil rather than the plant environment is assumed to exert the controlling effect (Strauss, 1985).
Crops harvested from fields which have been fertilized with human excreta prior to planting or, at the latest, shortly thereafter may carry only few or no viable bacterial pathogens. The risk that humans become infected if consuming night soil-fertilized vegetables would accordingly be relatively small because concentration of surviving bacterial pathogens are likely to be lower than the required infective doses (Strauss, 1985).
Multiplication of bacterial pathogens on food products is possible only if specific nutrients are available to the microorganisms, and if there is a warm and humid micro-climate. Evidence on growth of excreted bacteria on raw crops is rather limited (Strauss, 1985).

Protozoa

Survival in soil and on crops

Protozoal cysts may survive for a limited period of time and are the transmitters of infection, whereas tropozoites rapid,y die upon excretion and do not play a role in transmission. It is assumed that Entamoeba histolytica is mainly transmitted by direct faecal-oral routes within homes, therefore, little attention has been attributed to its survival in nightsoil-manured soils and crops. Furthermore, cysts are difficult to detect (Strauss, 1985).

Survival of cysts appears to be largely temperature dependent unless they are exposed to particular physical stresses such as desiccation. The survival period of Entamoeba histolytica cysts in soils and on crops in warm climates tends to be of similar duration as in water or sewage (in the order of a few days) whereas Gardia lamblia cysts may survive longer in water than in soil or on crops (survival period of several weeks in water) (Strauss, 1985) Cysts are rather resistant to chemical stresses. The average cyst survival periods in soil tends to be in the order of 10 days or less (20-35°C). Survival on crops, notably on high-growing crops, is shorter than in the soil: 10 days is a conservative upper boundary, but in most cases 3 days of warm, dry weather will suffice to cause die-off of all cysts (Strauss, 1985).

Helminths

Survival in soil

Helminth survival on or in soils is dependent mainly on:

- soil type and moisture holding capacity
- actual moisture content
- exposure to protection from direct sunlight
- relative air humidity and
- temperature.

The development and survival of helminth eggs and infective stages are impeded if night soil is spread evenly on dry, sandy soils exposed to direct sunlight, and if low air humidity and high temperatures (30-35°C) prevail. Helminth development and survival are enhanced if excreta are disposed of on wetted soils possessing a substantial moisture holding capacity (soils with large clay and loam fractions or a good humus cover); when soil and faecal matter are protected from direct sunlight either by clouds or a plant cover and fairly warm temperatures (20-30°C). Thus survival might be substantial if faecal matter is disposed of in lumps in shady places (Strauss, 1985).

Water soaking of nightsoil disposal places such as paddy fields will very likely cause rapid death, probably due to lack of oxygen (Strauss, 1985).

Survival on crops

The use of nightsoil in agriculture may lead to contamination of root crops via the soil, as well as of the low-growing leaf and fruit crops. The same environmental factors which influence development and survival on soil are responsible for the fate of helminths on crops. Sunlight and desiccation are the major factors causing death or degeneration of helminth eggs on leaf or fruit crops. Survival on leaf crops tends to be shorter and egg maturation is slower than on soil. Egg inactivation lies in the order of a few weeks (as opposed to an average of up to a few months on soil). 75% relative air humidity appear to be a critical value below which helminth eggs will rapidly degenerate (Strauss, 1985).

Root crops may carry higher loads of infective pathogens than leaf crops at the time of harvest (Strauss, 1985).

In spite of adverse effects and limited survival periods on crops, viable helminths may be transmitted via vegetables if nightsoil containing high pathogen loads is spread on the crops a few weeks prior to harvesting (Strauss, 1985).

6.2 Pathogen survival in disposal facilities

Survival of pathogens is determined by the type of disposal facility.

Survival in pit latrines

Most pit latrines are filled in when 2/3 to 3/4 full and are either never dug up again or only dug up after many years. In either case pathogen survival is of no concern because all pathogenic organisms will be dead (Feachem et al, 1983).

In some areas, however, a pit is dug out a year or two after closing, and its contents are used as fertilizer. If the pit has been left for a minimum of one year, there will be no viable pathogens (except, possibly a few Ascaris eggs). The chances of viable Ascaris eggs being present are greater if the pit is wet and partly below the groundwater table. The risk involved in reusing material that has been buried for at least 12 months is small, however, and the pit contents may immediately be used on the fields with confidence (Feachem et al, 1983).

Construction, operation and maintenance of latrines rarely follow ideal patterns. It is realistic to assume that the faecal product, originating from latrine pits, has in many instances been stored for an insufficient time. Such situations may arise particularly:

- in urban areas where lack of space renders the shifting of latrine locations impossible. Single pit systems are then in permanent use and emptied upon becoming full.
- if the pits of latrines which are designed and built to operate as alternating pit systems but are in fact used simultaneously (Strauss, 1985).

When full pits need to be emptied to allow continued use, a portion of the pit content will be fresh and may contain high loads of viable pathogens. Its handling involves health risks and therefore definitely requires further storage or treatment (Strauss, 1985).

Survival in composting latrines

There are two basic kinds of composting toilets, continuous and batch. Both require the addition of a carbon source, such as garbage, vegetable leaves, or sawdust. (Feachem et al, 1983).

In both kinds of composting toilet, the composted product is used as an agricultural fertilizer and soil conditioner. It is important, therefore, that pathogen destruction should be as complete as possible. The two main factors affecting the survival of excreted pathogens are time and temperature. Temperature in a composting pit or vault depends on the air supply, the C:N ration, and the moisture content. If the digestion is anaerobic the temperature may remain ambient or it may rise at most around 35°C. If it is aerobic, the temperature will rise to 50-70°C range if the C:N ration and moisture content are correctly regulated. These conditions may be difficult to achieve, especially in arid developing countries where little organic material (needed as a source of carbon) is available for adding to the wastes. It is certain that double-vault composters will be anaerobic, an it is probable that muldrums will be also. Anaerobicity and ambient temperature certainly are the correct, conservative assumptions to make where pathogen removal is the concern. Pathogen removal then depends on the retention time in the unit. A minimum retention time of 3 months will yield a product free of all pathogens except the more persistent helminth eggs. Three possible pathogen control strategies can be adopted for these composts:

- to use the compost as produced and except the level of risk involved. The risk could be reduced to sufficient low levels by using the compost only to prepare the ground prior to planting or by not applying compost within 2 months of harvesting
- to apply the compost only to industrial or fodder crops
- to provide further treatment for the compost through heating it (probably impracticable) or through mixing it with an ovicide (also often impracticable) (Feachem et al, 1983)

Data on probable pathogen contents in the final product of anaerobic composting toilets, operating at ambient temperatures in warm climates, are provided in appendix 4.

Survival in cartage systems
Cartage systems include a variety of technologies by which night soil is periodically removed from containers in or near the house. One of the oldest - and, generally, least hygienic - systems is the bucket latrine. Many households in East Asia, and elsewhere, store their excreta (plus small amounts of water used for pour flushing or anal cleansing) in sealed vaults under or besides the house. The bucket is a smaller vessel than the vault (Feachem et al, 1983).

Vaults and buckets systems need emptying on a regular basis. Collection of night soil from vault latrines by vacuum trucks can be hygienic and risk free, provided that the outlet pipe from the vault is in good repair and that all fittings in the truck and suction hose are well maintained. A little spillage is inevitable but it can be reduced to an acceptable minimum by good equipment and well trained operating personnel (Feachem et al, 1983).

The worst system in the collection stage is the one in which buckets are emptied by hand into open carts or into larger buckets, which are then carried by hand or on yokes. Under these circumstances there will always be spillage of fresh night soil. The risk is not only to the sweepers themselves, but also to anyone who lives on or walks, plays, or works in the streets or back lanes where the night soil has been spilled (Feachem et al, 1983).

Cartage systems encompass handling of fresh excreta that may contain a high load of pathogenic organisms. Storage or treatment of the material prior to application in agriculture is thus needed.

Survival in septic tanks and aquaprivies
Aquaprivies and septic tanks produce both liquid and solid waste. The waste water comprises the greywater from bathroom, kitchen and washing activities, as well as the water used for excreta flushing (Strauss, 1985).

Two fundamental processes are affecting pathogen removal in septic tanks and aquaprivies. First, solids settle to the sludge layer at the bottom of the chamber; with them settle any bacteria or virus absorbed onto the solids and any helminth eggs or protozoal cysts sufficiently dense to settle. The settling action of the tanks is their chief function and their efficiency depends on retention time and design (particularly with regard to baffles or compartments designed to prevent hydraulic short-circuiting and to create quiescent conditions). Those pathogens which do not settle will remain in the liquid layers and eventually pass out of the tanks in the effluent (Feachem et al, 1983).
Generalizations about pathogen removal in aquaprivies and septic tanks are difficult to make because designs and retention times vary enormously[4]. Moreover, as the sludge layer of a septic tank builds up, retention times decrease and the pathogen content of the effluent increases. It is common to find operating aquaprivies and septic tanks that are long overdue desludging; in these cases any good design features and pathogen removal abilities initially present will largely have been negated by the failure to desludge at the correct regular intervals. In a septic tank having a normal retention time (1-3 days) the effluent produced will be rich in all pathogens contained in the influent (Feachem et al, 1983).

Aquaprivies and septic tanks are used predominantly in urban and peri-urban areas. Periodical emptying is needed. The waste collected is composed of excreta of variable age: some faecal solids have settled and undergone anaerobic decomposition since the previous emptying, and might therefore be half a year to several years old, depending on the number of users and emptying frequency. Another portion of the faecal solids is still fresh and undercomposed at the time of emptying. It must accordingly be assumed that the sludge removed from these units contains the whole spectrum of viable pathogens. They require further extended storage or active treatment prior to application (Strauss,

[4]The quality of aquaprivy effluent depends greatly on retention time, the system is sensitive to variations in hydraulic loading. If the loading rate is too low and the water level is allowed to fall below the drop pipe line, the result will be the release of offensive odor and, probably, large scale mosquito breeding. Attempts to guarantee and adequate level by running sullage into the tanks, however, will shorten retention times and raise pathogen content of the effluent (Feachem et al, 1983).

1985).

Survival in sewage systems
In big cities provided with underground sewage and flush systems a good deal of night-soil and urine dissolved in water used for flushing is available. This is known as sewage. In smaller towns, the bathroom and kitchen washing, urine, etc. are carried in open gutters. This is known as sullage (Gaur et al, 1984). Both the sewage and sullage are carrying fresh excreta and thus the full load of pathogenic organisms. Storage or treatment are needed before application of the material in agriculture.

7 Treatment methods

From the time of excretion, the concentration of all pathogens usually declines from the death or loss of infectivity of a proportion of the microorganisms. Viruses and protozoa will always decrease in number following excretion, but bacteria may multiply if they find themselves in a suitable nutrient-rich environment with a minimum of competition from other microorganisms (salmonella in food, E coli in chlorinated sewage effluent when many other bacteria have been eliminated). Multiplication of bacterial pathogens is generally rare, however, and is unlikely to continue for very long. Intestinal helminth - except the trematodes, which have a multiplication phase in their molluscan intermediate host - will decrease in numbers following excretion. The natural death of organisms when exposed to a hostile environment is of the utmost importance because it reduces the infectivity of excreta independently of any treatment process. In fact, some treatment processes have little effect on excreted pathogens and simply allow the necessary time for natural die-off to occur. Certain treatment processes however, create conditions that are particularly hostile to excreted pathogens and that promote their rapid death (activated sludge, thermophilic digestion). The primary objective in treatment of night soil or sewage from communities in which excreted infections are endemic is the destruction of excreted pathogens. The essential environmental factors limiting pathogen persistence are time and temperature[5]. Other conditions of the extra-intestinal environment are also important, oxygen availability and sunlight (Feachem et al, 1983).

The degree to which night soil and sewage are treated is largely influenced by what is to be done with the sludge, compost, sewage effluent. It is thus accepted engineering practice to discharge untreated sewage into the sea, provided that the outfall is designed to ensure that no pollution of beaches or shellfish-growing areas will occur; but if reuse of an effluent for the irrigation of edible crops is intended, the designer's goal should be the absence of excreted pathogens on the surface of crops, and he should accordingly design the treatment works for a very low degree of pathogen survival (Feachem et al, 1983).

In search of suitable types of treatment which would enable excreta use in agriculture, the following pathogen-related as well as socio-economic aspects must be considered:

- In order for a faecal product to be "safe" for unrestricted use as fertilizer, it is crucial that those pathogens with low infective dose be reduced to very low numbers. These are notably viruses and helminths. In addition, since helminths, particular Ascaris eggs are very persistent, they are of major concern in excreta utilization. The performance of treatment systems, including storage, should therefore be measured primarily by their potential for attaining a product which is free of or which contains a very low count of Ascaris eggs. Such product would then be also free of other pathogens.

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[5]Most organisms survive well at low temperatures. As the temperature falls survival increases; thus at 10°C, for instance, Ascaris eggs may survive for several years, enteroviruses for 12 months, and shigellae for 2-3 months. The organisms die rapidly at high temperature (>40°C). It appears that no excreted pathogen - with the exception of spore-forming bacteria (e.g., C perfringens) and possibly hepatitis A virus - can survive a temperature of more than 65°C for a few minutes.
It is useful to know the persistence of pathogens at ambient temperatures in different environments so that the likely pathogen content of various fecal products can be predicted (Feachem et al, 1983).

- In general, feasibility of treatment and type of treatment method used (including storage) depend on a number of factors: (1) the kind and degree of community and institutional organization, (2) the cultural role of excreta and its utilization, (3) excreta handling patterns, (4) economic and technical constraints (Strauss, 1985).

The treatment methods which are considered to have a reasonable good chance of success in tropical countries are: (1) thermophilic composting, (2) stabilization pond, (3) biodigesters (Strauss, 1985).

Thermophilic composting
In contrast to anaerobic composting[6] of organic matter occurring under natural conditions, aerobic composting can be induced to proceed in the thermophilic range, i.e., between 45° and 65°C. Oxygen content, carbon:nitrogen (C:N) ratio, moisture, pH and particle size are determining factors in the composting process. Organic matter subjected to optimum conditions (high oxygen content[7], C:N=20-30, moisture percentage of min. 20 and max 60%, pH 6-8, and well disintegrated waste matter) is more rapidly decomposed (within a few weeks) than if anaerobic conditions prevail (several months) (Strauss, 1985).

The application of fresh excreta induces a mesophyllic composting process, in which the temperature in the faeces pile or pit is low, and intestinal viruses and bacteria which cause diarrhoea, cholera and dysentery and parasitic eggs are not eliminated (Polprasert et al, 1981). In order to achieve a thermophilic composting conditions[8], nightsoil must be mixed with other wastes, such as manure and plant waste. These act as organic amendments and help raise the C:N ration of night soil from 10-15 to 20-30. They also act as bulking agents which contribute to the air and water control. It appears that the compost mixtures are typically composed of one part night soil and two to five parts by weight of organic amendments[9] (Strauss, 1985).

In the thermophilic composting method, faeces are ready for use in 1-2 months. The process, because of temperatures ranging from 50-60°C lends itself to rapid and effective inactivation of pathogens - including helminth eggs (Strauss, 1985). Literature indicates that a well-designed system under good management produces a pathogen-

[6]If the excreta must be quickly decomposed at an ambient temperature of 20°C, some soybean leaves should be placed in the excreta. Quick fermentation is now possible since on the soybean leaves there are some kinds of yeasts which can readily decompose and ferment the organic matters in human feces. Soybean shells and cakes can also be used instead of soybean leaves (Polprasert et al, 1981)

[7]There are three methods commonly used to sustain the supply of oxygen and therefore maintain thermophyllic temperatures: the pile is regularly turned, or ventilation tubes are arranged in the pile, or forced aeration is provided by blowers or suckers. Pathogen survival depends in compost systems depends upon the time-temperature characteristics of various parts of the pile (Feachem et al., 1983).

[8]The temperature of the feces pile rises to 50-60°C. The temperature lasts for some time before there is a gradual reduction (Polprasert et al, 1981)

[9]Composting pile alternatively spread feces and filler in thickness of 10 and 20 cm respectively. When the pile is to 1.2-1.5 meter high it is covered and surrounded with rice stubble or dried grass and finally daubed with a layer of mud about 5-7 cm thick. Superphosphate or apatite powder may also be added in layers of 1-2 cm thick to the top layers of the pile. If the quantity of excreta is insufficient and farmyard manure is available, the two can be composted together. Use 10 parts of farmyard manure to 1-2 parts of human excreta. This increases the fertility of the farm yard manure and the compost should be used on crops with a high market value, such as vegetables, potatoes and beans (Polprasert et al, 1981)

free, or almost pathogen-free, compost if all sections of the pile reach the required temperature for the required time[10] (Feachem et al, 1983).

In cities and town with large populations, the daily quantity of excreta produced is very high. With large daily quantities of faeces, the thermophilic composting method is not suitable, because an inadequate quantity of fillers, except in areas where peat and sea mud are available (Polprasert et al, 1981).

It is reasonable to assume that, if ascariasis is endemic and there is no viable Ascaris egg present in the wastes analyzed then the other pathogens are absent as well, since Ascaris eggs are so resistant. In China, standards of 95% Ascaris egg mortality have been adopted for the agricultural use of excreta (Feachem et al, 1983). Faecal coliform is particularly unsuited as faecal indicator for pathogen survival in composted faecal material, since they may regrow in finished compost (Strauss, 1985).

A graph indicating the influence of time and temperature on selected pathogens in night soil and sludge is provided in appendix 5.

Stabilization ponds
The main factor contributing to pathogen inactivation in ponds is the long retention time, which is more than 20 days in properly designed stabilization pond systems[11]. This leads to 100 percent removal of protozoal cysts and helminth eggs which settle and accumulate in the bottom sludge (Strauss, 1985). The effluent may, however, still contain viral and bacterial pathogens (Feachem et al, 1983). For good bacteria and virus removal, the waste water should pass through three or more cells connected in series with an overall retention time of ≥20 days (Strauss, 1985).

Because a routine analysis of pond effluent for pathogenic bacteria and viruses is not yet feasible (nor likely to become so in the nearest future) the choice of a suitable pathogen indicator is exceedingly difficult. Bacteriophages - and more specifically, coliphages - may provide a solution in the future but the laboratory techniques are not yet widely known. Faecal coliforms or faecal streptococci would seem an obvious choice, but there is little information on the usefulness of either as viral indicators. Effluent reuse for irrigation of crops that may be consumed raw must have faecal coliform and faecal streptococci counts that are both below 100 per 100 millilitres. Viral and bacterial pathogens may or may not be absent at these indicator organism densities, but in general the risks will be so minimal that further treatment will not normally be economic (Feachem et al, 1983)

Biodigesters
Experiments show that through biogas fermentation (anaerobic digestion of organic waste slurries) every kilogram of organic material will produce about 0.20-0.38 m^3 gas, leaving 32-60% organic C, which may serve as a source

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[10]One of the major problems in managing composting operations is fly control. Fly larvae cannot survive temperatures above 50°C, and so, as for other pathogens, the achievement of high temperatures in all parts of the pile is the essential requirement for control. Fly larvae may, however, migrate along temperature gradients to seek the cooler parts of the pile. These larvae may be destroyed by effective and well-controlled turning or by lagging unturned piles. The use of insecticides is not desirable unless it has been demonstrated that these chemicals will not affect the composting process or the acceptability of the product to farmers. Daily fly catches provides a continuous and immediate check of management and temperature control that is most useful to the staff in charge. Fly breeding will, of course, fluctuate markedly with the seasons, irrespectively of the compost pile (Feachem et al, 1983)

[11]For complete helminth removal, waste water should pass through at least 2 cells with ≥10 days total nominal retention time. In single-cell systems, retention times must be longer. Protozoa can also be completely removed, however, longer retention peiods are required and short-circuiting must be avoided. Two-cell systems with ≥15 days nominal retention are necessary (Strauss, 1985)

of organic matter (Wen, 1984).

Biogas plants do not produce pathogen free effluent and their direct use as fertilizer is therefore associated with certain risks (Strauss, 1985) If possible digester effluent should undergo additional storage before field application.

The bottom sludge of digesters, which is periodically removed to maintain proper operation, contains high concentrations of helminth eggs and must be treated further or extensively stored prior to final use (Strauss, 1985.

Data on survival of excreted pathogens during pre-application, storage and treatment in the ideal situation are provided in appendix 6.

8 Fertilizer quality influenced by storage and treatment methods

Composting is done to reduce bulk, facilitate handling and enhance nutrient concentration. Extensive microbial decomposition during composting stabilizes an organic material. Subsequently on field use a manure is slower to act compared to fresh plant and animal residues (Katyal, 1993).

It should be mentioned that although composting increases the concentration of heavy metals due to the weight loss sustained by the fresh products during the process, the extent to which some of the metals can be taken up by plants decreases since the stabilized organic matter of the composts can form complexes with part of the metals, rendering them insoluble to plants. Some metals can also become insoluble due to the formation of oxides, hydroxides, or salts (Ayuso et al, 1996).

Biological tests which were carried out, have shown that when fresh materials (particularly sewage sludge) are used, seed germination is strongly inhibited, the degree of inhibitation decreasing as wastes with a more stabilized organic matter are used. Since most of the organic products which can be considered phytotoxic and which may be found in these wastes (phenols, residues from herbicides and pesticides, organic acids with a low molecular weight, etc.) are degraded during the composting, the inhibitory effect on seed germination of those composts is less pronounced than that of fresh products (Ayuso et al, 1996).

A serious problem that faces all agricultural scientists when investigating the production of organic fertilizers is the large loss of N-nutrient from the fertilizer products[12]. Human faeces contain not only species of microorganisms which catalyze the formation of ammonia, but also many other species which contribute to the process of decomposition of the organic matters containing nitrogen (nitrosomonas, nitrobacter, etc). (Polprasert et al, 1981). Polprasert et al (1981) suggest the following measures to reduce N-losses during composting: (a) the composting house must be roofed and have a hard floor, (b) the faeces must be mixed with fillers (soil powder, superphosphate, apatite powder), (c) the faeces pile mast be tightly daubed with mud.

Fresh urine is generally free from bacteria and viruses and can be used directly in agriculture. Once outside the human body, urine is quickly hydrolysed by microorganisms which cause ammonification and the loss of N-nutrient. The smell which is detectable around urine tanks is due to the evaporation of ammonia. To limit the loss of N-nutrient from urine:

- the urine tank or container should be covered.
- a layer of kerosene or vegetable oil should be poured on the layer of urine.
- superphosphate should be added (reactions occur between the ammonia and super phosphate and ammonium sulphate and phosphate is formed, which prevents the evaporation of ammonia (3% superphosphate for each portion urine).

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[12]Method of composting is crucial in preserving the N contained in an organic waste. Between 20-50% N value of an organic manure is lost if composting is done in heaps (aerobic) than in pits (anaerobic) (Katyal, 1993)

- dried rubbish and soil powders should be added (2-3 portions soil powder for each portion urine).
- the use of ashes contributes to the N-loss in urine. The alkaline compounds in the ashes cause the evaporation of ammonia (Polprasert et al, 1981)

Sanitation system determines the conditions for recycling. Dry or water-borne systems influence the recycling possibilities because of technical constraints and the difference in appearance of the waste product from the different sanitation systems.

For example, in China, Subba Roa et al (1993) noted that "Since domestic waste disposal methods have improved, most of the human waste is diluted and sent to a septic system and not collected for further use. In the near suburbs of cities, some diluted human wastes are transported to vegetable fields. However, this is rarely undertaken because of the labour-intensive and unpleasant nature of the work.

9 Application of human excreta to the field

When waste is recycled in agriculture, the soil should not be treated as a dumping ground. Its physical, chemical, biological and use-capability characteristics have to be respected and taken into account. The soil is a living and breathing system which can be choked and damaged if its capacity to absorb and retain water, to keep a balance in air/water relations and the needs and limitations of the diverse organisms which live in it are lost sight of. The term "loading rate" which is often used by environmental engineers to describe the rate of waste discharge/application needs to be integrated with the soil's assimilation rate as far as the farming sector is concerned (Tandon, 1995)

Agricultural soil should always be treated with a composted product, while it is possible to use fresh wastes on a degraded soil which should be rehabilitated and where the physical, chemical and biological properties need to be improved since there will be no negative influence on these properties (Ayuso et al, 1996).

The fertility of fresh excreta is wasted if it is applied directly. Experiments have shown that with the same amount of faeces, the composted faeces help to increase crop yields by 20-25% as compared with fresh faeces (Polprasert et al, 1981).

The method of application of farmyard manure generally adopted in India is defective. Most of the cultivators unload farmyard manure in small piles in the fields and leave it as such for a month or so before it is spread and subsequently ploughed in or disced in the field. Plant nutrients are lost considerably during the exposure of the manure to sun and rain. In summer, it results in rapid drying and considerable loss of nitrogen, whereas in the rainy season the available nitrogen and a good portion of soil humus are washed away. In order to derive maximum benefit, farmyard manure which has been brought to the fields should be immediately spread and mixed in the soil. Manure can also be applied in furrows (Gaur et al, 1984).

Human faeces and urine produce very little humus, or none as in the case of urine. Therefore they should not be used as a basal dressing or the main fertilizer, because the valuable nutrients would be wasted and the soil would become aggregated and compacted (Polprasert et al, 1981).

Composted human faeces and urine contain a higher percentage of N-nutrient than many other organic fertilizers. About 80% of the total available N-nutrient is in the form of ammonia which can be easily absorbed by crops. The composts can cause crops to overgrow and produce underdeveloped grains if they are applied in large amounts, and moreover, the extra amounts are used by weeds and/or wastefully washed away (Polprasert et al, 1981).

Composted human faeces and urine should because of their high fertility and easy availability, only be used for dressing application and on crops with high market value (Polprasert et al, 1981)
Considering the high concentration of nutrients in human excreta, it should be effectively utilized for growing plants.

The first priority should be for the use of treated excreta or waste water for growing trees. The second in order or priority is the use in growing food grains and cereals. Growing vegetables is the next in the sequence of priorities (higher chance of infection) (Panicker in Tandon, 1995).

Treated effluent is used for purposes of irrigation and fertilization. Since available sewage and sullage water are in quite a concentrated form, its dilution with the raw water in the proportion 1:1 has been found to be beneficial. The raw water may either be from well, tube-well or river. Sewage and sullage waters have been estimated to give 30-50% increase in yield of food crops and 100% increase in fodder yields as compared to ordinary irrigation water. Fodder crops like oats, berseem, and lucerne, cereals like rice, wheat, bajra, jowar etc., fruits like papaya, banana, etc. and sugarcane used for gur or sugar making but not for chewing, and vegetables eaten in a cooked form could be grown with considerable profit (Gaur et al, 1984)

Urine contains 2-3% urea, some uric acid, hippuric acid etc., which are beneficial to crops when hydrolysed to ammonia. However, concentrations of urea greater than 0.05% can be toxic to some crops. Urine also contains about 33% mineral salts and therefore it should not be applied to crops such as sugar cane where it reduces the sugar content and tobacco where it lowers the quality (Polprasert et al, 1981)

Heavy metals and phytotoxic substances
Municipal sewage may contain high concentrations of heavy metals which may prove toxic to plants. The excessive amounts of these metals are added into sewage through discharge of industrial wastes without pre-treatment. The elements of general concern are B, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, and Zn. The presence of large quantities of heavy metals such as Zn, Cu, Ni, Cd, Pb and further pollution with industrial organic wastes make them unsuitable for land application. These elements can be toxic to plants grown on sewage amended soils or to the animals which consume these plants (Gaur et al, 1984).

Germination experiments on aqueous extracts of municipal wastes can reveal the possible degree of phytotoxicity of the products contained in these wastes (Ayuso et al, 1996). The presence of these substances indicates that the use of the wastes is not advisable or, at least, that their use should be limited in terms of the amount applied or the frequency of application (Ayuso et al, 1996)

10 Conclusion, discussion and recommendations

Human excreta have potential to contribute to the productivity and sustainability of agricultural systems through an increase in soil fertility, and therefore to food security at household level. Human excreta are a rich organic fertiliser. In addition, faeces, like other organic fertilisers, have long-term beneficial effects on the soil: it amends the soil's organic and humus fraction, an advantage not offered by mineral fertilisers. Humus, in turn, helps to maintain soil characteristics as moisture and air regulation as well as nutrient storage and release.
The use of human excreta as fertiliser in agriculture has proved to be feasible, acceptable and a very ancient practice in the majority of Asian countries. In China, for example, over 90% of the national night soil (faeces and urine) production is applied to the land. This represents fully one third of all nutrients actually used by the crops. In Africa, there is no tradition in the use of human excreta in agriculture.

There is considerable scope to improve the exploitation of human excreta (faeces and urine) in sub-Sahara Africa. The human excreta potential is about 27 million tonnes annually, providing 2.2 million tons of nitrogen, 0.5 million ton of phosphor (P_2O_5), and 0.4 million tons of potassium (K_2O).

Excreta carry many pathogens, depending on the diseases endemic in the society. Use of excreta should always be accompanied by appropriate treatment of the material, to ensure the principals of sanitation to continue: decreasing the occurrence of excreta-related diseases. Present treatment methods have proven to produce a pathogen-free product from the excreta that poses no public health risk.

In sub-Saharan Africa, sanitation (collector of excreta), waste management (disposer of excreta) and agriculture (potential user of excreta) have been operating in isolation. Since the Sanitation Decade (1981-1990), the coverage of latrines has increased to 35% in the rural areas. This increased coverage and the lack of integration between the agricultural, sanitation and waste management sectors implies that sanitation facilities form a permanent drain of nutrients from the agricultural systems.

The use of human excreta as fertiliser in agriculture implies that the agricultural, sanitation, and waste management sectors are linked. Apart from beneficial effects on agricultural systems (improved soil fertility and food security), the use of human excreta as fertiliser will have beneficial spin-off effects on the sanitation sector and the waste management sector. The sanitation sector will be given a new impetus, because excreta will be no longer considered a cause of nuisance to be abated, but rather a valuable source. This will motivate people to empty, use, and maintain sanitary facilities. A high degree of coverage and use is a prerequisite to assure health benefits from sanitary facilities. Agriculture directs curative health care towards preventive health care. In addition, the recycling of excreta effectively reduces waste management problems. Agriculture has a great renewed opportunity in being not only the food supplier for the whole society, but also the waste collector and receiver.

The following factors determine the possibilities for the use of human excreta in agriculture:

Demographic factors	density and structure of population urbanisation availability of agricultural land availability of space for sanitary purposes infrastructure
Factors in the agricultural sector	food security level demand for agricultural products productivity and sustainability of agricultural systems soil fertility level need for fertilisers availability of mineral and organic fertilisers crop response to fertiliser tradition in nutrient re-usage in agricultural system
Factors in the sanitation sector	type of facilities sustainability of facilities emptying possibilities available equipment coverage of facilities use of facilities policies of sanitation programs
Factors in the waste management sector	available equipment methods of collection possibilities to recover nutrients in waste policies in waste management
Socio-cultural factors	cultural values attached to raw and processed human excreta perception of value of raw and processed excreta type of religion and interpretation/influence of religious laws gender roles convenience and comfort of sanitary facilities

	commitment of households to use and maintain sanitary facilities education level awareness of production processes related to distance between food producer and consumer
Economical factors	commercial value of excreta and market possibilities costs of constructing, maintaining and emptying sanitary facilities cost of mineral and organic fertilisers price of agricultural commodities need for employment (inter)continental trade
Political factors	subsidies legislation institutionalisation promotion control training
Institutional factors	organisation of and structures among farmers involvement, responsibilities and mandates of - private sector - non-governmental organisations - local authorities - national government
Medical factors	presence of pathogenic organisms pathogen survival in disposal facilities infection routes infective doses immunity level of diseases of population level of medical care possibilities for immunisation knowledge of diseases
Treatment factors	methods of treatment required period of time for treatment transformation of excreta to socially accepted manure contamination of excreta with heavy metals or phytotoxic substances

These factors are dynamic, and form either constraints or opportunities to the use of human excreta in agriculture, depending on the specific setting. Because these factors were never related to each other, it is not clear how opportunities outweigh constraints. Socio-cultural factors (e.g. taboos) are often called the major constraints to the use of human excreta as fertiliser in sub-Sahara Africa.

The changing socio-economic environment in sub-Sahara Africa today is providing new opportunities for the use of human excreta as fertiliser.

First of all, *increased demands for agricultural products, decreasing soil fertility levels, increasing prices for mineral fertiliser and increased poverty* are changing the ideas about the value of waste, and have created opportunities for the use of human excreta as fertiliser. In general, the use of excreta is dictated by survival economies. It is used in societies, where intensive cultivation practices have evolved in response to the need to feed a large number of people living in an area of limited land availability, necessitating the careful use of all the resources available to the community, including excreta. This situation is comparable to sub-Saharan societies, where agricultural practices have changed from land abundance and shifting cultivation to intensive cultivation, due to increased demands for agricultural products.

The second opportunity to the use of human excreta in agriculture is provided by *increased demands for employment and food, and increased poverty*, leading to the development of initiatives in the collection and use of human excreta. The occupation of people handling excreta may be in strong demand if alternative sources of employment are unavailable. Within Africa's sprawling peri-urban, there are reports of ingenious informal sector uses for a variety of waste products (e.g. fishing, often illegally, in waste stabilisation ponds is reported from several cities).

The third opportunity to the use of human excreta is provided by *urbanisation*. Crowded urban environments imply that space becomes scarce. People are urged to use latrines, because the bush becomes inaccessible. They are urged to empty sanitary facilities when space to build new latrines becomes unavailable.

The fourth opportunity to the use of human excreta is created by *new policies in the sanitation and the waste management sectors*, claiming that sustainability of sanitation programs demands their being part of a long term, overall health, community welfare, and socio-economic planning, including environment, agriculture and education. Policy instruments have been proven a strong instrument in changing sanitation and waste management practices.

Literature on sub-Sahara Africa is not complete and not current enough to make a definite statement on the possibilities for the use of human excreta as fertiliser. A diagnostic research, considering all factors and the opinions of all stakeholders in the agricultural, sanitation and waste management sector, is necessary to understand possibilities of the use of human excreta as fertiliser in agriculture in sub-Sahara Africa.

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Appendix 1 Quantities of excreta and urine produced daily by one person and their nutrient contents

Production of faeces per person		Production of urine per person		Source
Quantity (kg/d)	Moisture content (%)	Quantity (l/d)	Moisture content (%)	
1.3-5.2	75-90	1-1.3	-	Feachem et al, 1983 1)
1.35-2.7	66-80	1.0-1.3	93-96	Popel, 1982; Mara, 1976; Gotaas, 1956
1.33	-	1.2	-	Gaur et al, 1984
1.3-1.4	77	1.5	95	Polprasert et al, 1981
1.0-4.0	70-85	1-1.3	93-96	Panicker, 1995

1) In calculations, the production of faeces per person is assumed to be 3.5 kg/day for rural areas and 2.5 kg/day for urban areas. The production of urine per person is assumed to be 1.2 l/day for both rural and urban areas.

Quantity of nutrients in faeces per person			Quantity of nutrients in urine per person			Source
N (g/d)	P_2O_5 (g/d)	K_2O (g/d)	N (g/d)	P_2O_5 (g/d)	K_2O (g/d)	
5.0-7.0	3.0-5.4	1.0-2.5	15-19	2.5-5.0	3.0-4.5	Panicker, 1995; Feachem et al, 1983; Popel, 1982; Gotaas, 1956
4.8	3.69	1.65	19.2	2.90	3.50	Polprasert et al, 1981[13]

Quantity of nutrients in excreta produced by one family			Members per family	Source
N (kg/y)	P_2O_5 (kg/y)	K_2O (kg/yr)		
13	3.2	2.4	5	Polprasert et al, 1981
3.2	1.4	1.0	5	Strauss, 1990 1)
5.1	1.2	1.1	1	Gaur et al, 1984
2.0	0.4	1.0	1	Hesse, 1984

1) Assumed is a 30-50% loss of nitrogen contained in the urine as ammonia due to anaerobic fermentation

[13]Research carried out in India showed that a man in a moderate level egion discharged about 60 kg excreta and 300 kg of urine. In Japan these figures are 72 kg excreta for an adult and 26.5 kg for a child. In China, it is 42.5 kg per capita (Polprasert et al. 1981)

Appendix 2 Basic epidemiological features of excreted pathogens by environmental category

Pathogen	*Excreted load*[a]	*Latency*[b]	*Persistence*[c]	*Multiplication outside human host*	*Median infective dose* (ID_{50})	*Significant immunity?*	*Major nonhuman reservoir?*	*Intermediate host*
CATEGORY I								
Enteroviruses[d]	10^7	0	3 months	No	L	Yes	No	None
Hepatitis A virus	10^6(?)	0	?	No	L(?)	Yes	No	None
Rotavirus	10^6(?)	0	?	No	L(?)	Yes	No(?)	None
Balantidium coli	?	0	?	No	L(?)	No(?)	Yes	None
Entamoeba histolytica	10^5	0	25 days	No	L	No(?)	No	None
Giardia lamblia	10^5	0	25 days	No	L	No(?)	Yes	None
Enterobius vermicularis	Not usually found in feces	0	7 days	No	L	No	No	None
Hymenolepis nana	?	0	1 month	No	L	Yes(?)	No(?)	None
CATEGORY II								
Campylobacter fetus ssp. *jejuni*	10^7	0	7 days	Yes[e]	H(?)	?	Yes	None
Pathogenic *Escherichia coli*[f]	10^8	0	3 months	Yes	H	Yes(?)	No(?)	None
Salmonella								
S. typhi	10^8	0	2 months	Yes[e]	H	Yes	No	None
Other salmonellae	10^8	0	3 months	Yes[e]	H	No	Yes	None
Shigella spp.	10^7	0	1 month	Yes[e]	M	No	No	None
Vibrio cholerae	10^7	0	1 month(?)	Yes	H	Yes(?)	No	None
Yersinia enterocolitica	10^5	0	3 months	Yes	H(?)	No	Yes	None
CATEGORY III								
Ascaris lumbricoides	10^4	10 days	1 year	No	L	No	No	None
Hookworms[g]	10^2	7 days	3 months	No	L	No	No	None
Strongyloides stercoralis	10	3 days	3 weeks (free-living stage much longer)	Yes	L	Yes	No	None
Trichuris trichiura	10^3	20 days	9 months	No	L	No	No	None
CATEGORY IV								
Taenia saginata and *T. solium*[h]	10^4	2 months	9 months	No	L	No	No	Cow (*T. saginata*) or pig (*T. solium*)

CATEGORY V								
Clonorchis sinensis[i]	10^2	6 weeks	Life of fish	Yes[j]	L	No	Yes	Snail and fish
Diphyllobothrium latum[i]	10^4	2 months	Life of fish	No	L	No	Yes	Copepod and fish
Fasciola hepatica[h]	?	2 months	4 months	Yes[j]	L	No	Yes	Snail and aquatic plant
Fasciolopsis buski[h]	10^3	2 months	?	Yes[j]	L	No	Yes	Snail and aquatic plant
Gastrodiscoides hominis[h]	?	2 months(?)	?	Yes[j]	L	No	Yes	Snail and aquatic plant
Heterophyes heterophyes[i]	?	6 weeks	Life of fish	Yes[j]	L	No	Yes	Snail and fish
Metagonimus yokogawai[i]	?	6 weeks(?)	Life of fish	Yes[j]	L	No	Yes	Snail and fish
Paragonimus westermani[i]	?	4 months	Life of crab	Yes[j]	L	No	Yes	Snail and crab or crayfish
Schistosoma								
S. haematobium[h]	4 per milliliter of urine	5 weeks	2 days	Yes[j]	L	Yes	No	Snail
S. japonicum[h]	40	7 weeks	2 days	Yes[j]	L	Yes	Yes	Snail
S. mansoni[h]	40	4 weeks	2 days	Yes[j]	L	?	No	Snail
Leptospira spp.[k]	urine(?)	0	7 days	No	L	Yes(?)	Yes	None

L Low ($<10^2$); M medium ($\approx 10^4$); H high ($>10^6$).

? Uncertain.

a. Typical average number of organisms per gram of feces (except for *Schistosoma haematobium* and *Leptospira*, which occur in urine).

b. Typical minimum time from excretion to infectivity.

c. Estimated maximum life of infective stage at 20°–30°C.

d. Includes polio-, echo-, and coxsackieviruses.

e. Multiplication takes place predominantly on food.

f. Includes enterotoxigenic, enteroinvasive, and enteropathogenic *E. coli*.

g. *Ancylostoma duodenale* and *Necator americanus*.

h. Latency is minimum time from excretion by man to potential reinfection of man. Persistence here refers to maximum survival time of final infective stage. Life cycle involves one intermediate host.

i. Latency and persistence as for *Taenia*. Life cycle involves two intermediate hosts.

j. Multiplication takes place in intermediate snail host.

k. For the reasons given in chapter 1, *Leptospira* spp. do not fit any of the categories defined in table 2-2.

Appendix 3 Survival times of excreted pathogens in soil and on crops at 20-30 degrees Celsius

Pathogen	Survival time (days)
Viruses	
Enteroviruses[a]	<100 but usually <20
Bacteria	
Fecal coliforms	<70 but usually <20
Salmonella spp.	<70 but usually <20
Vibrio cholerae	<20 but usually <10
Protozoa	
Entamoeba histolytica cysts	<20 but usually <10
Helminths	
Ascaris lumbricoides eggs	Many months

a. Includes polio-, echo-, and coxsackieviruses.

Pathogen	Survival time (days)
Viruses	
Enteroviruses[a]	<60 but usually <15
Bacteria	
Fecal coliforms	<30 but usually <15
Salmonella spp.	<30 but usually <15
Shigella spp.	<10 but usually <5
Vibrio cholerae	<5 but usually <2
Protozoa	
Entamoeba histolytica cysts	<10 but usually <2
Helminths	
Ascaris lumbricoides eggs	<60 but usually <30

a. Includes polio-, echo-, and coxsackieviruses.

6. These reports are reviewed in the appropriate sections of Part Two, chapters 9 through 35.

Appendix 4 Probable pathogen contents in the final product of anaerobic composting toilets, operating at ambient temperatures in warm climates

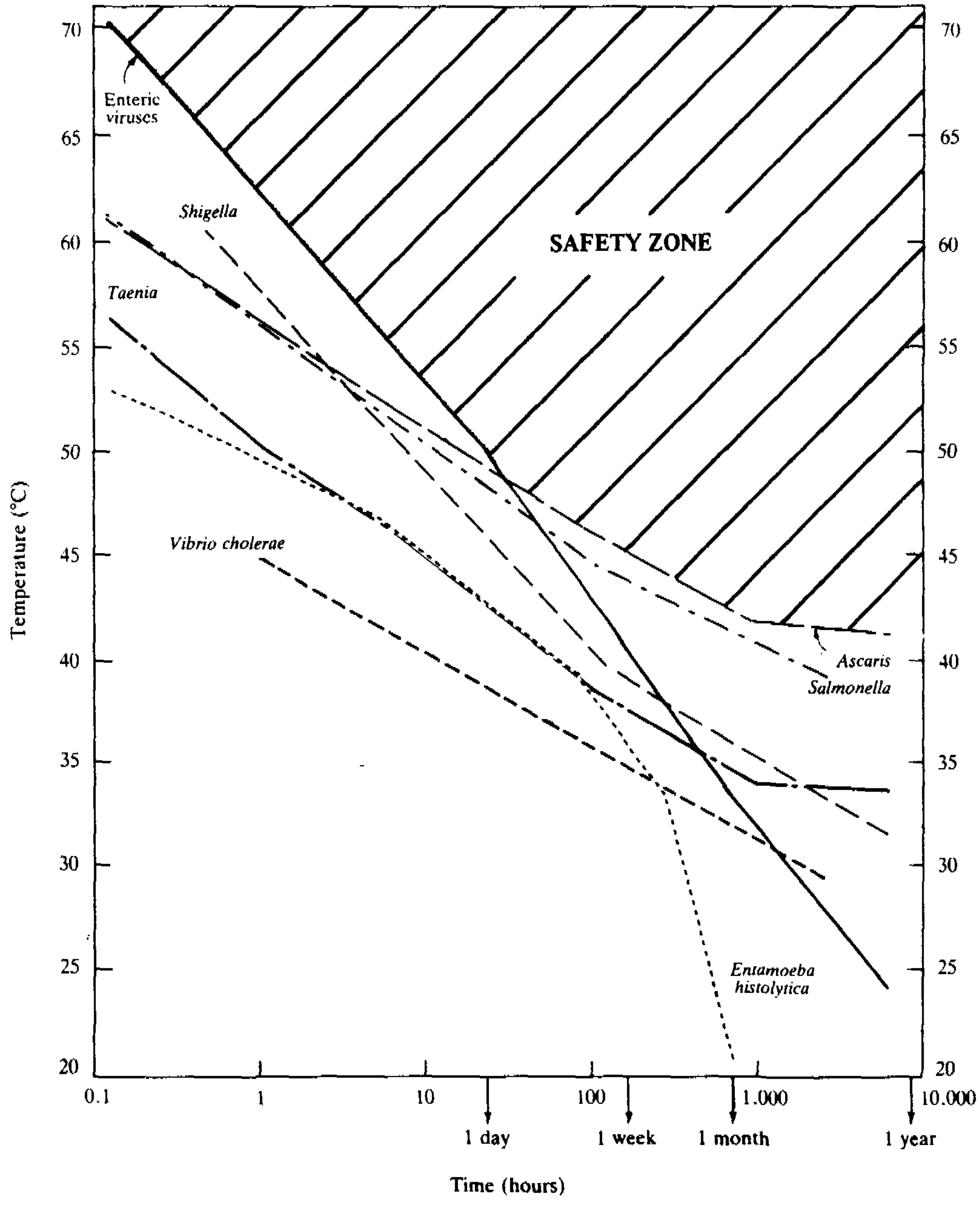
Pathogen	*Retention time* (months)						
	1	2	3	4	6	8	10
Viruses							
Enteroviruses[a]	+	+	0	0	0	0	0
Bacteria							
Fecal coliforms	+	+	0	0	0	0	0
Leptospira spp.	0	0	0	0	0	0	0
Salmonella spp.	+	+	0	0	0	0	0
Shigella spp.	+	0	0	0	0	0	0
Vibrio cholerae	+	0	0	0	0	0	0
Protozoa							
Balantidium coli	+	0	0	0	0	0	0
Entamoeba histolytica	+	0	0	0	0	0	0
Giardia lamblia	+	0	0	0	0	0	0
Helminth eggs							
Ascaris lumbricoides	++	++	++	++	+	+	+
Hookworms[b]	+	+	0	0	0	0	0
Schistosoma spp.	0	0	0	0	0	0	0
Taenia spp.	++	++	++	++	+	+	+
Trichuris trichiura	++	++	+	+	+	+	0

0 Complete elimination; + low concentration; ++ high concentration.

a. Includes polio-, echo-, and coxsackieviruses.

b. *Ancylostoma duodenale* and *Necator americanus*.

Appendix 5 Influence of time and temperature on selected pathogens in night soil and sludge



The lines represent conservative upper boundaries for pathogen death—that is, estimates of the time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effects falling within the "safety zone" should be lethal to all excreted pathogens (with the possible exception of hepatitis A virus at short retention times). Indicated time temperature requirements are at least: 1 hour at ≥62°C, 1 day at ≥50°C, and 1 week at ≥46°C. For more detail on the time-temperature combinations lethal to these and other pathogens, see the graphs in chapters 9, 15–17, 20, 22, 23, 32, and 34 of Part Two (from which this composite was made)

Appendix 6 Survival of excreted pathogens during pre-application, storage and treatment in the ideal situation

Storage/Treatment System	Ideal-World System Characteristics Relevant for Pathogen Die-off/Survival	Survival of Pathogens			
		Helminths	Viruses	Bacteria	Protozoa
· Pit-Type Latrines:					
- Pit Latrines w. 1 Pit	Latrine abandoned when pit is full; contents let to rest for $t \geq 1$ year	◑[3]	○	○	○
- Pit Latrines w.2 Pits	$t \geq 1$ year	◑[3]	○	○	○
- Double-vault ("Vietnamese"-type) Latrines	t = 4-8 months; urine separation, dry conditions; use of ash	○[3]	○	○	○
- Pour-Flush L. w. 1 Pit	(Handling of fresh excreta when emptying pit)	●	●	●	●
- Pour-Flush L. w.2 Pits	$t \geq 1$ year	◑[3]	○	○	○
· Aqua Privies and Septic Tanks[1]	Continuously operated systems: always contain portions of fresh excreta at times of emptying	●	●	●	●
· Thermophilic Composting	T = 50-70°C, $t \geq 1$ day T = 40-45°C, $t \geq 1$ week for all parts of waste piles	○	○	○	○
· Biogas Digesters	$t \geq 60$ days, T = 30-35°C; effluent draw-off from bulk slurry not from settled sludge	●	◑	◑	○
· Waste Stabilization Ponds[2]	$t \geq$ 20-30 days; min. 3 cells in series; no short-circuiting	○	○	○	○

○ - zero or near-zero survival
◑ - survival in low concentrations
● - survival in substantial "
t - excreta retention time
T - temperature

[1] Survival in sludge
[2] Survival in treated wastewater (assumption that desludging is not required)

[3] Possible survival of *Ascaris* eggs