IRCWD Report No. 04/85

HEALTH ASPECTS OF NIGHTSOIL AND SLUDGE USE IN AGRICULTURE AND AQUACULTURE

Part I
Existing Practices and Beliefs in the Utilization of Human Excreta

PIERS CROSS

Part II
Pathogen Survival

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Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland

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WASTEWATER REUSE

Farmers in Tula river basin, Mexico, irrigating a chili field with wastewater from Mexico City (Photo by Ursula Blumenthal).

USE OF STORED NIGHTSOIL

Removal of decomposed, humus-like material from a dry-alkaline-fertilizer ("DAF") latrine in Guatemala. This material is used on the fields as soil conditioner and fertilizer.

NIGHTSOIL FERTILIZATION OF FISH PONDS

Excreta fertilization of small fish or vegetable ponds through the use of overhung latrines is an old tradition in the Indonesian highlands. Fish and vegetables are always consumed cooked.

This fish pond owner grows fingerlings in his excreta-fertilized pond in Bogor, Indonesia. Others buy the fingerlings and grow them to consumable size in ponds not receiving any excreta.

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FOREWORD

Animal and human wastes have been used in all parts of the world and for many centuries to fertilise fields and ponds where fish and aquatic vegetables are grown. No country could afford to waste this important nutrient source. However, only in the last few decades, after having developed a high energy consuming technology to produce mineral fertilisers, many industrialized countries ceased to recycle the nutrients contained in faecal wastes. This tendency was probably reinforced mainly by the increasing awareness of the health risks related to the use of faecal matter in agriculture, and by the low energy prices. In the United States for instance, where energy prices were very low until recently, it is still common practice to incinerate the sludge produced in communal sewage treatment plants, whereas in many European countries, where energy prices have always been considerably higher, all the animal manure and most of the sludge generated from human waste is applied to fields after appropriate treatment. As a result of increasing energy prices, the growing awareness of natural resource limitations, and for ecological reasons in general, the concept of recycling nutrients has recently regained popularity in the industrialized countries. Unfortunately, these countries are faced today with a new problem: the contamination of sludge with heavy metals and other industrial pollutants is limiting sludge use in agriculture.

Unlike the situation in industrialized countries, in most developing countries animal and human excreta have always been regarded as the most important and often only affordable nutrient source in agriculture and aquaculture. Due to economic reasons, the concept of recycling nutrients was never abandoned in these countries. In many countries in Asia, even raw or only marginally treated human excreta (nightsoil) are traditionally and widely used to fertilise fields and fish ponds. Such practices create potential health risks to those who consume vegetables or fish grown there. Over the past decades, research has been focused on the potential health risks associated with the outside-host environment, i.e. in water, wastewater, sludge, soil and on crops. However, relatively little is known about how and to what extent disease transmission is really associated with the practice of recycling nutrients of human wastes. Nor does one know much about the relative importance of excreta fertilisation in comparison with other possible routes of pathogen transmission. Consequently, existing basic concepts and standards relating to the use of human wastes have been based on potential risks and are therefore very conservative. However, unduly restrictive standards on human waste reuse which are not justified on health grounds, can lead - especially in countries with great economical difficulties - to situations where unregulated reuse projects become tacitly accepted even if they actually pose real health risks.

In 1982, the International Reference Centre for Wastes Disposal (IRCWD), in collaboration with WHO, started a project on the actual (as opposed to the theoretical or potential) health risks related to the use of human excreta. A further objective of the project is to highlight sociocultural, technical and institutional aspects of such excreta-use practices. In the first phase of the project three state-of-knowledge reviews were prepared based on three types of perspectives. Part I, prepared by Piers Cross, a sociologist presently working in Harare, Zimbabwe, highlights cultural differences in excreta management practices, discusses beliefs and habits, and suggests ways to strengthen the role of sociocultural perspectives in programmes dealing with excreta disposal and hygiene-related problems. Part II presents compiled information reviewed by Martin Strauss, a sanitary engineer working at IRCWD, on survival of excreted pathogens in excreta and faecal sludges prior to utilisation (i.e. during storage and treatment), and reports about the fate of these pathogens in the soil, on crops and in nightsoil-enriched fish ponds. Part III has been prepared by Deborah Blum and Richard Feachem of the London School of Hygiene and Tropical Medicine, with the objective of providing an overview of the existing documented epidemiological evidence regarding disease transmission through nightsoil and sludge use as a fertiliser. It highlights gaps in epidemiological knowledge and outlines possible epidemiological approaches to field investigations of health risks of excreta use.

The reviews presented in this publication series focus on the use of excreta, nightsoil and sludge, and not on the use of wastewater for agricultural purposes. This separation is artificial and was done for practical reasons only. It is even reasonable to assume that the range of pathogens is the same for both nightsoil and wastewater, and that health risks associated with their use as fertilisers are of a similar nature. The World Bank as executing agency for the United Nations Development Programme (UNDP) on the Integrated Resource Recovery Project, has commissioned a team of consultants headed by Professor Hillel Shuval to do a parallel review on the health effects of wastewater irrigation. This report "Wastewater Irrigation in Developing Countries" has been published as World Bank Technical Paper Number 51.

The project on the "Health Aspects of Nightsoil and Sludge Use in Agriculture and Aquaculture" will continue. After field visits to several countries where use of human wastes is practised, we hope that further epidemiological studies will be initiated and conducted in the near future. Based on these field visits, a further report describing actual case studies will be prepared and published as Part IV of this publication series. On the same topic "Wastewater and Excreta Use in Agriculture and Aquaculture", Engineering and Managerial Guidelines for Health Risks Minimization are presently being prepared for UNEP/WHO by Professor Duncan Mara and Dr Sandy Cairncross.

I would like to express my gratitude to all the people involved in this interdisciplinary project for their enthusiasm and good collaboration. particularly to Deborah Blum, Ursula Blumenthal, Piers Cross. Richard Feachem. Gunnar Schultzberg, Martin Strauss and Somnuek Unakul.

Roland Schertenleib
Director IRCWD

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Piers Cross
Martin Strauss

SUMMARY
(Parts I, II and III)

Fertilization of fields and fish ponds with human faecal wastes is a century-old practice in many areas, particularly in Asian countries. There, the utilization of faecal wastes appears to be rooted in the society's concept of economic use of valuable nutrient resources to sustain food production. Elsewhere, utilization of faecal wastes, whether treated or untreated, is abhorred. Religious cultural and aesthetic norms prohibit the use of nightsoil. Embedded in this may also be the notion that excreta are sources of pathogens and therefore pose a potential health risk.

Part I of this document focuses on the sociocultural aspects of excreta utilization. **Part II** deals with the potential health risks resulting from the survival of excreted pathogens in soil, on crops and in fish. The role of excreta as fertilizer is discussed in the **Introduction.** A review of existing epidemiological evidence (Part III) which allows to determine actual - as opposed to potential - health risks, forms a separate document (Blum and Feachem 1986). Its summary is contained in the introductory chapter of this document.

Human excreta contain the major nutrients essential for plant growth. Phosphorus and potassium occur in similar concentrations as in other organic fertilizers, whereas nitrogen concentrations are high if urine is conserved. The application of nightsoil to fields and fish ponds takes on various forms: in some places, it is collected daily from family latrines, carried to the site of application and applied to the field either untreated or stored (and dried) prior to fertilization. Elsewhere it is collected periodically from individual latrines on a community or town basis and discharged in a controlled or uncontrolled manner. In China, nightsoil is often mixed with other organic material (e.g. manure, plant residues) and composted prior to utilization. In fish ponds, nightsoil enhances bacterial and algal growth. Algae and their direct predators become the food of fish. Carp and *Tilapia* are the most common species raised in such ponds.

Based on secondary sources, **Part** I considers the sociocultural dimension to the usage of human excreta. Behavioural, cultural and social factors are distinguished as being of importance in programmes promoting excreta usage. Three case-studies are presented to illustrate the manner in which sociocultural factors influence excreta utilization: China, where reuse of human excreta is an ancient and well-accepted custom; Islamic cultures in many of which contact with human excreta is abhorred; and Subsaharan African cultures in which little usage of excreta is practised but where there are no overriding religious convictions prohibiting its use.

The chapter argues that sociocultural factors are of significance both to the adoption and improvement of excreta utilization. In the latter cases, improvements in post-defecation hygiene and in behavioural patterns in collection, storage, treatment, and excreta usage may be crucial in limiting disease transmission. In cultures which do not use human excreta, the question of the cultural acceptability of excreta use innovations is of great importance. This question needs to be tackled with considerable sensitivity: culture is not an invariable entity and acceptance depends to a large extent on the method of approach and the level of communications support promoting the innovation. The paper presents examples of approaches which may facilitate cultural acceptance.

Notwithstanding several calls for further research on sociocultural aspects of human excreta utilization, little serious research has been carried out. The section concludes that such research become a priority and that social anthropological field methods be adopted as the principal methodology for this research. Priority social research topics are proposed. These include: applied research into cultural constraints in human excreta use in cultures in which the use of human excreta is not practised; the development of strategies and communications support components to promote excreta utilization; measurement of the real value of benefits against the costs of both physical and educational programme inputs to make reuse innovations viable; and joint anthropological/epidemiological research on actual excess disease transmission risks in areas in which human excreta are used.

Part II comprises the state of knowledge review on excreted pathogen survival on crops, in soil and in fish grown in nightsoil-enriched ponds. Pathogen survival outside human hosts depends on the die-off rate of pathogens. This rate is exponential in most instances. It is influenced by the pathogen characteristics (resistance to adverse environmental effects, life cycle) and environmental effects (e.g. macro and microclimate, type of soil). The die-off rate increases the higher the temperature. Survival times increase in ascending order from protozoa (e.g. *Entamoeba*) to viruses and bacteria, and to helminth eggs (e.g. eggs of the roundworm *Ascaris*). During storage and decomposition of excreta in latrines and septic tanks, a certain percentage of pathogens are inactivated. Inactivation varies with each type of pathogen and depends on the period of excreta storage or treatment. Under real-life conditions, faecal contents of typical installations and end products of different types of treatment systems will contain viable excreted pathogens as indicated in the table below.

Survival of Excreted Pathogens During Pre-Application
Storage and Treatment: REAL-World Situation (improve :)

Storage/Treatment System	Real-World System Characteristics Relevant to Pathogen Die-off/Survival	Survival of Pathogens			
		Helminths	Viruses	Bacteria	Protozoa
• Pit-Type Latrines:					
- Pit Latrines w. 1 Pit	Handling of fresh excreta if pits are (or have to be) emptied immediately upon becoming full;	●	●	●	●
- Pit Latrines w.2 Pits	Handling of fresh excreta when emptying twin pits which have been in simultaneous use;	●	●	●	●
- Double-Vault Latrines	No urine separation, no addition of ash, wet and anaerobic conditions: t ≪ 1 year	●	○	○	○
- Pour-Flush L. w.2 Pits	t < 1 year; alt'g. use of twin pits;	◑	◑	○	○
- Pour-Flush L. w.1 Pit	handling of fresh excreta during emptying	●	●	●	●
• Aqua Privies and Septic Tanks[1]	Continuously operated systems; *always contain portions of fresh* excreta at time of emptying	●	●	●	●
• Thermophilic Composting	$T \leq 40\text{-}50^{0}C$; $t \leq 1$ month; not all parts of waste piles subjected to sufficiently high temperatures	◑[2]	◑	○	○
• Biogas Digesters	$T \leq 20\text{-}25^{0}C$; $t < 1$ month; withdrawal of bottom sludge where helminths and protozoa concentrate	●	◑	◑	◑
• Waste Stabilization Ponds[3]	t < 20 days; shortcircuiting; system having less than 3 cells in series	○	◑	◑	◑

○ - zero or near-zero survival
◑ - survival in low concentrations
● - survival in substantial concentrations

[1] Survival in sludge

[2] *Ascaris* and possibly also some hookworm, *Taenia*, *Schistosoma* and *Trichuris* eggs

[3] Survival in treated wastewater

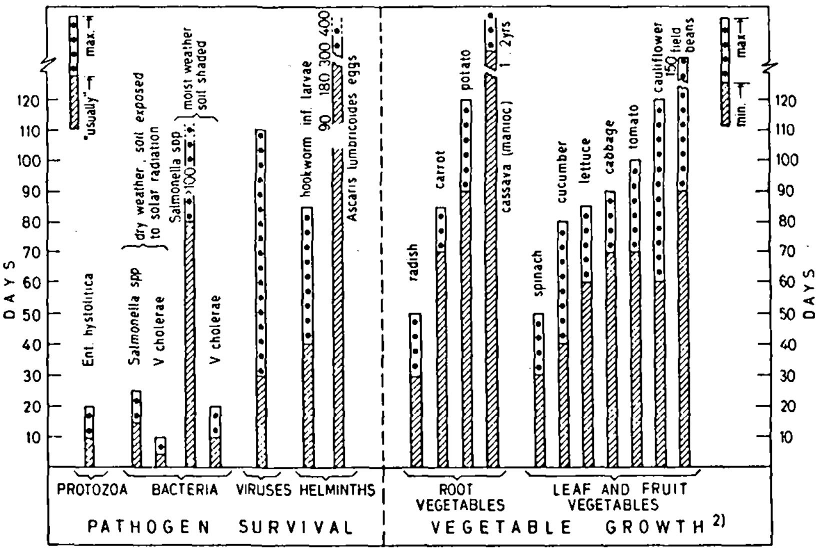
The excreted pathogens are subjected to further adverse effects when the stored or pretreated nightsoil is applied to fields. Typical survival periods of freshly excreted pathogens in soil and on crops in warm climates are given hereafter.

Survival Times of Excreted Pathogens in Soil and on Crops in Warm Climates

Type of Pathogen	Survival in Days			
	in Soil		on Crops	
	average	max.	average	max.
Protozoa	10	20	3	10
Bacteria (Salmonellae)	80	>100	25	50
Viruses	30	110	15	60
Worm Eggs (Ascaris)	<180	>300	25	60

Pathogen survival periods on leaf and fruit crops tend to be shorter than the growth periods of most of these plants. In soil, however, survival of viruses, salmonellae and *Ascaris* eggs may exceed the growth period of crops. Viable pathogens are therefore more likely found on root than on leaf crops as illustrated below.

PATHOGEN SURVIVAL IN SOIL VS. VEGETABLE GROWTH PERIODS IN WARM CLIMATES[1)]



[1)] Determined under widely varying conditions

[2)] Maturation period from transplanting or from sowing if not transplanted

Tentative recommendations for excreta **storage** periods in warm climates are made based on the current knowledge of pathogen survival in faecal wastes. The minimum storage period which might have to be aimed at in a particular situation would then depend on the local circumstances and on factors such as: type of excreted infections prevalent in the area, local excreta disposal and use patterns, hygiene and dietary habits, as well as socioeconomic considerations.

Tentative Recommendations for Excreta Storage Periods in Warm Climates

Storage Period	Hygienic quality achieved
≥ 2 days	Inactivation of *Clonorchis* and *Opisthorchis* eggs
≥ 1 month	Complete inactivation of viruses, bacteria and protozoa (except, possibly, *Salmonella* on moist, shaded soil); inactivation of schistosome eggs
≥ 4 months	Inactivation of nematode (roundworm) eggs, e.g. hookworm and whipworm (*Trichuris*); survival of a certain percentage (10-30% ?) of *Ascaris* eggs
≥ 12 months	Complete inactivation of *Ascaris* eggs

For most excreted pathogens, there are several alternate potential transmission routes. The route via excreta-fertilized soil, crops or fish ponds is but one of them. The important determinants of actual transmission of excreta-related infections are hygiene customs, dietary habits, the custom to eat or not eat uncooked food, vegetable fertilization practice, food marketing patterns, and the host's susceptibility to infection.

The review of epidemiological literature (Part III) revealed that only a few studies have been published on the epidemiology and actual - as opposed to potential - health risks of human waste utilization. Most of the reported investigations have methodological shortcomings. Moreover, they almost exclusively focus on helminth (worm) infections and on raw or minimally treated excreta. There is nevertheless reasonably good epidemiological evidence that utilization of raw nightsoil or sludge in agriculture may lead to the transmission of hookworm or *Schistosoma* (an occupational risk), and *Ascaris* or *Trichuris* (a risk associated with consumption).

The use of raw nightsoil in aquaculture may be associated with *Chlonorchis and Opisthorchis* (liver fluke) and *Fasciolopsis* (intestinal fluke) transmission.

Risks of transmission appear to be high particularly where people eat vegetables or fish raw or undercooked.

In general, little is known about the attributable risk of nightsoil utilization; i.e. the extent to which prevalence or incidence of particular infections would change if the practice of excreta utilization is introduced or altered. Local prevalence of alternate routes, along which most excreted pathogens can also be transmitted, is a decisive factor in establishing this risk measure. There are indications that the actual risk of helminth transmission is reduced if treated rather than raw nightsoil is used in agricultural fertilization.

INTRODUCTION

1. Purpose and Scope of Review

Excreta constitute a valuable source of nutrients. In many countries (e.g. China, Taiwan, Japan, Korea, Indonesia) they are traditionally and widely used to fertilize fields and ponds where fish and aquatic vegetables are grown. In these areas, faecal wastes carry considerable economic importance. This may increase in the years to come elsewhere too as a result of the growing cost of mineral fertilizers (unaffordable to many farmers) and increasing demand for basic food supplies.

In the majority of situations, excreta are presumably utilized in a raw or only marginally treated state. Such a practice leads to potential health risks for those who work in excreta fertilized fields or ponds as well as for those who consume vegetables or fish grown there. Whether, how and to what extent disease transmission and actual health risks are really associated with this practice is, however, hardly known. Neither does one know much about the relative importance of excreta fertilization compared to other possible routes of pathogen transmission.

Great efforts have been made over the past decades to investigate the fate of excreted pathogens in the outside-host environment, i.e. in water, wastewater, sludge, soil and on crops. The results are widely documented. The rationale for most of these investigations lies in the intention to use information gathered about pathogen survival to arrive at meaningful judgements regarding health risks of excreta management practices. Thus, an environmental perspective is applied to solve a problem which is largely of an epidemiological nature!

Inferences based purely on an environmental perspective may lead to intuitive or speculative conclusions. This has important repercussions on excreta or wastewater utilization strategies. While intuitive inferences may constitute a feasible approach in many instances, it certainly does not suffice as a basis for determining the actual health risks of excreta utilization. Fig. 3.1 shows that pathogen characteristics, anthropological factors and the biology of the human host must interact in a rather complex manner to enable transmission of surviving pathogens to a new human host and to cause infection in that host. Therefore, an epidemiological perspective is required besides the environmental one to determine actual - as opposed to potential - excess risks of disease transmission of a particular reuse practice, and to determine the factors and human behavioural patterns which cause these excess risks. Furthermore, an anthropological perspective is necessary to understand the sociocultural framework of human waste management practices and the behavioural patterns which might play a role in related disease transmission.

The review is divided into three parts which are based on the three types of perspectives introduced above. The purpose of **Part I** is to demonstrate the importance of sociocultural issues when considering human excreta reuse, and to identify the principal sociocultural issues and questions in the sector.

The data gathered in the review are presented in two different ways. First three case studies are presented to illustrate different sociocultural conditions affecting reuse practices. The case studies are not intended to exhaust the range of sociocultural responses to the problem of excreta reuse, but have been chosen to illustrate three broad cultural areas:

1. An area in which excreta utilization is an ancient and well-accepted custom (China);
2. An area in which use of excreta is abhorred (certain cultures of Islamic religion);
3. An area in which excreta utilization is little practised but where there are no overriding religious convictions prohibiting it (Subsaharan Africa).

The case studies are followed by a more general discussion of sociocultural aspects of excreta use. The review concludes with a preliminary examination of implementation strategies for reuse programmes and recommendations for further research.

Moreover, based on a review of existing literature, recommendations are made on the need, focus and study methods for further social research in the field of human excreta use.

Part II presents compiled information on survival of excreted pathogens in excreta and faecal sludges prior to utilization (i.e. during storage and treatment), and reports about the fate of these pathogens in the soil, on crops and in nightsoil-enriched fish ponds.

Part III has been prepared with the objective to gain an overview of existing documented epidemiological evidence - scarce as it be - regarding disease transmission through the use of nightsoil as a fertilizer (Blum and Feachem 1985). It determines gaps in epidemiological knowledge and outlines possible approaches to enhance the evidence by field investigations. Part III is published as a separate document.

The reviews presented herein focus on the utilization of excreta, nightsoil and sludge. Health risks related to the use of wastewater for agricultural and aquacultural purposes are dealt with elsewhere (Shuval et al. 1986). The truncation is artificial. It is reasonable to assume that the range of pathogens is the same for both nightsoil and wastewater, and that health risks associated with their use as fertilizers are of similar nature.

2. Excreta as a Resource

In places where excreta or similar human waste products have long been used in agriculture and aquaculture, the materials are highly valued resources necessary to support food production. Nightsoil is carefully preserved and efficiently utilized. King (1911), Scott (1952) and McGarry (1976) give impressive accounts of the agricultural and economic importance of excreta in China, Korea and Japan.

2.1 Agricultural Use

The agricultural value of excreta mainly derives from its nutrient content. In addition, nightsoil is a valuable supplier of moisture particularly where soils seasonally tend to turn dry for lack of rainfall. Nightsoil, 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 such important soil characteristics as moisture and air regulation as well as nutrient storage and release.

The amount and composition of human excreta mainly depend on climatic conditions and on a person's age, diet, physical activity and state of health. Table 2.1 contains excreta characteristics which can be considered representative of developing countries.

The value of excreta as nutrient supplier can be judged by comparing its nutrient content with that of cattle manure, composted plant residues or mixtures of organic wastes including nightsoil. Table 2.2 lists typical nutrient values of various natural organic fertilizers. Human faeces or nightsoil are as good suppliers of essential nutrients as any other natural fertilizer and composted material. Human excreta surpass a number of other fertilizers in their relative contents of nutrients, even though some of the nitrogen may be lost prior to fertilization. Apart from the actual nutrient content, the form in which the nutrients are contained in the fertilizing media as well as the C:N (carbon to nitrogen) ratio of the medium are important parameters. On the one hand, the chemical form of the nutrient determines its availability for plant uptake and, on the other hand, it influences its interaction with the soil. Phosphorus and potassium fertilizer components become strongly linked with the soil's matrix. Soils usually constitute a longer-term reservoir and buffer for these nutrients, which will then become available for plant uptake over a longer period of time. Nitrogen in organic

Table 2.1 Characteristics of Fresh Human Excreta and Nightsoil[1,2]

	Faeces		Urine		Excreta/Nightsoil		
Quantity and Consistency							
g/cap,d (dry weight)	50		60		110		
g/cap,d (wet weight)	250		1200		1450		
g/cap,d (wet), including 0.35 l of ablution water					1800		
water content, %	80		95		94		
Chemical composition					% weight in nightsoil		
	% dry wt.	g/cap,d	% dry wt.	g/cap,d	dry	wet	g/cap,d
Carbon	48	24	13	8	29	1.8	32
Org. matter	92	46	75	45	83	5	91
P_2O_5	4	2	3.7	2.2	3.8	0.23	4.2
N	6	3	17	10	12	0.7	13
K_2O	1.6	0.8	3.7	2.2	2.7	0.17	3

[1] After Gotaas (1956)

[2] Nightsoil includes faeces, urine and ablution water

Table 2.2 Nutrient Values of Various Natural Fertilizers[1]

	Nutrient Content (% of dry matter)		
	N_{tot}	P_2O_5	K_2O
Human faeces	5 - 7	3 - 5.4	1 - 2.5
Human urine	15 - 19	2.5 - 5	3 - 4.5
Fresh nightsoil[2]	10.4 - 13.1	2.7 - 5.1	2.1 - 3.5
Fresh cattle manure	0.3 - 1.9	0.1 - 0.7	0.3 - 1.2
Pig manure	4 - 6	3 - 4	2.5 - 3
Plant residues	1 - 11	0.5 - 2.8	1.1 - 11
Composted material[3]	0.4 - 3.5	0.3 - 3.5	0.5 - 1.8
Digested biogas sludge	1.5	1.1	1.1

[1] Figures are taken from miscellaneous sources and relate to widely varying conditions

[2] Comprises faeces, urine and ablution water (see also Table 2.1)

[3] Values vary according to the raw materials used

waste occurs partly as non-decomposed organic nitrogen and partly in mineraized form, i.e. ammonium (NH_4) and nitrate (NO_3). Ammonium is converted to nitrate by microbial activities. Plants require large quantities of readily available nitrate-nitrogen compared with phosphorus and potassium demands. Findings by Chao (1970) (cited in McGarry 1976) suggest that nutrients applied with nightsoil are more easily available to plants than those supplied by cattle manure or composted plant residues. This difference is probably due to the relatively high content of mineralized nitrogen contained in nightsoil. The value of excreta as a nitrogen supplier is also reflected in the C:N ratio, which is low in nightsoil ($\leqslant 2$ if urine is stored together with faeces) and faeces (6-8), compared to low-urine cow manure (12-17) and plant residues (30-40).

The risk of nitrogen losses due to leaching and volatilization which occurs during drying or composting, is a problem not only encountered with nightsoil but also shared by other organic fertilizers of high nitrogen content (Scott 1952; misc. literature on agricultural fertilization).

There are different practices of nightsoil utilization: in some places, it is applied to fields as essentially raw and wet excreta, in others, it is stored and dried prior to field disposal or mixed with other organic material such as farm manure, plant residues or food wastes and composted to various degrees prior to utilization..

In composting a mixture of nightsoil and other materials (e.g. plant residues), it is possible to obtain a better C:N ratio. Nightsoil is relatively rich in nitrogen, while plant residues have a relatively high carbon content. The significance of composting in reducing human excreted pathogens is dealt with in Part II, Chpt. 2.4.

Very few data have been published on the actual quantities of nightsoil applied to fields. During 1952-1966 an estimated 70-90 % of all nightsoil produced in Chinese cities and villages were collected and utilized in agriculture. At the time, this amounted to approximately one third of the nutrients supplied for cultivation (Chao 1970, cited in McGarry 1976). Application rates of 60-100 tons/ha/year of farm compost and 20-30 tons/ha/application of nightsoil, are reported from China (McGarry 1979, FAO 1977).

Where nightsoil is traditionally used in agriculture, it constitutes a suitable and needed complement to other fertilizers and is therefore of great economic importance in these areas. According to Scott (1952) the point must be made, however, that proper storage, treatment and application of nightsoil on fields is a delicate undertaking if nutrient (nitrogen) losses and failures in cultivation are to be avoided. The balanced use of nightsoil and other organic fertilizers is an art which the farmer acquires over years and generations.

The importance of nightsoil as a very essential and easily accessible commodity particularly for poor and "small" farmers has been documented by McGarry (1976), Briscoe (1978) and Djadjadiredja et al. (1979). The impact on the economics and traditional social patterns of collection and use of organic fertilizers must be duly considered when planning to change existing methods or strategies of nightsoil utilization.

2.2 Aquacultural Use

Fish produced in ponds constitute an important food supply in many parts of the world. Aquaculture is practised extensively in China, Taiwan, Indonesia, the Philippines, Thailand, Malaysia, and West Bengal (India). The practice also exists in Bangladesh and Pakistan. For a large number of fish ponds in these areas, human excreta or animal manure constitute important nutrient inputs (McGarry 1977). It is reasonable to assume that informal as well as institutionalised rearing of fish is also practised in many other locations around the world where nutrient-rich ponds (e.g. waste stabilization ponds) are operated. This may also be the case in countries where excreta-fed fish production has not been known or practised previously, or even where respective taboos have been prevailing. Easy access to food production may gain priority over sociocultural norms, particularly if fish rearing is organized in an informal way by individuals or small social units.

The role of human excreta in fish production consists mainly in the supply of degradable organic matter as food for bacterial decomposition. During decomposition, CO_2, phosphorus, nitrogen, and other nutrients are liberated to form essential constituents for algal growth. Algae and their direct predators such as rotifers and crustaceans serve as fish food. McGarry (1977) suggests that nightsoil also acts as direct fish feed, as fish have been observed to gather at the input point and to feed on the fresh nightsoil when it is discharged into the pond. Carp and *Tilapia* are the most common fish produced in culture. They are either stocked as single species or as a mixture of several species (poly-culture). Fish reach maturity and grow to marketable size within four to six months. Average productivity in fertilized ponds in rural areas amounts to a few hundred kg of fish/ha/year . Effects of pond fertilization on productivity have been investigated. At a fishfarm in Taiwan, 132 kg/ha/year and 619 kg/ha/year have been observed in unfertilized and in nightsoil-fertilized ponds respectively. Productivities of more than 1 ton/ha/year are reportedly not uncommon for well-maintained nightsoil-fed ponds in Asia (McGarry 1977).

The use of human excreta in aquaculture takes on variable forms. In rural areas in Java, there are thousands of small family or community fish ponds which are fertilized by human and domestic wastes. Latrines are built on piles over a pond into which excreta are directly dropped. In other reported cases, there is a market for nightsoil: municipal authorities collect nightsoil which is then purchased by fish rearing farmers. A documented example is the city of Tainan (Taiwan) which is surrounded by about 6000 ha of fish ponds (McGarry 1979). An example is cited where nightsoil is seasonally at such high demand that it is stolen from private vaults and black-marketed. Elsewhere, fish production takes place in wastewater treatment ponds. There, fish are commonly reared at the polishing or maturation stage of the pond system as most fish do not grow well at the low oxygen/high organic levels which prevail in primary or facultative ponds. The organisational forms of fish culturing in wastewater ponds differ widely: they vary from informal rearing by individuals (whether prohibited and/or tolerated by municipal authorities), to community-based production and marketing (e.g. China, Israel). Alternatively, there may be a large-scale production in municipality-owned wastewater stabilization pond systems (e.g. Munich, Berlin), or in privately-owned ponds at fish farms fed raw, diluted or partially treated municipal sewage (e.g. Calcutta: McGarry 1977 and 1979; Edwards 1985; Strauss 1986, unpublished). Meadows (1983) points to the fact that waste stabilization ponds are usually not designed to ease and optimize fish farming. Economic evaluations must be made to decide whether additional investment costs - if any - would be justified.

2.3 Conclusion

It can be concluded that in some parts of the world and for millions of people, excreta have since long been playing and will continue to play an eminent role in providing basic food supplies and thus securing human survival. The compatibility of nutrient requirements for food production, the need for long-term soil conservation and human waste disposal habits are fundamental factors for cycling excreta back to fields and ponds for the production of fish or water vegetables. Use is made of what constitutes the cheapest and most easily accessible fertilizer and soil conditioner for millions of farmers. It may be added that in many countries excreta actually represent a major pillar of national economy.

3. Excreta as a Health Risk

3.1 Introduction

Excreta, originating from individuals who overtly suffer from or are carriers of enteric infections, pose a risk to human health. They contain variable levels of pathogens which may be transmitted if personal hygiene is insufficient, if excreta are not properly disposed of or if excreta are not sufficiently treated prior to utilization. Inappropriately disposed of nightsoil also provides a breeding site for insects which are transmitters of pathogens, both excreta-related and non-excreta-related (e.g. malaria, filariasis). In many areas, excreted infections are endemic, often with seasonal patterns, and individuals may be affected by different infections simultaneously or within short periods of time.

To simply classify excreta as "risky" is not enough for conceiving long-term strategies and measures although it might serve as a first precautionary characterization. It is necessary to define the type of pathogen, its load and its fate outside the human host. Investigations on disease and disease transmission patterns are also necessary to understand the actual (as opposed to potential) health risks. Finally, human behaviour (e.g. defaecation habits, personal and household hygiene) is of prime importance in potential and actual disease transmission. These various appraisals can serve to make better choices for effective sanitation strategies, both with respect to the choice of technology as well as to the selection of accompanying measures.

In recent years, a number of comprehensive reviews on excreta-related diseases and their causative organisms have been completed. Some of the reviews center mainly on or were written in view of the problems of disease and sanitation in warm climates (Feachem et al. 1980; Feachem et al. 1983), others originated from unresolved problems of health risks associated with wastewater and sludge disposal on agricultural land in industrialised countries (Pike and Carrington 1970, and Yeager and Hain 1980, cited in Nell et al. 1983; Burge and Marsh 1978 ; Duboise et al. 1979; Little 1980; Sagik et al. 1980; Hannan 1981; Pederson 1981; WHO 1981; Kowal 1982; Golueke 1983; and many others). Benenson (1980) gives an excellent systematic description of communicable diseases in humans.

Early literature on occurrence, prevalence and control of excreted pathogens deals to a large extent with the "classical" parasites (helminths and protozoa) and bacteria (Rudolfs et al. 1950/51; Headlee 1933; Faust 1924). As a result of progress in virus detection and analytical techniques, recent literature contains extensive information on excreted viruses and related diseases (Bitton 1980; Feachem et al. 1981; Pederson 1981; WHO 1981, Feachem et al. 1983). Over 100 different viruses have so far been detected in human excreta. Research on the detection of new viruses and excreted virus behaviour in treatment and reuse systems is continuing as human health improvement and waste recycling are gaining increasing attention worldwide.

The study of antibody-antigen reactions and analysis of antibody levels in blood serum are important tools for the detection and specification of viral and other infections; both subclinical and clinical. This approach is based on the fact that the human body develops defence mechanisms (immunity) against specific invading pathogens and toxins of pathogens.

With regard to infectious disease, a person's health status is influenced by a multitude of host and pathogen-related factors which interact in a complex manner. This interaction determines the response of the person exposed to infectious organisms. These organisms may be transmitted from an infected person's excreta to a new host along many different routes. The relative importance of each of the routes in a given setting depends on human behavioural factors, social habits, the socioeconomic situation, and environmental effects on pathogen viability. These factors vary in each locality and so does the relative importance of the different transmission routes. Fig. 3.1 illustrates dominant transmission paths and the role of pathogen-host relationship. It also shows that nightsoil fertilization of vegetables and fish ponds represents only one or two of the numerous potential pathogen transmission routes. The establishment of the relative importance of nightsoil utilization in the spreading of infections is therefore a matter of sound epidemiological research. These aspects are dealt with in Chapt. 5.

The paragraphs below contain listings of widely occurring excreted pathogens and their environmentally relevant characteristics, as well as a sub-listing of pathogens which are of major importance and most frequently reported in the excreta utilization context. Furthermore, pathogen transmission paths are evaluated and indicator organisms discussed.

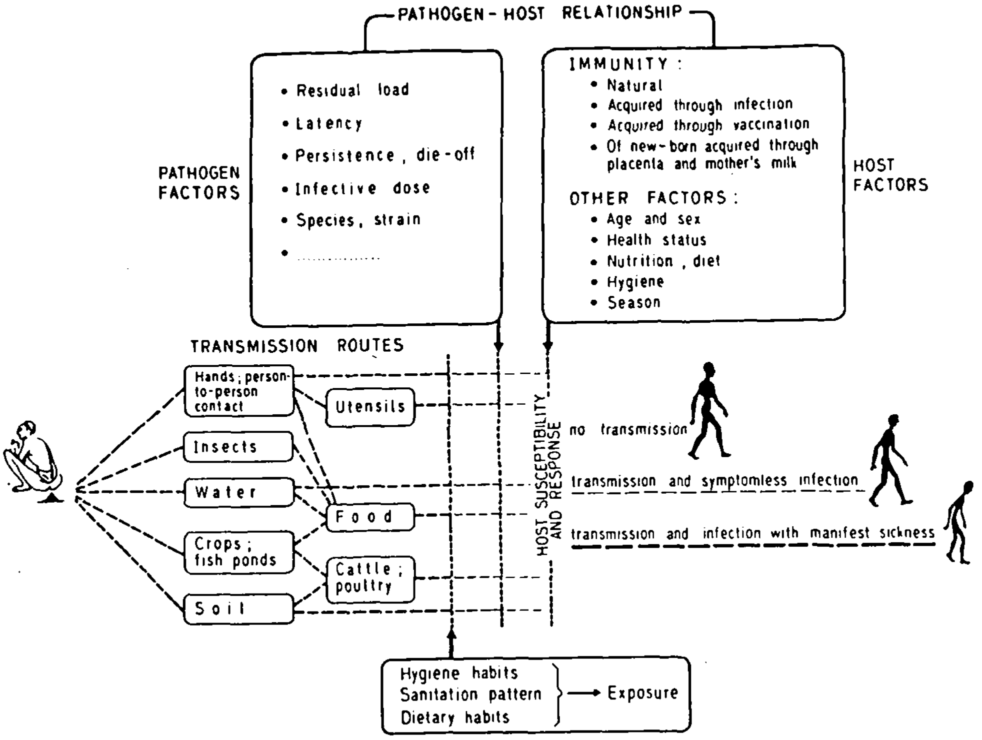


Fig. 3.1 THE PATHOGEN-HOST RELATIONSHIP, AND POSSIBLE TRANSMISSION ROUTES OF EXCRETA-RELATED INFECTIONS
(based on Pike and Carrington 1979, cited in Nell et al. 1983, and on Feachem et al. 1980)

3.2 Feacal Microflora of Healthy, Non-Infected Persons

The human intestinal tract is inhabited by a variety and large number of commensal bacteria responsible for the digestion of the intestinal contents. Accordingly, faeces of non-infected, healthy persons contain these bacteria in large numbers. 25-33 % of human faeces consist of bacteria, most of them dead (Kowal 1982). Table 3.1 lists concentrations of different viable bacteria commonly found in faeces. They are usually non-pathogenic. For some of them, however, strains exist which can give rise to disease (e.g. pathogenic *E. coli*).

Table 3.1 Viable Bacteria Commonly Found in Faeces of Healthy, Non-Infected Persons[1]

Designation	Range of bacterial concentration (mean $\log_{10}$ p.gram of faeces)
- Enterobacteria[2,4] (comprising *Escherichia coli* mainly)	7.0 - 9.4
- Enterococci[3,4] (faecal *Streptococcus*)	5.8 - 8.1
- *Lactobacillus*	6.1 - 9.0
- *Clostridium*	4.7 - 9.3
- *Bacteroides*	7.3 - 10.3
- *Bifidobacterium*	8.5 - 10.0
- *Eubacterium*	8.5 - 9.6

[1] according to Feachem et al. 1983
[2] encompasses several genera of the family "Enterobacteriaceae"
[3] designates specific types of *Streptococci* inhabiting the intestines
[4] the most commonly used faecal indicator bacteria

The bacterial composition in the stool of non-infected persons varies according to dietary habits. The figures in Table 3.1 refer to countries and areas where the staple food largely consists of carbohydrates such as rice or maize (e.g. in many parts of Asia and Africa).

The urine of healthy, non-infected persons does not contain any micro-organisms. However, urine of infected persons may contain a few pathogenic organisms, such as *Leptospira* or *Schistosoma haematobium*.

Specific groups or species of commensal enteric bacteria (e.g. *Escherichia coli*, faecal streptococci or *Clostridium*) are used as indicators of faecal pollution as they are regularly and substantially discharged in human faeces.

3.3 Excreted Pathogens, Diseases and Symptoms

3.3.1 Overview

In many tropical areas, the majority of communicable diseases are excreta-related. The pathogens are shed either in the faeces or in the urine of infected persons, therefore making excreta a very prominent "vehicle" for the transmission of diseases among humans. Therefore, the proper handling, treatment and disposal of excreta are a major focus of sanitation work. Bancroftian filariasis is a disease related to excreta, which is, however, not excreted. It is a widespread helminthic infection frequently causing elephantiasis whose transmitters are mosquitoes (usually *Culex pipiens* species) which feed or breed in excreta or excreta-contaminated water. The vehicle for filariasis transmission is the human blood. Excreted infections are actually transmitted from the excreta, generally the faeces, of infected persons, to the mouth (for the faecal-oral infections) or the skin (for schistosomiasis and hookworms) of new hosts.

Excreted pathogens belong to one of four kinds of organisms, i.e. viruses, bacteria, protozoa or helminths (enumerated in ascending order of size). Although this classical way of classifying organisms is not a very meaningful tool for sanitation work - possible impacts of sanitation measures do not necessarily adhere to this truncation - it is used here to give a short overview of the organisms involved. A more meaningful classification based on epidemiological criteria is contained in Table 3.3 (p. 22).

Table 3.2 contains a listing of the important excreted viruses, bacteria, protozoa, and helminths as well as their associated diseases, symptoms, excreted concentrations, and whether man alone or man and animal harbour the organisms[1].

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[1] For more exhaustive listings of excreted pathogens, see Benenson (1980) and Feachem et al. (1983).

Table 3.2: Important Pathogens Excreted in Faeces[1]

Agent	Disease or major symptoms
a) Viruses	
- Enteroviruses	
Polio-	Poliomyelitis, paralysis, meningitis, fever
Echo-	Diarrhea, fever, meningitis and others
Coxsackie A and B	Meningitis, respiratory disease, fever and others
New enterov.	Encephalitis, meningitis, conjunctivitis and others
- *Hepatitis A virus*	*Infectious hepatitis*
- Rotaviruses, Norwalk agent and other viruses	Gastroenteritis (diarrhea, vomiting etc.)
b) Bacteria	
- Campylobacter *fetus ssp[2].jejuni*	Diarrhea, vomiting
- Pathogenic Escherichia coli	Gastroenteritis (diarrhea)
- Salmonella	
S. Typhi	Typhoid fever
S. paratyphi	Paratyphoid fever (incl.diarrhea)
other Salmonellae	*Food poisoning and* other salmonelloses
- Shigella species	Shigellosis (bacillary dysentery) (incl. diarrhea)
- Vibrio	
V. cholerae	Cholera (diarrhea)
other vibrios	*Diarrhea*
- *Yersinia entero*colitica, Y.pseudotuberculosis	Diarrhea, miscell. conditions
c) Protozoa	
- Balantidium coli	Diarrhea, dysentery, colonic[3] ulceration
- *Entamoeba histo*lytica	Colonic *ulceration*, amebic dysentery, liver abscess
- Giardia lamblia	Diarrhea, malabsorption
d) Helminths	
Nematodes (Roundworms)	
- Ancylostoma duodenale, Necator americanus - (Hookworm)	Hookworm (anemia)
- Ascaris *lumbricoides* (Roundworm)	Ascariasis (*respiratory*, digestive or abdominal disturbances, bowel obstruction)
- Enterobius vermicularis (Pinworm)	Enterobiasis (anal itching)
- Strongyloides stercoralis (Threadworm)	Strongyloidiasis (often asymptomatic; skin inflammation; lung or abdominal disturbances)
- Trichuris trichuria (Whipworm)	Trichuriasis (often asymptomatic; bloody stool, diarrhea
Cestodes (Tapeworms)	
- Diphyllobothrium latum (Fish tapeworm)	Diphyllobothriasis (often asymptomatic; anemia, diarrhea, obstruction)
- Hymenolepis nana (Dwarf tapeworm)	Hymenolepiasis
- Taenia saginata (Beef tapeworm)	Taeniasis (often asymptomatic; digestive disturbances)
Taenia solium (Pork tapeworm)	Taeniasis (often asymptomatic; digestive disturbances Cysticercosis[4] (disturbances e.g. of eye, heart, central nervous system)
Trematodes (Flukes)	
- Chlonorchis sinensis (Chinese liver fluke)	Chlonorchiasis, Opisthorchiasis (often asymptomatic; diarrhea, abdominal and liver disturbances)
- Opisthorchis	
- Schistosoma	Schistosomiasis, bilharziasis
S.haematobium[5]	(obstruction, blood urination, bladder tumors)
S.japonicum S.mansoni	(dysentery-like symptoms, liver cirrhosis)
- Paragonimus westermani (Lung fluke)	Paragonimiasis (blood coughing; cerebral disturbances)

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[1] after Feachem et al. 1983

[2] ssp.-subspecies

[3] colon = part of large intestine

[4] infection with larvae of T. solium, formation of cysts

[5] excreted in urine

All of the diseases listed in Table 3.2 are endemic in many areas of tropical countries. However, prevalence patterns vary across regions and continents, between rural and urban areas, and with climatic zones. Agricultural practices, climate, eating habits, cultural norms, and social environments are important factors determining prevalence patterns and rendering particular diseases typical of a given community or area.

High prevalence of schistosomiasis is for instance found in many areas of intensive irrigation and near tropical freshwater lakes. In general, hookworm infestation is highly prevalent where excreta are disposed of openly, and where people walk about barefoot. However, hookworm prevalence in one hill area of Nepal was found to vary with altitude (Sattler 1980): Below 2000 meters (6000 ft), 60-70% of examined persons are hookworm (*Ancylostoma duodenale*)-infested. The percentage tapers off to 40% above 2000 m and to 20% above 2300 m. Although community defaecation and general sanitation habits are similar at all altitudes, the particular climatic conditions and differences in agricultural patterns apparently restrict the survival and transmission of hookworms at higher altitudes.

Trichuris prevalence in the same rural hill area of Nepal was found to also vary with altitude, i.e. from 60% between 700 and 900 meters to 0-12% between 900 and 1300 meters, and to 20-32% above 1300 meters. The variation which depends on altitude, is attributed to ethnic and caste grouping as well as settlement pattern (population density). The ethnic and caste grouping in turn determines such factors as domestic hygiene and social contact.

A description of each kind of organism is given below. This enables: (1) to understand the respective roles of viruses, bacteria, protozoa and helminths as regards people's status of morbidity and mortality, and (2) to select rational approaches for the "management" of excreta once they enter the outside-host environment.

3.3.2 Viruses

A characterization of viruses is contained in Bitton (1980). Viruses are the smallest infectious particles. They are colloidal in size ($<1\mu m$), and many of them have negative surface charges, which is a typical property of colloids. Viruses depend on host cells for growth and reproduction since they have no cell structure of their own. The virus redirects the growth of the host cell towards the production of new viruses. Once passed into the environment with the host's excreta, all viruses degenerate, although their protein coat imparts them a certain resistance to environmental stresses.

The enteric viruses constitute the largest group among the animal viruses (which are the viruses infecting man). They multiply in the intestine and are excreted in numbers of up to 10^{10} or more organisms per gram of faeces (Bitton 1980).

A large portion of the viruses which is spread in a community is shed by symptomless carriers, i.e. infected persons who do not show signs of disease. Communities of a low socio-economic level and with low hygienic standards are primarily affected, especially small children, as their intimate contact with other children and their sanitary behaviour are particularly conducive to pathogen transmission. 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 (Feachem et al. 1983). According to Bitton (1980), viruses account for approximately twice as many gastroenteritic infections as bacteria. The main viruses involved are chiefly rotavirus, Norwalk-type virus and echovirus. Their common characteristics are their mode and place of infection: they infect the outer cells of the small intestine's lining (Bishop 1983). The death of these cells causes rapid loss of large volumes of fluid (dehydration) and electrolytes which in turn causes diarrhoea and electrolyte imbalance. Viral gastroenteritis - caused predominantly by rotavirus infection - is the major cause for infant death in developing countries.

In temperate zones, viral enteric infections occur primarily in late summer and early autumn. In areas with subtropical and tropical climate incidence rates of enteric virus infections often also exhibit, though to a lesser extent, seasonal variations. All viruses decrease in number once they are shed into the environment. However, some viruses such as the rotavirus, poliovirus and Hepatitis A virus, are particularly resistant and can survive and retain infectivity for several months under suitable conditions. The protein coat is one factor contributing to this resistance. Furthermore, since viruses have colloidal characteristics (surface charge, large specific surface area, extremely small in size), they have an affinity for and can easily bind to small particles in soils or suspended particles in water or wastewater. While this causes immobilization of the virus, it may at the same time prolong its period of infectivity (see also Chpt. II.3.4).

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" (Berg et al. 1976, Bitton 1980).

Feachem et al.(1981) conclude that enteric (i.e. excreted) viral infections are predominantly transmitted through person-to-person contact (faecal-oral or oral-oral) due to: (1) the highly infectious nature of viruses, (2) the large proportion of young children among those infected and (3) the high incidence of symptomless infections. Other faecal-oral transmission routes such as water or food (including fish) have been found to play a less prominent role with hepatitis A, poliomyelitis and gastroenteritis transmission (Bitton 1980).

3.3.3 Bacteria

The excreted bacterial pathogens of major epidemiological importance are listed in Table 3.2. *Campylobacter jejuni* has only recently been discovered and is now thought to be an as common cause of gastroenteritis and diarrhoea (particularly in children) as *Salmonella* and *Shigella* (Kowal 1982, Feachem et al. 1983). Pathogenic *Escherichia coli* has also been recently found to be a major cause of diarrhoea occurring mainly among infants in poor communities with low standards of hygiene and sanitation.

According to the current state of knowledge, salmonellae are the bacterial pathogens of prime importance in association with excreta use on fields. Due to their universal spread in both temperate and tropical countries, occurrence in man as well as animals and due to their substantial resistance to adverse environmental conditions, salmonellae may be transmitted along many routes. *S. typhi* and *S. paratyphi* are pathogens for which man is the exclusive or almost exclusive reservoir. "Enteric fever" is generelly the symptom for these two infections. *S. typhimurium, S. dublin, S. enteritidis* for example are present in both animals and humans and may be transmitted from animals to humans and vice-versa (so-called "zoonoses"). They cause salmonellosis with gastroenteritis and diarrhoea as typical symptoms. Symptomless as well as overt infections occur in animals and humans (Feachem et al. 1983, Golueke 1983). The man-specific *S.* infections (*S. typhi* and *paratyphi*) are transmitted through faecal-oral routes, i.e.:

- person-to-person contact
- contamination of food at markets or in kitchens while preparing food with faecally contaminated fingers
- faecal contamination of kitchen utensils or cutlery and crockery by humans or pet animals feeding on openly disposed of excreta
- consumption of faecally contaminated water
- consumption of raw vegetable grown on nightsoil-fertilized soil (e.g. root crops, low-growing leaf crops).

The common transmission routes for zoonotic *S.* infections (e.g. *S. typhimurium, S. enteritidis*) are:

- from humans to animals:
  - via nightsoil-fertilized pastures
  - poultry feeding on openly disposed of human excreta (e.g. in yards where children defaecate openly)
- from animals to humans:
  - via meat and dairy products of *S.* infected cattle, poultry (chickens, turkey, ducks), and possibly fish respectively
  - via soil and crops fertilized by *Salmonella*-infected cattle manure.

The relative importance of man-specific *Salmonella* and zoonotic *S.* infections, as well as of the various routes listed above depends largely on hygiene and dietary habits, and on food preparation and agricultural patterns. Transmission of *S.* infections from animals to humans through meat and dairy products is likely to play a greater role in industrialised countries than in many developing countries. In many developing countries, meat is of minor importance in people's daily diet. This is either due to cultural-religious reasons or because the economic, agricultural and ecological situation does often not allow for protein production through large-scale cattle raising. An exception to this is protein from fish which are grown in excreta or wastewater-fertilized ponds; a common practice e.g. in South-East Asia. As regards human infections with salmonellae, the routes listed under "man-specific *Salmonella* infections" (see p. 15) are therefore of prime concern in the developing country context.

Persons whose resistance to diseases is impaired (e.g. due to malnutrition or due to other infections) may become infected already with small *Salmonella* doses. For them, infection through person-to-person contacts might play an important role, particularly if personal and domestic hygiene is poor.

Shigella-induced dysentry (the frequent passing of bloody stools), like many other intestinal diseases, mostly affect young children who represent the largest group of *Shigella* disease and death cases (Feachem et al. 1983). Its prevalence varies according to the geographical areas of the world. The minimal infective dose and persistence of *Shigella* is lower than that of most other bacterial pathogens listed above. Contrary to *Salmonella* infections, its transmission may therefore be assumed to take place along short transmission routes, i.e. mainly through personal contacts.

Cholera, which is caused by different types of *Vibrio cholerae* species, is known mainly as an epidemic disease associated with vigorous diarrhoeal loss of water and electrolytes and a high fatality rate. In many parts of the world, however, cholera is endemic and constitutes but one of a variety of diarrhoeal diseases (Feachem et al. 1983). Like *Campylobacter* and pathogenic *E. coli, Yersinia* has been recognized only relatively recently as a causative agent of gastroenteritis. Its epidemiology is not well known yet.

Common environmental characteristics of excreted bacterial infections are:

- faecal-oral transmission primarily through person-to-person contacts; "longer" infection cycles such as through food, dishes, insect vectors, water crops play a variably important role
- immediate infectivity upon release into the environment (zero latency)
- medium to high infective dose (in contrast to viral pathogens)
- ability - though limited - to multiply outside the host (also in contrast to viruses).

Of the bacterial pathogens listed and described above, *Campylobacter, Salmonella* spp. (excl. *S. typhi* and *S. paratyphi*) and *Yersinia* may also infect animals which in turn will shed the pathogens with their excreta, and thus represent a source of infection for humans. Animals such as cattle, dogs, cats, rodents, wild animals may be the carriers. Minimum standards of personal hygiene should therefore be adhered to also when handling cattle manure.

Bacterial pathogens confer immunity to variable degrees, i.e. immunity may last for a limited period of time only or may depend on the dosis and protect against a specific strain only (Feachem et al. 1983).

3.3.4 Protozoa

Entamoeba histolytica and *Giardia lamblia* are excreted protozoal pathogens of major public health importance. Infection is transmitted through environmentally-resistant cysts which develop from the vegetative, environmentally non-resistant form (trophozoite) in the lower parts of the large intestine and are shed in the excreta. Infection which occurs through hatching of the cysts in the new host's intestine is either directly via faecally-contaminated hands or through ingestion via contaminated food or water.

There is a significant prevalence of *E. histolytica* and *G. lamblia* worldwide (in the order of 10 percent). It can reach 30 or more percent in communities with low standards of sanitary practice. Children are particularly affected. Loads of excreted cysts from infected persons are high especially in asymptomatic carriers (10^5 - 10^8 per gram of faeces) (Kowal 1982, Feachem et al. 1983). The median infective dose, however, is in the order of 10 to 100 only (Feachem et al. 1983), and there is reason to assume that even single cysts can cause infection (Kowal 1982). These phenomena, coupled with a high prevalence of healthy carriers who continuously contaminate a community's environment, and immediate infectivity of the cysts, make the person-to-person contact the most prominent transmission path. Other paths such as via food, kitchen utensils or cutlery and crockery, water, and possibly soil and crops, may also play a certain role because of the cyst's ability to survive outside the host if conditions are suitable. Multiplication outside the host is, however, not possible. There is evidence that an immune response (formation of antibodies) does occur in persons who become infected with *E. histolytica* or *G. lamblia*. However, the acquired immunity appears to be neither fully protective nor lasting (Feachem et al. 1983).

3.3.5 Helminths

The most important excreted helminthic pathogens infecting man are listed in Table 3.2. Worm infestation is a worldwide phenomenon. Prevalence of helminthic infection is high in many areas of developing countries, where it is closely linked with low economic status and high contamination of the domestic and village environment (yard, foot paths, fields, defaecation grounds) (Faust 1924, Headlee 1933). Although, as a result of changes in sanitation practice over the last 100 years, helminthic infections have been drastically reduced in more affluent communities and in industrialized countries, helminthic pathogens continue to infect parts of the population in such communities (Center for Disease Control 1977 cit. in Akin et al. 1978). It is assumed that this is due to the great resistance of helminthic eggs in the non-host environment, climatic conditions, and personal hygiene. Helminths are of public health importance in industrialized countries, particularly where communities opt to make agricultural use of treated wastewater and sludge containing helminth eggs or larvae which are pathogenic to humans or animals (Bryan 1977, Akin et al. 1978, Hannan 1981, Little 1980, Kowal 1982).

Viral, bacterial and protozal pathogens reproduce asexually within the host. Among the helminthic pathogens, the trematodes (flukes) - with the exception of schistosomes - and cestodes (tapeworms) follow the same reproductive pattern. Nematodes (e.g.*Ascaris*) and schistosomes, however, are different in that they have separate sexes. Concerning these infections, only those persons are epidemiologically important who become infected with both male and female worms which meet, mate and produce eggs. Eggs or larval forms which are shed with the excreta require suitable non-host conditions or an intermediate host to pass through one or more development stages before being "taken up" by a new human host.

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 the particular helminthic pathogen. This leads to an increased burden of adult worms, which then causes damage and symptoms inside the host. Symptoms of worm infections depend on the specific helminth. They often comprise mechanical obstruction within the digestive system, anemia and deprivation of nutrients. The infection cycles of helminths (except *Enterobius*) are long compared to those of viruses, bacteria or protozoa, and the latency lasts from several days (e.g. hookworms, *Ascaris*) to several weeks (e.g. *Taenia, Trichuris, Clonorchis*).

Similarly, persistence of infective helminth forms tends to be longer (e.g. up to one year or more for *Ascaris* eggs) than that of most other pathogens. It is therefore obvious that openly disposed of faeces on the soil or in water bodies constitute the most prominent path for helminth transmission as other people may eventually get in contact with the infective forms of helminths (eggs, larvae, cercariae). Open defaecation, e.g. in yards by children or on footpaths, appears to be the major cause of nematode (e.g. *Ascaris*, hookworm) transmission. Uncontrolled disposal of fresh faeces on soil, crops or in fish ponds and improper handling and processing of excreta-fertilized crops or fish represent additional risks.

A number of helminthic pathogens are transmitted without intermediate hosts, others require one or two intermediate hosts along their passage from one human host to the next. *Ascaris, Trichuris* (faecal-oral transmission), hookworm and *Strongyloides* (transmission via skin of new host), are examples of the first category of helminthic infections. These helminths are of particular interest in the context of nightsoil use in agriculture: transmission may occur either through handling and consumption of excreta-fertilized crops such as vegetables or salad (*Ascaris, Trichuris*), or through contact with nightsoil-treated soil when working in the field (hookworm, *Strongyloides*).

As regards the helminthic infections requiring intermediate hosts, some are associated with terrestrial hosts (*Taenia saginata* and *T. solium*, the beef and pork tapeworm, respectively), others with aquatic hosts. These include *Schistosoma* species with snails as intermediate hosts and numerous others which require two aquatic hosts, such as snails (or copepods) and fish, or snails and aquatic plants. *Clonorchis* and *Opisthorchis* for example require a specific snail host and fish for multiplication and transmission. They are of public health importance in certain areas of Thailand, China, Taiwan, Korea and Japan where fish is an important dietary component and where nightsoil-fertilized aquaculture is widely practised. Nightsoil treatment prior to its application to fields or ponds is probably very rare. Depuration[1] and cooking of the fish, where practised, may often be insufficient to inactivate human pathogens taken up by the fish.

Helminthic infections requiring an intermediate host can be prevented not only by improved excreta disposal practices but also by proper handling and thorough cooking of meat, fish, or edible water plants, by controlling snail populations, or by avoiding contact with water harbouring intermediate snail hosts (Feachem et al. 1983). In practice, the choice and suitability of a particular measure, however, will depend to a large extent on sociocultural, economic and other influencing factors.

3.4 Towards an Epidemiologically Useful Classification of Infections and Sanitation Measures

In the previous section we have classified excreted infections according to types of organism. In order to associate particular pathogens with specific transmission paths and sanitation measures, it is useful to reclassify excreted infections according to an epidemiological perspective. As emphasis of this study is placed on excreta use in agriculture and aquaculture, it will therefore be necesssary to focus on those pathogens and their characteristics which are, as assumed, of significance in excreta utilization practices. Furthermore, it is relevant to know the role played by routes others than those via nightsoil disposal on fields and in fish ponds in transmitting particular pathogens.

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[1] Keeping the fish in clean water prior to its harvest

Meaningful concepts and classifying criteria have been developed and discussed in detail by Feachem et al. 1983 and Feachem 1983. Important epidemiological criteria are:

- latency of pathogens
- length of infection cycles
- persistence outside the host, and
- median infective dose.

Latency is the minimum time from excretion to infectivity. It is zero for all excreted viral, bacterial and protozoal pathogens like rotavirus infection, *Campylobacter* entiritis, giardiasis, and for the helminthic infections enterobiasis and hymenolepiasis. For other helminthic pathogens, latency amounts to several weeks. In general, with zero-latency-infections, the most direct transmission routes, i.e. faecal-oral by personal contact and oral-oral, are the most dominant ones, and improved personal and domestic hygiene is assumed to be the most effective preventive measure. Length of infection cycle - length in terms of both space and time - is closely related to latency, as increased latency will lead to a long infection cycle in terms of time and space as is the case for most helminthic pathogens. To prevent diseases with long infection cycles, one must focus on measures which either prevent contact with untreated excreta or provide proper excreta treatment for pathogen inactivation. Persistence is the maximum survival time of the pathogen's infective stage. It is also associated with the length of the infection cycle as persistent organisms may survive even rigorous treatment measures and remain a public health hazard beyond the time of final use or disposal. The median infective dose (ID_{50}), i.e. the dose required to infect half of those exposed, is low for all excreted pathogens ($\leqslant 10^2$) except for the bacterial infections (e.g. *Salmonella* infections, cholera or shigellosis) with ID_{50} of $\geqslant 10^4$. Some bacteria, notably *Salmonella* spp., can multiply outside their host if they find suitable substrates such as starchy food or lesioned crops. They are thus associated with an infection cycle which is often longer than would be expected by their zero latency.

Table 3.3 classifies excreted pathogens according to their epidemiological characteristics (Feachem et al. 1983).

Table 3.3 Classification of Excreted Pathogens Based on Epidemiological Features (Feachem et al. 1983)

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

Figure 3.2 shows the relationship between pathogen density and persistence (survival time) outside the host. It also illustrates how latency and intermediate development stages of organisms affect the length of infection cycles for the various infection categories.

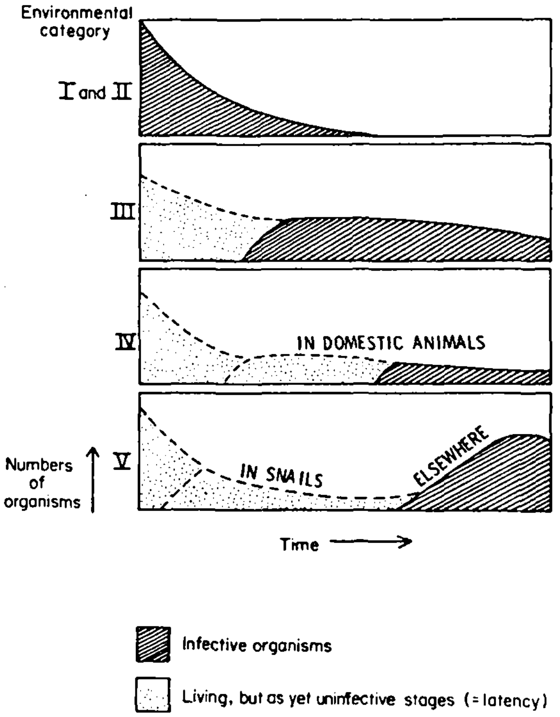

Fig. 3.2 Pathogen Density and Survival Time Outside the Host (Feachem et al. 1983).

Figure 3.3 illustrates how the length of infection cycle varies with infection category and shows transmission routes typically associated with these categories.

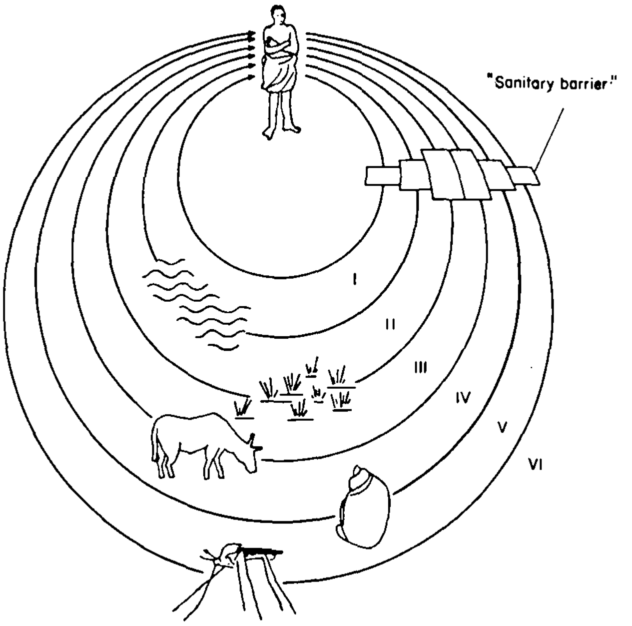

Fig. 3.3 Length and Dispersion of Transmission Cycles of Excreted Infections as Categorized in Table 3.3 (Feachem et al. 1983)

With the above basic epidemiological information it is possible to establish for each category of pathogen what are considered dominant transmission foci, routes and possible preventive measures from the sanitation engineer's "tool box" (Table 3.4). Furthermore, it allows to make preliminary suggestions as to what types of pathogens are likely to require particular attention in the context of nightsoil use for the fertilization of crops and fish ponds.

Table 3.4 Dominant Transmission Foci of Excreted Pathogens and Suggested "Soft"[1] and "Hard"[2] Control Measures (after Feachem et al. 1983)

Category and epidem. features	Organisms	Dominant transmission foci or routes	Suggested major control	
			"Soft"	"Hard"
I - Infective immediately upon excretion; low infective dose; viruses moderately persistent	Viruses, Protozoa	Short routes such as person-to-person contact; household (food, utensils, water) contamination; food handling on markets; food contamination through flies? longer routes for viruses (e.g. through nightsoil fertilization) possible	Improved personal and domestic hygiene;	Secured and enhanced water supply (emphasis more on quantity than on quality of water)
II - Immediately infective; medium to high inf. dose; moderately persistent	Bacteria	Both short and moderately long routes: person-to-person; household contamination; unprotected water supplies/points?; Contamination of crops during fertilization with nightsoil or during market handling; fly transmission?	as for cat.I; raising awareness on reducing risks of night soil fertilization; local institution building for n'soil collection, treatment and use?	as for cat.I; appropriate nightsoil collection and treatment facilities if required
III - Deferred infectivity; persistent	Helminths	Yard; defaecation grounds and footpaths; soil and crops; fly transmission?	changing defaecation habits; changing nightsoil use patterns (as for cat.II)	installation or improvement of excreta disposal facilities (latrines etc.); extra storage before use
IV - Deferred infectivity; persistent; cow or pig as intermediate host	Helminths	———— " ————	as for cat.III; thorough cooking of meat; health information	as for cat.III;
V - Deferred infectivity;	Helminths	Excreta-contaminated surface water (ditches, fish ponds, lakes)	as for cat.I; thorough cooking of fish; reducing water contact	as for cat.III and IV;

The information contained in Table 3.4 may be used to set up a tentative classification model of environmental infection categories based on the role played by nightsoil in transmitting the particular types of pathogens when it is used as fertilizer or soil conditioner (Table 3.5).

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[1] "Soft" measures: non-engineering activities such as health education, extension and follow-up organizational/institutional

[2] "Hard" measures: construction of installations such as water schemes or latrines

Table 3.5 Tentative classification model of environmental infection categories associated with the relative importance played by nightsoil in transmitting certain types of pathogens

"Ranking"	Category / Organisms	Basis for proposed ranking
+++	III; Helminths with no intermediate host (e.g. *Ascaris*, *Trichuris*)	Deferred infectivity, high persistence, long infection cycle
+++	V; Helminths with fish as intermed. host (e.g. *Clonorchis*, *Diphyllobothrium*)	—— " ——
++	II; Bacteria (e.g. *Salmonella*)	Moderate persistence
+...++	I; Viruses (e.g. Enteroviruses)	—— " ——
+	IV; Helminths with cattle as intermediate host (e.g. *Taenia*)	Cattle grazing on human waste fertilized pastures is rare, and cattle meat is of minor importance for protein nutrition in many tropical areas

+++ Of suggested major importance in nightsoil fertilization context
++ " " intermediate importance in nightsoil fertilization context
\+ " " minor importance in nightsoil fertilization context

Table 3.5 lends itself to draw some preliminary conclusions about the health implications of excreta use in agriculture and aquaculture:

(1) The handling and use (or disposal) of nightsoil on fields and in fish ponds represent major transmission foci particularly for helminthic pathogens (except *Enterobius* and *Hymenolepis*) (categories III-V in Tables 3.3 - 3.5). This is due to the long infection cycles and extended persistence of the helminths and their intermediate development stages respectively.

(2) Transmission via person-to-person contact and consumption of contaminated drinking water are of little importance for this category of pathogens.

(3) Some pathogens classified under category I and II have infection cycles of intermediate length (see Fig. 3.2.). They exhibit considerable persistence or have to undergo multiplication before infecting a new host and are therefore also of interest in the context of excreta utilization.

- *Salmonella* spp. (other than *S. typhi* and *paratyphi*), pathogenic *E. Coli* and *Yersinia enterocolitica* are important members of category II. They are rather persistent and may multiply outside the host to reach infective doses if they find a suitable substrate (such as starchy food or lesioned crops). Excreta-fertilized crops (e.g. salad and vegetable) or fish can thus be transmission foci for these bacterial pathogens.

- Similarly, enteroviruses, as rather persistent agents of category I, may survive on excreta-contaminated soil, on crops or in fish and therefore pose potential health risks due to their low infective doses.

(4) In general, however, epidemiological evidence suggests that in areas where standards and means for personal hygiene are low, the major transmission paths for category I and II infections (the faecal-oral non-bacterial and bacterial pathogens) are person-to-person contacts, domestic contamination, as well as water and food contamination (see Table 3.4). For these pathogens, one may therefore assume that the transmission routes via faecally-contaminated soil, crops or fish are of secondary importance.

3.5 Pathogen Detection and Interpretation of Results

In order to assess the potential risk posed by pathogens contained in untreated or treated human excreta, the concentration of viable pathogens in the particular product should be known.

However, detection of pathogenic organisms usually requires rather sophisticated equipment and involves laborious analytical procedures. In order to avoid infection during analytical work, great care should be taken when analysing particularly for viral pathogens.

In the water supply sector, the need to assess potential health risks which may arise through faecal contamination of drinking water has been recognized long ago, i.e. probably with the introduction of urban water supply networks and the systematic use of surface waters in drinking water supply systems. Routine methods were thereby developed using nonpathogenic enteric bacteria (mainly faecal and total coliforms) to determine the presence or absence of pathogenic organisms in the water. The use of such faecal indicator bacteria (nonpathogenic bacteria living in the intestinal tract of man and other warm-blooded animals) for the detection of faecal contamination is universal. The safety of water supply systems is thereby tested. The rationale behind this is to prevent transmission of infections which may be water-borne (e.g. *Salmonella* spp., *Shigella*, Hepatitis A).

The usefulness of faecal coliform data for assessing the risk of pathogen transmission has been strongly questioned since faecal coliform enumeration procedures are extremely sensitive and difficult to control in simple infrastructured laboratories. They may easily lead to misinterpretation.

Faecal coliforms, though a valid parameter for potential faecal water pollution in temperate climates, do not carry the same validity in hot climates where non-faecal coliforms have been found to grow under the same conditions as faecal coliforms. Prediction of infection risks from untreated human wastes (wastewater, excreta) on the basis of non-pathogenic indicator data has proven very unreliable or impossible under tropical climates. The ratios of indicator organisms to bacterial and non-bacterial (viral, protozoal, helminthic) pathogens respectively, contained in faecal waste products in hot climates are either unpredictable or unknown. Yet, Bartone et al. (1985) found that faecal coliforms were useful indicators for pathogenic bacteria removal performance of waste stabilization ponds.

In spite of the many limitations in the use and interpretation of faecal coliform analysis, the test continues to be performed almost universally because of its relative simplicity, the availability of routine methods and the lack of better alternatives.

The use of faecal streptococci as indicator organisms in water and wastewater analyses is questionable since certain streptococci strains, which also occur in unpolluted environments, cannot be distinguished from true faecal streptococci in routine analyses. The parameter, however, appears valid in human waste analyses.

To differentiate human from non-human faecal pollution poses a major difficulty. The ratio of faecal coliforms to faecal streptococci was once thought to be typical for both human and non-human faeces, thereby enabling the establishment of a clear distinction. More recently, this parameter has been found unreliable since the ratio varies substantially according to animal species and geographic location. Ratios in human and non-human faeces do not follow a unified pattern.

It can therefore be concluded that extreme caution is necessary when using bacteriological quality data derived from bacterial indicator analyses of tropical waters or human waste products. The parameters developed for water quality testing in temperate climates are of limited value when used in environments exhibiting very different climates, and where people have different hygiene and disease patterns, as well as excreta management and dietary habits.

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. Data on specific pathogens, their occurrence and behaviour are therefore of main interest and should allow meaningful inferences with regard to other important pathogens and health risks posed by a particular waste product or by excreta-fertilized crops and fish.

Therefore, increased interest should be given to pathogen indicators and to the development of suitable detection techniques. It is proposed to distinguish between human waste effluents, i.e. untreated and treated wastewater, and non-effluents, i.e. nightsoil, stored and/or treated excreta and solids from latrines, privies and septic tanks. As regards the effluents, emphasis should be placed on the determination of bacterial and viral pathogens, because effluents from properly designed and operated stabilization ponds are essentially free of helminth eggs and larvae as well as protozoa.

Nightsoil, however, cannot be treated by liquid-solid separation but through a suitable combination of time and temperature (e.g.storage, anaerobic digestion, composting). Occurrence and count of viable *Ascaris* eggs is proposed as the parameter of choice for a meaningful judgement of the quality and safety of waste products, soils and crops in areas where *Ascaris* is endemic. *Ascaris* eggs are extremely resistant to environmental stress. Therefore, if viable *Ascaris* eggs are absent, one may conclude that all other pathogens are also dead or have lost infectivity. In areas where helminthic diseases other than ascariasis are endemic, the quality of nightsoil-derived products should be tested for the eggs of the respective helminths. As regards wastes such as septage (contents of septic tanks or aqua privies) which might be treated by liquid/solid separation (settling) prior to their application on fields or in fish ponds, the quality of the liquid portion might be assessed through analysis of either helminth eggs or bacteria, depending on the method of application and the kind of disease transmission risk (occupational or consumer) involved. The settled portion is rich in helminth eggs and its hygienic safety is best assessed by determining the presence or absence of viable helminth eggs.

3.6 Excreted Pathogen Levels in Raw Human Wastes

Table 3.6 lists average values and ranges of pathogen and indicator organism concentrations in raw human excreta, sewage sludge and wastewater. Pathogen levels in septic tank contents are assumed to be similar to those encountered in sewage sludge.

Table 3.6 Levels of Excreted Pathogens and Indicator Organisms in Raw Human Wastes

Organism	Reported levels[a]			Reference
	In fresh faeces [no./gram]	In raw sewage sludge[b]	In raw sewage [no./l]	
Indicators				
Faecal coliform (*E. coli*)	$10^7 - 10^9$		$10^6 - 10^9$	Feachem et al. (1983)
" "		10^9/100 ml		U.S. EPA (1984)
" "		1.9×10^5/gram dry weight		U.S. EPA (1981)
Pathogens				
Enteric viruses	$10^6 - 10^7$		5×10^3	Feachem et al. (1983)
" "		3,600 PFU/gram dry weight		U.S. EPA (1981)
Viruses		2,500 - 70,000/100 ml		U.S. EPA (1984)
"		38-120 PFU/l		Berg and Berman (1980) cited in Farrah and Schaub (1983)
Enteroviruses			9×10^2	Hurst et al. (1980)
Salmonella	$10^6 - 10^8$		7×10^3	Feachem et al. (1983)
"		8,000/100 ml		U.S. EPA (1984)
"		290/gram dry weight		U.S. EPA (1981)
"		$< 10^7$/l		Hess and Breer (1975)
"		250-300/l		Watson (1980)
Ascaris eggs	10^4		6×10^2	Feachem et al. (1983)
"		200 - 1,000/100 ml		U.S. EPA (1984)
T. saginata eggs	10^4		10	Feachem et al. (1983)

[a] Most reported values are "typical" or "average"

[b] Usually meant to be the untreated mixture of "primary" and (wasted) "secondary" sludge

The values reported in the literature and compiled in Table 3.6 are characteristic of a great variety of conditions and environments and should accordingly be taken as indicative.

Pathogens die-off immediately after the faeces have been passed, and most pathogen levels decline substantially within minutes or hours (see also Chpt. II.1). The figures listed in Table 3.6 for fresh faeces therefore apply to fresh faeces only and not to the contents of pit latrines. There, pathogen density, which is established by a balance between die-off and addition of pathogens from fresh faeces, will be lower than in the fresh faeces themselves.

It is unlikely that the entire spectrum of excreted pathogens will occur at the same time in a particular waste sample. Actual occurrence depends on the specific infections existing in a particular area and their actual prevalence in a particular community at the time of investigation.

4. Development of Sanitation Measures

The appropriate management of human wastes, notably excreta, in developing countries has received increased attention in recent years. There are numerous reasons for the growing concern, e.g. the tremendous deterioration of public hygiene in many urban areas as a result of a rapid population increase and lack of basic infrastructures. Furthermore, it is now well-known that the development of water supply infrastructures which lack complementary improvements in excreta disposal and personal hygiene habits usually do not bring about the assumed health benefits.

Many governments are faced with the enormous task of devising excreta disposal methods for large populations. This is of prime importance in urban and peri-urban areas where population densities are high and space for open defaecation has become limited in the course of time.

In industrialised countries, historical development has led to the flush-toilet-sewerage system as the means of excreta collection and off-site disposal. Formerly, much of the nightsoil produced in urban areas was stored and collected within the residential compounds and then used as fertilizer in kitchen gardens or on farm land. During industrialization, when urban areas became densely built-up and populated and the dwellers started to depend on outside farm products, nightsoil gradually turned into an unwanted commodity. Yet, the flushing of excreta out-of-sight and the transporting of the diluted media out-of-town called for tremendous investments in the construction of sewerage and sewage treatment works. Similarly, operation, maintenance and replacement of these installations, demands a high price and significant national investment. The solution chosen for the disposal of excreta in industrialized areas does not represent the best standard solution in absolute terms to be copied throughout the world (Feachem et al. 1980, Kalbermatten et al. 1980). On the contrary, it is now well recognized that its uncritical large-scale transfer to developing countries for the solving of human waste disposal problems is totally inappropriate. Except possibly for densely built-up commercial and business centres, flush-toilet-sewerage systems are technically unfeasible, economically unaffordable and require disproportionate institutional inputs for construction, operation and maintenance. Furthermore, conventional sewage treatment methods such as activated sludge or trickling filters used in industrialized countries are relatively ineffective for the inactivation of excreted pathogens, a performance criterion which is of great importance in areas where the effluents are reused.

The prime hazard resulting from inadequate excreta disposal in developing countries is the transmission of diseases. Therefore, the prime objective of improved excreta disposal is to interrupt the infection cycles of excreted pathogens. Moreover, the systems and technologies chosen should be financially within reach of the national economy and the users. They should reflect users' preferences, be socioculturally appropriate and based on locally available skills and materials.

Technical alternatives to the flushing and sewering of excreta do exist as described by the commonly used systems below:

- For **individual household/family** use:
  - Single-pit latrine (pit either directly under or off-set)[1]
  - Alternating (double) pit or vault latrine[1]
  - Pour-flush latrine with alternating leaching pits
  - Aqua privy } with soakage
  - Septic tank } with soakage

- For **communal** use:
  - Latrine block with sealed pits (vaults) (vaults either off-set or directly under; regular vault emptying service)
  - Sanitation block with septic tank/soaking pit system (comprising defaecation, laundering and bathing facilities)

Individual designs of these facilities greatly vary according to available construction material, user preference, affordability and cultural setting. All these systems will perform satisfactorily if used as intended and properly maintained. Apart from latrines which are abandoned when full, stored excreta or faecal sludges need to be periodically collected and disposed of.

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[1] possibly ventilated

In the years to come, the number of households and public facilities with controlled excreta disposal will doubtlessly increase rapidly. Where agricultural and aquacultural use of excreta is already practised or planned, double-pit (either dry or pour-flush) or double-vault latrines are feasible technologies. Where, in turn, any of the above mentioned systems are already in use, their increase may lead to an enhanced potential or need for expansion, improvement or introduction of excreta utilization.

5. Theoretical vs. Actual Health Risks

Part II of this document presents the current state-of-knowledge on the survival of excreted pathogens in soil, on crops and in fish. The literature on which the review is based is voluminous. The majority of respective investigations was made under the assumption that it is merely necessary to follow the fate of the pathogens in the soil, on crops or in fish to establish, on the basis of their persistence, whether there is an actual risk of infection.

The fact that excreta represent a major source of pathogens responsible for communicable diseases is not disputed, neither the need to control as much as possible the handling and disposal of excreta, and to influence personal hygiene behaviour in such a way as to minimize the spread of excreted pathogens. However, it is too simplistic to establish a true risk of infection merely on the basis of a given number of a specific pathogen detected in the soil or on crops. This disregards or misinterprets the role of important disease transmission factors (see Chpt. 3.1), which include anthropological aspects such as post-defaecation hygiene, dietary habits and the custom to eat or not to eat uncooked food. Such disregard, intuitive judgements of health risks, and what may be called "zero-pathogen thinking", prevalent among many people in industrialised areas, have led a number of countries to adopt stringent regulations regarding the use of human wastes. Too stringent rules may, however, curtail the economic potential of nightsoil and wastewater and lead to uncontrolled disposal or use.

Many excreted pathogens can be transmitted via several different routes. The route via excreta-fertilized soil, crops or fish ponds is but only one of them (see Chpt. 3).

Survival of pathogens outside the human host, i.e. in soil, on crops or in fish ponds fertilized by human excreta, is a prerequisite for transmission to occur. Data pertaining to pathogen survival in these particular environments are therefore extensively discussed in Part II. They constitute the basis for what may be designated as theoretical or **potential** health risks.

In order to establish with reasonable certainty **actual** health risks associated with excreta utilization, sound epidemiological data are required. Part III of this document series has been prepared towards this end (Blum and Feachem 1986). It gives a critical and detailed review of available epidemiological information pertaining to the use of excreta in agriculture and aquaculture. There is a scarcity of sound and methodologically reliable data. The review therefore suggests further epidemiological field investigations dealing specifically with excreta utilization practices. This will enable to establish the actual health risks with more confidence. A summary of Part III is given below.

The scarce epidemiological evidence is based on observations dealing exclusively with the use of raw nightsoil. Regarding **agricultural** use, observations made in China where use of raw excreta is widely practised indicate that under specific circumstances, helminthic infections, notably *Ascaris* (roundworm), *Trichuris* (whipworm), hookworm and *Schistosoma japonicum* are occupationally acquired. In a good number of studies, foodborne outbreaks of e.g. amoebiasis, paratyphoid fever and typhoid fever at various locations are found to be associated with excreta-fertilized vegetables eaten raw. However, epidemiological data are considered insufficient and therefore the suggested evidence must be questioned. This contrasts with a well-documented case of a foodborne cholera epidemic in Jerusalem where rather good evidence revealed that raw wastewater-irrigated vegetables were the likely vehicles for the cholera bacteria.

As regards zoonotic infections, which are diseases transmitted via vertebrate animals, there exists, though scarce, epidemiological evidence of cattle becoming infected on pastures fertilized with wastewater sludge. It was found that there is risk of cattle infection by certain *Salmonella* species (Hess and Breer 1985), *Cysticercus bovis*, the larval stage of the beef tapeworm, and *Taenia saginata*. The risk appears to be high particularly in areas of intensive cattle grazing and/or relatively high sludge loading rates applied to pastures or fodder crops. Multiple routes of transmission besides the route via cattle are known for salmonelloses. The potential relative importance of excreta use on pastures is therefore uncertain. For *T. saginata*, cattle is the compulsory intermediate host. Pasture fertilization with human faecal wastes may therefore creates a potential risk for the transmission of this infection. The epidemiological importance of the purposeful use of faecal wastes for pasture fertilization in relation to open defaecation on pastures is unknown. It depends mainly on the cultural and economic settings, i.e. defaecation habits, use of excreta disposal installations, importance of cattle in the local agriculture, and human waste utilization practices. There is only one documented case of salmonellosis transmission to humans from cattle grazing on pastures irrigated with sewage effluents, where the milk of cattle became the vehicle of paratyphoid B. It is reasonable to assume that there are risks of cattle infection by *C.bovis* if raw nightsoil or sewage sludge is used to fertilize pastures. Subsequent human infection depends on food preparation habits in areas where taeniasis is endemic.

Taenia solium, the pork tapeworm, is transmitted through disposal of excreta on the soil. The relevant transmission route is through indiscriminate disposal of excreta rather than via nightsoil or sludge-fertilized pastures.

There are two basic transmission routes associated with the **aquacultural** use of excreta: one is the passive transmission of pathogens on the surface of fish or aquatic vegetables or in fish viscera. Viruses, bacteria and protozoa may be potentially transmitted along this type of route. The other type includes fish as intermediate hosts for helminth, particularly trematode infections. True infection risks from virus, bacteria or protozoa transmission through fish or vegetables grown in excreta-fertilized ponds are unknown since no respective epidemiological study could be traced. As regards trematode infections, there is reasonably good epidemiological evidence for actual risks of *Clonorchis* or *Opisthorchis sinensis* (Chinese liver fluke) transmission through fish cultured in nightsoil-fertilized ponds. The same holds true for *Fasciolopsis buski*, an intestinal fluke which is transmitted to humans via aquatic vegetables grown in excreta-enriched ponds. However, these latter infections were also observed in areas where purposeful utilization of nightsoil is not practised. There, transmission occurs through incidental faecal contamination of fish and plants grown in water bodies.

A small number of studies deal with occupational risks of nightsoil utilization. Epidemiological evidence derived from these studies suggests that people working on raw nightsoil-fertilized fields are subjected to hookworm or *Schistosoma* infection risks. Climate, patterns of cultivation and methods of nightsoil application are important factors influencing this risk. No published data could be located documenting additional occupational risk due to the introduction of treated nightsoil fertilization in areas where nightsoil had not been used before.

Table 5.1 below summarizes the epidemiological knowledge regarding infectious disease risks from raw nightsoil or sludge use in agriculture. The equivalent information for aquaculture is contained in Table 5.2.

The tables illustrate the apparent actual risks of helminth transmission associated with excreta utilization. What the tables cannot show is that many factors must interact in a particular way to render actual transmission possible in a given setting. These factors, which vary significantly from one area to another, include habits of defaecation, diet and food preparation, personal hygiene behaviour, and methods and timing of nightsoil fertilization.

Table 5.1 Current Epidemiological Evidence of Excreted Infection Transmission Risks from Excreta Utilization in *Agriculture* (after Blum and Feachem 1986)

Exposure Group	Transmission Risks from Nightsoil or Sludge Fertilization of: Crops for humans	Crops for animals	Non-consumable crops
. Persons consuming crops	V △B $\boxed{P}$ Ⓝ	-	-
. Persons consuming meat or milk	-	△B Ⓒ	-
. Those working on excreta-fertilized fields or sites	$\underline{V}$ B P Ⓝ Ⓣ	$\underline{V}$ B P Ⓝ	$\underline{V}$ B P Ⓝ

V - Viruses	V	- *Potential* risk; no epidemiological data
B - Bacteria	Ⓥ	- *Actual* risk supported by epidemiological data
P - Protozoa	△V	- Actual risk likely according to the wastewater epidemiological data
N - Nematodes		
C - Cestodes	$\boxed{V}$	- Actual risk reported but insufficient epidemiological data for confirmation
T - Trematodes	$\underline{V}$	- Actual risk inconsistently supported by epidemiological data
- - not applicable		

Table 5.2 Current Epidemiological Evidence of Excreted Infection Transmission Risks from Excreta Utilization in *Aquaculture* (after Blum and Feacnem 1986)

Exposure Group	Transmission risks from excreta or nightsoil-fertilized ponds		
	Crops[1] for humans	Crops[1] for animals	Non-consumable crops
. Persons consuming crops	V B P C Ⓣ	-	-
. Persons consuming meat or milk	-	B	-
. Those fishing or harvesting in excreta-fertilized ponds	V B P T	V B P T	V B P T

[1] Fish or plants grown in ponds

V - Viruses
B - Bacteria
P - Protozoa
C - Cestodes
T - Trematodes
- - not applicable

V - *Potential* risk; no epidemiológical data

Ⓥ - *Actual* risk supported by epidemiological data

6. Sources of Information

Parts I and II are both based entirely on published and secondary sources and are not the result of new field work. In the course of the review of **Part** I, a keyword computer search for literature on sociocultural aspects of excreta reuse was undertaken which revealed only a handful of references which had a direct bearing on the human aspect of the topic. This supports the findings of previous reviews (see for example McGarry 1979) which comment on the paucity of data essential to the planning of appropriate sanitation provisions for developing countries.

A more fruitful, though somewhat dated ancillary source of data has been a cross-cultural review of established ethnological sources. Ethnographic information on excreta reuse practices and attitudes was gathered among several cultures with the assistance of the Human Relations Area Files. It constitutes a unique cross-tabulation of reasonable to good quality ethnographic sources across a wide selection of world cultures and cultural items. Even among this large collection of material, comments on these most private aspects of human behaviour are scarce, and in many important publications this topic is completely omitted.

Recent literature on the utilization of human excreta abounds with pleas for more attention to sociocultural aspects. Allen (1976) for example argues that:

> "...non-biological problems may seriously limit the acceptance of products reared in wastewaters of domestic origin due to social, aesthetic or cultural reasons.... The active assistance of social scientists may be needed to assess public attitudes and develop scientifically sound and sociologically acceptable procedures to promote public approval of such uses".

Others who have endorsed similar views include Rybczynski (1979, cited above) and Feachem et al. (1983). The importance of sociocultural information when considering reuse options appears now well established in some sections of the literature. Despite this newfound recognition, the literature on sociocultural aspects of excreta reuse remains remarkably thin.

This is not the place for a full examination as to the causes of the neglect of social research with respect to renewable resource technologies but the fact that the research funds remain to a large extent securely within the technical disciplines is probably a decisive factor. Inappropriate choice of study methodology seriously limits the value of much current social research in this field. We return to this point below.

The paucity of sociocultural data which would be of great importance in the planning and implementation of cost and nutrient-effective, minimum-health-risk excreta use options, points clearly to the need for further field work. Respective proposals are developed in Part I.

Part II makes use of the comprehensive review on excreta-related diseases and concepts of excreta management prepared by Feachem et al. (1983) and based on literature published prior to 1980. A keyword computer search was therefore undertaken to trace additional relevant information published between 1980 and 1983. Further documents were provided by bibliographic references as well as by institutions and individuals who are working on reuse aspects or in related fields.

PART I: EXISTING PRACTICES AND BELIEFS IN THE UTILIZATION OF HUMAN EXCRETA

I.1 Why Consider Socio-cultural Aspects of Excreta-Re-use?

The core subjects in environmental health are generally considered to be microbiology, epidemiology and environmental health engineering. The literature in these fields is considerable and relatively easily accessible, and much of this review is devoted to it. In this chapter we consider a field of study whose literature falls outside the environmental health establishment: the human dimension. It is, we believe, a severely neglected concern in environmental health and one that is of central importance to a full understanding of the potential of human waste re-use applications.

Why should the study of human behaviour be relevant to the prevention of disease transmission and the re-use of nutrients? What are the socio-cultural issues of practical importance in considering promoting nurient re-use?

Many infections are transmitted from infected human excreta to human mouths. To achieve cost-effective interventions in disease transmission it is necessary to identify the primary routes of pathogen transmission. A determinant factor in disease transmission is the precise human behaviour (or what Bradely (1978:22) has called the "social geometry") facilitating transmittion. Transmission is influenced by frequency, duration and other variables of human behaviour. A first reason why socio-cultural data is of importance in environmental health is that changing **behaviour** is one method of breaking the chain of disease transmission. Before an attempt can be made to change behaviour it is necessary to have an understanding of what existing practices are.

A second reason for considering socio-cultural factors is that patterns of human behaviour are shaped, among other important factors (such as physical environment etc), by a **cultural domain**, by social and economic pressures and by volition. In order to change a pattern of behaviour it may be necessary to change factors which determine that behaviour. A full understanding of behaviour requires knowledge of a range of cultural, social and economic factors.

By **culture** is meant people's knowledge, attitudes and beliefs. People's explanation for their behaviour is important not only to understand a behaviour better, but also because the cultural domain influences the scope for changing behaviour. This is not to say that cultural patterns are immutable and that improved technologies should only be designed around a fixed set of beliefs, but that culture sets limits to behaviour change. Existing beliefs may also provide the mechanism through which actual behaviour changes can be achieved.

A more neglected but equally important set of factors influencing behaviour is the **social context**. Human behaviour is affected by the structure of social relations both at the family or community level and, in the larger society, by the distribution of power and access to resources. Theories of society have not in general fulfilled the promise of a scientific understanding of society and it is not always possible to disentagle the threads of social causation in the abstract. A situational analysis of social influences on behaviour on the other hand may well throw considerable light on patterns of human behaviour. Finally, society is both an objective and subjective phenomenon and the premise to changing a behaviour is the active participation of a community to effect that change.

A third reason why it is important to have a knowledge of the socio-cultural dimension is that proposals to encourage nutrient re-use, or indeed affect behavioural change in any culturally sensitive area, will have limited success unless the changes are culturally acceptable. Where proposed changes are culturally unacceptable, a knowledge of local cultural values and practices will be of significance in seeking to develop a strategy to make proposed changes more acceptable, or indeed to reject proposed innovations.

I.2 Cultural Variation in Excreta Utilization Practices

Human society has developed culturally diverse responses to the problem of disposal or (depending on how it is viewed) challenge of utilization of human excrement. The global categorization of cultures according to their attitude towards utilization of human excreta is complicated by the range of uses to which human excreta is put, and the diversity of social units which utilize nutrients from human excreta.

These facts together with the shortage of published social field studies on this most private aspect of social life prevent the development of a global cultural guide reflecting utilization of human excreta. Table I.1 gives an indication however of the range of excreta utilization practices in different countries.

The distribution is influenced clearly by many factors including: cultural tradition, cost and availability of alternative resources; technical and managerinal capacity to exploit excreta utilization on an institutional basis.

Since the present state of accessible knowledge is insufficient to exhaust the range of socio-cultural responses to excreta utilization in this review the present three case-studies which illustrate categories of cultural variation. These are:

Table I.1 Examples of Human Excreta Re-use Practices

	Practice	Social Unit	Examples
1.	Soil fertilization with untreated or stored night soil	family or community	China, Korea, Taiwan, Japan, Thailand, India
2.	Night soil collected and composted for use in agriculture	community or local authority	China, India
3.	Night soil fed to animals	family	Melanesia, Africa
4.	Use of composting or mouldering latrines	family	Vietnam, Tanzania, Guatemala
5.	Biogas production	family or community	China, India, Korea
6.	Fish pond fertilization with treated or untreated nightsoil	family or community	Taiwan, Korea, China, Malaysia, Indonesia
7.	Fish farming in stabilization ponds	family (illegal) or commerical farmer	India, Israel
8.	Aquatic weed production in ponds	family, community or local authority	Vietnam, S.E.Asia
9.	Agricultural application of sewage	local authority or commerical farmer	India, Saudi Arabia, Kuwait, Tunisia, South Africa, Mexico, Peru, Chile, Argentina
10.	Irrigation with stabilization pond effluents	local authority or commerical farmer	Israel, India, Peru
11.	Algae production in stabilization ponds	local authority	Mexico, Japan

I.3 Case-Studies A: CHINA

I.3.1 Traditional Beliefs and Practices

A thousand years before the Christian era a Chinese emperor wrote:

"The inspectors of agriculture will see to it that (human excreta) is not lost nor wasted ... for it is the strength and health of the people" (quoted in Cressey, 1955).

Excreta disposal and re-use are inseparable in Chinese conception and practice. The recognition that nightsoil is a desirable, economically valuable natural source of plant and fish nutrients exemplifies a tradition of frugality in Chinese peasant culture (McGarry, 1976). Early western observers noted "the meticulous care with which everything is used" (Buxton, 1929). Chinese acceptance of nightsoil re-use is moreover in accordance with strong themes in Chinese folk "religion", beliefs derived from an amalgam of Confucianist, Taoist and Buddhist thinking (Chan, 1953).

Folk beliefs in China are less concerned with salvation or the supernaural, but are sustained by earthly fears and rewards. Man's one-ness with nature is stressed rather than the sence of his supreme importance in the order of things. Ancestoral cults existed in arlier 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" (Cressey, 1934) - remains a continuing theme in Chinese culture.

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 tradtionally 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.

I.3.2 Direct Use

Reports indicate that the direct and immediate use of raw excreta in agriculture is not a common traditional practice. In certain localities fresh human excreta and urine are collected in a bucket mixed with water and fed raw to rice and vegetable plants (McGarry and Stainforth, 1978). More commonly fish ponds are traditionally fed raw human excreta from latrines overhanging ponds (FAO, 1977). This ancient practice is little documented in the literature (but see Prowse, 1966) but is widespread in freshwater pond fishing in Southern China. Pig consumption of raw human excreta in privy/pigsties is a widespread traditional practice and is described in more detail below.

I.3.3 Indirect Use

The prominent traditional excreta disposal and re-use methods are indirect. Two traditional methods are well established in China: the "wet" method in Southern China; and the "dry" method in the North (Winfield, 1948, and Shen, 1951).

The "Wet" Method: Fertilization. Traditional rural practice in the South is to store all family excreta in large earthenware vats. Women and small children defecate indoors (Faust, 1927) in wooden buckets with covers (Hommel, 1937) and the excreta are transferred on each occasion to the storage vat in the courtyard outside. The vats may either be free-standing or sunk into the ground up to their edges (Hommel, 1937) and men either defecate directly into them from simple wooden privies, or use buckets outdoors and transfer the contents into the vat.

A measure of the value placed on nightsoil collection is the practice, reported by several commentators, of increasing nightsoil supplies by constructing privies for public use alongside canals, paths and public places (Faust, 1927, and Buxton, 1929). Children are encouraged from an early age to defecate in the courtyard where mothers collect and deposit their stools in the family vat. Sexual differentiation in toilet habits begins by age three or four, and children are fully contributing to the family nutrient reserve by age four (Levy, 1949).

The nightsoil is customarily stored in vats for up to three months before the liquid is scooped into wooden or wicker baskets suspended each side of a bamboo pole carried over the shoulder. Women generally have the task of carrying this liquid fertilizer to the ponds or fields. Frequent spillage is reported. In the case of plant fertilization the fertilizer is diluted and a long-handled wooden dipper used to scoop out and pour the fertilizer on each plant (Hommel, 1937). The tools and buckets involved in the transport, storage and utilization of excreta are commonly washed directly in rivers or ponds (Zhong-xian et al., 1982).

The "Dry" Method: Composting. The "dry" method involves the creation of compost. Men defecate in a courtyard in a privy adjoining the family pigsty and animal shed. Nightsoil from other family members is also deposited into the hard-bottomed pit extending into the pigsty. Urine is often not conserved nor aded to this drier mix (Buck, 1930). Pigs commonly feed on the human excreta (McGarry and Stainforth, 1978). Earth is often put under other household animals by day, and each morning the urine-soaked earth together with the animals by day, and each morning the urine-soaked earth together with the animal doppings is shovelled into the pit (Winfield, 1948) together with straw ashes, green manure, vegetable wastes, crop residues, waterweeds, oil seed cakes, pond mud, bones and other animal wastes (Shen, 1951). There are reports that the pile was sometimes turned (Buck, 1930), but decomposition appears traditionally to have been anaerobic. The dry mixture is dug out "every six months or year" (Winfield, 1948), hauled to the fields where it is dried, pounded to a powder, spread on the soil and ploughed in.

I.3.4 Nightsoil Collection in Cities

City nightsoil collection earned municipal authorities a considerable income in prereveolutionary China. Its collection was generally contracted out to enterpreneurs or "faecal despots" (Streefland, 1978), who hired nightsoil collectors to do the actual collection, cartage and sale of city wastes. Several early visitors to China report on the morning parade of "long lines of wheel barrows, carrier coolies or canal boats" (Cressey, 1934) transporting nightsoil to the villages. Winfield comments on how the cyclical exchange of nutrients fed the cities:

> "...the flow of nitrogen and other plant foods in the form of grain from farms to cities and the return flow of feces (sic) from cities back to the farms for use as fertilizers has resulted in zones around the city ... the city appears to be the centre of a green oasis which fades gradually to the brown of the distant countryside" (1948).

I.3.5 Traditional Hygiene

The literature on hygiene associated with excreta re-use and hygiene generally within the Chinese household does not identify priority behaviours most likely to facilitate disease transmission from infected excreta, though authors severally point to collection, cartage, treatment and usage as all being occasions with a high risk of disease transmission.

Traditional food preparation and eating practices undoubtedly limit the potential for disease transmission via vegetables and fish grown with human waste. Vegetables are commonly boiled or stir-fried, and fish is boiled, salted or dried. Litte or nothing is eaten raw. Similarly cold water is not drunk and all beverages are drunk hot. Food is eaten from communal bowls, but chopsticks are used and food is generally not eaten by hand.

I.3.6 Improving Excreta Disposal and Reuse Practices

At the time the communists took power in 1949 levels of public health were very low. Many infectious diseases related to inadequate water and sanitation facilities, in particular ascariasis, typhoid, cholera, hookworm, shigellosis, entamoebiasis and schistosomiasis were highly prevalent. The success in the creation of an effective and integrated primary health care system is well-documented elsewhere (see, for example, Horn, 1969, or for a succinct summary, Macleod in Akhtar, 1975).

Policies in the improvement of waste disposal and environmental health have included: traning and expansion of primary and preventive health workers; mass mobilization compaigns to eradicate pests; greatly strenthened community-level management of development activities; improved techniques in water supply, excreta disposal and re-use practices; and better agricultural practices.

Nightsoil re-use remains a cornerstone of agricultural practice in modern China despite the expansion of industrial fertilizer production in recent decades. The amount and efficiency of human waste re-use has greatly increased. As a result of intensification of agriculture and a mass campaign to "accumulate fertilizer" during the winter of 1955-6 Chao estimates that the amount of human excreta that was re-used increased from 70% in 1952 to 90% by 1966 (quoted in McGarry, 1976).

Specific improvements in excreta disposal and usage practices include the following:

Community Hygiene: The reorganisation of rural society and the creation of community production units has given local authorities greater power to implement and control improved environmental health practices. It has become possible now, for example, to ban the direct application of raw excreta to fields and the washing of nightsoil buckets and excreta removing tools in public waters. Improved personal hygiene is now both a personal and public duty and sanitation and fertilizer collection are part of the daily routine of commune life. Management is through a two-tier system: a "management team" for direction, and a "professional fertilizer collecting team" to carry out communal duties (McGarry and Stainforth, 1978).

Toilet Provision: Toilet provision has been extended and designs improved. Privy designs emphasize easy cleaning and efficient re-use of nightsoil (McGarry and Stainsforth, 1978).

Liquid Fertilizer: One of the first steps taken in improving traditional techniques of using nightsoil as fertilizer was the removal of excreta vats from water sources to prevent schistosomiasis. The establishment of community production led to a major reorganization of fertiliser production techniques. Excreta from all commune members was gathered and stored in centralised banks of vats, which, when full, were sealed to allow anaerobic digestion (Zhong-xian et al. 1982). From 1964 fermentation-settling tanks were introduced for the storage of urine, faeces and wastewater.

Composting: Traditional composting practices have been upgraded and standardized. Several aerobic, high temperature composting methods have been developed which involve the careful and separate collection of ingredients (McGarry and Stainsforth, 1978, and FAO, 1977). Toilets are designed to enable separate collection of urine and faeces, privies are kept separate from pigsties, separate fertilizer and urine storehouses are built, and an excreta treatment field is prepared according to public health criteria. Sanitary procedures are laid down for fertilizer collection, sanitation and composting.

Biogas: More recently some communes have adopted community-managed biogas generators which utilize human excreta and other wastes. Their popularity is reported to be growing (FAO, 1977), among other reasons because of the superior quality of manure produced.

Use of City Waste: City wastes continue to contribute to rural production. Traditional transport methods are now supplemented by piping sewage to some communes where it is stored, dried and used as a basal dressing (FAO, 1977).

I.4 Case Study B: Islamic Cultures

Muslims profess to avoid all contact with human excreta. Excreta and urine, along with semen, corpses and other specified substances are regarded as spiritual pollutants by Koranic edict, and Islamic custom demands that Muslims minimize contact with these substances. Muslim principles of personal hygiene include: ablution with water after elimination; using only the left hand for contact with the anal area and using the right hand for human contact and when eating; and forbidding contact with (or the consumption of) dogs, pigs or other animals which eat carrion or waste matter.

In general Islam demands absolute obedience in carrying out the edicts and laws of the Koran, and Muslims are placed in a very direct relationship to Allah with little mediation by an established church. Islamic proscriptions, such as those prohibiting contact with human wastes, are widely acknowledged and upheld in Islamic societies. The use of human excreta in agriculture and aquaculture and re-use of wastewater are not condoned in Islamic society.

Despite the power, influence and clarity of Islamic law with regard to contact with human wastes, 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 behaviours.

Firstly, the proscriptions certainly do not succeed in limiting contact with human excreta. A review of defecation practices in Egypt indicate that roughly 5 % of the rural population have access to sanitation facilities. Most defecation occurs in and around homesteads, villages, canal banks and fields wherever privacy might be found and a high level of contact with faecal matter is reported (Headlee, 1933, and Farooq and Mallah, 1966). Water for anal cleansing is obtained either from hand-carried ablution jars or from rivers or canals. These water courses consequently carry heavy faecal loads and are a major source of transmission of schistosomiasis and other excreta-related diseases.

There is, moreover, evidence that, despite the strictures against the use of faeces in agriculture in practice much defecation occurs in fields (Cheesemond and Fenwick, 1981). Land fertilization along the Nile was traditionally a product of annual floods, but the development of land irrigation has lead to a great dependence on imported fertilizers, and a great reliance on the part of subsistence farmers on gathering local wastes including donkey manure, pigeon and chicken droppings and ashes for regular distribution on the fields (Ammar, 1951, and Ayrout, 1945). Levels of hygiene after collecting these materials are reported to be low.

Ritual handwashing too has a distant relationship to hygiene in the sense of pathogen removal, as has been illustrated in several studies on the efficacy of ritual handwashing (see Khare, 1962, for an Indian example). Proscriptions on cleansing after defecation are clearly a function of ritual purity and not hygiene.

Secondly, Koranic edicts are variously interpreted among different Islamic movements, and Islam has various degrees of penetration into indigeneous cultures across the great breadth of nations and peoples that proclaim Islad in North Africa, Arabia, Asia and elsewhere. In Iran where Shiite fundamentalism is recreating the Islamic state proscriptions against the re-use of waste water are followed to the letter. In Indonesia where Islamic culture is superimposed upon a strong indigenous culture fertilizer is sold from nightsoil collection in Jakarta (Morrow, 1975). 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).

In a survey on the use of nightsoil in aquaculture in West Java Djajadiredja et al. (1979) report that human excreta is fed directly into fishponds by means of overhang latrines. Eighty five per cent of the 700 village and backyard latrines in the study area have overhang latrines. In addition to having a latrine for private use it is reported as "not uncommon for a fish farmer to build three or four public defecation latrines" to increase his fish feed. The economic value of nightsoil in aquaculture is clearly recognised and the survey reveals that the majority of survey repondents quote fish feed as the priority motive for having pond latrines. Interesingly, almost all of the 120 houshold heads interviewed in the study were Muslims. Djajadiredja et al. comment that villagers in West Java:

"...prefer to perform their defecation habit in flowing water ... (and that the) fishpond is often the most favourable and convenient place for this purpose" (1979).

I.5 Case Study C: Sub-Saharan Africa

The African continent contains a great diversity of cultures, and the cultural traits which bind the continent are not underlain by an embracing system of thought as in the Islamic world or in China. African cultures are in considerable flux in the Twentieth Century having undergone and continuing to undergo immense social changes.

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 maximized. There is no tradition in the use of human excreta in agriculture or aquaculture in Africa. Many societies do practice agricultural composting and fertilization 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 fertilization (FAO, 1975). Domestic animals (principally pigs and dogs) commonly feed upon human excreta in many African cultures (see for example Ouma and Van Ginneken, 1980 for a Kenyan example).

A disaffection for contact with human excreta is a custom common to most, if not all African cultures. Reports from a great many African societies confirm this (see, for example, Nigeria - Adenyi, 1973, Ghana - IDS, 1978; Tanzania - Muhondwa, 1976; Lesotho - Cross, 1979; and Madagascar - n.a., 1983). Human excreta are commonly regarded as defiling and those who touch them are distanced from the main body of society. As the body protects itself from pollution by excrement, so does society from those who handle faeces (Curtis, 1978). In many African cities in which nightsoil is collected the munipal workers responsible for bucket collection are often regarded as being of inferior status.

Notwithstanding these generalizations there are several examples of instances of excreta re-use in Africa. Within Africa's sprawling peri-urban populations there are reports of ingenious informal sector uses for a variety of waste products. Fishing (often illegally) in waste stabilization ponds is reported from several cities (for example the Kenyan city of Kisumu). Fish farming in sewerage ponds is also formally endorsed by several local authorities, for example in Lusaka. The formal sale 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 (see Oberholster, 1983).

Whereas in South Africa sludge is sold almost exclusively to wealthy commercial farmers, elsewhere on the continent there have been attempts to compost nightsoil and sell the compost to peasant farmers. Composting nightsoil and the sale of compost to peasant farmers was introduced to many Nigerian cities in the 1950s. Gillis (1946) reports that when the system was first introduced local farmers were reluctant to handle a product of human faeces; in time and through demonstration and education a considerable demand was generated for the compost (Gillis, 1946). In a review of this early Nigerian experience and other municipal composting experiments in Africa, Peel (1976) concludes that although there may well be initial prejudices against the use of compost which contains human excrement these may be overcome through education and practical demonstration.

The progress of pilot programmes promoting composting latrines are of great interest to those concerned with the possibilities of introducing excreta re-use techniques in Africa: so much so that the focus on composting may even detract from the development of more affordable, less culturally-sensitive technologies aimed simply at the safe disposal of human excreta. Several composting or mouldering latrines have been pilot-tested in Botswana (Blackmore et al., 1978) and Tanzania (Winblad, 1975) in recent years in the wake of the progress of double vault composting in Vietnam. Despite the considerable interest in the progress of these experiments a major limitation to concluding on their experience is the absence of in-depth socio-cultural studies on the acceptability of the technology or detailed analyses of the programme costs both, in physical inputs and in promotional support, to achieve user acceptance.

Available reports only give preliminary or suggestive conclusions. In both Tanzania (Fogel, 1977) and Botswana (Blackmore et al., 1978) there are reports that users were not prepared to touch material containing human faeces. A more recent study of the acceptability and use of compost latrines in Tanzania concluded that user's prior beliefs regarding handling human excreta had little bearing on the efficacy of composting technology, (Killewo, 1980). It is interesting to note that (though the sample is small) over half the respondents were Muslims and no significant difference was demonstrated in willingness to use the fertilizer from the latrines between Muslims and Christians (1980). The compost was judged to be sufficiently dissimilar from fresh human faeces not to be regarded as a taboo resource.

The Tanzanian programme is however not without its problems in other respects and it is by no means clear yet that composting is a viable technology in Africa. Whereas many users had traditionally used pit latrines as washrooms the fact that this was discouraged in the composting latrines was disliked by users. Only a third of respondents were able to use the fertilizer, partly because the sample contained a number of peri-urban dwellers, and partly as a result of user fears that the compost would spread disease. Other problems experienced both in Tanzania and Botswana were the high cost, a poor standard of construction and/or design which lead to a high breackdown rate, and users' lack of education or motivation in the management of the latrines.

In an earlier review of the Tanzanian programme Simbeye (1981) points out that no community-initiated composting latrines have been built following the pilot programme and that the poor level of household operation and maintenance has greatly limited the numer of latrines which produce viable compost. Simbeye comments that:

> "People did accept the composters but the acceptance could well be due to the fact that they did not have to pay for the latrines and they needed them anyway".

The future for human excreta re-use in Africa hangs in the balance. The questionmarks hang not only over the question of cultural acceptability but also on both the oppportunity and real cost of these innovations, and on the ability of African countries to mobilise the resources for effective project promotion and management.

I.6 Discussion

Clearly the case-studies presented can only be illustrative of the range of cultural variation in re-use attitudes and practices. Table 1 below gives an indication of a fuller range of re-use systems practised in developing countries.

The rough distinction between cultures which have a tradition of re-use, those which actively discourage the concept, and an intermediary category of cultures in which the situation is more variable provides a useful categorization for the purposes of this discussion.

I.6.1 Cultures that Use Excreta

The Chinese case study is perhaps the most remarkable in nutrient re-use, both in the extent of re-use practice and in the pragmatic Government policies adopted. The mass programmes to promote sanitation and nutrient re-use are undoubted reflections of a committment to improving the rural environment and rural production.

At the same time they are consistent not only with Chinese traditions of frugality (Orleans and Suttmeier, 1970), but they also propose practices within an ancient framework of ideas regarding excreta disposal and re-use. Practices have been made more efficient, are now less injurous to health and the unit and organization of management for disposal and re-use has changed. The indigenous cultural understanding of relations between man, his bodily products, the fertility of the soil and food production has not changed. Similarly a reason for the successful development of double vault composting latrines in Vietnam is undoubtedly largely attributable to a prior cultural acceptance of the use of human excreta in agriculture (see McMichael, 1976).

When attempting to improve systems of excreta usage and re-usage in cultures that have a tradition of using human excreta the critical areas in which socio-cultural issues are important are:

1. health risk behaviours when using human excreta;
2. effective local-level management and communications support for re-use upgrading programmes;
3. social costs of extending or altering traditional systems.

a. *Health Risks*

The health risk behaviours associated with excreta re-use systems include: hygiene with respect to defecation and post defecation behaviour; practices in the collection and storage of night soil; hygiene in the course of treatment; hygiene associated with re-usage; and methods of food preparation.

Our detailed understanding of the behavioural risks associated with human excreta use are limited and there is an important need for joint anthropological/epidemiological research to determine key behaviours associated with disease transmission. Such research would need to combine field observational studies and social anthropological fieldwork within the framework of an epidemiological study.

In the Chinese case study the principle health benefits of present policies would seem to derive from more efficient and hygienic collection practices, more hygienic latrines, better storage arrangements, and more effective treatment of excreta to eliminate health risks in re-use. There is little information available on the improvements in post defecation hygiene, handwashing and personal hygiene, disposal of children's excreta, methods of transporting raw excreta and practices with regard to rearing pond fish in waters with raw excreta. These might well constitute foci for future health promotion.

Most cultures have traditiohnal codes of hygiene which undoubtedly go some way towards limiting disease transmission. The Chinese practice of always consuming hot or cooked food and beverages is such an example: especial caution should be taken when introducing excreta re-use practices in cultures where traditional hygiene does not take account of contact with excreta. Hygiene promotion is often most successful when it builds upon traditional beliefs and practices.

b. *Local-level Management and Communications Support*

Implementing successful improvements in re-use practices, as in any sanitation programme, demands especially careful project planning (see for example the World Bank studies on sanitation, especially Volume 2, Kalbermatten et al., 1982). A multidisciplinary approach is necessary in considering the financial, economic, social, managerial, educational and technical aspects of project planning. Other important components are: a committment to adhering to priciples of community involvement in programme planning and implementation; effective local-level (family, community or local authority) organization and management; and sufficient communications support to educate, inform and motivate communities in technology usage. Perrett (1982) provides a useful introduction to planning communication support activities for sanitation programmes.

The success of Chinese initiatives toward improving excreta re-use practices is in no small measure a consequence of the development of community production units and the emphasis on effective local- level management of excreta re-use systems. McMichael's report (1976) on the Vietnamese programme moreover illustrates that the growth of the programme was not without setbacks. Acceptance was by no means immediate but required a patient campaign of education and demonstration (Rybczynski, 1981), and considerable support for local-level organisations on the part of political workers. In much of Africa and South America by comparison, the establishment of effective local- level management units has not generally been achieved and adequate educational, health and political support to communities is lacking.

c. *Social Costs*

Briscoe (1978) makes the point that in developing more efficient exploitation of natural resources it is also necessary to take into account existing social relations in order to understand potential social costs of these changes. Where the rural poor are dependent upon waste nutrients, promoting the usefulness of wastes among wealthier classes serve to further disadvantage the poor.

The Chinese policy of collective rural development to some extent obviates this problem. The conflict between community and individual usage of nightsoil is present (McGarry, 1976), but has been resolved to some extent by allowing individual farmers to keep a standard proportion of their wastes for their own purposes. It is not known what the social costs in terms of rural inequality of this policy.

I.6.2 Cultures that do not Use Excreta

The socio-cultural issues raised above with respect to health, project management, communication support and social costs are also of relevance where human excreta re-use projects are being considered in cultures where no experience of excreta usage exists. However in the latter cases there are the additional tasks of deciding whether excreta re-use could ever be culturally acceptable and, if so, of adopting a strategy to overcome taboos against using human excreta. The planner is faced with two basic options: either to plan around fixed beliefs; or to attempt to change these attitudes.

Where taboos are endorsed by central and active religious ideas, such as in the case of fundamentalist Islamic cultures it would seem obvious that the chances of gaining political, let alone cultural, acceptability would be remote, and that sanitation measures not involving re-use of human excreta would be more appropriate.

In the majority of other cases the decision is more difficult, but, given sufficient resources, serous consideration should be given to strategies for changing prevailing atitudes. Culture as we have said is not a fixed entity and cultural boundaries change. Julius illustrates rises and falls in re-use practices in Japan, Korea and Taiwan relative to income levels (1978). In India attitudes towards excreta re-use are diverse and authors variously ascribe differences in attitudes to caste, class, religion and education. Subramanian (1978) argues that taboos against contact with humn excreta are more prevalent among upper castes and the urban middle classes, that among much of the peasantry atttudes are mixed and unrelated to education or religion, and that the attitude among those who themselves handle excreta or slurry is largely indifferent.

Other authors, for example Chowdhury et al. (1981), report members of low Hindu castes undertaking tasks which involve physical contact with human excreta, while Muslim sweepers restrict their refuse collection and cleaning work which does not involve contact with human faeces. Hindu Brahmin custom on the other hand severely restricts contact with human excreta (Dubois, 1906). Despite the cultural complexity the literature appears to concur with Briscoe's general conclusion that the prospect of introducing re-use of human excreta may have less social costs and may ultimately be more acceptable in India than the further exploitation of agricultural wastes (Briscoe, 1978).

Preliminary results from the Tanzanian experience with compost latrines cited above bear out the point that overcoming the initial cultural response to the prospect of re-using human excreta may be the least of the problems of rural sanitation programmes in Africa.

In cultures where there is no experience of re-use of human excreta the following points may be of significance in designing a suitable programme.

Pilot. Innovations need to be pilot-tested before embarking on a large-scale programme.

Community Involvement. Communities need to be brought into programme decision-making at the planning phase. Rural dwellers often know far more about local constraints than urban planners, and user support for a technical innovation is essential before it has any chance of success.

Communications Support. Appropriate support in information dissemination, education and motivation is an essential compliment to enable communities to participate in programmes. A review of communications support in sanitation programmes more generally (Perrett, 1982) includes the following comments on communication support in sanitation programmes:

- keep the plan simple and do not rely on managerially complex activities;
- the timing and message content of communication support activities needs careful planning for maximum impact and to avoid raising expectations which may not be met;
- use existing communication networks and media;
- and express messages and ideas within the context of local knowledge and local experience.

Incentives. Programmes will only run if users appreciate programme benefits. Users should need and be able to use the nutrients collected in re-use programmes. The Tanzanian experience of piloting composting latrines in a peri-urban area where users had no use for the compost exemplifies the point (Killewo, 1980). Clearly the financial cost of the final product to users as against other alternatives is of critical concern to the success of the innovation.

End product not excreta. Much of the resistance to excreta re-use programmes rests on the fallacy that users will have to handle fresh excreta. Rybczynski makes this point in concluding that:

> "...it would be premature to make any judgements about the reuse of composted excreta in agriculture since there are so few instances of successful composting actually in operation. Most traditional (negative) attitudes towards the reuse of excreta (in Africa or elsewhere) have been formed on the experience of raw or partially digested human excreta, not compost" (1981).

Emphasis should be placed, preferably through demonstration, on the fact that the end product of many re-use technologies is inoffensive, odourless, and bears little relation to fresh human excreta.

Separate Production from Consumption. A useful distinction to be made in planning re-use programmes in cultures reticent about contact with excreta is that between production and consumption. Just as many foods are culturally acceptable in their cooked but not their raw state, so cultures might be convinced that excreta undertake a similar transformation from a socially unacceptable to a socially acceptable product once it has become composted or treated. It may be easier to gain acceptance of re-use for consumption of recycled products rather than to involve users in all stages of production.

Social Unit Options. Most re-use technologies allow for several options as to the social unit of production or consumption (see Table I.1). The decision on which option to adopt might be made with reference to the degree of opposition to the practice of re-using excreta. Clearly individual production for individual consumption requires greatest social acceptance. Production of high quality compost by an enterpreneur, for example, if affordable and produced for an agricultural community requiring soil fertilization, is far more likely to be acceptable. Institutionalised labour-intensive production techniques as adopted in many Indian cities may be one method of initiating re-use practices in an inobtrusive manner.

Step by Step. Bruvold and Ward, (1972) endorse the adoption of a step-by-step approach in attempting to convince Californians of the merits of using reclaimed wastewater, whereby uses such as lawn irrigation are first promoted. Only when acceptance for these have been established (and reclamation techniques improved) would authorities attempt to extend the usage of reclaimed water to within houses. In a similar manner sequences of innovation might be developed leading to full acceptance of reclaimed nutrients. Human excreta may, for example, first be used in cattle feed in societies where beef is eaten before an attempt is made to introduce more immediate uses of recycled products.

I.7 Conclusions and Recommendations

Social and cultural problemes severely constrain the imlementation of several human excreta re-use technologies that might otherwise be beneficial in easing resource constraints in poor countries.

The most prominent socio-cultural question asked in considering human excreta re-use is: is re-use culturally acceptable? This is an important question but its importance relative to other socio-cultural and programme management questions may have been overstated. Re-use technologies that are of real benefit to a populace, that are affordable and that do not entail unacceptable social costs may well gain acceptance even where there are religious or cultural taboos to the concept of human excreta re-use.

It is moreover not a question which can always be simply answered. Firstly, cultures are rarely homogeneous and frequently contain a complexity of subcultures with quite different orientations. Secondly, cultures are not fixed entities: values, beliefs and customs change and can be made to change. Thirdly, the most appropriate study methodology for gathering data on this culturally sensitive area - principally social anthropological fieldwork - has rarely been employed.

Properly implemented social anthropological fieldwork entails relatively little cost but considerable time and the recruitment of professional expertise capable of gathering and interpreting qualitative data. Behavioural patterns and attitudes need to be studied through time and over agricultural seasons. Attitudes will vary across age, sex, class and social status categories, and will differ according to the social context in which they are expressed.

Social anthropological fieldwork techniques, properly undertaken, will take these distinctions into account in attitudinal analysis and may obviate many of the problems of questionaire-based studies. Social anthropological fieldwork does have methodological shortcomings which need to be acknowledged in the course of analysis. These include problems of intrusiveness of fieldwork, subjective interpretation and generalization from in-depth case-studies.

Other major socio-cultural questions less frequently asked concern what has been referred to above as behavioural and social dimensions: what are the principle re-use behaviours facilitating disease transmission; and how would social relations, at the family, community and macro level affect and be affected by a change in re-use practices?

Related questions asked by programme planners include: what level and type of communication support (information, motivation and education) is necessary to implement an effective re-use programme? What is the real financial value of excreta re-use to users? What is the real economic value of human excreta re-use in a particular physical and cultural setting relative to the costs of both the physical inputs and commuications support necessary for public acceptability? Clearly socio-cultural factors cannot be viewed in isolation from either financial and economic, technical or health considerations.

There remains, therefore, an urgent need for detailed field studies of social, cultural and behavioural aspects of human excreta re-use.

What is required is not research into technologies with a minor social research component, but mainstream research into the behavioural, cultural and social aspects of the implementation and improvement of re-use technologies. Aspects of this research might be purely theoretical, such as in analysis of the meaning and position of particular cultural traits. The emphasis, however should be placed on applied research in which, for example, different technologies or communications support components are piloted and closely monitored with the objective of learning about social and educational aspects of human excreta re-use rather than restricting the pilot investigation to technical investigations.

Priority areas for reaseach and development with regard to socio-cultural aspects are as follows:

1. Anthropological field research on social aspects of defecation and re-use practices and beliefs to detail precise behavioural practices, cultural attitudes and social relations in a wide variety of cultures.

2. Joint epidemiological/anthropological research on behavioural aspects of disease transmission related to existing re-use practices.

3. Applied field research monitoring user's response to a variety of innovations and modifications, with especial emphasis on experience in cultures in which contact with excreta is considered culturally unacceptable. The objective would be to pilot re-use projects to examine the potential for changing cultural attitudes in a variety of cultures. Aspects which need monitoring include: financial costs to users; the real and opportunity costs of physical and communications support inputs necessary for a viable programme relative to economic benefits; the social costs of introducing technologies which use human excreta; the development of appropriate local-level management structures tailored to re-use technologies; and the development of communications support methods, media and techniques used in supporting re-use programmes.

   Priority pilot projects include: the sale of nightsoil composted by local authorities in cultures in which there is both an expressed need for additional soil fertilization and in which re-use of excreta is not customarily practiced; and composting technologies which are adequately supported by communications support programmes.

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PART II: PATHOGEN SURVIVAL

II.1 Principles of 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. i.e. there is a rapid decrease in numbers in the first few hours or days after excretion with a reduced number surviving over an extended period. 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. *Schistosoma, Chlonorchis sinensis*) which have a multiplication phase in intermediate hosts.

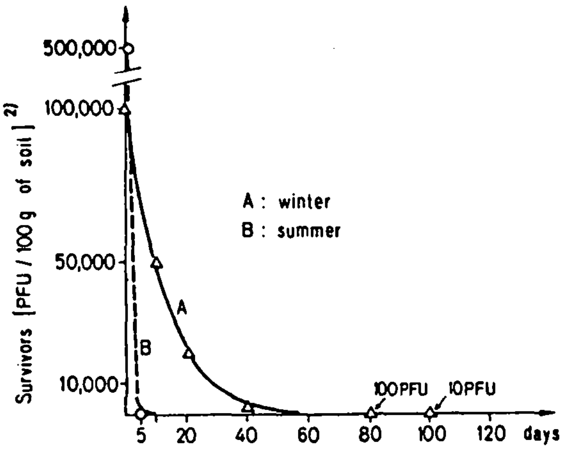
Typical pathogen die-off patterns are illustrated in Fig. II.1. It shows arithmetically-plotted die-off curves for poliovirus 1 recovered from soil sampled in field plots which had been flooded with polivirus 1-inoculated sewage sludge (Tierney et al. 1977). The two curves represent virus survival under winter and early summer conditions respectively.

Fig. II.2 is another illustration of the exponential die-off pattern of pathogenic organisms in the non-host environment: *Salmonella* survivals were determined on lettuce which was fertilized with digested sewage sludge. The sludge was inoculated with a high load of cultured *Salmonella* cells for experimental purposes (Larkin et al. 1978).

Pathogen die-off basically follows the same exponential-type pattern independent of the kind of environment, such as soil, crops, sludge, or excreta stored in a latrine or leaching pit. Particular environmental factors, however, determine the actual die-off rate and the number of organisms surviving within a given time period. This, in turn, determines the time necessary to obtain a "safe" or "reasonably safe" product. Based on Figures II.1 and II.2 and on a wide range of relevant references (Gerba et al. 1975, Bryan 1977, Golueke 1983), it is possible to list the main environmental factors which influence pathogen die-off (Table II.1).

Table II.1 Major Environmental Factors Influencing Pathogen Die-Off

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 or soils or in waste product), humidity	- Generally longer survival in moist environment and under humid weather conditions, rapid die-off under conditions of desiccation
• Nutrients	- Accelerated die-off if essential nutrients are scarce or absent
• Competition by other microorganisms	- Longer survival in an environment with few or no microorganisms competing for nutrients or acting as predators
• Sunlight (ultraviolet 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

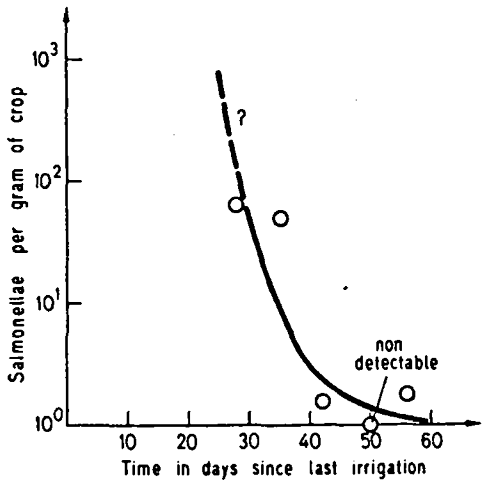


	Initial conc. [PFU/100g of soil]	Die-off rate [no. of org./day] day 1	day 5	d.5-10	day 20-40	T_{90} [days]	T_{99} [days]
Curve A (winter)	100,000	← 5,000 →			900	~30	~50
Curve B (summer)	>500,000	450,000	16,000	75		~1	~2

[1] after (Tierney et al. 1977)

[2] PFU - Plaque Forming Unit

Fig. II.1 Poliovirus Die-Off in Sludge-Fertilized Soil



[1] after (Larking et al. 1978)

[2] hot and dry weather ; intense solar radiation

[3] sludge inoculated with cultured Salmonellae typhimurium to give 10^7 Salm./ml of sludge !

Fig. II.2 *Salmonella* Die-Off on Sewage Sludge-Irrigated Lettuce

The number of pathogens initially present in the waste product or in the particular environment such as soil, crops or fish, is a further decisive factor determining the number of viable pathogens which may be detected after a set period of time. The higher the initial number of viable pathogens, the longer the period during which viable pathogens will be detectable in waste products, or excreta-fertilized soil, crops or in fish ponds (environmental conditions remaining the same otherwise).

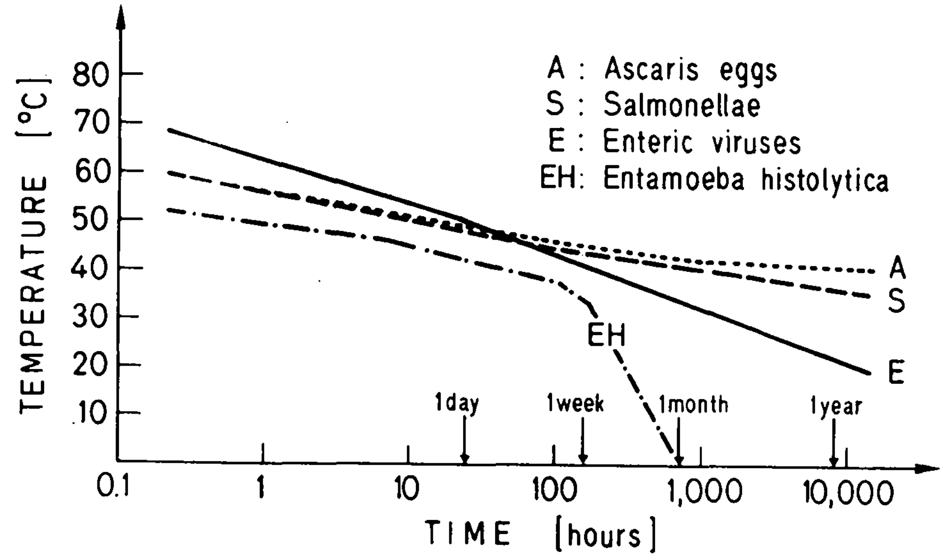


Fig. II.3 Time-Temperature Relationship for Excreted Pathogen Survival in Nightsoil and Sludge (after Feachem et al. 1983)

Figure II.1 illustrates the role of temperature for survival; it shows that die-off of poliovirus 1 in soil is substantially faster in summer (at elevated ambient temperature) than in winter. For the count of viable organisms to be reduced to 10, it took approximately ten days only in summer, but about 100 days in winter although the initial virus concentration was higher in the summer than in the winter experiment. Temperature was the overriding factor determining die-off rates.

After reviewing the results obtained from numerous investigations on pathogen survival conducted under widely differing conditions, Feachem et al. (1983) plotted temperature vs. survival time for a number of pathogens. In these graphs, boundaries are drawn above which combinations of sufficiently high temperatures with a sufficiently long "waiting" period will ensure complete inactivation or death of the pathogen. Fig. II.3 is a schematic representation of such time-temperature relationships for the survival of enteric viruses, *Salmonella, Ascaris* eggs and *Entamoeba histolytica* in faecal matter and sludge during storage or treatment at different temperatures. The lines represent "safety" boundaries above which complete inactivation of the pathogens can be assumed. The relationship is logarithmitic, i.e. every 10°C increase reduces survival time 10 to 100-fold. The graph shows that viruses are the most "sturdy" organisms at elevated temperatures (> 50°C), whereas at ambient temperatures *Ascaris* eggs and *Salmonella* are the more resistant organisms. Amoeba exhibit relatively weak resistance in the non-host environment.

II.2 Survival during Storage and Treatment

This chapter deals with the effects of passive and active (i.e. induced) nightsoil treatment on the die-off or inactivation of pathogens. Each of the relevant types of treatment systems is briefly described and its pathogen inactivation efficiency or, more important, the potential risk of pathogen survival characterized.

Only these treatment methods which are considered to have a reasonably good chance of success in tropical countries are discussed. Thus, processes requiring treatment by chemicals or heat are not dealt with.

II.2.1 Objectives and Boundary Conditions

The main objective behind nightsoil storage and treatment is to render the faecal product "safe", i.e. as risk-free as necessary for subsequent handling, disposal or use. The reason is to help attain the interruption of infection cycles of excreted pathogens by allowing for or inducing the die-off of pathogens or loss of their viability.

Fig. II.4 shows in schematic form the role played by excreta storage and treatment in pathogen inactivation: the treatment sought should either subject the faecal product to high temperatures for a relatively short period of time (e.g. thermophilic composting), or provide extended retention time at ambient temperature (e.g. retention in pit latrines). The retention time required to achieve a desired "safety" decreases with increasing temperature.

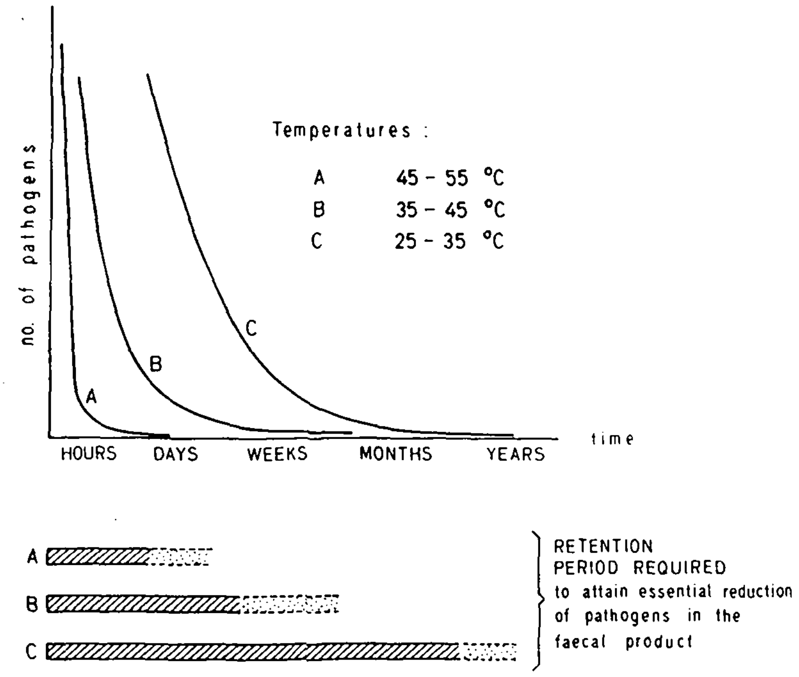


Fig. II.4 Pathogen Die-Off in Faecal Products and Treatment Periods Required at Different Temperature Regimes

In search of suitable types of treatment which would enable excreta use in agriculture and aquaculture, the following pathogen-related as well as socioeconomic 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 (see Chpt. 3). 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 a product would then be also free of other pathogens.

- 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, and (4) economic and technical constraints.

II.2.2 Latrines

The following systems are discussed with regard to their pathogen reduction potential: **"dry" disposal latrines** and **pour-flush toilets.**

In **dry latrines**, the faeces are disposed of in the pit or vault without the use of flush water. There are many different types of design and methods of latrine construction which fall under this category. Prevalence depends on local conditions and preferences. The basic latrine types either have a pit directly under or offset, or two adjacent pits or vaults which are alternately filled, let to rest and then emptied.

Pour-flush latrines can be called "wet" systems as the excreta have to be flushed to a nearby collection/soakage pit with one to two litres of water. Toilets may be built with either one or two alternately operated leaching pit.

Fig. II.5 illustrates some common latrine types. A distinction is made between single and alternating-pit systems. This truncation is particularly useful in the nightsoil utilization context: when full, single-pit latrines need to be either abandoned or emptied to allow continued use. In the latter case, 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 treatmeent prior to its use. In contrast, the contents of properly operated twin-pit or double-vault latrines carry much

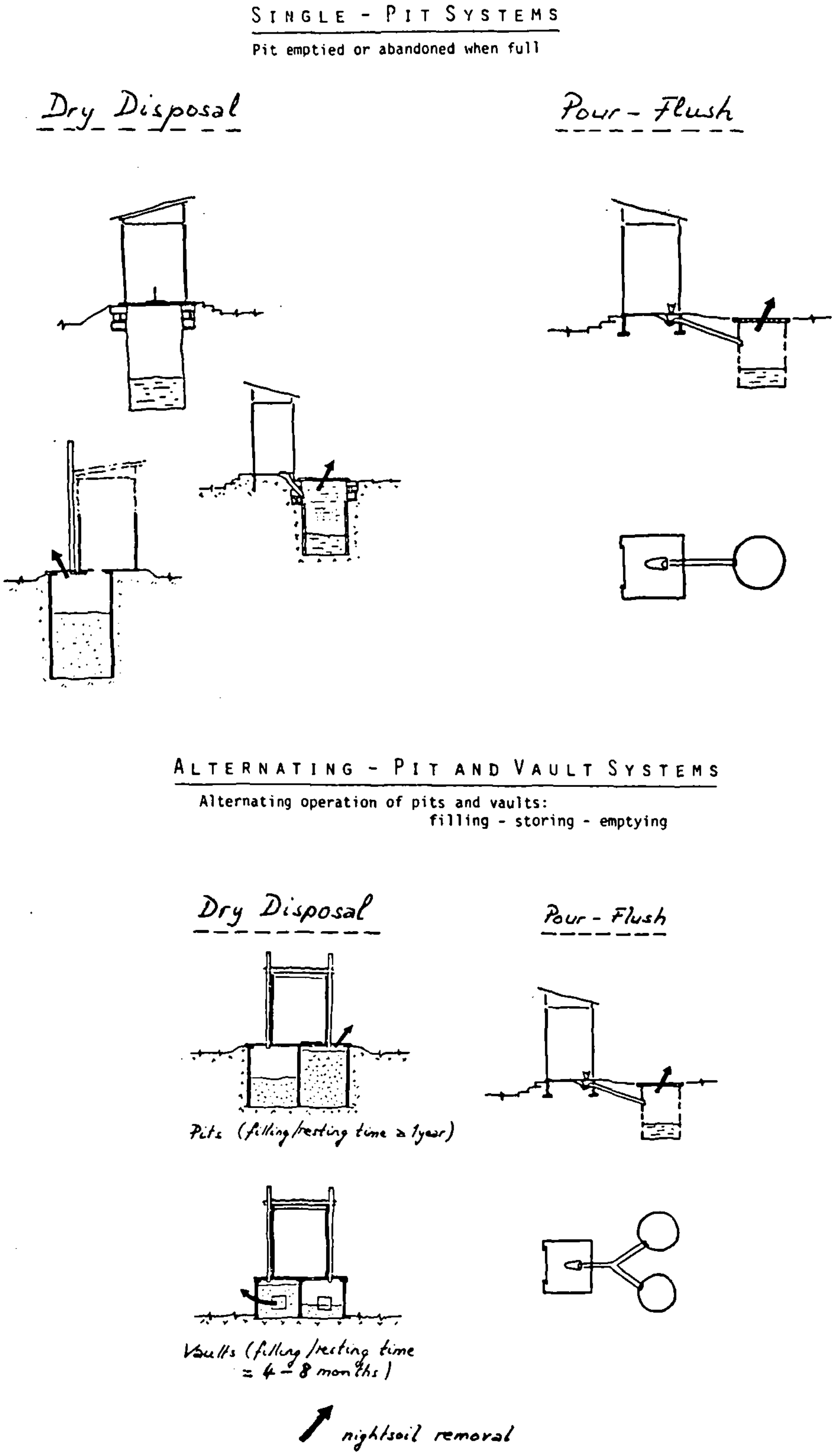


Fig. II.5 Single and Alternating-Pit (or Vault) Latrines

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[1] "Pits", either lined or unlined, are built so that liquid may seep into the underground, whereas "vaults" are constructed in such a way that there is minimal or no seepage.

lower health risks as most pathogens will have died off . Alternating-pit latrines therefore constitute attractive and appropriate excreta disposal options where nightsoil utilization is traditionally practised or where its use is planned.

To date, little research has been conducted on the die-off rate of pathogens in pit, vault or pour-flush latrines. Feachem et al. (1983) have tabulated data from relevant investigations on pathogen survival in nightsoil, faeces and in sewage sludge. They suggest that pathogen survival is essentially similar in the three media. Expected survival times are shown in Table II.2.

Table II.2 Survival of Excreted Pathogens in Nightsoil, Faeces and Sludge at 20-30°C (Feachem et al. 1983)

Pathogen	*Survival time* (days)
Viruses	
Enteroviruses[a]	< 100 but usually < 20
Bacteria	
Fecal coliforms	< 90 but usually < 50
Salmonella spp.	< 60 but usually < 30
Shigella spp.	< 30 but usually < 10
Vibrio cholerae	< 30 but usually < 5
Protozoa	
Entamoeba histolytica cysts	< 30 but usually < 15
Helminths	
Ascaris lumbricoides eggs	Many months

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

The data in Table II.2 probably apply to the conditions for pathogen survival in pit and pour-flush latrines. In general, latrine pits have filling times lasting from one to several years, depending on the pit size, soil conditions and the number of users. Under ideal conditions, both systems would be constructed and operated in such a way as to provide extended nightsoil storage prior to pit emptying or use or use of the decomposed pit contents. Single-pit latrines are abandoned when full and a new latrine built next to it. In alternating-pit systems, the material from pits at rest is removed when the pit in use becomes full, i.e. after one or more years.

Where people practise **aquaculture**, i.e the growing of fish or water vegetables for human consumption, trematode (fluke) infections might be transmitted through excreta fertilization of the ponds if the respective diseases occur in the area, and if the fish or vegetables are not properly cooked.

Clonorchis and *Opisthorchis*, two closely related trematodes known to be endemic in eastern Asia (Thailand, China, Korea, Taiwan, Japan) are transmitted through the consumption of uncooked or insufficiently cooked fish grown in excreta-fertilized ponds. From the little research done on the survival of *Clonorchis* or *Opisthorchis* eggs in nightsoil, one may conclude that eggs are inactivated within a few days (Feachem et al. 1983).

Fasciolopsiasis is another trematode infection endemic in several areas of south-east Asia (India, Bangladesh, Thailand, Taiwan, China, Vietnam). Transmission occurs through raw eaten water vegetables grown in excreta-fertilized ponds. Eggs of *Fasciolopsis* seem to be more resistant than those of *Clonorchis* and *Opisthorchis* and may survive up to several weeks in faecal sludges (Feachem et al. 1983).

In areas where *Schistosoma* (bilharzia) is endemic, the infection might be transmitted when people catch fish or harvest water vegetables grown in excreta-fertilized ponds, or in ponds into which people, particularly children, defaecate or urinate accidentally during water contact. Transmission may also occur during work in paddy fields if they are used for open defaecation. Of the three main species of *Schistosoma* (*S. haematobium, S. mansoni and S. japonicum*), *S. japonicum* appears the most resistant with respect to egg survival in nightsoil: egg survival of several weeks has been reported. *S. mansoni* eggs, however, are inactivated within a few days in warm climates (Feachem et al. 1983). Table II.2a summarizes trematode egg survival in faecal sludge.

Table II.2a Survival of Trematode (Fluke) Eggs in Faecal Sludge at 20-30°C (after Feachem et al. 1983).

Trematode	Survival time (days)
Schistosomes	
· *S. japonicum*	$\leqslant$ 30
· *S. mansoni*	$\leqslant$ 10
Fasciolopsis	$\leqslant$ 30
Clonorchis, Opisthorchis	$\leqslant$ 2

In areas where these diseases are endemic and carried by fish or water vegetables, excreta should be stored prior to use as indicated, e.g. in alternating-pit or vault latrines.

Construction, operation and maintenance of latrines rarely follow ideal patterns. It is realistic to assume that the faecal product, originating from latrine pits or used as fertilizer or simply disposed of, has in many instances been stored for an insufficient length of time, and therefore contains viable pathogens, notably helminth eggs. 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 immediately upon becoming full.
- If the pits of latrines which are designed and built to operate as alternating-pit systems are in fact in simultaneous use. This will also lead to the handling of fresh excreta when pits are emptied.

In Vietnam and China, so-called **composting latrines** have been in widespread use for many years. They have only quite recently been tried in other tropical countries. The prospect of achieving both a valuable soil conditioner and fertilizer from the latrine and a hygienic way of excreta disposal, has induced many planners and field workers to believe that this could promote or increase acceptance of latrine programmes among potential users. Composting latrines were therefore thought to constitute a logical and attractive solution to improved excreta disposal.

The Vietnamese type composting toilets are batch-operated double-vault latrines. The vaults are small in relation to other twin-pit latrines and become full within approximately 4-6 months. Thus, relatively little time is available for excreta decomposition and pathogen inactivation. Urine is disposed of separately. Vegetable or other organic wastes must be added to the excreta to sufficiently increase the carbon:nitrogen ratio to enable good composting. At the same time, moisture, air and nutrient supply must be at appropriate levels. Under such conditions, the temperature will rise to over 50°C during composting, and both volume reduction and pathogen die-off will be relatively rapid. Within a few months, the respective vault content will be hygienically safe for removal and use.

Experience shows that with the exception of areas such as Vietnam and China, where the use of composting latrines is traditional (Polprasert et al., 1981), the great operational care required to achieve proper aerobic decomposition is usually not given due to a lack of necessary carbon sources, information or awareness, or because the technology is not accepted. The DAF (dry alkaline fertilizer) latrine used by CEMAT[1] in Guatemala in its village bioenergy programme appears to constitute an exception. The Vietnamese type double-vault latrine is well accepted by many users who previously practised open defaecation. Urine is disposed of separately and ash added regularly.

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[1] Centro de Estudios Mesoamericanos sobre Tecnología Apropiada (Guatemala)

Farmers use the product on their fields. Investigations are under way to assess pathogen die-off in the latrines and the main factors influencing it.

Feachem et al. (1983) suggest that so-called composting latrines usually operate under anaerobic and ambient temperature conditions similar to pit and pour-flush latrines. The waste product from such latrines may, however, be of inferior hygienic quality due to the relatively short retention time - a few months only compared with one year or more in dry alternating-pit latrines and pour-flush latrines with twin leaching pits. Table II.3 shows that helminth eggs are probably the main survivors in "composting" latrines.

Table II.3 Pathogen Content Expected in Final Product of Composting Latrines Operating Anaerobically at Ambient Temperature in Warm Climates (Feachem et al., 1983)

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*.

II.2.3 Aqua Privies and Septic Tanks[1]

Aqua privies and septic tanks produce both liquid and solid wastes. The wastewater comprises the greywater from bathroom, kitchen and washing activities, as well as the water used for excreta flushing. It is either allowed to soak away into the underground or it is discharged into a sewerage system. The sludge fraction consists mainly of faecal matter disposed of directly (aqua privy) or flushed through a sewer (septic tank). In contrast to the contents of pit-type latrines, the faecal sludge in aqua privies and septic tanks is continuously stored under water and therefore of rather liquid consistency similar to sewage sludge.

Fig. II.6 contains schematic drawings of an aqua privy and a septic tank with their respective waste fractions.

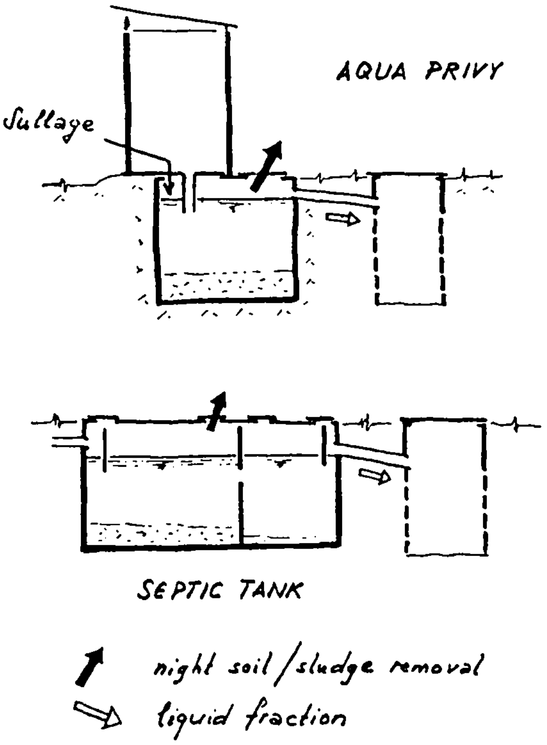

Fig. II.6 Aqua Privy and Septic Tank (Schematic)

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[1] Only the sludge portion of aqua privy and septic tank contents are dealt with here. Aspects of pathogen survival in wastewater and wastewater reuse in agriculture are reviewed by Shuval et al. (1986).

Aqua privies and septic tanks are used predominantly in urban and peri-urban areas. Periodical emptying is usually catered for by town or government departments, or by private enterprises. Depending upon the local circumstances and waste disposal infrastructure, the sludge which is removed and collected from privies and septic tanks is disposed of in one of the following ways:

- Direct discharge into wastewater stabilization ponds
- Discharge into underground sewers which drain into treatment ponds or receiving waters (e.g. sea outfall)
- Discharge on bare, uncultivated land
- Discharge into drainage ditches or seasonal water courses.

The waste collected from privies and tanks 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 undecomposed at the time of emptying, as privies and septic tanks are in continuous operation. It must accordingly be assumed that the sludge removed from these units contains the whole spectrum of viable viral, bacterial, protozoal and helminthic pathogens in substantial concentrations. Such wastes are thus unsuitable for direct use on fields and probably also in fish ponds. They require further extended storage or active treatment prior to application. Fig. II.7 illustrates pathogen survival in privies and septic tanks. Properly operated aqua privies may provide liquid retention times of up to 20 days and thereby yield higher pathogen removals from the liquid than indicated in Fig. II.7. Viruses and bacteria may adsorb to settling particles.

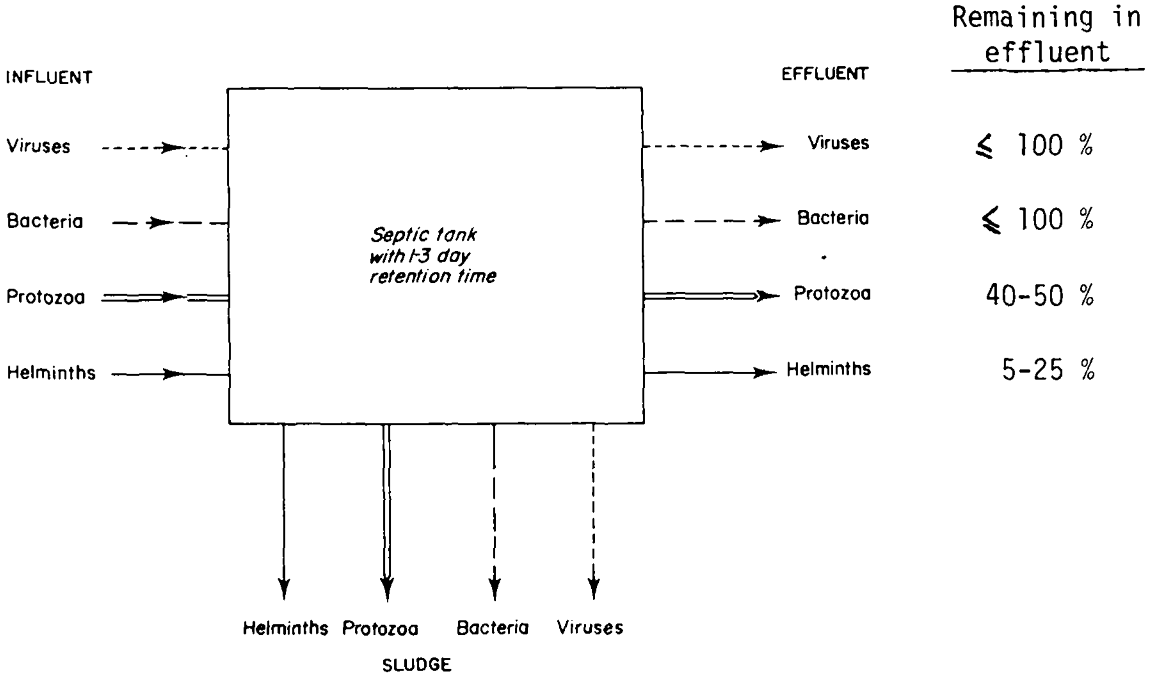

Fig. II.7 Pathogen Survival in Privies and Septic Tanks (after Feachem et al., 1983 and Shuval et al., 1986).

II.2.4 Thermophilic Composting

The Process: The following description is based on summarized accounts of Shuval et al. (1981), Obeng (1982), and Feachem et al. (1983). A thorough discussion of both mesophilic and thermophilic composting is contained in Gotaas (1956).

Composting is a biochemical process continuously going on in nature: organic matter is decomposed by microorganisms to humus-like substances. Under natural conditions or with the use of simple methods as applied by farmers, decomposition mainly takes place at ambient or slightly above ambient temperature; the organic material being decomposed under mixed aerobic-anaerobic conditions by microorganisms working in the mesophilic temperature range between 8°C and 45°C.

In contrast to anaerobic composting of organic matter occurring under natural conditions, aerobic composting can be induced to proceed in the thermophilic range, i.e. between approximately 45° and 65°C. This is mainly achieved by providing an ample oxygen supply to the composting matter through suitable methods of forced aeration, which facilitates aerobic microbial activity. A mass of composting mixture will then pass from ambient temperature through successive stages of mesophilic, thermophilic and again mesophilic bioactivity with related changes in kind and concentration of bacteria, actinomycetes (= filamentous-type bacteria), fungi, and protozoa present in the waste material or imported from the atmosphere.

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, C:N = 20-30, min. 20 and max. 60 % moisture, pH 6-8 and well-disintegrated waste matter[1]) is more rapidly decomposed (within a few weeks) than if anaerobic conditions prevail (several months). The attractive feature of well-managed thermophilic composting is the rapid self-heating to temperatures ranging from 50°-60°C. The process thus lends itself to rapid and effective inactivation of pathogens - including helminth eggs - in human excreta.

Nightsoil alone does not lend itself to aerobic/thermophilic composting. In order to satisfy the above criteria, nightsoil must be mixed with other wastes such as manure and plant wastes. These act as organic amendments and help raise the C:N ratio of nightsoil from 10-15 to 20-30. They also act as bulking agents which contribute to the air and water control. It appears from the cited references that the compost mixtures are typically composed of one part nightsoil and two to five parts by weight of organic amendments.

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[1] Ambient temperature is of less importance if appropriate composting conditions are provided.

During properly controlled composting, the temperatures within the compost heaps will remain above 60°C for five to ten days. Under such circumstances, human excreta will be converted into a humus-like product no longer hazardous to health when used as fertilizer.

The Practice: Detailed accounts of century-old patterns of nightsoil application to soil and fish ponds and nightsoil composting in Asia (e.g. Japan, Korea, China) are contained in King (1911), Howard (1940), Scott (1952), and McGarry and Stainforth (1978). Variable methods of composting nightsoil together with farm wastes (cattle manure, crop and vegetable wastes, ashes, soil) or with urban organic wastes have evolved over the centuries or have been developed in the 20th century as an outgrowth of traditional methods such as the "Indore" method developed by Howard in India and the "Four-combined-into-one"[1] high-temperature composting method in China reported by McGarry and Stainforth (1978). Both the traditional and adapted methods vary with the kind and number of organic waste components used and way of physically arranging the material, i.e. in pits fitted with walls, in heaps, or in stacks. A further distinction is the method of maintaining aerobic conditions which allow for the growth of heat-generating thermophilic microorganisms: aeration can be achieved by regular turning of the compost heaps, by aeration channels laid at the bottom of heaps, by aeration vents made by the space left by pipes which had been removed from the compost pile, and by a combination of these means of aeration.

With the intensive use of nightsoil as fertilizer, risks of disease transmission are substantial if the excreta are applied to the soil or on crops untreated or only partially treated (Faust 1924). Improved methods of composting nightsoil in combination with farm wastes, as introduced in China and reported by Scott (1952) and McGarry and Stainforth (1978), aim at converting the high-risk fresh excreta into a hygienically safe product (see p. 14 below).

Pathogen Survival: As noted previously, if during thermophilic composting all parts of the compost mixture are subjected to temperatures of 50-60°C for at least a few days, destruction of essentially all pathogens including *Ascaris* eggs[2] are ensured. Fig. II.3 on p.II-3, which is based on numerous reported data, may be used in practice to estimate the degree of pathogenic safety of a composted mixture of nightsoil and other wastes by means of temperature monitoring of the compost. If the required (thermophilic) temperatures are not reached - a situation which may well occur under real-

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[1] The term refers to the four components added to produce fertilizer: human excreta, animal manure, waste plant matter, and soil.

[2] Feachem et al. (1983) suggest Hepatitis A virus as a possible exception to this. Its ability to survive at temperatures around 60°C is unknown.

life operational conditions - the additional time required to attain a safe product may be estimated from the graph.

Those who wish to go one step further from temperature monitoring may want to determine the concentration of *Ascaris* eggs in samples taken from the compost pile. Faecal coliform, as previously mentioned, is not a meaningful parameter for pathogen survival in excreta. With composted faecal material, faecal coliforms are particularly unsuited as indicators, since they may regrow in finished compost (Burge et al. 1981), (Burge 1983). In such a case they would be of no value as indicators of the hygienic quality of the compost.

Fig. II.8 below illustrates the temperature and pathogen (*Ascaris* egg) inactivation history of proper thermophilic composting of a mixture of fresh nightsoil, dry vegetable matter (straw), ashes and soil as conducted in China by Scott (1952). The graph also shows that the process has worked smoothly even though ambient temperatures have been as low as 15°C or less.

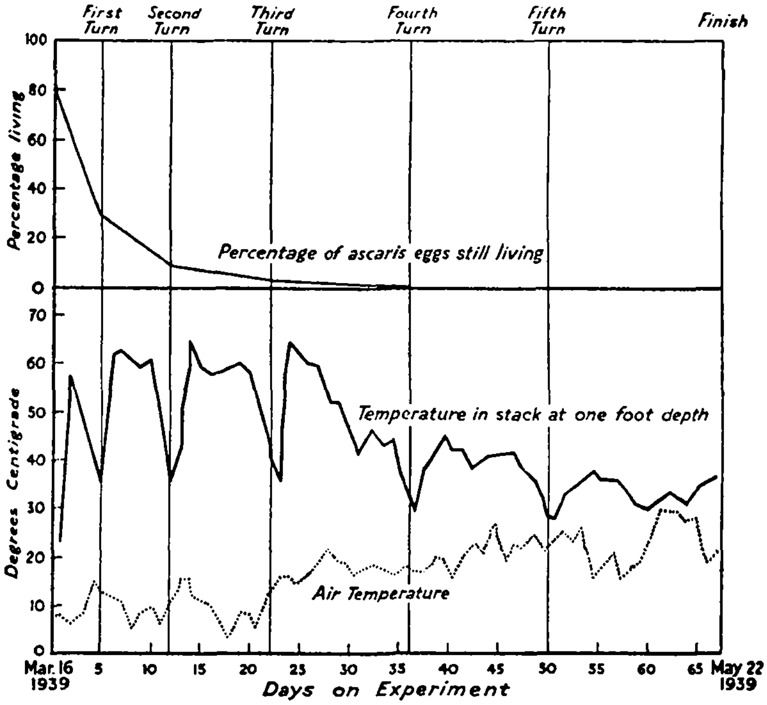


Fig. II.8 Inactivation of *Ascaris* Eggs by Thermophilic Composting (Scott 1952)

Similarly, in experimental composting of a 1:1 mixture of nightsoil and municipal refuse from the city of Calcutta, Bhaskaran et al. (1957) found essentially all *Ascaris* eggs inactivated after a period of two months.

Compost produced also from 1:1 mixtures of nightsoil and municipal refuse in several cities in India (probably under less stringent operational control) required 3-4 months for total inactivation of *Ascaris* eggs.

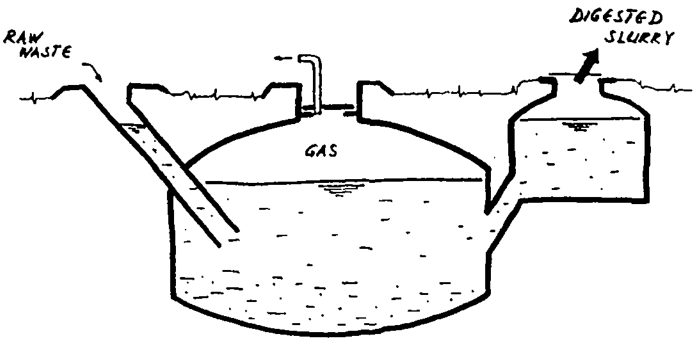
Nell et al. (1983) conducted pathogen survival tests in pilot-scale composters and full scale composting plants, composting sewage sludge and refuse or wood chips at mass ratios of 1:2 to 1:7. In pilot tests, where maximum temperatures of 60°C to 70°C were reached after at most one week, all Ascaris lumbricoides eggs were inactivated the latest after 8 days. In one pilot run, the maximum temperature attained was only 39°C, resulting in essentially zero reduction of *Ascaris* eggs within the first ten days. In full-scale composting with temperatures rising to 72°C, 8 weeks were required for total inactivation of *Ascaris* eggs.

Fly breeding may not only be a problem in latrines but also on compost piles since most of the raw material used in composting is attractive to flies seeking places to lay eggs. Fly breeding, though not completely avoidable, is reduced substantially if all parts of the pile reach the required temperatures during thermophilic composting. This can be achieved by regular turning of the pile or by making permanent vents at the time of piling the mixture.

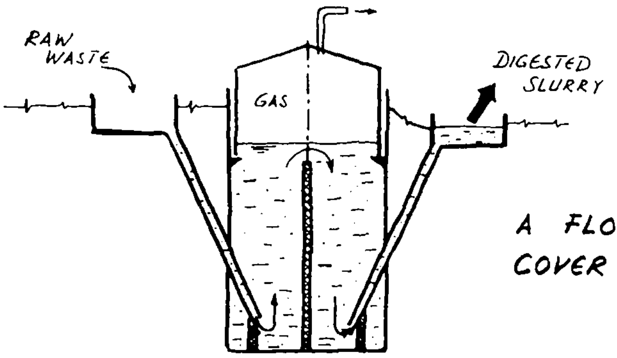
II.2.5 Biogas Digesters

Process and Design. Biogas production through anaerobic digestion (fermentation) of organic waste slurries is practised both in developing and industrialized countries since approximately half a century. In developing countries, the prime objective of biogas production is to substitute firewood as a fuel in order to reduce deforestation. Organic waste feeds consist of different proportions of animal (cow, water buffalo, swine) manure, waste plant matter and nightsoil. The digested slurry is used as agricultural fertilizer. In industrialized countries, anaerobic digestion with biogas production is widely used for biochemical stabilization of wastewater treatment plant sludges. The thereby produced biogas is usually recycled to the system to produce heat to maintain the necessary process temperature. Agricultural fertilization/soil conditioning is the prevailing method of digested sewage sludge end use and disposal.

Fig.II.9 shows schematic drawings of the two most widespread digester designs. In China, 5-6 million fixed dome digesters were in use by 1982 (Sam 1982, cited in Stuckey 1982). Digesters with a floating cover for storing gas are widely spread throughout the world. This system is popular in India where ten thousand units have been built.



A FIXED DOME DIGESTER



A FLOATING COVER DIGESTER

Fig. II.9 Biogas Digester

In rural-type digesters, design detention times of slurries are in the order of 1 month with ambient operating temperatures or slightly above, i.e. 25-35°C under tropical climates.

Pathogen Survival: With a slurry detention time of 1 month and digester operating temperatures between 25-35°C, pathogen survival is probably high. This is not surprising as biogas plants are primarily used to supply energy. Pathogen inactivation, which is less effective than in thermophilic composting, is considered only as a useful side-effect. The time-temperature graph in Fig. II.3 suggests that helminths and bacteria, such as salmonellae, will survive and thus be found in the effluent. Helminth eggs are again of major concern as they are the most likely pathogens to survive in large numbers.

If merely time-temperature effects are taken into consideration, estimates of pathogen inactivation may be too pessimistic. The chemical environment within the digester, notably ammonia (NH_3) concentrations, oxygen levels and microbial activities will, under suitable conditions enhance pathogen inactivation. Proper digester configuration and operation can also effectively help to reduce helminth eggs in effluent slurries. Stuckey (1983) reviewed literature on pathogen survival during anaerobic digestion. Ammonia which is formed during anaerobic digestion appears to be particularly effective for virus inactivation. Experimental investigations conducted in China have shown that the survival period of *Schistosoma* eggs is shortened with increasing ammonia concentration, which in turn increases with the organic wastes : water ratio. A factor which may possibly extend virus survival is virus affinity for particle surfaces, which will result in slowing down virus inactivation and increase the possibility of finding virus in the effluent. However, competition from other organisms in the microbially complex digester environment will most likely shorten pathogen survival. (Pathogen survival tends to be longest in sterile environments.)

Helminth eggs, especially *Ascaris*, survive for prolonged periods in the digester environment. Up to 50% of the *Ascaris* eggs were found viable both in the bulk and the sediment after 4-9 months of digestion, varying slightly during the summer and winter months. It is the settling of the eggs from the bulk of the slurry to the digester bottom which leads to potentially low egg numbers in the digester effluent. In one investigation, slurry which was withdrawn from the bulk of the liquid rather than from the plant bottom were helminth ova accumulate, contained only 3-6% of the original parasite egg concentration (Zhao 1982). Concentrations of viable eggs will be high in the bottom slurry. Digesters must therefore be constructed so that slurry withdrawal occurs from the bulk of the content and not from the bottom.

Though biogas plants do not produce pathogen-free effluents and their direct use as fertilizer is therefore associated with certain risks, digester effluents do exhibit a considerably improved hygienic quality compared to fresh nightsoil or digester influent to which nightsoil is added.

Health data from one area in China where biogas digesters have been installed reveal that the use of these plants has lead to substantial reduction of helminthic and other disease transmission (Stuckey 1983). 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. It may be composted together with other organic wastes as practised in some areas in China (Stuckey 1983).

II.2.6 Ponds

Operational: The disposal of urban and suburban nightsoil, septic tank contents and aqua privy slurries into waste stabilization ponds is common practice in many tropical countries. This is a good excreta disposal and treatment method if the ponds receiving the wastes have an appropriate capacity and lay-out to guarantee the desired (microbial) effluent quality under the added waste load. It is important for the pond system to be composed of a series of at least three ponds (see Fig. II.10), and for the slurries to be discharged near the influent of the plant in order to become subjected to the full pathogen inactivation effect of the stabilization pond scheme.

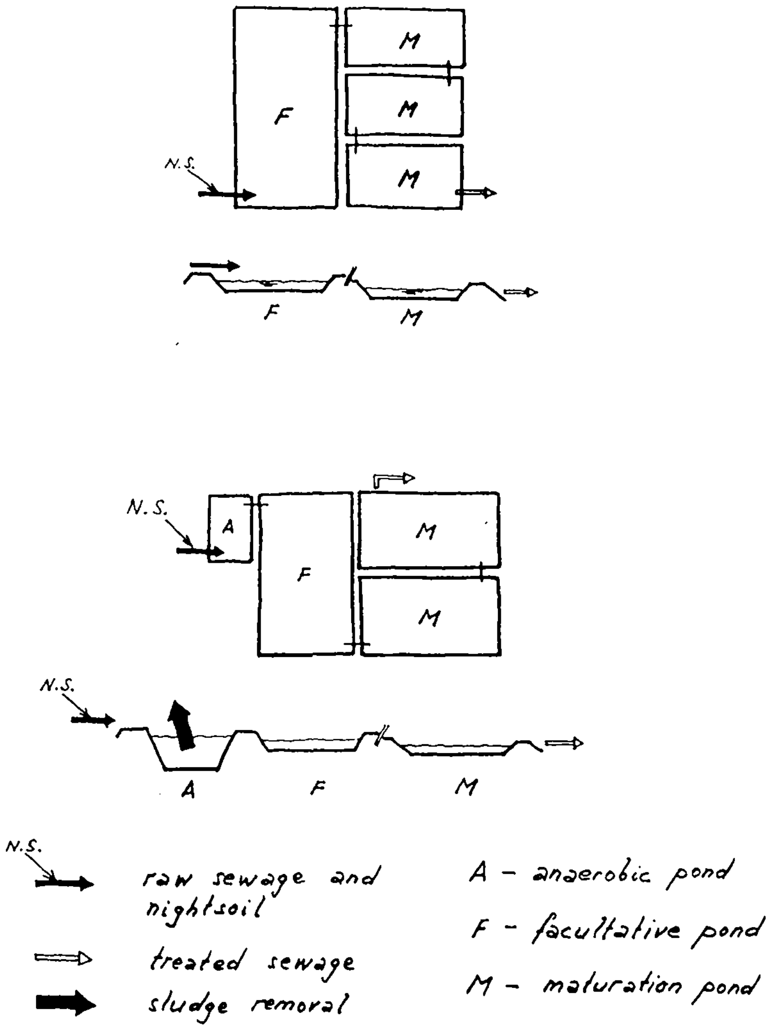


Fig. II.10 Waste Stabilization Ponds (Schematic)

Fig. II.10 shows two different lay-outs of waste stabilization pond systems which have proven to be effective in reducing the organic waste loads and in achieving pathogen inactivation. Most systems consist of a facultative (F) pond followed by one or two maturation (M) ponds. In the facultative[1] pond, organic waste degradation takes place through the activity of aerobic and anaerobic bacteria; the former receiving their oxygen from algae and the atmosphere. In the maturation ponds, the wastewater undergoes "microbial maturation", i.e. pathogen inactivation before it can be reused in agriculture.

Where organic concentrations of raw sewage are high or where facultative ponds are overloaded, anaerobic ponds (or septic tanks for small systems) may be added as a pretreatment step for organic waste removal (Fig. II.10).

Design retention times range between 1-5 days, 10-40 days and 5-10 days for anaerobic, facultative and maturation ponds, respectively (Feachem et al. 1983). Total system retention times of 20 days or more are desirable.

Nightsoil and septic tank slurries should be discharged into the sewer just upstream of the first pond if the wastewater flow is large enough for the slurries to be easily flushed into the first pond. The slurry can also be discharged directly into the first pond, in such a way that short-circuiting of the added wastes is avoided or minimized.

Pathogen Survival: It is assumed that the excreted pathogens discharged into stabilization pond systems with nightsoil, septic tank and aqua privy slurries, follow the same die-off pattern as the pathogens entering the system with the wastewater. In comparing stabilization ponds with other types of sewage treatment systems, Feachem et al. (1983), apart from pointing to the great economic advantage of pond systems particularly where land costs are low, state the following:

"... their principal advantage in warm climates is that they achieve low survival rates of excreted pathogens at a much lower cost than any other form of treatment, with maintenance requirements simpler by several orders of magnitude. In fact, a pond system can be designed to ensure, with a high degree of confidence, the total elimination of all excreted pathogens. This is not usually achieved in practice because the incremental benefits resulting from achieving zero survival, rather than low survival, are less than the associated incremental cost. Yet waste stabilization ponds are the best form of (wastewater) treatment in tropical, developing countries because they can

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[1] The term "facultative" refers to the concurrence of aerobic conditions (near the surface) and anaerobic conditions (near the bottom and in the sludge). Accordingly, both aerobic and anaerobic bacteria live and are responsible for organic waste degradation in the pond.

achieve any level of pathogen removal desired. From a strictly health-directed viewpoint, the fact that ponds can do this at lowest comparable cost is an additional advantage."

The main factor contributing to pathogen inactivation in ponds is the long retention time, which is $\geqslant$ 20 days in properly designed stabilization pond systems. This leads to 100 percent removal of protozoal cysts and helminth eggs which settle and accumulate in the bottom sludge.

In studying helminth removal in a three-pond system treating municipal sewage in India, Lakshminarayana and Abdulappa (1972) found that essentially all ova of *Ascaris lumbricoides, Ancylostoma duodenale* and *Hymenolepis nana* were removed in the first (facultative) pond by settling, but remained viable in the bottom sludge. Hookworm larvae which were detected in the plant effluent probably originated from eggs retained in the facultative pond. The overall system retention time was six days only. Therefore, the larvae which have longer survival times could escape the system. 16 days retention time seem to be sufficient to obtain an effluent free from hookworm larvae. The anaerobic conditions prevailing at the bottom of facultative ponds or in anaerobic ponds have also been observed to substantially reduce or even fully inhibit hatchability of helminth eggs.

In the San Juan de Miraflores district of Lima, Peru, a waste stabilization pond system has been in operation since 1964. The scheme which comprises 21 ponds, covers an area of 20 ha and receives an average flow of 30,000 m^3/d from approximately 100,000 inhabitants. The effluent from the maturation ponds is used by smallholders for furrow-irrigation of 36.5 ha of maize, potatoes, root and leaf vegetables, alfalfa, and banana trees. CEPIS (Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente, Lima) has conducted intensive investigations to assess, among other things, pathogen removal performance in the ponds. Based on the data collected during three years, the following removal results were obtained with BOD loads of250-350 kg/ha per day, 15°C average temperature in winter and 23°C in summer (Yanez 1980 and 1983; Bartone et al. 1985):

- Faecal coliform (FC) removal:

- Influent	10^8 MPN/100 ml
- Effluent from 2-cell system with total nominal[1] ret. time of 10 days	2 log reduction
- Effluent from 3-cell system with total nominal ret. time of 20 days	3 log reduction
- Effluent expected from 3-cell system with total nominal ret. time of 30-40 days	$\leqslant 10^3$ MPN/100 ml

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[1] "Nominal" means "as designed". The true retention periods are usually shorter due to short-circuiting. With good design, short-circuiting can be minimized and performance would be better than indicated.

- Parasite (helminth and protozoa) removal:
    - Complete helminth removal in 2-cell system with 5.5 days total nominal retention time
    - Complete parasite removal in 2-cell systems with 15 days total nominal retention time
    - Use of baffled effluent weirs prevents carry-over of protozoa from primary to secondary ponds

- *Salmonella* removal:

- Influent	10^3 MPN/100 ml
- Effluent from 3-cell system with 20 days total nominal retention time	1 MPN/100 ml
- Effluent from 3-cell system with 30-40 days total nominal ret. time	0.1 MPN/100 ml

- Data show that a 3-log reduction of faecal coliforms in the pond system indicates complete parasite removal.

Further investigations at San Juan revealed that due to short-circuiting, actual pond retention periods are often substantially shorter than the nominal (design) periods. It is important to design ponds in such a way as to minimize short-circuiting and to achieve the desired pathogen removal efficiencies at minimum pond surface requirements (e.g by use of multi-cell systems, proper inlet/outlet arrangements, elongated pond shape).

Oragui et al. (1986) studied the removal of excreted bacteria in deep stabilization ponds in north-east Brazil. The pond system consisted of a series anaerobic, facultative and maturation ponds (depth range: 2.8-3.4 m), with an overall retention time of 21 days and a mid-depth temperature of 27°C. Thermophilic *campylobacters*, bifidobacteria and salmonellae were not detected after 11, 16 and 21 days retention time respectively. Faecal coliforms, faecal streptococci and *Clostridium perfringens* were reduced by 4, 4 and 2 orders of magnitude respectively.

In another study in north-east Brazil, the removal of intestinal nematode eggs in waste stabilization ponds treating domestic wastewater was investigated (Mara and Silva 1986). Anaerobic and primary facultative ponds achieved 88-98 % and 99-100 % *Ascaris* removal, and 91-97 % and 98-100 % hookworm removal, respectively. Egg-free effluents were produced by a single primary facultative pond with a retention period of 18.9 days, as well as by an anaerobic and a secondary facultative pond constructed in series with retention times of 6.8 and 5.5 days. It can be concluded that effluents with $\leq$ 1 egg per liter can be produced by a 1-day anaerobic pond followed by a 5-day secondary facultative and a 5-day maturation pond.

Polprasert et al. (1983) in their work on bacterial die-off kinetics in two-stage waste stabilization pond systems constructed in series confirm findings and assumptions from others that bacterial die-off is not only time and temperature dependent but also subject to a number of physical and biochemical factors which are typical of the highly complex environment found in ponds. The bacterial die-off rate appears to be enhanced by a high pH (pH $>$ 8). pH increase occurs daily due to the diurnal light-dependent variations in algal activity. The bacterial die-off appears to be influenced also by the amount of organic load (the amount of waste discharged into the ponds in relation to the ponds' surface area). Increased loads might lead to slower die-off on account of greater nutrient supplies available to the pathogenic bacteria. It has further been hypothesized that antibacterial substances, produced by algal activity and the highly oxidative environment in the upper pond strata, might also enhance pathogenic bacteria reduction.

Stabilization ponds are regarded as effective treatment systems also for virus inactivation. Though data on virus survival in ponds are very scarce, the few that are available indicate that long detention times ($\geqslant$ 20-30 days) and proper design to minimize short-circuiting of wastewater between pond inlet and outlet, are guarantors of good virus inactivation. Rao et al. (1981) observed up to 96 % removals of non-specified viruses in ponds exhibiting short-circuiting with retention times between 2.7 and 17.2 days only. It is suggested that at temperatures of $>$ 25°C and no short-circuiting, the rate of bacteriophage[1] removal lies within 1-2 orders of magnitude per 5 days, i.e. at least 99.99 % - 99.999 % at 20-30 days retention. Such figures have been attained by Polprasert et al. (1982) during bacteriophage removal studies in fish culture experiments in ponds treating cesspool sludge in Thailand. Oragui et al. (1986), in their study with deep ponds in north-east Brazil, observed

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[1] Bacteriophage = viruses parasitic to bacteria

entero and rotavirus reductions of 3 orders of magnitude with a total of 21 days retention time and at 27°C mid-depth temperature (depth range 2.8-3.4 m). Basically the same factors which are thought to be detrimental to pathogenic bacteria (notably high pH and temperature, supersaturation with oxygen) are assumed to also enhance virus inactivation. Furthermore, virus adsorption to solid surfaces will have a scavenging effect since viruses will be removed from the bulk of the liquid and then accumulate at the bottom of ponds with the settled solids. There they may, however, survive for long periods of time.

In other words, it may be concluded that **helminth** eggs are generally fully removed in most pond systems, except possibly in heavily overloaded schemes with only one cell or where multiple cells are operated in parallel instead of in series. For complete helminth removal, wastewater should pass through at least 2 cells with ⩾ 10 days total nominal retention. In single-cell systems, retention times must be longer. **Protozoa** can also be completely removed in waste stabilization ponds, however, longer retention periods than for helminths are required and short-circuiting must be avoided. Two-cell systems with ⩾ 15 days total nominal retention are necessary. For good bacteria and virus removal, the wastewater should pass through three or more cells connected in series with an overall retention time of ⩾ 20 days. With 3 cells and 20 days nominal retention, a reduction of indicator bacteria, salmonellae and viruses of 3-4, 2 and 3 orders of magnitude, respectively, can safely be expected. Fig. II.11 illustrates expected pond performance with 20 days retention time and with 3 cells operating in series. Higher reductions are achieved by using more than 3 cells in series, by extending the overall retention period, by reducing short-circuiting, or by a combination of all these measures.

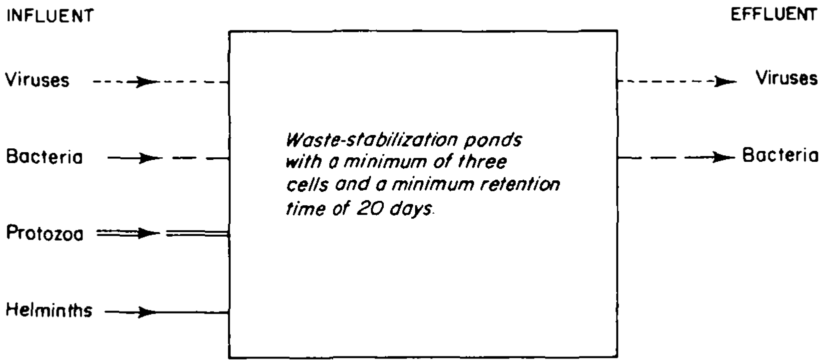

Fig. II.11 Pathogen Removal in Waste Stabilization Ponds (Feachem et al., 1983)

II.2.7 Summary and Evaluation

Pathogen survival patterns during excreta storage and treatment are summarized in Tables II.4 and II.5. Under ideal conditions, most systems can yield a product which has very low or undetectable levels of viable pathogens as shown in Table II.4. Pit, vault and pour-flush latrines represent excreta disposal systems which, if built and operated as alternating systems, i.e. with twin pits or vaults, can meet rather strict hygienic standards. A few eggs of *Ascaris lumbricoides* may remain viable. Whether this carries epidemiological significance is not well known yet. Systems likely to yield unsatisfactory products are aqua privies, septic tanks and biogas digesters, though none of them are designed for pathogen removal or inactivation.

Since ideal conditions are hardly ever met, Table II.5 was therefore set up to suggest survival patterns as may be expected in many places in present-day practice where conceptualization, system construction, use and maintenance tend to be non-optimal. Then, none of the listed systems yield products which are hygienically "safe". Consequently, handling and use of such products involve increased theoretical risks whose epidemiological relevance is, however, not as yet fully understood. Although the characteristics of the systems listed in Table II.5 are "worst case" they are certainly realistic and

Table II.4 Summary: **Survival of Excreted Pathogens During Pre-Application Storage and Treatment: IDEAL-World Situation** (To be aimed at !)

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 ≥ 1 year	◑[3]	○	○	○
- Pit Latrines w.2 Pits	t ≥ 1 year	◑[3]	○	○	○
- Double-vault ("Vietnamese"-type) Latrine;	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 ≥ 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 ≥ 1 day T = 40-45°C, t ≥ 1 week for all parts of waste piles	○	○	○	○
· Biogas Digesters	t ≥ 60 days, T = 30-35°C; effluent draw-off from bulk slurry not from settled sludge	●	◑	◑	○
· Waste Stabilization Ponds[2]	t ≥ 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

representative of systems in use. There are, of course, excreta disposal facilities in use which work to standards intermediate to those described in Tables II.4 and II.5. The aim must be to operate and maintain the installed systems in such a way that performance approaches the "ideal-world" levels, which would minimize the potential health risks during excreta handling and use.

Table II.5 Summary: Survival of Excreted Pathogens During Pre-Application Storage and Treatment: REAL-World Situation (improve !)

Storage/Treatment System	Real-World System Characteristics Relevant to Pathogen Die-off/Survival	Survival of Pathogens			
		Helminths	Viruses	Bacteria	Protozoa
· Pit-Type Latrines:					
- Pit Latrines w. 1 Pit	Handling of fresh excreta if pits are (or have to be) emptied immediately upon becoming full;	●	●	●	●
- Pit Latrines w.2 Pits	Handling of fresh excreta when emptying twin pits which have been in simultaneous use;	●	●	●	●
- Double-Vault Latrines	No urine separation, no addition of ash, wet and anaerobic conditions; t $<$ 1 year	●	○	○	○
- Pour-Flush L. w.2 Pits	t < 1 year; alt'g. use of twin pits;	◑	◑	○	○
- Pour-Flush L. w.1 Pit	handling of fresh excreta during emptying	●	●	●	●
· Aqua Privies and Septic Tanks[1]	Continuously operated systems; always contain portions of fresh excreta at time of emptying	●	●	●	●
· Thermophilic Composting	$T \leq 40\text{-}50^{\circ}C$; $t \leq 1$ month; not all parts of waste piles subjected to sufficiently high temperatures	◑[2]	◑	○	○
· Biogas Digesters	$T \leq 20\text{-}25^{\circ}C$; t < 1 month; withdrawal of bottom sludge where helminths and protozoa concentrate	●	◑	◑	◑
· Waste Stabilization Ponds[3]	t < 20 days; shortcircuiting; system having less than 3 cells in series	○	◑	◑	◑

○ - zero or near-zero survival
◑ - survival in low concentrations
● - survival in substantial concentrations

[1] Survival in sludge

[2] *Ascaris* and possibly also some hookworm, *Taenia*, *Schistosoma* and *Trichuris* eggs

[3] Survival in treated wastewater

II.3 Survival in Soil and on Crops

II.3.1 Basic Considerations

The preceding chapters show that raw nightsoil usually carries a large spectrum and high loads of pathogens as a reflection of the subclinical and clinical occurrence of excreta-related diseases in a particular area. Treated nightsoil will - with the exception of effective treatment by thermophilic composting and extended storage - still contain variable loads of pathogens. In tropical and subtropical climates, however, their concentrations are usually expected to be considerably lower than in the fresh excreta. Some of the pathogens, even though they might be recoverable analytically, will have lost part or all of their viability, i.e. their infectivity.

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 microclimate, the type of crop (root crops vs. low-growing vs. high-growing crops), and the time and method of excreta application to the field. Crops may become pathogen carriers either by direct contamination or indirectly through excreta- contaminated soil (root crops; leaf crops through splashing caused by rainfall). However, high-growing vegetables or fruits will most likely not be contaminated by excreta fertilization if the excreta are carefully applied to the ground, and if the fruits or vegetables do not fall on the ground before the harvest.

Except for *Ancylostoma duodenale*, whose larval stages can also be transmitted orally, soil is the only transmission focus for hookworms (*Ancylostoma*). *Schistosoma japonicum*, *Schistosoma mansoni* and *Schistosoma haematobium* are usually transmitted through water contact in pools, canals or lakes. *S. japonicum* can also be transmitted in paddy fields if people infected with this worm defaecate in the field and if the appropriate snail host grows there.

The load of viable pathogens found in the soil or on crops of a particular nightsoil-fertilized plot also depends on the intervals of nightsoil disposal on that plot: if nightsoil is disposed of repeatedly during the vegetation period of a particular crop, the risk of pathogen transmission to those working in the field as well as to those consuming the harvested crop will be greater than if nightsoil fertilization occurs only once or twice during the early part of the vegetation period. Fertilization practices and the amount of agricultural land available in relation to the amount of nightsoil produced and used in the agriculture of a particular area are therefore major factors determining the health implications of excreta recycling.

This chapter tries to answer two relevant questions:

- How long do excreted pathogens survive in soil and on crops of predominantly tropical and subtropical climates ?
- How do pathogen survival periods compare with the growth periods of crops ?

II.3.2 Survival of Helminths

Due to the "long" infection cycles which follow the general pattern indicated in Fig. II.12, and due to the extensive resistance of many helminth eggs to outside-host environmental conditions, helminth survival tends to be the longest among all pathogens. The nature of helminth infection cycles makes soils and crops fertilized with raw or only partially treated excreta important potential transmission foci.

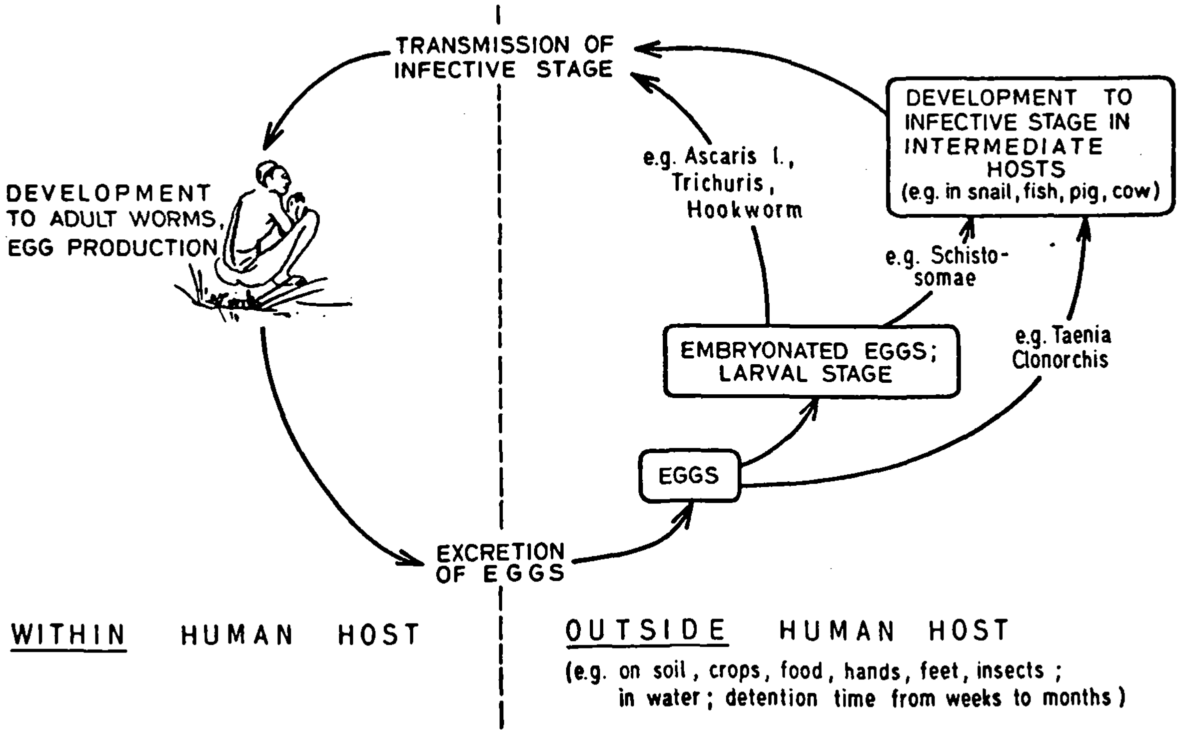

Fig.II.12 Pattern of Helminth Infection Cycles

a. Survival in Soil

Concerning the endemicity of helminth infections, Faust (1924) reports about the important role and century-old practice of fertilization with human excreta in China and other countries in eastern Asia. According to him, the development of *Ascaris* and *Trichuris* could not be prevented even under arid conditions in North China and elsewhere in the region. Present-day practice in some parts of China therefore consists in treating collected excreta through extended storage[1] or thermophilic composting (combined with animal manure and plant wastes) at "transfer" sites en route from the latrines to the field (McGarry and Stainforth 1978, Barua et al. 1981, Lu et al. 1982).

Since the early studies of helminth survival on nightsoil-fertilized fields in China, numerous investigators have attempted to elucidate related health risks by determining helminth, notably *Ascaris*, survival under various environmental conditions. Table II.6 lists reported data on helminth survival periods in soil.

When considering helminth survival, it is important to note the difference between total number of eggs or larval-stage organisms, the number or percentage of viable organisms and consequently the number or percentage of viable organisms reaching infective stage and thus having the "power" to cause infection in the invaded host. In general, only a relatively small percentage of helminth eggs excreted by an infected person will eventually reach infective stage.

Results of a wide range of investigations on helminth survival reveal that the survival on or in soil is dependent mainly on:

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

Thus, development and survival of helminth eggs and infective stages are impeded if nightsoil is spread evenly on dry, sandy soils exposed to direct sunlight, and if low air humidity and high temperatures (30-35°C) prevail.

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[1] 30 days storage is variously mentioned as a design figure. Barua et al. (1981) report that farmers in China reject nightsoil which is stored for more than 30 days because of alleged poor fertilization properties (loss of nitrogen). From a strictly pathogen survival point of view, a much longer storage period would be advantageous.

Table II.6 Helminth Development and Survival in Soil

Organism	Environmental conditions	Development, Survival	Remarks	Reference
. Hookworm eggs	20 - 50°C	Most favourable temperature for eggs to hatch and develop to infective stage		Rudolfs et al. 1950 (II) quoting others
. Hookworm infective larvae	"favourable"	6 - 12 weeks survival		"
. Hookworm larvae	35°C	3 weeks survival		"
	27°C	> 9 weeks survival		"
	15°C	10 - 12 weeks survival		"
	0°C	1 week survival		"
. Hookworm eggs	exposure on soil	"few" eggs, only, hatching into larvae		"
. Hookworm infective larvae (*Necator americanus*)	rainy season (Nigeria, Imo State)	2 - 4 weeks survival; up to 86 % of recovered larvae life and infective; larvae mostly at or near soil surface		Udonsi et al. 1980
	dry season (—— , ——)	< 2 weeks survival; up to 17 % of recovered larvae life and infective; larvae mostly beneath soil surface		"
. *Ascaris lumbricoides* mature eggs	Underneath soil in winter	5 - 6 months survival		Rudolfs et al. 1950 (II) quoting others
. *Toxacara canis* (dog ascarid) egg	< 27 - 30°C, < 75 % humidity	incomplete development	(laboratory investigation)	"
. *Ascaris* eggs	on sandy soil, in sun	degeneration in 21 days (eggs not developing)	Panama	"
	on sandy soil, in shade	motile embryos in 90 % of eggs after 35 days	"	"
	on "heavy" soil, in sun	up to 70 % of eggs embryonating within 21 days	"	"
. *Ascaris* eggs	T = 5 - 20°C; in wet soil	survival up to 2 years		Hannan (1980) quoting others
. *Ascaris* eggs	on/in soil	< 7 years survival	(= max. recorded)	Feachem et al. (1983) quoting others
. *Ascaris* eggs	soil surface, clean silty soil	survival < 29 days	USSR	"
	clean silty soil, 10 - 20 cm underneath surface	< 1.5 years survival	"	"
	clean silty soil, 40 - 60 cm underneath surface	< 2.5 years	"	"
. *Ascaris* eggs	sewage irrigated fields (Germany)	≤ 1.5 years survival		Feachem et al. (1983) quoting others
. *Ascaris* eggs	sewage irrigated pasture; dry, hot weather (southern Africa)	inactived within a few days due to desiccation		"
. *Ascaris suum* eggs	sewage sludge mixed with eggs and added to soil	infective eggs recovered from soil in second and third growing season after sludge application	climatic and soil conditions unknown	Bergstrom and Langeland (1981) (abstract only)
. *Ascaris suum* eggs	sewage sludge spread on various forest soils; 8,3°C average temperature	17 - 76 days survival	Germany	Strauch et al. 1981
. *Trichuris trichiura* eggs	clay-flint soil; in 0 - 23 cm depth (England)	21 % of eggs still potentially infective after 18 months		Feachem et al. (1980) quoting others
. *Strongyloides stercoralis* larvae	"soil"	< 18 days survival		"
. *Strongyloides* eggs	cattle faeces; T = 15 - 35°C dry season (Nigeria)	24 hours for hatching; 6 - 7 days to develop to infective larvae; 6 - 8 weeks larvae survival		Okon and Akinpelu (1982)
	——,——; wet season (Nigeria)	24 hours for hatching; 5 days to develop to infective larvae; 10 weeks larvae survival		"

Contrary to this, helminth development and survival are enhanced if excreta are disposed of on wetted soils possessing a substantial moisture holding capacity, i.e. soils with large clay and loam fractions or a good humus cover. Protection of the soil and faecal matter from direct sunlight either by clouds or a plant cover and fairly warm temperatures (20-30°C approx.), will further support the development and survival of helminth eggs and the infective stages. Thus, survival might be substantial if faecal matter is disposed of in lumps in shady places. Investigations by Bergstrom and Langeland (1981) confirm the role of plant cover in prolonging *Ascaris suum* egg survival in soil.

Water soaking of nightsoil disposal places such as in paddy fields, however, will very likely cause rapid death (Rudolfs et al. 1950, II, quoting others), probably due to lack of oxygen.

Hookworm larvae were found to penetrate the soil to a depth of 20 cm, particularly during dry weather conditions (Udonsi et al. 1980). Hookworm larvae were also observed to creep up vegetation as far as moisture films extended on the stem but could apparently not reach green plant leaves (Rudolfs et al. 1950, II, citing others).

When considering health risks related to nightsoil use in agriculture, the transmission potential for schistosomiasis should also be regarded. Infected persons shed *Schistosoma* eggs with their excreta. The eggs develop into a first larval stage (miracidium). The larvae search for the specific intermediate host snail whom they require to develop into second-stage larvae (cercariae). The cercariae leave the snail host and, after coming into contact with the human skin, will rapidly penetrate it and thus infect a new person or add an additional *Schistosoma* load to an already infected person.

Each of the three main *Schistosoma* species has a specific snail host. Usually, only one or two schistosome types with their specific snail hosts occur in a particular area.

Basically, fields with crops standing in water during part or the whole of the vegetation period - notably paddy rice - are potential transmission sites for schistosomiasis if either fresh excreta are used to fertilize such fields or if the schistosome eggs are deposited through open defaecation.

Similarly, there is also a potential risk for people who wade, wash or bathe in ponds, where excreta are disposed of on purpose for fertilization or deposited in a non-purposeful manner.

As a whole, the reports on schistosomiasis almost exclusively deal with irrigation canals and ditches as transmission foci. Little is known about transmission through fields receiving excreta. Feachem et al. (1983, quoting others) point to water contact and excretion behaviour as being the main factors in schistosomiasis transmission. With regard to occupational behaviour, it has been shown that women from a village in the Nile Delta in Egypt who regularly work in the fields have higher schistosomiasis prevalence than women who only work around their homes.

Schistosomiasis is endemic mainly in subsaharan Africa and South America. It is interesting to note that it is essentially absent from most Asian countries with intensive rice cultivation, which is often coupled with man-made irrigation systems. In Asia, schistosomiasis (*S. japonicum*) is endemic only in a few areas in Indonesia, the Philippines, eastern China and Japan (Feachem et al. 1983).

Table II.7 Helminth Development and Survival on Crops

Organism	Environmental Conditions	Development, and Survival	Remarks	Reference
. *Ascaris suum* eggs	tomatoes and lettuce heavily sprayed with 20'000 eggs/ml suspension; hot, dry weather	On tomatoes: all eggs degenerated or incapable of development after 27.days On lettuce: 59 % and > 99 % of eggs incapable of development after 3 and 19 days, respectively	USA	Rudolfs et al. (1951; 111)
. *Ascaris* ova	water used for washing various root and leaf vegetables received from town market;	zero egg detection	North China; use of night-soil very common	Scott (1952)
	various root and leaf vegetables	—·—	"	"
	—·—	57 % of samples positive for eggs (thereof 26 % dead, 9 % embryonated and 64 % developing)	"	"
. *Ascaris* ova	leaf vegetables;	< 35 days survival		Feachem et al. (1980) quoting others
. *Taenia saginata* eggs (beef tapeworm)	contaminated grass; - in summer - in winter/spring	 < 58 days survival < 159 days survival	Denmark	"
. *Taenia saginata* eggs	contaminated hay; 0 - 30°C	< 3 weeks survival		"

b. Survival on Crops

The use of nightsoil in agriculture may lead to contamination of root crops via the soil, as well as of low-growing leaf and fruit crops through direct contamination during the spreading of the faecal matter and splashing of deposited nightsoil caused by rainfall. Investigations on helminth survival on crops were carried out primarily in Asia where excreta use in agriculture plays an important role in fertility and soil conservation. Table II.7 lists some relevant information as gathered from the literature.

The same environmental factors which influence development and survival on soil are reponsible for the fate of helminths (and other pathogens) on crops. Sunlight and desiccation are the major factors causing death or degeneration of helminth eggs on leaf or fruit crops. Exposure of helminths to these lethal influences is certainly greater on plants than on soil, where the pathogen may be embedded in lumps of soil or faecal matter, protected by plant shade or by soil cover. Survival on leaf crops therefore 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 rapidly degenerate. In tropical climates, however, relative humidity is usually over 75 %.

Based on the longer survival periods on or in the soil, it can be concluded that root crops may carry higher loads of infective pathogens than leaf crops at the time of harvest.

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. Hookworm[1], *Ascaris* and *Trichuris* eggs were found on root and leaf vegetables sold on South Korean markets (Feachem et al., 1983, quoting others). Vegetable ("truck") gardens heavily fertilized with municipal raw nightsoil may represent sources of helminth infections which are brought back into the cities. This type of transmission may play an important role in areas where general levels of public and personal hygiene are relatively high, and where other routes of pathogen transmission have therefore become of minor importance.

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[1] *Ancylostoma duodenale* is the only hookworm which can infect via the oral as well as the percutaneous (penetration through skin) route.

Effects on helminth inactivation by vegetable pickling - a customary method of food conservation e.g. in Japan, Korea and China - have been investigated (Faust, 1924; Scott 1952). Scott (1952) obtained zero recovery of *Ascaris* eggs from pickle liquor in which excreta-fertilized vegetables had been treated in own experiments. He cites others who in fact found viable eggs on seven percent of the pickled vegetables.

Depending on local circumstances and sanitary customs, different routes of helminth transmission other than through nightsoil fertilization can be of particular importance. Scott (1952) reports of an example in northern China of low personal hygiene, particularly among children, promiscuous defaecation by children, lack of latrine hygiene which lead to yard contamination and unhygienic food handling. He believes that these are the main factors, rather than nightsoil fertilization, responsible for the transmission of helminth diseases. The same author has analysed root and leaf vegetables grown on nightsoil-fertilized plots and sold on markets to determine the importance of excreta-fertilized crops in helminth transmission. No helminth eggs were recovered from the water which had been used to clean the vegetables. It was therefore assumed that the washing of the crops prior to their sale on the market resulted in the removal of the helminth eggs.

Recent investigations point to the contrasting fact that, due the stickiness of *Ascaris* eggs, it may be very difficult to recover them from specimens under investigation. Therefore, only few specific analytical methods can guarantee a reliable recovery (Jackson et al. 1978). Data, particularly those of earlier date, on *Ascaris* contamination of crops (and probably also soil), should therefore be interpreted with caution.

II.3.3 Survival of Bacteria

The excreted bacteria known to play a major role in the disease pattern of tropical countries are listed in Table 3.2 along with some relevant epidemiological characteristics. Important bacterial pathogens are:

- *Campylobacter fetus* ssp. *jejuni*
- Pathogenic *Escherichia coli*
- *Salmonella*
  - *S. typhi* and *S. paratyphi*
  - other salmonellae
- *Shigella* species
- *Vibrio (v. cholerae* and others)
- *Yersinia.*

Salmonella species are the most widely investigated and documented excreted pathogenic bacteria with regard to their survival in the outside-host environment. Little is known yet or has been investigated about *Campylobacter*, pathogenic *E. coli* and *Yersinia* survival. Documentation on the survival of *V. cholerae* in soil and on crops is also scarce (Feachem et al. 1980, citing others).

In addition to salmonellae, non-pathogenic faecal indicator bacteria such as coliforms, faecal coliforms, *E. coli*, faecal streptococci and others are a group of bacteria whose survival patterns are also widely documented (Rudolfs et al. 1950, I; Feachem et al. 1980, citing others). The indicator bacteria are excreted in large numbers by healthy warm-blooded animals (including humans). Their use as indicators of faecal contamination originates from the water supply industry which uses them for quality control of treated drinking water. Limitations concerning their role as indicators of pathogen survival in excreta storage-handling-utilization systems have been discussed in Chpt. 3.5. The main limitations of these bacteria, particularly of faecal coliforms and faecal streptococci, are that they originate from humans as well as from other animals, and may temporarily increase in concentration on soil and crops given suitable conditions, i.e. nutrients, moisture and protection from direct sunlight. The source of faecal pollution may therefore remain uncertain especially in rural and periurban areas where quantities of excreta and indicator bacteria from cattle and pets are possibly larger than those from humans (Feachem et al. 1983). Tables II.8 and II.9 below nevertheless list some data pertaining to indicators due to abundant accumulated information in literature. Furthermore, survival patterns of non-pathogenic *E. coli* will have to serve for the time being also as guidelines for the survival behaviour of pathogenic *E. coli* for which meaningful and sufficient data are still lacking (Feachem et al. 1983).

Salmonella species and faecal indicator bacteria tend to have longer survival times in the outside-host environment than other bacteria. This fact and the widespread worldwide occurrence of faecal indicators as well as salmonellae account for the extensive documentation on these two bacteria types.

a. Survival in Soil

Table II.8 contains representative information on survival and development of epidemiologically important excreted bacteria, including faecal indicator bacteria. The compilation is based on a number of reviews, including those by Rudolfs et al. (1950, I), Feachem et al. (1980), and Feachem et al. (1983).

Table II.8 Survival of Excreted Bacterial Pathogens in Soil

Organism	Environmental Conditions	Survival[1] period (days)	Remarks	Reference
Salmonella typhi[2]	broth culture added to sterilized soil	> 216	temperature?	Rudolfs et al.1950 (I.) quoting others
	unsterilized soil	> 100	"	
S. typhi	ordinary or polluted (...) soil	≤ 74	range of survival period soil moisture dependent	" "
	dry sand	< 25	temperature?	" "
S. typhi	surface soil layer; 122 *hr* sunlight exposure within 22 days	> 22	"	
S. typhi	dry soil	< 14 for 99 % of organisms	"	"
S. typhi	garden soil; 5 months storage of feces in latrine prior to use	< 14	"	"
S. typhi	soil surface; 30 days storage in latrine prior to use	< 20	"	"
	buried in soil; 30 days storage in latrine prior to use	< 40	"	"
S. typhi	various soils	29-58	"	"
	sandy soil; hothouse conditions; addition of sterile sewage	< 74	"	"
S. typhi	various soils and conditions: - in peat - in frozen moist soil - generally	 < 1 > 730 < 100	summary	
Salmonella ssp.[3]	digested sewage sludge sprayed on sandy soil (temp. climate; t = 8...25°C)	42-49 (T_{90} = 14-16)[4]		Watson 1980
	digested sewage sludge sprayed on "richer, more organic" soil (temp. climate; t = 4...17°C)	49 (T_{90} = 22)		"
S. typhimurium	S. inoculated with cattle manure on clay soil - in moist soil	T_{90} = < 3-42 (t = 5°C) < 21 (t = 22°C) < 3 (t = 39°C)	in laboratory	Zibilske and Weaver 1978
	- in dry soil	<< 3 (t = 5...39°C)	"	"
Salmonella	sewage sludge irrigated plots planted with radish and lettuce; summer; intense solar radiation and high temperature	T_{90} = 7 $T_{99.99}$ < 20-42 few organisms > 84		Larkin et al. 1978
Salmonella serotypes	sewage sludge injected 25-30 cm deep into light sandy soil - winter-spring (soil-temp. 8-11°C)	 T_{90} = 17 non-det. after 30 days		Andrews et al. 1983
	- summer (soil-temp. 15°C)	T_{90} = 4 non-det. after 7 days		
Salmonella senftenberg	spreading of S. senftenberg (10^7/ml) infected municipal sludge on broad-leaved coniferous experimental forest plots; various soil regimes; average yearly temp. = 8.3°C; - sludge spread in winter - sludge spread in summer	 < 104-350 < 424-640		Strauch et al. 1980
S. dublin	autumn in s. England	< 84		Feachem et al. 1983 quoting others
S. dublin	northeast England: - in winter - in summer	 < 168 < 91		Feachem et al. 1983, quoting others
S. typhimurium	? (England)	> 245		"
S. typhimurium	? (N. Zealand)	< 28 - 70		"
S. typhi	rainy season in California	< 119		
Escherichia coli	exposed sites; summer	T_{90} = 3		"
	shaded sites; autumn and winter	T_{90} ≤ 14		"
Streptococcus faecalis	shaded sites; autumn and winter	T_{90} ≤ 20		"
E. coli	dry soil saturated soil	T_{90} = 1 T_{90} > 21		"
E. coli	soil with 30 % moisture; 20°C soil with 10 % moisture; 20°C	T_{90} = 18 T_{90} = 2.5		"
V. cholerae	in soil at 20 - 28°C; 10^7/g soil initially - slowly drying soil - soil regularly remoistend with uncontaminated sewage	 < 4 < 10		"
V. cholerae	inoculation in sterile potting soil; 26°C	> 6		"
Fecal coliform	coarse loam rich in organic materials; shaded - spring - summer - autumn - winter	 T_{90} = 8 - 18 15 - 25 45 - 55 25 - 40		Feachem et al. 1980, quoting others
	dense clay exposed to sunlight - spring - summer - autumn - winter	 T_{90} = 15 - 25 10 - 15 15 - 25 25 - 40		
E. coli	loam - 15 % moisture - 30 % moisture	 < 136 < 176		"

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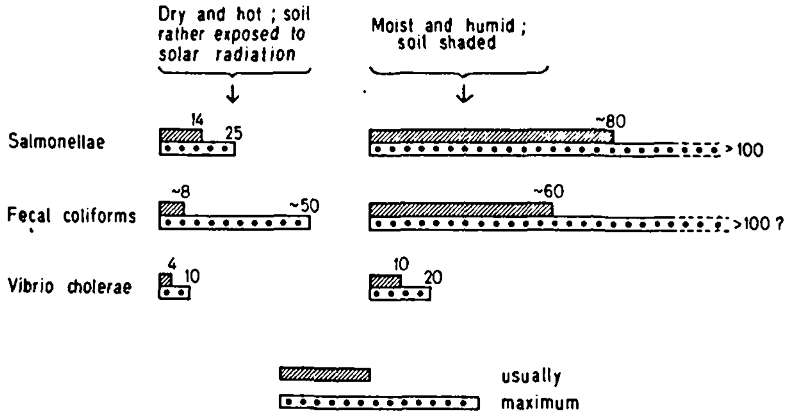
[1] Unless indicated otherwise "survival period" is usually to be understood as the period beyond which no more survivors could be detected with the particular method used to count the organisms

[2] in early publications the synonym "Eberthella typhosa" is used

[3] spp. = species

[4] T_{90} = time required for 90 % die-off

In condensing the data from Table II.8 which were obtained for a variety of bacterial pathogens, soils and environmental conditions, survival of excreted bacterial pathogens may be quantified in a general way as can be seen in Fig. II.13. The Figure depicts survival periods of *Salmonella* spp., faecal coliforms and *V. cholerae* in warm climates. A truncation between survival on dry sunlight-exposed soil and survival on moist, shaded soil is made.



[1] Conservative figures condensed from literature data ; periods are as defined by the survival of a few most resistant organisms and by the sensitivity of the analytical method applied ; periods for, say, 90, 99 or 99.9 % tend to be substantially shorter.

Fig. II.13 Survival Periods in Days of Excreted Bacterial Pathogens in Soils of Tropical Climates

Above data confirm the survival pattern of other pathogens:

- 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 a few weeks, a small number of hardy organisms may survive for an extended period of time.

Most bacterial pathogens, notably *Salmonella* species, have high ($>10^6$) median infective doses (Feachem et al. 1983). The few surviving organisms which are analysed as still viable after extended periods may therefore signify a reduced risk. Their occurrence may be due to very high initial numbers, and their detectability depends on the particular analytical method used. 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. Salmonellae in particular appear to be good survivors under such conditions. To predict bacterial pathogen survival any closer than this is both impractical and impossible because numerous environmental factors interact with the pathogen. The most distinct lethal effect, however, comes from hot and dry conditions and solar radiation (Zibilske and Weaver, 1978).

b. Survival on Crops

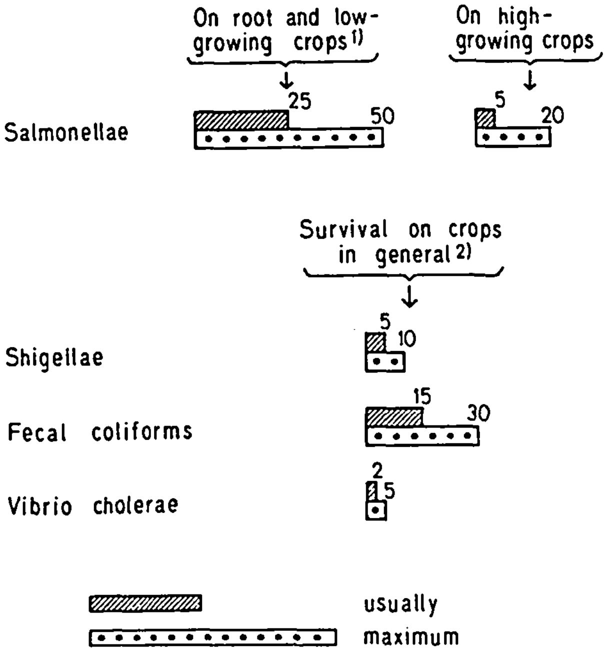
Survival of excreted bacterial pathogens on crops has been widely studied in industrialized countries. There the risk of pathogen transmission originates from the use of sewage sludge in fields where fodder or food crops are cultivated or on pastures and intensively cultivated grassland. Major concern arises with the two latter uses, where grazing cattle may become infected. Focus should be placed on potential transmission of such *Salmonella* infections for which humans as well as animals are reservoirs. Though cattle raising on pastures is of minor importance in most tropical countries, related pathogen survival data collected in industrialized countries may give valuable guidance as to the risk potential of pathogen transmission to humans through excreta-fertilized and contaminated crops. In "translating" survival data from temperate zones to conditions prevailing in tropical or subtropical areas, one will have to consider that tropical and subtropical climates tend to be more lethal to pathogens because temperatures are higher, duration of sunshine is longer and solar radiation is more intense than in temperate climates. On the other hand, air humidity is usually higher in tropical as compared to temperate zones.

Table II.9 contains data on excreted bacterial pathogens survival on crops for widely varying climatic conditions, study arrangements and crop types.

Survival data in Table II.9 lend themselves to indicate in a general manner survival times of bacterial pathogens on crops. In Fig. II.14 a truncation is made between survival on root and low-growing crops (e.g. between radishes or carrots, and lettuce, spinach, or cabbage respectively) and survival on high-growing crops, i.e. those which are usually not in direct contact with the soil (e.g. tomatoes, maize). 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. This has been observed and concluded from experimental results by a number of authors (Sadovski 1976; Bryan 1977, citing others; Larkin et al. 1978).

Table II.9 Survival of Excreted Bacterial Pathogens on Crops

Organism	Environmental Conditions	Survival (days)	Remarks	Reference
Salmonella typhi	Soil fertilized with "typhoid" stool; sludge bolstered with agargrown S. typhi		temperature?	Rudolfs et al. 1950 (I), citing others
	- radishes	< 28 - 37	root crop	
	- lettuce	< 21		
S. pullorum	laboratory (constant temperature) conditions; various vegetables			"
	- at 2 - 4°C (icebox)	< 28 - 56		
	- at room temp.	< 14 - 35		
Salmone' a cerro	S. suspensions sprayed on tomatoes			Rudolfs et al. 1951 (VI)
	- "field"	< 5	temperature?	
	- "laboratory"	> 20	uniform temp. and humidity; absence of direct sunlight	
Shigella	tomatoes sprayed with fecal suspension			
	- dry and hot (25°C; initial conc. = 10[illegible]-10[illegible]/g)	< 3		
	- cool and wet (15°C; initial conc. = 10[illegible]- 10[illegible]/g)	< 10		
S. typhimurium	S. contaminated pasture; temperate climate			Hess and Breer (1975), citing others
	- exposed to sunshine	< 84 - 168		
	- shaded	< 98 - 154		
Salmonella spp.	sewage sludge spread on grass; initial conc. in sludge = 10^4/ℓ		laboratory tests	Hess and Breer (1975)
	. at >90 % rel. air humidity: - 4°C	< 119		
	- 18°C	≥ 287		
	. at <30 % rel. air humidity: - 4°C	≥ 287		"
	- 18°C	≥ 266		
S. tokoin	sewage sludge spread on grassland; summer, Switzerland (15 - 20°C)	≥ 49		"
S. typhimurium	lettuce and radish fields fertilized with S. typhimurium inoculated sludge (initial conc. in sludge = 10^7/ml;); temp. <45°C, intense solar radiation		method of irrigation or sludge spreading?	Larkin et al. 1978
	- on lettuce	< 49 - 63		
	- " "	$T_{99.99}$ = 35		
	- on radishes	> 49	root crop	
S. typhi	on leaves and stems of vegetables	< 10 - 31	temperature?	Bryan (1977); citing others
	on radishes	< 28 - 53	root crop	
	on lettuce	< 18 - 21		
Salmonella spp.	on carrots	> 10	root crop;temp.?	"
	on tomatoes	3		
Shigella spp.	on tomatoes	2	temperature?	"
	in tomato tissue	10		
V. cholerae	vegetables			Feachem et al. (1980), citing others
	- at room temp.	< 7		
	- refrigerated	< 14		
S. typhi	soil fertilized with fresh typhoid feces			Feachem et al. (1980); citing others
	. feces spread prior to planting; 21°C:			
	- radishes	< 24	root crop	
	. feces spread 4 days after planting:			
	- lettuce (14°C)	< 21		
	- radishes (16°)	< 37	root crop	
Salmonella spp.	fodder	> 42	fertilizing medium?	"
	root crops	< 53	temperature?	
	leaf vegetables	< 40	" "	
			hight of plant?	
	berries	< 5	" "	
	orchard fruits	> 2	"	
Salmonella spp.	cabbage; 4 - 25°C; digested sewage sludge sprayed from tanker prior to planting; initial conc. ≤ 300/ℓ	< 49		Watson 1980
Fecal coliforms	greenhouse; digested, f. coliform seeded sludge sprayed over Bermuda- and Rhodesgrass; initial conc. = 10[illegible] - 10^4 f.c./ml	≥ 27		Brown et al. 1980
E. coli (resistant mutant)	E. coli seeded into oxidation pond effluent drip fed to cucumber plots (initial conc. = 10[illegible]/ml)	$T_{99.9}$ = 8		Sadovski et al. 1976



[1] For these crops survival of pathogens in soil is important.

[2] For these organisms reported data do not allow to differentiate between survival on root vs. survival on high-growing crops.

Fig. II.14 Survival Periods in Days of Excreted Bacterial Pathogens on Crops in Tropical Climates

Survival times of excreted pathogens on crops - with the possible exception of root crops - are shorter than in soils due to the pathogens' greater exposure to climatic influences (sunshine, radiation, elevated temperature, 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 effects. 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 nightsoil-fertilized vegetables would accordingly be relatively small because concentrations of surviving bacterial pathogens are likely to be lower than the required infective doses. If, however, fields are fertilized also during later stages of growth periods, the concentrations of viable bacterial pathogens on harvested crops will accordingly be higher. This will increase the potential risk of infection, particularly if vegetables are eaten raw.

Some excreted bacteria have been observed to grow outside the host if appropriate environmental conditions prevail and if nutrients are available. Such growth is reported mainly in relation with food-borne transmission of gastro-intestinal diseases: milk, dairy products, cooked meat, poultry, cream-filled bakery products, ice-creams, fish and shellfish are typical foods where bacterial pathogens such as *Salmonella* spp., pathogenic *E. coli, Shigella, Campylobacter*, and *V. cholerae* can grow and proliferate, thereby making food a prominent transmitter of infections (Bryan 1983). The same author also lists raw vegetables and salad[1] as potential media for growth and transmission of pathogenic *E. coli, S. typhi* and *V. cholerae*. Rudolfs et al. (1950, I., also citing others) stipulate that pathogenic bacteria cannot penetrate the intact epidermis (thin surface layer) of vegetables and fruits. In the case of undamaged crops, bacterial growth will therefore hardly take place because nutrients may not be available on the crop's surface and the pathogens will remain exposed to the adverse effects of sunlight, elevated temperature or desiccation. Injured or decayed parts of crops may offer access to bacterial pathogens which have been observed to remain viable for periods of 7 to 42 days (Rudolfs et al. 1950, I., citing others).

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. With the absence of nutrient sources, however, the same elevated temperature combined with solar radiation enhances pathogen die-off !

Evidence on growth of excreted bacteria on raw crops is rather limited. Related data are presented in two reports which deal with the survival of excreted bacteria on vegetables fertilized with sludge or effluent (Sadovski et al. 1976; Larkin et al. 1978). Both authors document the growth of faecal indicator organisms. Sadovski et al. (1976) observed that after drip-feed irrigation of cucumber fields with *E. coli*-mutant seeded oxidation pond effluent, the *E. coli* count on the cucumbers increased from about 10^2 to 10^5 per 100 g dry weight within the first two days after irrigation. Thereafter, E. coli die-off proceeded to undetectable levels within six more days. Air temperatures were above 20°C. Larkin et al. (1978) report about the survival of faecal indicator bacteria on lettuce irrigated with sewage treatment plant effluent. The growth of faecal coliforms and faecal streptococci was substantial, i.e. in the order of 10^2 and 10^4 organisms per gram of lettuce

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[1] It is unclear whether the author means raw or dressed salad, and therefore if the pathogens draw nutrients from the salad or from the dressing.

respectively, between the fourth and seventh week after irrigation and under rather harsh climatic conditions ($\leqslant$ 45°C, intense solar radiation). Due to the substantial growth potential of faecal coliforms and streptococci as reported above, these organisms are likely to give too conservative estimates of pathogen survival on crops.

The literature survey did not reveal any reported evidence on growth of pathogenic bacteria on either damaged or undamaged raw crops. It may be inferred, as do a number of authors, and based on the few data available, that injured vegetables and fruits may offer "shelter" to pathogens in their damaged parts, thereby enabling prolonged pathogen survival.

There are indications that bacteria rather tenaciously hold onto vegetable surfaces which become faecally contaminated: Rudolfs et al. (1951, IV.) have investigated several means of bacterial decontamination of faecally contaminated tomato surfaces, e.g. vigorous washing with plain water. Original *E. coli* concentrations of 10^6-10^7/g of tomato skin were reduced by a maximum of 10^2 only. Water hardness appeared to slightly enhance *E. coli* removal. Brown et al. (1980), in studying the effect of rainfall (25 mm/h up to 1 hour) on faecal coliform counts on narrow and broad-leaved grasses which had been sprayed with digested sewage sludge, found that the counts were reduced by one to three orders of magnitude only, leaving behind 10^1-10^6 faecal coliforms per gram of leaf. Initial and residual concentrations were higher on leaves sprayed with 4% solids sludge than on those sprayed with 2% solids sludge. The stickiness of waxy vegetable surfaces, the protection provided by attached lumps of faecal sludge and/or by groves on the leaf's surface where organic residues and moisture necessary for microbial survival are retained, are supposedly responsible for faecal coliform immobilization and survival. Rain may enhance bacterial survival rather than remove appreciable numbers of bacteria from vegetables. This is due to a relative air humidity increase, a decrease in temperature and an additional contamination by splattering (Rudolfs et al. 1951, VI).

The strong attachment of faecal coliforms to vegetable surfaces is not necessarily representative of the attachment behaviour of other pathogens, e.g. viruses: Brown et al. (1980) observed that coliphages contained in digested sewage sludge sprayed on grass were effectively washed away from the grass leaves by simulated rainfall. Their concentrations were reduced from 10^2-10^3 PFU/g dry grass to non-detectable levels within 30-60 minutes of rain.

II.3.4 Survival of Viruses

Investigations into the survival of viruses in soils and on plants were carried out mainly because of the interest and problems raised by the potential health effects of sewage sludge application on agricultural land in industrialized countries. Irrigation with wastewater has more recently become a pressing need and has therefore gained increasing interest in many arid areas (e.g. Eastern Mediterranean, Gulf States, Saudia Arabia, Mexico, Peru) where scarce water resources require to be utilized economically. Regular disposal of wastewater or wastewater sludge may endanger groundwater due to virus travelling in the soil and being adsorbed onto soil particles. The capacity of the soil to retain viruses and therefore to provide protection to the groundwater has been dealt with on numerous occasions[1]. Little is known yet about quantitative virus survival on and in the soil and on crops.

Several authors have elucidated the role of soil characteristics and other parameters related to the soil environment in virus immobilization and die-off. Comprehensive reviews on the fate of viruses in the environment, including groundwater, soil and crops, have been made by Feachem et al. (1981) and Vaughn and Landry (1983; contained in Berg, 1983).

The techniques of virus detection and determination of virus infectivity are elaborate and expensive and can only be handled by specialized laboratories. Virus survival data must therefore be interpreted more in indicative than in absolute terms. Thus, zero survival means that either all viruses have been inactivated or that the number of viruses have been reduced beyond detectability. This seemingly trivial difference is quite relevant in the case of viruses, as infective doses for viruses, notably enteroviruses[2], are low. One or few organisms can suffice to cause infection in a susceptible host.

A further difficulty is to differentiate between actually inactivated viruses and viruses which have not been detected due to their becoming adsorbed to soil particles and therefore not recovered in routine analysis. The use of purified radioactively-labeled viruses seeded into the fertilizing waste medium would permit calculation of virus recovery efficiency (Yeager and O'Brien 1979).

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[1] The subject of groundwater pollution risks posed by excreted pathogens has been reviewed in Lewis et al. (1982) in the context of on-site excreta disposal systems (e.g. latrines, leaching pits).

[2] Enteroviruses include echo, coxsackie and polioviruses

Though it is reasonable to assume that excreta application to agricultural land could constitute a possible transmission route for excreted viral infections, there is a multitude of alternate faecal-oral transmission routes for excreted viruses, such as person-to-person contact, or via food, utensils or water. These "short" routes may play the dominant role in many situations because viruses are infectious immediately upon excretion (zero latency) and have very low infective doses.

a. Survival in Faecal Sludge Spread on Soil

In many parts of the world, the solid contents of emptied faecal sludges from various types of latrine pits or vaults (e.g. single and double-pit latrines; pour-flush latrines) are high enough to cause "matting" of the sludge on the soil's surface. Matting usually occurs if the solid fraction of the sludge is greater than 10-15 %. Values of 14 % (Thailand), 47 % (Botswana) and 54 % mean solid contents (Tanzania) have been reported (Boesch and Schertenleib 1985; Hawkins 1982). Little pathogen-soil interaction is expected upon application of such a kind of faecal waste, unless the field is tilled after spreading of the waste (which must be done prior to sowing or transplanting).

It has been suggested on the basis of both field and laboratory studies that most of the viruses contained in sludge which originates from sewage treatment are in fact adsorbed to the sludge particles and flocs (Farrah and Schaub 1983). In undecomposed sludge, these solids consist mainly of dead and living cells, whereas in decomposed sludge they are made up of stable organic material (cells and stabilized degradation products). Minor fractions of inorganic particles are also present. Adsorption to high-molecular proteinaceous substances is likely to play a role in fresh and partly decomposed sludge. Solids contained in faecal wastes from latrine pits and vaults, as well as in septic tank sludge are of a chemical composition comparable to that of sewage treatment sludge. Thus, viruses are quite likely also found in an adsorbed state in nightsoil and will be largely retained in the faecal sludge "matting" on the soil's surface.

Upon surface spreading, the nightsoil will not only undergo a drying process during periods of no rainfall, but will also be subjected to further microbial decomposition. Intensity and duration of the drying process depend on climatic factors such as temperature, humidity, wind, rainfall and shading effects by plants. Virus survival is accordingly affected. Feachem et al. (1983) and Farrah and Schaub (1983), summarizing investigations by several researchers on virus survival in sludge spread on land or let to dry in sludge drying beds, conclude that it is mainly the drying process which enhances virus die-off, except at rather low temperatures (< 10-15° C) which lead to prolonged virus survival. Rapid virus inactivation was observed when sludge was allowed to dry under controlled conditions to > 65 % solids content. Yet, in humid tropical climates, nightsoil or sludge would hardly dry to > 60 % solids. Prolonged periods of dry, hot weather as often encountered in tropical and subtropical areas during dry seasons will, however, result in higher solids content and entail rather rapid virus die-off. Table II.10 lists the few data which exist on virus survival in sludges spread on land or in drying beds.

Table II.10 Virus Survival in Spread-Out, Drying Sludge

Organism	Type of investigation	Temperature/ Climate	Survival/ Inactivation	Ref.
Poliovirus	sewage sludge air-dried during 4 days in 1 cm-thick layers; 10^7 viruses/ml seeded			Feachem et al. 1983; citing others
	. < 65 % solids	21° C	75 % inactivation	
	. < 85 % solids	21° C	+ 99,9 % inactivation	
Enteroviruses[1]	sewage sludge on drying beds	temperate	> 14 days	"
Echovirus	"	?	> 13 days	Farrah and Schaub 1983; citing others
"indigenous viruses"[2]	sewage sludge spread on land and drying	hot, humid	2 $\log_{10}$ /week	"
Coxsackievirus	virus seeded into sludge placed in lysimeter	< 10° C	0,2 $\log_{10}$ /week	"

[1] Includes also polio, echo and coxsackie viruses

[2] Viruses "naturally" present in the sludge (in contrast to viruses seeded for the experiment)

Based on the data listed in Table II.10 one can conclude that in hot, humid climates a period of about 20 days is sufficient for complete virus die-off in nightsoil spread on land. In dry, hot climates, however, shorter periods will suffice.

If nightsoil of low (< 10 %) solids content is spread on fields or if there is prolonged rainfall, the waste matter will partly penetrate the upper soil layers. There, viruses will then become subjected to antagonistic effects prevailing in the soil or, if desorbed from sludge solids due to excessive rainfall, the viruses will most probably become adsorbed to soil particles near the soil's surface.

b. Survival in Soil

Numerous publications have accumulated in recent years which elucidate the fate of viruses in soil and the great complexity of soil-pathogen interactions. Yet, the "reliable" quantitative prediction of pathogen survival on the basis of known soil properties remains extremely difficult or even impossible.

Many experiments on virus survival and behaviour in soil have and are being conducted in the laboratory to obtain closely controllable environmental conditions (e.g. temperature, soil moisture, pH, soil microbial activity). Experiments frequently make use of particular laboratory-cultivated virus types and strains which are seeded into soil or sludge samples. This has enabled scientists to determine the influence of those environmental factors (e.g. soil characteristics) which play a dominant role for virus survival or die-off. When it comes to virus survival periods, however, some authors point to the fact that laboratory experiments appear to furnish rather conservative results: field conditions are usually harsher than laboratory environments as field parameters, notably temperature, humidity, moisture and radiation vary continuously and often significantly within a short period of time. These effects tend to shorten natural microbial survival and viability (e.g. Hurst et al. 1980a).

Table II.11 lists data on virus survival periods in soil as previously reviewed by Feachem et al. (1980) and Feachem et al. (1983), and investigated by Hurst et al. (1980a).

Based on Table II.11, survival times of excreted viruses in soils of tropical climates (20-30° C) tend to fall within the following range:

- maximum: $\leqslant$ 110 days
- normally: $<$ 20-30 days.

As regards excreted bacteria, these periods refer to the survival of a relatively small number of the most resistant organisms. The periods required for 99 % or 99.99 % die-off tend to be substantially shorter. Furthermore, survival periods also vary according to initial pathogen loads; smaller loads lead to shorter overall survival periods.

Table II.11 Survival of Excreted Viruses in Soil

Organism	Environmental conditions; soil	Survival (days)	Remarks	Reference
Enteroviruses	sterile[1] sandy soil	< 90 - 110	soil moist. 10-20 % T = 18-23° C pH = 7.5	Feachem et al. (1980); quoting others
	sterile loamy soil	< 70 - 110	—— " ——	
	non-sterile sandy soil	< 40 - 110	—— " ——	
	non-sterile loamy soil	< 70 - 110	—— " ——	
Poliovirus	sand dunes			"
	. dry	< 77	temp. = ?	
	. moist	< 91		
Poliovirus 1	fine loamy sand			"
	. at 4°C	T_{90} = 84		
	. at 20°C	$T_{99.999}$ = 84		
Polioviruses 1, 2 and 3	wastewater effluent irrigated soil; pH = 8.5; T = 12-33°C; soil moist. = 9-20%	> 8		Feachem et al. (1980); quoting others
Coxsackie B3	clay; pH = 7.1-7.4; T = - 12-26°C; total rainfall = 300 mm	< 161		"
Poliovirus 1	sludge, irrigated soil;			"
	. T = - 14-27°C (winter); total rain = 180 mm	< 123		
	. T = 15-33°C (spring); total rain = 190 mm	< 11		
Enteroviruses (natural isolates)	loamy sand flooded with wastewater (raw or effluent); "fall" (T ≅ 20°C?); soil moist. 20-15%		titer 1 day after flooding:	Hurst et al. (1980a)
	. at surface	< 5	1.6 x 10^2PFU/100 g dry soil	
	. at 5 cm depth	< 3	2.5 x 10^1PFU/100 g dry soil	
Poliovirus 1 (seeded)	loamy sand flooded with wastewater (raw or effluent); "fall" (T ≅ 20°C?); soil moist. 19-6%		initial titers:	Hurst et al. (1980a)
	. at surface	< 8	2.5 x 10^4PFU/100g dry soil	
	. at 5 cm depth	< 8	2.7 x 10^3PFU/100g dry soil	
Coliphages T 1 and T 7; Reovirus 3	clayey soil; T = 24°C	< 49-63	temp. = ?	Vaughn and Landry (1983) quoting others
	soil without clay; T = 24°C	< 7	"	

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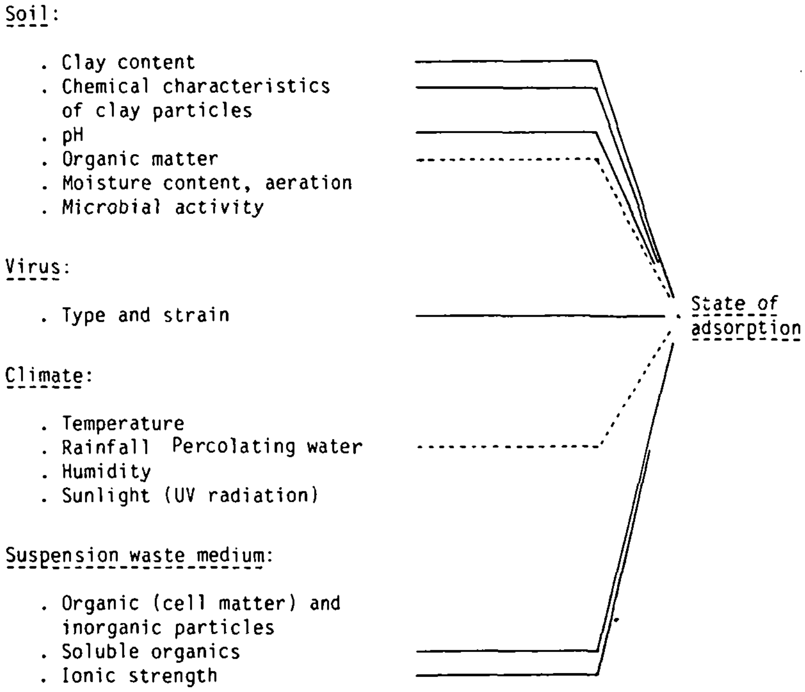
[1] Soil sample has been sterilized prior to seeding with "experimental" viruses in order to study the role of soil microbial activity on virus survival through comparison with non-sterilized soil.

Factors Affecting Virus Survival in Soil

Viruses are minute colloidal particles ranging from 20-350 nm[1] in size. They fall within the size range of clay particles. It is therefore reasonable to assume that characteristics related to soil structure (both at its surface and below) also affect the fate of viruses which are contained in nightsoil spread on fields. Soil characteristics, climatic factors, chemical properties of the virus, and the characteristics of the suspension medium (here: faecal sludges) interact in a complex manner and produce combined effects on pathogen survival and infectivity. Table II.12 lists the various factors affecting the survival of viruses in soil.

Table II.12 Factors Affecting the Survival of Viruses in Soil[2]



Soil:

- Clay content
- Chemical characteristics of clay particles
- pH
- Organic matter
- Moisture content, aeration
- Microbial activity

Virus:

- Type and strain

Climate:

- Temperature
- Rainfall Percolating water
- Humidity
- Sunlight (UV radiation)

Suspension waste medium:

- Organic (cell matter) and inorganic particles
- Soluble organics
- Ionic strength

——————— major
----------- minor or suspected
} influence on state of adsorption which in turn affects survival

[2] Based mainly on Gerba et al. (1975) as well as Vaughn and Landry (1983)

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[1] 1 nm = 10^{-9} m

The possible intimate association of viruses with soil particles through adsorption is of interest to those concerned with groundwater quality protection as well as in the context of disease transmission through excreta fertilized soils and crops. Specifically, virus association with soil relates to the following questions:

- Does adsorption of viruses to soil particles enhance virus die-off or does it prolong virus survival ?
- What are the major factors contributing to the die-off of viruses associated with soil particles ?
- May viruses become dissociated from soil particles through rain or flooding and move further downward, thereby losing their transmission potential through contact with contaminated crops and soil (but posing a risk to groundwater) ?

Most investigations on the fate of viruses in soil have been conducted with treated wastewater or sewage sludge. Though their survival when applied on soil through wastewater or sludge may somewhat differ from their survival in land-disposed faecal matter collected from latrines, the observed phenomena are certainly comparable.

Hurst et al. (1980a) investigated virus inactivation and downward migration of cultured enteroviruses seeded into pretreated sewage. They also studied enteroviruses occurring naturally in this sewage at a level of 768 PFU/liter and disposed on land through rapid infiltration basins. The investigators found and thereby confirmed results obtained by others (Lance et al. 1976, quoted by Hurst et al. 1980a), that virus concentration in the upper surface layer of sewage-irrigated soil was about 1 $\log_{10}$ (10 x) higher than at a soil depth of 2.5-25 cm. An even higher virus concentration was observed in the sludge layer which was formed on the surface of the soil. This lead the authors to assume that many of the viruses occurring in the wastewater were associated with the solids contained in that wastewater and which were then filtered out along with the sewage solids. Viruses were detected on the surface and top layers of the soil (0-5 cm) over longer periods of time than at greater depths. This is due to higher initial numbers concentrating near the soil's surface.

Alternating flooding and drying of the soil yielded the following results with respect to virus inactivation (Hurst et al. 1980a):

- Average rate of inactivation for poliovirus 1 and echovirus 1 seeded in buried soil:

  - during flooding of surface: 0.04-0.15 $\log_{10}$ per day
  - during drying: 0.11-0.52 " " "
    (soil moisture decreasing from approx. 20 to 15 %; autumn temperature in Arizona, U.S.A.)

Rates of reduction were similar for the various types of enteroviruses, but migration and immobilization respectively, were different for poliovirus 1 and echovirus 1. The results further indicated that virus inactivation is strongly related to decrease in soil moisture during drying cycles. Loss of moisture is associated with aeration of the soil, which in turn supports the activity of aerobic microorganisms. There is strong evidence that these are detrimental to enterovirus survival (Hurst et al. 1980a). Intervals of several days between wastewater or sludge applications to fields will therefore contribute substantially to avoiding virus build-up and enhancing virus inactivation.

Hurst et al. (1980b) studied in the laboratory the effects of various soil characteristics and environmental variables on the survival of enteroviruses, rotaviruses and bacteriophages in soil. Experiments were conducted with various types of soil (clay contents ranging from 3-54 %, sand contents from 15-92 %, representing different virus adsorption capacities), in sterilized and unsterilized soils (representing varying degrees of soil microbial activities). These experiments were carried out under aerobic and anaerobic conditions as well as at different temperatures in order to study the role of aerobic and anaerobic soil microorganisms respectively. Initial virus titers ranged from 10^4-10^5 PFU/g of soil. The major findings are summarized as follows:

- The time required for 99.9 % reduction of poliovirus 1 under unsterilized conditions at 23° C and 15 % soil moisture (saturation) ranged from 23 to $>$ 30 days.

- At 1° C, there was essentially no reduction in poliovirus 1 counts within 75 days of observation.

- At 37° C, poliovirus 1 was reduced by 99.9 % within 10 days or less independent of soil microbial activities (sterilized vs. unsterilized conditions).

- At intermediate soil temperatures (23° C), the time required for 99.9 % poliovirus 1 die-off under aerobic conditions was two to four times less (20-40 days) under unsterilized than under sterilized conditions (75 days).

- 20-40 days were required for 99.9 % poliovirus 1 die-off at 23° C under unsterilized conditions when the soil was aerobic, but $\geqslant 75$ days when the soil was anaerobic.
- Independent of the types of viruses tested, increasing degrees of virus adsorption to soil resulted in extended virus survival.
- Soil pH had a rather significant effect on virus survival: at $pH < 7$, survival time was long, whereas survival periods decreased sharply when pH increased above 7.0-7.5[1].
- Effects on virus survival from varying soil moisture contents were investigated in sandy loam: at 15 % soil moisture which corresponded to saturation for this particular soil, rates of virus die-off were highest, whereas at lower and higher moisture levels the virus survival period was longer. The authors suppose that moisture-level-dependent differences of virus adsorption and antagonistic microbial activity in the soil affect virus survival.

Adsorption: Duboise et al. (1979) have presented an extensive review about the fate of viruses in soil systems. Protection from or retardment of virus inactivation upon adsorption to soil, notably clay particles, are widely observed phenomena. The possibility that key-infective or host-adsorbing sites of viruses become "occupied" or chemically unavailable is a theory put forward by various authors. It is assumed that enzymes or other substances antagonistic to viruses are also adsorbed to the clay and rendered harmless for viruses. Virus structural stability may possibly be enhanced by adsorption to clay particles. Finally, clay adsorption may induce aggregate formation among viruses.

Type and amount of clay: These appear to be key factors of adsorption. Vaughn and Landry (1983) reviewed several investigations which attempt to elucidate the roles of various clay types and different clay contents. Though virus adsorption is not in all cases proportional to the clay contents, silty, loamy and clayey soils of $>$ 20-30 % clay tend to adsorb more and a larger variety of virus types and strains than soils with minimal ($<$ 5 %) clay content.

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[1] Soil pH appears to affect virus adsorption to soil particles through chemical equilibria between soil and water, involving among others aluminum and phosphorus compounds. Adsorption in turn affects virus survival.

Black cotton soil and laterite are widespread soil types in the tropical hemisphere. Black cotton soils are usually of high (> 50 %) clay contents and therefore tend to be good virus adsorbers. Lateritic soils generally exhibit much lower clay contents (< 10 - 15 %). In these soils it is likely that large numbers of viruses will remain unadsorbed.

Adsorption of viruses is observed not only in relation to inorganic soil particles but also to dead and living microbial cells. This enables to elucidate why enteroviruses have been observed to survive longer in polluted than in unpolluted water. This also explains the long virus survival periods in faecal matter where viruses are partially protected from desiccation, ultraviolet radiation and high temperature.

Soil moisture: As mentioned above, this is an important determinant in soil-virus interaction. Water is present in the soil in various forms such as e.g. free-moving pore water or water attached to mineral surfaces (notably clay) and held in place by strong adsorptive forces. Such strongly held water, which is removed by extreme dryness only, may well be a factor enhancing virus survival. Yeager and O'Brien (1979) investigated moisture effects on poliovirus 1 survival in soil. A major finding was that die-off rates were low and essentially the same at moisture levels ranging from 18-3 % (< 90 % in 10 days at 22° C). Only at moisture contents of < 1 % did the die-off rate increase to approx. 90 % in 1 day. Furthermore, Duboise et al. (1979) point to the fact that changes in soil moisture may affect virus survival in a complex way, because other factors such as solute concentrations and pH, which also affect virus survival, will be altered as well. Soil moisture mostly determines the degree of soil aeration, a factor which was found relevant for virus survival by several investigators, who suggest that aerobic soil microorganisms appear to be virucidal. Even in well-aerated soils, however, small voids in soil aggregates may remain without oxygen and give viruses "shelter" from the antagonistic effects of aerobic microorganisms. Where faecal sludges are repeatedly applied to fields at short intervals, soil conditions may remain anaerobic over long periods and thereby retard virus die-off and lead to virus build-up.

Organic soil fraction: Similar to organic solids in faecal sludges, the organic soil fraction interacts with viruses through adsorptive forces, thereby influencing virus survival and infectivity. Organic soil fractions, notably humic substances, are adsorptive and may thus enter into intimate contact with viruses, probably in association with soil particles. While such interactions tend to contribute to the protection of the viruses from adverse effects, the pattern of virus die-off could on the other hand become closely linked to the decomposition process to which organic matter is subjected (for humic substances such decomposition is, however, rather slow) (Duboise et al. 1979, quoting others). The role of organic matter on virus adsorption in soil reportedly varies with the type and strain of virus. The surface structure of the virus is mainly responsible for the adsorptive behaviour (Gerba and Goyal 1981). The same authors found a significant inverse correlation between soil organic matter and adsorption of specific strains of coxsackie and echoviruses in soils containing 0.27-4.2 % organic matter.

Other virus types and strains were less sensitive to variations in such soil characteristics as organic content and pH. Vaughn and Landry (1983, citing others) report that good agricultural soils containing at least 0.5-1 % organic matter were observed to adequately remove (i.e. adsorb) viruses. The cited investigators stipulate that a minimum content of organic matter is required for adsorption of viruses to become effective. Moore et al. (1982) and Burge and Enkiri (1978) conclude on the basis of their virus adsorption studies that soils with high (> 4-6 %) organic content are poor adsorbents of specific types of viruses. Soluble organic substances which are added to soil when wastewater, sewage sludge or nightsoil is used for fertilization were found to hinder or even reverse virus adsorption to soil. This is probably due to potential adsorption sites becoming occupied by organic substances (Schaub and Sagik 1975; Moore et al. 1982, also citing others; Vaugn and Landry 1983).

Soil pH: Several investigators found that soil pH has a marked influence on virus adsorption, i.e. increased adsorption at decreasing pH (Schaub and Sagik 1975, Gerba and Goyal 1981, Moore et al. 1982).

The important question to ask in relation to virus adsorption to soil particles is whether adsorption prolongs virus survival or shortens it. Hurst et al. (1980b) discovered that a variety of enterovirus strains and other virus types in different test soils exhibit prolonged survival with increasing degrees of adsorption. Schaub and Sagik (1975) report that encephalomyocarditis viruses adsorbed to clay particles retained their infectivity as determined on tissue cultures as well as in mice. In contrast, Moore et al. (1982) conclude on the basis of experiments conducted to investigate reovirus adsorption to artificially suspended soils that reovirus was rapidly inactivated upon contact with minerals and soils. They attribute this behaviour to the adsorptive interaction between solids and viruses although reovirus does not lose its physical integrity. Only the presence of humic organic matter caused reovirus infectivity to be retained. In spite of this one report, one may conclude on the basis of extensive documentation that, in general, adsorptive interactions provide protection to viruses and therefore assist in prolonging their survival (Duboise et al. 1979). Not considering the adverse effects of heat, desiccation and radiation, a similar fate may be expected for viruses which aggregate or become adsorbed to solids in faecal wastes such as nightsoil and septic tank sludges.

Vaughn and Landry (1983) have reviewed literature regarding the effects of virus adsorption states on survival times in quantitative terms. Table II.13 lists survival times and indicates the role of virus adsorption in the particular investigations.

Table II.13 Effects of Virus Adsorption State on Virus Survival (Vaughn and Landry 1983)

Organism	Survival		Experimental set-up
	"Non-adsorbed"	"Adsorbed"	
Polivirus 1	t_{90} = 75 min.	t_{90} = 163 min.	exposure to solar radiation; nontronite as adsorbent
Viruses	< 10 sec survival	t_{45} = 30 sec	0.012 mg/l ozone disinfection; adsorption to fecal particulates and cellular material
Virus	t_{99} = 86 days	t_{99} = 167 days	adsorption to "cecil soils"; temp.?
Coliphage T7	< 5 weeks	< 31 weeks	adsorption to clay minerals at 4°C
	< 1 week	< 9 weeks	adsorption to montmorillonite clay at 24°C
		< 7 weeks	adsorption to kaolinite clay at 24°C

It may be inferred from the data in Table II.13 that the presence of clay minerals or organic particles as contained in faecal wastes exerts a substantial effect on virus survival: survival "prolonging factors" from two to nine have been recorded.

c. Survival in Soil: Summary

In summarizing the results of the growing number of investigations carried out in recent years on the fate of viruses in soil, one becomes aware of the extremely complex soil-virus interactions. The soil's microenvironment varies continuously. Furthermore, repeated applications of human waste on fields will cause additional changes and fluctuations in soil properties. Soil moisture, temperature, pH, ionic strength, organic substances, and indigenous soil microorganisms are important factors influencing the fate of viruses (as well as other pathogens). 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 on the findings presented above, a number of inferences regarding the fate of viruses in soil can be made:

- 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, however, to cause rapid (< 10 days at 22°C) virus die-off.
- Acid pH enhances virus survival, whereas alkaline pH leads to rapid virus 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 applications to the same plot. This will help ensure soil aeration and prevent accumulation of viable viruses (and other pathogens).
- Virus adsorption to soil particles is an important phenomenon with a substantial impact on virus survival. Clays variably adsorb viruses, which are then protected from antagonistic effects and tend to survive longer than in an unadsorbed state. Thus, viruses deposited with faecal matter on agricultural land tend to survive longer in "heavy" (loamy, clayey) soils than in "light" (more sandy-silty) soils. While some viruses lose infectivity in an adsorbed state, possibly due to key infecting sites of the virus being occupied by adsorption, most of the others remain infective. Soils of high organic content (>4-6 %) are bad virus adsorbers. They leave the viruses exposed to adverse effects which enhance their die-off.
- Extent and rate of adsorption varies with the type and strain of virus.
- Viruses contained in nightsoil deposited on land as fertilizer are mostly solids-bound, i.e. adsorbed to organic, microbial and inorganic particles. Viruses also tend to accumulate at or near the sludge/soil interface because the sludge solids are largely filtered out by the top soil. This accumulation can be avoided if the field is ploughed after nightsoil application.

- Viruses may be desorbed by percolating rainwater but are likely to be readsorbed within shallow soil depths unless the soil is very sandy in which case it has little adsorptive capacity.

d. Survival on Crops

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, since nightsoil is usually spread by hand or through flooding.

Virus survival data are listed in Table II.14.. Major reviews have been previously carried out by Feachem et al. (1980) and Feachem et al. (1983).

Sewage effluent and sludge were used in most of the investigations cited in Table II.14. They were either applied by spraying or flooding, and most of them were artificially seeded with viral suspensions. Based on the data listed in Table II.14, virus survival on crops in warm (> 15-20° C) climates can be summarized as follows:

· maximum:	30-40 days
· normally:	15 days.

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. This is not surprising as environmental effects are more lethal during exposure on plants than during exposure in the soil. Temperature, sunlight, air humidity, and wind are the determining factors, i.e. hot and dry conditions being most lethal to viruses (as well as other pathogens). Data indicate that survival periods as short as a few days are not uncommon in hot and dry weather.

It is reasonable to assume that, beside climatic factors, virus and vegetable type influence the survival period.

Brown et al. (1980) have studied the effect of rainfall on virus reduction from sludge-irrigated grass leaves in greenhouse experiments. They have observed that coliphages were usually removed from the plants within 30 min. or at most 60 min. of rainfall. It is not known whether decontamination through rainfall is also valid for other plants, crops or for other viruses. Rainfall may also have undesirable effects: originally not contaminated crops - notably low-growing vegetables - can become contaminated by sludge or

Table II.14 Survival of Excreted Viruses on Crops

Organisms	Environmental conditions; crop	Survival (days)	Remarks	Reference
Enteroviruses	Tomatoes infected with (artificial) viral suspension			Feachem et al. (1980); citing others
	. at 3-8°C . at 18-21°C	90 % die-off 99 % die-off } in 10 days		
Poliovirus	Radishes at 5-10°C	> 60 (99 % die-off in 20 days)	contaminating medium ? root crop	"
Enteroviruses	Root crops or leaf vegetables	< 60	—— " —— ; temperature ?	"
Poliovirus 1 (attenuated)	Tomatoes indoor . 22-25°C . 37°C	 < 12 < 5	contamination by waste stab. pond effluent	"
	Tomatoes outdoor	< 1	—— " —— ; temperat.?	"
	Parsley at 15-31°C	< 2	"	"
Poliovirus 1	Lettuce and radishes spray irrigated with inoculated sewage effluent (>10^8 poliov./l); 19-34°C, periodic rain, much sunlight (Ohio, USA)	< 36 (99 % die-off in 6 days)		"
Poliovirus 1	Lettuce, radish tops, radishes grown in soil flooded with inoculated sewage sludge or effluent (summer, Ohio, USA); flooding done 3 days after and 1 day before sowing respectively; tilling 2 days after flooding	18-23	> 15-20°C (?)	"
Poliovirus 1	Lettuce and radish plots flooded with sludge and effluent seeded with ~ 10^9PFU/l			
	. sludge irrigated	150-4400 PFU/g of leaf 24 h after irrigation	temperature ?	Larkin 1982
	. effluent irrigated	25-500 PFU/g of leaf 24 h after irrigation	"	"
Polioviruses	Drip irrigation of cucumbers with seeded oxidation pond effluent (eastern mediterranean/ fall climate)			Sadovski et al. (1976)
	. experiment 1	> 8	poliov. conc. on cucumbers immediately after irr. ≅ 10^3PFU/100 g	
	. experiment 2	< 8	— " — ≅ 10^4PFU/100 g	
Coliphage	Common bermudagrass and bell rhodesgrass sprinkle irrigated with digested sewage sludge (2-4 % solids) in greenhouse ($5x10^2$ - $3.8x10^3$ PFU/g dry grass immediately after irrigation)	< 1-2	15-20°C (?)	Brown et al.(1980)

nightsoil splashing. A related phenomenon has been observed by Sadovsky et al. (1976) who noticed that the fluctuation in the viral contamination levels on drip-irrigated cucumbers resembled the fluctuation in the soil. Moreover, rainfall will delay desiccation effects through the wetting of crop surfaces and increasing of the air humidity.

II.3.5 Survival of Protozoa

Persons infected by the protozoa *Entamoeba histolytica* or *Giardia lamblia* excrete both the vegetative form (trophozoites) of the respective protozoa and the protozoal cysts. The cysts may survive for a limited period and are the transmitters of infection, whereas the trophozoites rapidly die upon excretion and do not play a role in transmission.

Although prevalence of *Ent.histolytica* and *Giardia* is substantial, little is known yet about the survival of cysts in the outside-host environment and the dominant transmission routes. It is assumed that *Entamoeba histolytica* is mainly transmitted by direct faecal-oral routes within homes (Feachem et al. 1983). Therefore, little attention has been attributed to its survival in nightsoil-manured soils and crops. Furthermore, cysts are difficult to detect. *Gardia* cyst concentrations in water for example may be grossly underestimated unless they are abnormally high. Analytical methods for the determination of *Gardia* cyst viability and infectivity are still not sufficiently developed and rather controversial (Feachem et al. 1983).

Survival of cysts appears to be largely temperature dependent unless they are exposed to particular physical stresses such as desiccation. The few data reported (Rudolfs et al. 1950 and 1951; Feachem et al. 1983) indicate that the survival period of *Ent.histolytica* cysts in soils and on crops in warm climates tends to be of similar duration as in water or sewage; i.e. in the order of a few days, whereas *Giardia lamblia* cysts may survive longer in water than in soil or on crops. Survival periods of several weeks have been observed for *Giardia* cysts in water (Feachem et al. 1983, citing others).

Although cysts are rather resistant to chemical stresses, they are extremely sensitive to dry conditions and desiccation. Rudolfs et al. (1951) have investigated survival of *Ent.histolytica* in soil and on crops of tomato and lettuce cultivations under warm, clear and humid weather conditions. The plants have been contaminated with suspensions of cysts. Cyst survival ranged from less than 18 hours in dry soil to a maximum of 42 hours in wet soil. Beaver and Deschamps, cited in Rudolfs et al. (1950), have also observed cysts surviving in the top 10-15 mm of a moist sandy/loamy soil. At temperatures ranging from 28-34° C, *Ent.histolytica* cysts survived for 6-8 days.

Rudolfs et al. (1951) while investigating survival of cysts on vegetable surfaces found that cysts were inactivated within three days. Survival time was slightly longer on leaf lettuce than in cracks of tomatoes, but shorter than underneath tomatoes which were resting on damp soil. In hot climates, survival is likely to be shorter.

Mills et al. (cited in Rudolfs et al. 1950) concluded that, similar to bacteria, cysts would not penetrate to any appreciable extent the (undamaged?) stem of fresh vegetables.

Winfield and Chin (cited in Rudolfs et al. 1950) reported that amoebic infection rates were higher in northern China where nightsoil was worked into the soil than in areas of southern China where wet nightsoil was poured directly over standing crops. This might be an indication that cysts survive longer within the soil's matrix than on vegetables, but must not be conclusive of the relative importance of soil vs. crops as transmitters of excreted protozoal cysts. The observed difference in amoebic infection rates may just as well be due to differences in personal hygiene (e.g. food handling habits) in the areas studied.

Feachem et al. (1983) suggest that further research on *Giardia* cysts and development of improved analytical methods for their detection are necessary. Till then, their survival period can be assumed to be similar to *Ent. histolytica* cysts'. These authors have made temperature-dependent "safety" estimates of *Ent. histolytica* cysts survival periods which are based on reported results obtained under widely differing conditions. These estimates which represent conservative figures for survival in **faeces, nightsoil and soil**, and which may also be applicable to *Giardia* cysts, range as follows:

- max. 8 days at 35° C
- max. 12 days at 30° C
- max. 23 days at 25° C
- max. 30 days at 20° C

Average cyst survival periods in soil tend to be in the order of 10 days or less within this temperature range.

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.

II.3.6 Summary; Pathogen Survival vs. Vegetable Growth Periods

All excreted pathogens will eventually die or become inactivated in the non-host environment. The pathogen reduction pattern is exponential. The actual rate, however, depends on the type of pathogen and on the environmental conditions.

Major environmental factors influencing pathogen die-off or survival in soil, on crops or in fish ponds can be summarized as follows:

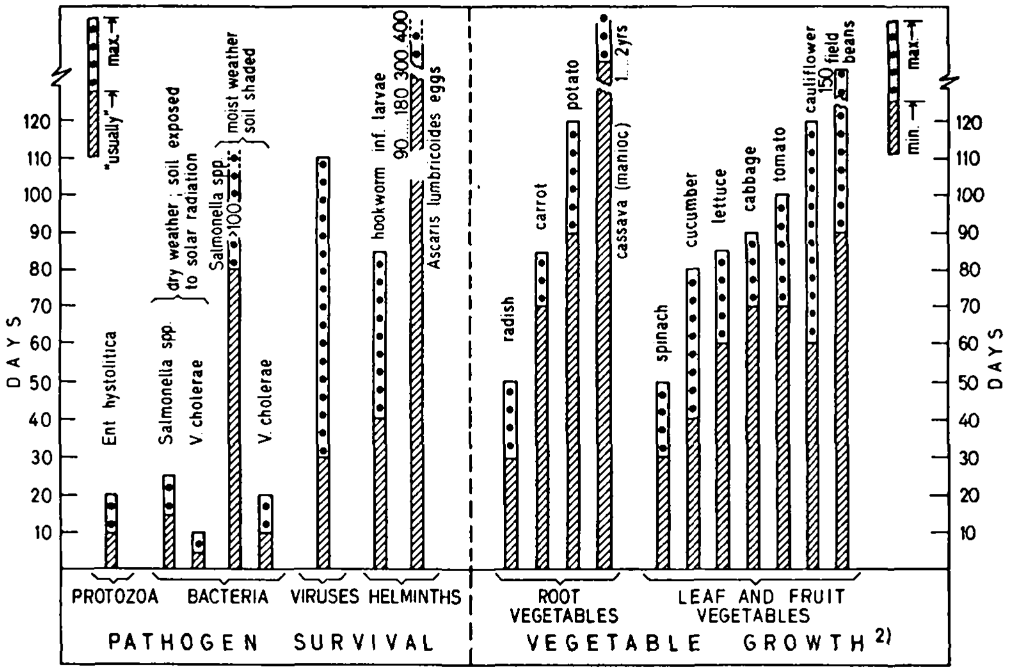
Table II.15

Environmental factor; process	Effect on pathogen die-off or survival
· Temperature	Accelerated die-off with increasing temperature; longer survival at low temperature (Fig. II.3)
· Moisture, humidity, desiccation	Generally longer survival in moist (soil) environment and under humid weather conditions: rapid die-off under conditions of desiccation
· Sunlight (ultra-violet radiation)	Exposure to sunlight enhances die-off
· Adsorption to particulate matter (in the soil or in ponds)	Important for virus and bacteria survival; scavenging effect; pathogen infectivity is longer in an adsorbed state
· pH	Neutral to alkaline pH tends to prolong bacteria survival; acid pH tends to prolong virus survival
· Biological activity	Antagonistic effects from bacteria or algae enhancing die-off; predation by protozoa

Most pathogens are inactivated within the first few hours or days after excretion. A few organisms will remain alive and infective for prolonged periods. This die-off pattern is valid for all nightsoil "environments", i.e. for latrine pits, soil and crops to which nightsoil has been applied, as well as for other excreta disposal sites or facilities. Thus, time allowed to elapse between nightsoil application to a field and cultivation or harvesting is decisive for the risk of pathogen transmission either through soil or crops.

The obvious question from the above is whether the excreted pathogens will die-off within the period during which the vegetable grows to maturity, or whether large numbers of pathogens will remain infective beyond the time of harvest.

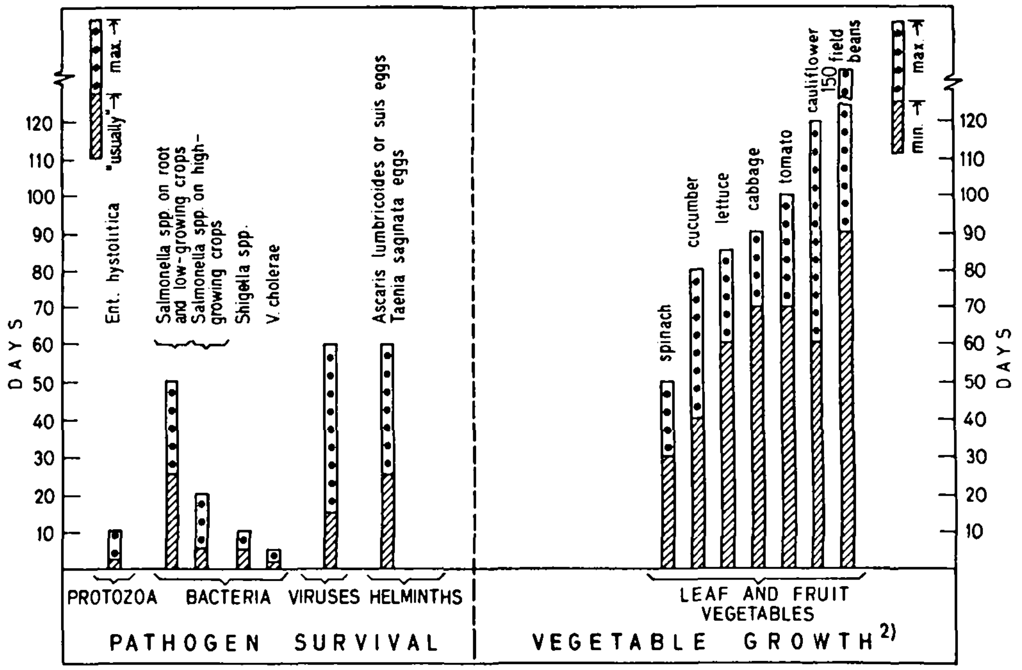
In Figs. II.15a and II.15b vegetable growth periods and excreted pathogen survival times in soil and on crops are presented in a comparative form. The data relate to warm tropical or subtropical climates.



1) Determined under widely varying conditions

2) Maturation period from transplanting or from sowing if not transplanted

Fig.II.15a Pathogen Survival in Soil vs. Vegetable Growth Periods in Warm Climates[1]



1) Determined under widely varying conditions

2) Maturation period from transplanting or from sowing if not transplanted

Fig.II.15b Pathogen Survival on Crops vs. Vegetable Growth Periods in Warm Climates[1]

Figure II.15a, which illustrates survival in soil, shows that *Ascaris lumbricoides* eggs have normal survival times tending to last longer than the period required by most vegetables to reach maturity. Excreta-fertilized crops are therefore potential transmitters of *Ascaris l.* eggs where ascariasis is endemic. Hookworm larvae, though normally dying off substantially faster than *Ascaris l.*, have survival periods in soil which are of the same order of magnitude as the growth period of vegetables such as radish, spinach and cucumber. They pose an occupational risk to those who perform weeding and thinning work in the nightsoil-fertilized fields. *Ascaris* eggs, in addition to being transmissible via crops, may also be carried into farmers' homes on the feet of those who work in the fields.

If environmental conditions favouring survival prevail (moisture, shading), a few *Salmonella spp.* survivors may be found in the soil throughout the growth period of several crops. Viruses too may outlast vegetable growth periods. Under harsh conditions, and for other bacteria as well as for the protozoal pathogens, however, survival periods in soil tend to be shorter than the growth periods of plants.

As a rule, pathogen survival periods on crops (illustrated in Fig. II.15b) tend to be substantially shorter (in the order of more than two times) than in the soil. This is not unexpected since pathogens are subjected to harsher environmental impacts (solar radiation, desiccation, temperature) on crops, notably high-growing crops, than in the soil. Most pathogens exhibit survival periods which are normally shorter than the growth periods of most vegetables. Exceptions have been observed with eggs of *Ascaris* or *Taenia saginata*, as well as with *Salmonella* which are attached to root and low-growing crops.

The risk of excreted pathogen transmission through nightsoil-fertilized crops is likely to be minimal if the nightsoil is applied to the fields prior to sowing or planting, i.e. during the tilling period, or at the latest shortly thereafter. Most pathogens which are either attached to the harvestable root, the leaves or the fruits growing above ground, will die off within the plant's growth period. Nightsoil fertilization during the growth period of the vegetables will replenish the reservoir of viable pathogens and enhance the risk of transmission through the harvested crops.

II.3.7 Patterns of Nightsoil Supply and Demand

Fertilization with nightsoil can be practised in many different ways. The actual practice depends on (1) the method and installations used for excreta collection, storage and transport, (2) the organisational unit which caters for nightsoil collection, use or disposal, (3) the amount of nightsoil collected in a given period of time versus land availability for nightsoil application, (4) the fertilizer requirements of the various crops and their demand for water or moisture which is often supplied in large quantities along with the faecal wastes, and (5) the farming pattern of the individual farmer or the farming community.

Thus, the pattern and timing of nightsoil application to fields may in one extreme instance consist in an individual farming family which removes nightsoil from its own latrine pit at biannual or annual intervals, then transports it to its fields in a simple hand-cart, in buckets hung on a yoke or as dried product packed in bags and applies it to a plot ready for tilling and cultivation. Another extreme instance consists in a town or municipality undertaking nightsoil and septic tank sludge collection by tanker trucks from which the liquid sludge is finally discharged by furrow or flood irrigation on fields of contracted farmers or institutional farms. The first situation may very well allow for carefully-timed nightsoil fertilization compatible with the traditional farming pattern of the individual farming family. Nightsoil quantities are likely to be rather small relative to the land available, which would allow for long intervals between nightsoil fertilization and harvesting. Nightsoil application during growth periods with consequent contamination of standing crops could therefore be avoided. Such a practice would allow for substantial die-off of remaining pathogens and therefore pose little risk of disease transmission via the soil or the crops.

The second situation requires rather large amounts of nightsoil and other sludges to be hauled and discharged daily onto fields in the town's outskirts. It can easily be imagined that both the method and timing of nightsoil application are often inappropriate, so that the risk of crop contamination becomes substantial. A possible shortage of crop area to be fertilized in relation to the sludge volume to be discharged and the fact that nightsoil producers, transporters and consumers belong to three different organisational entities are aggravating factors.

"Epidemiological soundness" of nightsoil use in agriculture, i.e. a fertilization pattern which allows for adequate reduction of excreted pathogen prior to crop harvesting, is obviously something which is difficult to achieve. A complex "web" of entities and influencing factors must be taken into consideration. These include patterns of cultivation, farming methods, excreta disposal methods, patterns and responsibilities of community organisation, nightsoil collection and disposal, dietary habits, and food hygiene. A very careful selection of long-term strategies and methods such as research into local habits of sanitation and agricultural patterns, as well as extension work in health, agriculture and institution building are required where existing practices of nightsoil use should be altered to reduce the risk of excreted pathogen transmission, or where the use of treated nightsoil is to be introduced and propagated.

II.3.8 Mulching or Ploughing ?

After having reviewed literature on excreted pathogen survival in soil, and on the role played by soil characteristics and environmental factors, one may wish to draw conclusions on how rapid pathogen inactivation can best be achieved in practice. The methods must be simple and available also to farmers who live on subsistence level and cannot afford extraneous inputs.

The best solution from a hygienic point of view would, of course consist in storing the nightsoil prior to use on the field for a minimum of several months, to make sure that essentially all pathogens, including helminth eggs, become inactivated. Introduction of latrines or other storage installations on a large scale is, in most cases, a lengthy process and will become an effective measure of risk minimization only on a long-term basis. Where fresh or insufficiently treated nightsoil is being used, the method of faecal waste application and **land preparation** by the farmer may have direct bearing on pathogen inactivation: faecal sludge may either be spread on the field and then left on the soil surface (mulching), or it can be mixed with the soil through ploughing.

Evaluation of data contained in the preceeding paragraphs aids in formulating particular effects of the two methods which may tend to either enhance pathogen inactivation or prolong survival (Table II.16). The wastes evaluated are mainly faecal wastes containing 10% or more[1] solids and which will therefore form a surface layer rather than percolate into the soil upon spreading on a field.

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[1] Contents of latrine pits and vaults were found to have widely varying solids contents (influenced primarily by the type and method of latrine construction, use and ablution method):

Location	% Solids mean	% Solids range	Reference
Gaborone, Botswana	47	11 - 87	Boesch and Schertenleib (1985)
Tanzania	54	26 - 74	Hawkins (1982)
Thailand	14	11 - 19	"
South Korea	5	4 - 6	" (citing others)
Taiwan	3	2 - 4	Hawkins (1982) (citing others)
Japan	3	2 - 3	" "

Table II.16 Suggested Effects of Mulching and Ploughing on Pathogen Survival on Nightsoil Fertilized Fields

	Factors leading to a likely tendency to	
	Enhance pathogen inactivation and/or prevent pathogen transmission	Prolong pathogen survival and/or facilitate pathogen transmission
(a) Mulching:	. exposure to sunlight (UV radiation) (on top layer only) . loss of moisture, accelerated desiccation (effective at or near surface, only)	. lumps of nightsoil protect pathogens from adverse effects . minimal exposure to soil microbial activities . inducing anaerobism in soil upon formation of "crust" on soil surface, possibly enhancing survival of pathogens contained in previously deposited nightsoil
(b) Ploughing:	. provides enhanced exposure of pathogens to soil microbial activities . formation of surface sludge layer (possibly leading to anaerobic conditions in the soil) can be prevented	. reduced exposure to UV radiation and desiccation . pathogens surviving in root zone may be transmitted via root crops . possibility of v. adsorption to clay particles providing protection against inactivation

If the combined effects of mulching versus ploughing on pathogen inactivation on or in soil are interpreted on the basis of Table II.16, a sensible option may consist in mixing the nightsoil with the upper 10-20 cm of the soil ("surface ploughing") after spreading and surface drying. The advantage of such a practice is that during surface drying accelerated pathogen die-off will take place due to the adverse effects of radiation and desiccation. Through ploughing, lumps of faecal waste will be disintegrated and thereby deprive pathogens from being protected against desiccation, radiation and soil microbial activities. Ploughing causes the faecal waste to become mixed with the top soil. The biochemical activities in the soil will cause further pathogen inactivation and build-up of additional humus.

Shallow ploughing of top soil with simple ploughs or hoes upon dressing with cattle manure is a widely practised method of preparing fields for cultivation. In contrast to deep ploughing and surface application of organic wastes, shallow ploughing is sound also from a soil treatment point of view. It enhances mineralization of the organic wastes through close contact with soil microorganisms in the upper soil layers where aerobic conditions prevail.

II.4 Survival in Fish

II.4.1 Basic Considerations

As outlined in Chpt. 2.2, the raising of fish in ponds fertilized with excreta or septage[1] is an old and widespread practice, particularly in Eastern Asia (Indonesia, China, Taiwan). More recently, i.e. in the past few decades, the growing of fish in wastewater stabilization ponds has also been practised increasingly, particularly in urban areas of tropical countries where the sewage is in many instances treated in waste stabilization ponds. Since sewage treatment plants must usually be sited in the urban fringe areas where land cost are often high due to the competition for land by housing and industrial developments or by intensive agriculture (e.g. vegetable farming), the use of maturation ponds for fish aquaculture will therefore improve the economic viability of pond systems which require large land areas.

In both practices, excreted human pathogens and the related infections can be transmitted during the handling and consumption of the fish. Fish might harbour pathogens on the surface of the scales, beneath the scales, in the gills, digestive tract, peritoneal fluid or in the muscles.

The fact that fish are grown in ponds where excreted pathogens are found, does not automatically result in the transmission of infection in each and every case. As described in Chpts. 3 and II.1, all excreted pathogens will eventually die. If hydraulic retention times in ponds are adequate, most pathogens will be reduced to relatively low levels, which will also reduce the potential risk of transmission. On the other hand, some pathogenic organisms might multiply in fish pond environments and thus pose a potential health risk. Furthermore, the infectious dose, i.e. the dose of organisms required to cause overt infection in humans, is an important factor determining transmission risks. Infections of low infectious doses are of greater concern than those of high infectious doses.

Transmission of pathogens can occur through persons handling and preparing the fish unless minimum standards of hygiene are adhered to. The risk of transmission through consumption is certainly minimal if fish is thorough-

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[1] Septage = septic tank contents

ly cooked. In Java, Indonesia, where people eat fish grown in excreta-fertilized ponds, this is a prevailing practice. On the other hand, if fish is eaten raw or undercooked like in parts of Taiwan, the risk of pathogen transmission increases accordingly. Fish preparation habits which form part of the local food culture is thus an important factor influencing transmission risks.

It can therefore be concluded that each type of aquacultural practice where fish is grown in excreta-fertilized or wastewater stabilization ponds should be considered individually in order to determine the most appropriate measures to minimize excess risks of infection. Such assessment studies must also encompass the diseases actually occurring in the area, the prevailing hygiene and fish preparation habits and the design and operation of existing or planned ponds.

II.4.2 Pathogen Transmission Routes Involving Fish

a. Helminths Requiring Fish as Intermediate Hosts

A number of human excreted helminthic pathogens whose transmission cycles are water-based, involve fish as intermediate hosts[1]. For all of these pathogens, the first development phase occurs in specific snails or copepods[2]. Fish acts as the second intermediate host. Fig.II.16 shows the life and infection cycles of helminthic pathogens with the described transmission paths.

Among the helminthic infections listed in Fig.II.16, clonorchiasis and the closely related opisthorchiasis are transmitted through fish grown in excreta-fertilized freshwater[3] ponds. They have significant public health importance in some areas in countries of Eastern Asia, notably China, Taiwan, Korea and Japan where fish is eaten raw by some part of the population.

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[1] There are helminthic pathogens (e.g. *Fasciola* and *Fasciolopsis*) with the same pattern of life cycle but which depend on aquatic plants (e.g. water chestnut, water cress, water bamboo) for secondary "hosts" onto which the free-swimming cercariae become attached and where they encyst. People become infected when they eat the vegetables raw or undercooked. These infections are not further discussed here because their survival and the protective measures against their transmission are the same as for fish-transmitted helminths.

[2] Copepod: any of a large subclass of usually minute freshwater and marine crustaceans (e.g. crabs)

[3] as opposed to brackish or salt-water

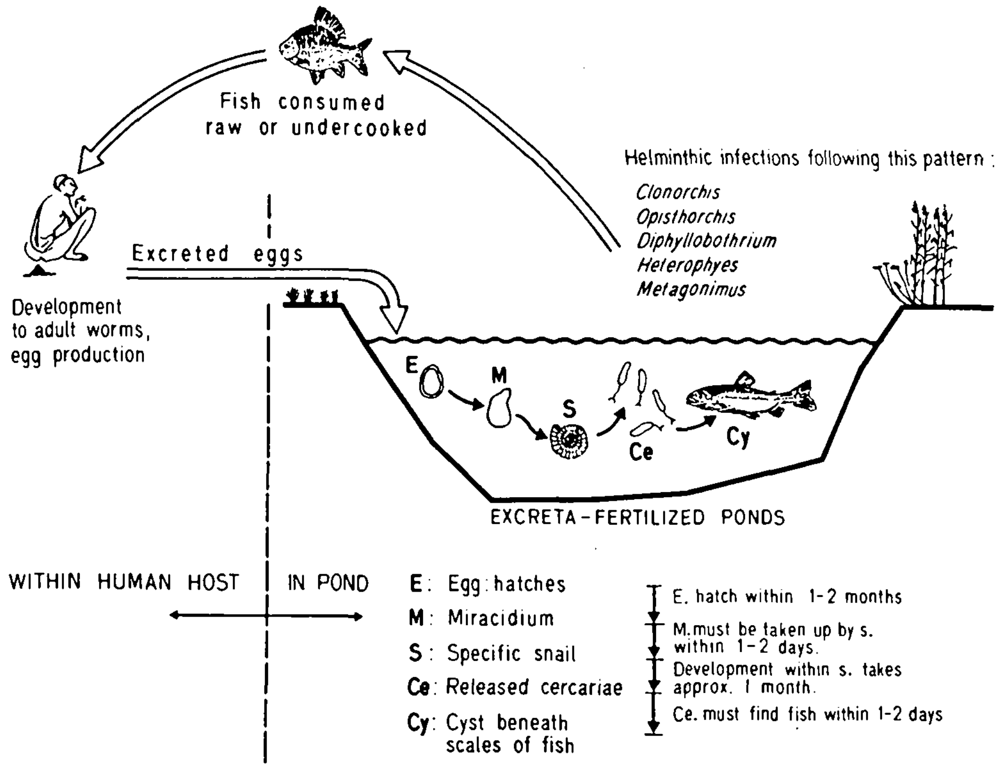

Fig. II 16
TRANSMISSION PATH OF HELMINTHIC INFECTIONS HAVING FISH AS AN INTERMEDIATE HOST

In the life cycle of *Paragonimus*, the second intermediate host - crab or crayfish - lives mainly in fast-flowing mountain streams with few species occurring in low-land rivers or paddy fields (Feachem et al. 1983). Consequently, it is of minor importance in the context of excreta-fertilized or wastewater-based aquaculture. Diphyllobothriasis, heterophiasis and metagonimiasis are also common in some areas, but they do not pose serious public health problems (Feachem et al. 1983).

The life cycle of *Clonorchis* and *Opisthorchis* is briefly described below. *Heterophyes, Metagonimus* and *Diphyllobothrium* have similar cycles. Excreted eggs reaching the water release a larva (miracidium) which must be ingested within 1-2 days by specific species of freshwater snails, each allowing further development of only one particular helminth larva. In the snail, the larva multiplies asexually into free-swimming cercarial larvae within about one month after which they are released from the snail. Within 1-2 days they have to find a fish as second intermediate host. They penetrate under the scales of the fish and form cysts in the connective tissues. Most fish can serve as secondary host for *Clonorchis* and *Opisthorchis*. When fish is eaten raw or undercooked, the cysts hatch and develop into worms in the human digestive tract. The female worms then produce eggs. The number of worms which develop depends on the number of cysts ingested. Up to 3000 cysts have been found in a single fish (Feachem et al. 1983).

b. Bacteria, Viruses and Protozoa

Fish can also be transmitters of bacteria, viruses and protozoa if they are grown in excreta-fertilized or wastewater treatment ponds. In contrast to helminth transmission, where fish are compulsory secondary hosts, bacteria, viruses and protozoa do not multiply in the fish, but are **passively** carried on the scales, in the gills, the intraperitoneal fluid, digestive tract or muscles of the fish. It is therefore reasonable to assume that bacteria, viruses and protozoa known or expected to be present in a fish pond are or can be expected to be found also in the fish themselves. The question often asked is whether a correlation exists between pathogen concentrations in the water and pathogen concentrations in the fish. Potential occurrence of human pathogens in the muscles is then of particular interest because the muscles are the edible parts of the fish (see also Chpt. II.4.3. below).

Theoretically, consumers of raw or undercooked fish can become infected with bacterial, viral or protozoal diseases whose pathogens are carried by the fish. There is, so far, no conclusive epidemiological evidence of such infections having actually occurred or occurring (Blum and Feachem 1983). This is in itself, however, not proof of zero excess risk from excreta-fertilized or wastewater-based fish production. Respective consumer risk studies would be very difficult to carry out. Investigations made to date have focused exclusively on the monitoring of indicator organisms and pathogens in the pond water and fish organs. Thereby, only **potential** or theoretical, as opposed to actual, risks of infection can be measured. However, in the absence of epidemiological studies, it is impossible to define the critical level of bacterial and viral pathogens or indicators in the pond or fish beyond which actual excess risks would exist.

II.4.3 Survival

a. Helminths

The helminths discussed in this chapter follow basically the same survival pattern as Category V pathogens in Fig.3.2: During the latent period[1], a certain number of eggs, larvae and cercariae lose their viability and die off. The cysts harboured by the fish survive as long as the fish is alive, i.e. until it is caught for consumption. Although the overall loss of infective load during the latency period might be substantial, it is epidemiologically of limited effect: A person needs to ingest but a few infective cysts to become a regular excretor of thousands of eggs as each worm, which develops out of one cyst, regularly produces hundreds to thousands of eggs per day.

The single most effective measure to control fish-transmitted excreted helminth infections would therefore consist in treating the nightsoil or septage prior to discharge into the fish ponds. Storage at ambient temperature in warm climates for a minimum of **one week** in areas where *Clonorchis, Opisthorchis* or similar trematodes are endemic is a simple and effective method. Where *Fasciolopsis* is endemic, excreta should be stored for about **3-4 weeks** for the eggs to lose infectivity.

So far little has been investigated on the occurrence of the discussed helminth eggs in wastewater and on their survival in wastewater treatment systems. From the behaviour of other helminth eggs in stabilization ponds, one may assume complete egg removal upon storage in a series of two ponds with a total nominal retention time of $\geqslant$ 6-10 days (see Chpt. II.2.6). Fish production should therefore be restricted to 3rd and 4th stage (maturation) ponds.

Little or no transmission occurs where fish is always eaten cooked. However, it is not wise to tell people to cook the fish if they are used to eat it uncooked or undercooked, as dietary habits are deeply rooted and can hardly be changed overnight or independently of other cultural entities.

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[1] The period between the excretion of eggs and the development of infective cysts; in the order of 1 1/2 months for *Clonorchis* and *Opisthorchis* (Feachem et al. 1983).

b. Bacteria and Viruses

Detailed information from the reviewed literature on excreted bacteria and virus survival in fish is contained in the Annex. The findings can be summarized as follows:

- In most investigations, fish were grown in ponds receiving wastewater treated to variable degrees. In one experiment (Nupen 1983), control tests were made with fish grown in tap water and, in another study, grown in freshwater (Phelps 1984; Cloete Toerien, Pieterse 1984).

- In the majority of experiments, high concentrations of indicator and pathogenic bacteria were found in the **digestive tract** (DT) and in the **intraperitoneal fluid** of the wastewater-grown fish.

- Pathogen invasion of the spleen, kidney and liver was observed in one study (Buras et al. 1982).

- In some experiments, concentrations in the DT at the end of the fish growing period were higher than in the ponds (Buras et al. 1982; Hejkal et al. 1983; Noé M. et al. 1984).

- Recovery from fish **skin** is reported in two references (Hejkal et al. 1983; Cloete et al. 1984): Buras et al. (1982) did not detect any *Salmonella*, bacteriophages or viruses on fish surfaces.

- Most studies focused on the invasion of the fish muscles by indicator organisms or pathogens. In some experiments, muscle tissues became invaded by indicator bacteria, pathogenic bacteria, bacteriophages or viruses but only if concentrations of these organisms in the pond or or in the neighbouring organs were very high (e.g. pond water bacteriophage concentrations of $7 \cdot 10^4$/ml and *Salmonella montevideo* concentrations of $5 \cdot 10^5$/ml in experiments of Buras et al. 1982). At normal levels of excreted microorganisms in the ponds, muscle tissues were only rarely invaded by faecal indicators or pathogens. The **threshold** level of excreted organisms in water, above which organs are invaded is higher for muscles than for other fish organs. Invasion of muscles appears to occur mainly from the digestive tract.

- Apart from the above threshold relationship, there is no conclusive correlation between the levels of faecal indicators or pathogens in the ponds and the respective levels in the fish organs. Buras et al. (1982) established a correlation on the basis of standard plate counts (SPC). However, SPC is a sum parameter and measures all heterotrophic bacteria of faecal as well as non-faecal origin. It is therefore not very representative as pathogen indicator.

- In the studies which contain a comparison between wastewater and freshwater-grown fish (Phelps 1984; Cloete, Toerien, Pieterse 1984), the counts of faecal indicators and *Salmonella* in the organs of fish grown in wastewater were not distinctly different from the levels found in freshwater-grown fish.

- Results from one investigation show that fish grown for 4-5 months in continuous-flow ponds receiving diluted activated sludge effluent, exhibited higher concentrations of excreted bacteria at the end of the growth period than at the beginning (Buras et al. 1982). In another study where *S. typhimurium* were inoculated into the ponds at the beginning of the experimental period, it took 2-4 weeks for the organisms to become undetectable in fish. Disappearance of *S.* from the pond water, from the fish epithelium and the inner organs was correlated (Baker et al. 1983). Similarly, *S. typhimurium* was isolated in the inner organs of freshwater-grown fish 15 and not 30 days after inoculation of viable organisms (Baker and Smitherman 1983).

- Contradicting effects were observed regarding **depuration**, i.e. the placing of the fish in clean water. Buras et al. (1982) still found bacteria in muscle tissues after eight weeks of depuration. In the investigations made by Noé M. et al. (1984), depuration for 80 hours and one week yielded only modest reductions of faecal indicator organisms in the digestive tract (1-2 orders of magnitude at levels of 10^5 - 10^7/100 ml of DT content).

- In one reference (Buras et al. 1982), differences in the recovery of indicator organisms from different species of fish were reported: recoveries in the organs and muscle of tilapia were much lower than in carp and silver carp at the end of the growth period.

c. Fish Survival: Summary and Recommendations

With respect to potential risks of bacteria and virus transmission through fish and concerning risk minimization, the following can be concluded:

1. Apparently, muscle of fish grown in excreta-fertilized or wastewater ponds might become invaded by pathogens if respective concentrations are very high in the pond water. On the basis of the literature reviewed, tentative threshold levels might be set as follows:

· FC (faecal coliforms):	10^4/100 ml
· *Salmonella*:	10^5/100 ml

   Other fish organs might become invaded at lower pond water concentrations.

2. The potential for invasion of muscle tissue appears to increase with the duration of exposure of the fish to contaminated water. This is probably due to the concentrating effect in the digestive tract.

3. Pathogen concentrations might be particularly high in the digestive tract and the intraperitoneal fluid of fish.

4. Therefore, even if the fish muscles do not become invaded by pathogens, there are two other potential transmission routes for bacteria and virus through the persons who handle and gut the fish:

   - The flesh can become cross-contaminated during gutting due to high levels of pathogens in the digestive tract and in the intraperitoneal fluid. A potential risk of infection therefore exists if the fish is eaten raw or undercooked.

   - The person who guts the fish might become a potential transmitter via routes others than fish (e.g. person-to-person contact, contamination of dishes and food) if personal and domestic hygiene is poor.

As regards **recommendations**, there is no single and instant measure or intervention by which one could achieve prevention of potential transmission of excreted bacteria and viruses through fish. Excreta-fertilization of aquaculture ponds and the consumption of fish uncooked form part of local culture. In many instances, aquaculture is practised in small schemes on a family or community basis and is therefore not amenable to change by authoritative decree.

As a technical measure, nightsoil might be stored e.g. in alternating-pit or vault latrines prior to its use in ponds to allow bacteria and virus die-off along with partial die-off of helminth eggs. Water supply improvement, particularly in terms of available quantity, may in the long run contribute to improving hygiene and thereby help lowering the potential risk of disease transmission through persons handling and gutting the fish.

Before a respective project or programme is introduced in a particular area, enough information must be available about the actual **excess** risk of infection by a particular disease caused by the aquacultural practice. The public health relevance of both, the existing excreta use practice and the envisaged control measures should be carefully assessed.

II.5 Overall Conclusions and Recommendations

II.5.1 Conclusions

Survival of *Ascaris* eggs and *Salmonella* spp. in soil tends to be longer than the growth period of most vegetable plants. Survival periods of viruses and hookworm eggs may also occasionally be as long as the growth period of certain vegetable crops (Table II.15a). On crops, the survival period of excreted pathogens tends to be shorter than the growth period of vegetables.

Thus, there is a potential - in contrast to an actual - transmission risk of helminthic, viral or *Salmonella* infections due to the fertilization of soils and vegetables with faecal wastes. Such risks may arise in particular either through handling and consumption of root crops or during work on "infected" soils. The potential risk of transmission via harvested vegetables is minimized if the faecal wastes are applied before or at the beginning of the plant growing period. If, in contrast, faecal wastes are repeatedly applied to the standing crops, there is increased likelihood of surviving pathogens being present in soil and on crops at the time of harvest.

Transmission risks in agriculture are mainly due to the use of raw faecal wastes. Based on epidemiological evidence, their untreated use can lead to the transmission of *Ascaris*, *Trichuris*, hookworm, and *Schistosoma* infections during field work. Similarly, transmission of trematode infections (e.g. *Chlonorchis and Opisthorchis sinensis*) exist through fish grown in excreta-fertilized ponds and when eaten raw or only partially cooked.

Helminthic infections thus play a major role in excreta utilization. In contrast to viral, bacterial and protozoal infections, the severity of helminthic infections is a matter of load, i.e. of the number of eggs or larvae entering the body through repeated intake and development into adult worms. By reducing helminth eggs and larvae in the outside-host environment, reduced intakes and therefore less severe states of morbidity will be achieved.

Pathogen inactivation is achieved by a suitable combination of time and temperature. Thus, extended storage and/or raising the temperature of the faecal wastes above ambient through specific treatment prior to their use on fields or in ponds will lead to low helminth loads. This, in turn, will reduce the egg or larvae loads by which soils, crops or ponds become initially contaminated. In stored or treated excreta, viral, bacterial and protozoal pathogen levels will also be lower (possibly by a few orders of magnitude) than in the raw excreta. This reduces the potential infection risks, particularly as regards pathogens with medium to high infective doses (e.g. *Salmonella* spp., *V. Cholerae*).

II.5.2 Recommendations

a. About Recommending

Excreta handling and utilization practices are entities of human life which are rooted in cultural and religious traditions. They are influenced by beliefs, social rules or, where utilization is practised, by agricultural and aquacultural patterns and economic considerations. Disease transmission risks depend to variable degrees on these factors. Furthermore, the transmission risks of excreted infections are determined by personal hygiene, food preparation and dietary habits. Infection risks are higher among people who eat uncooked excreta-fertilized vegetables or fish than among those who consume their food cooked.

In view of the multitude of determinants associated with excreta management and related infection risks, it would be presumptuous to make recommendations as to what would constitute the most suitable solution, both technically and non-technically. Each setting requires a specific approach and calls for its own individual solution. In general, where people's or a society's preferences, needs, habits and beliefs are involved, changes may come into effect in an evolutionary manner only. To achieve long-term effects, working in close contact with the "project" population becomes an absolute necessity since it makes people's and project planners' objectives compatible with each other. The aspects of human waste utilization and disease transmission risks must be seen and dealt with within the framework of culture, socioeconomic aspects and people's vital needs and interests. The following suggestions must be viewed in this light.

b. *Recommendations*

Where utilization of nightsoil is considered to be introduced, the possibility of using the nightsoil untreated should obviously be discouraged (1) in order to avoid the introduction of potential pathogen transmission routes previously unknown in the area and (2) for aesthetic reasons. Such a rule may be easily accepted by societies which have no tradition of excreta utilization since they will abhor handling and use of fresh human faecal wastes.

Where raw nightsoil is currently used as fertilizer, efforts should be made to introduce excreta storage prior to utilization on fields or in ponds[1]. The required length of "safe" storage periods cannot at this stage be specified with absolute certainty. Related epidemiological evidence is lacking, i.e. the specific information on how much pathogen reduction is required to significantly reduce transmission risks in existing utilization practice or to avoid creation of excess infection risks where excreta use is considered to be introduced. It is assumed that there is a trade-off between minimum levels of treatment required from an epidemiological point of view and the cost of providing storage or treatment. Stipulating 100% pathogen removal is unfeasible in most instances and probably unnecessary as well. Current knowledge of pathogen survival in faecal wastes indicates that storage periods at ambient temperatures in warm climates should be observed as shown in Table II.17 .

Table II.17 Tentative Recommendations for Excreta Storage Periods in Warm Climates

Storage period	Hygienic quality achieved
≥ 2 days	Inactivation of *Clonorchis* and *Opisthorchis* eggs
≥ 1 month	Complete inactivation of viruses, bacteria and protozoa (except, possibly, *Salmonella* on moist, shaded soil); inactivation of schistosome eggs
≥ 4 months	Inactivation of nematode (roundworm) eggs, e.g. hookworm and whipworm (*Trichuris*); survival of a certain percentage (10-30% ?) of *Ascaris* eggs
≥ 12 months	Complete inactivation of *Ascaris* eggs

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[1] Where latrines are purposely placed over ponds this is obviously not a viable measure.

Storage of nightsoil best takes place in family-owned latrines. Alternatively, depending on local culture and social organization, storage can be provided in community-owned and operated tanks which are centrally located. Dry-disposal alternating-pit or vault latrines, and pour-flush latrines with twin leaching pits are suitable choices for latrine systems where excreta utilization is practiced.

Treatment of nightsoil in wastewater stabilization ponds may constitute a feasible solution in areas where large volumes of nightsoil or other faecal wastes are regularly collected, and where utilization of nightsoil is not sought or possible otherwise (II.2.6). Methods of thermophilic composting of mixtures of nightsoil and other organic residues such as manure or plant wastes should be tried or promoted if prospects of cultural acceptability and economic feasibility are good. Properly composted nightsoil carries very little if any load of viable pathogens (Table II.4).

Potential risks of pathogen transmission through crops fertilized with raw or insufficiently treated nightsoil can be reduced by allowing long periods of time to elapse between nightsoil application and the working in the field or harvesting. Thus, from the point of view of pathogen die-off, an optimum practice would consist in restricting nightsoil application to fallow fields. Thereby, the risks of leaf and fruit crops becoming contaminated and acting as potential pathogen transmitters are minimized. Use of fresh or insufficiently stored nightsoil constitutes, however, an occupational risk for the persons handling the faecal material and working in the freshly fertilized fields.

In contrast to this, the use of nightsoil which has been stored for a certain period can be less restrictive to the extent indicated by the values in Table II.17. Thereby, due merit must be given to the specific circumstances; i.e., "risk management" or relaxation of restrictions depends on the effective period of nightsoil storage, the type of crop fertilized, the application method and frequency, dietary habits, the level of hygiene, and the disease pattern in the area under consideration.

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Fish.

Reference	Purpose/type of study	Aquaculture system	Species studied	Stocking density	Duration of exposure	Indicators and pathogens tested	Results
Buras, Hepher, Sandbank (1982)	Finding bacterial threshold conc. in ponds over which bacteria would be found in muscle and other organs of fish; laboratory (inoculation and immersion) and field ponds experiments	Inoculation	Tilapia, Carp		Dissections 1/2-48 hrs after inoculation	E. coli B., S. montev., Streptococcus faecalis, Polio I virus	Threshold concentrations (no./fish) above which organism appeared in muscle: E.coli B: $\sim 10^6$; S.montev.: 10^4-~10^5; S.faecalis: 10^5-~10^4; T : $\sim 10^4$; Polio I virus:.inoculation with 2×10^4/fish caused recovery in Tilapia of 2×10^2 PFU/g and of 90 PFU/g in Carp; highest recoveries in intra-peritoneal fluid. Generally, recovery of organisms in fish was higher after inoculation than after immersion.
		Lab. immersion in 1:100-diluted "effluent water"	Tilapia, Carp	?	1-4 weeks	T_2 Bacteriophages; Salmonella montevideo	Phage appeared in muscle of fish (2 per gram) after 9 days if concentration in water reached 7×10^4/ml; highest recoveries (5.5×10^5/ml) in digestive tract content (DTC). S. montevideo appeared in muscle when conc. in water was 5×10^5/ml; lower threshold for DTC, spleen, kidney and liver.
		400 m^2-ponds receiving diluted activated sludge effluent	Tilapia, Carp (Cyprinus carpio), Silver Carp	?	4-5 months	Coliforms, Faecal coliforms, Salmonella, E. coli bacteriophages, human enteric viruses	Most fish organs exhibit higher concentrations of bacteria at end of growing season than at beginning; according to the data presented, there was no conclusive evidence of correlation between bacteriological quality of the pond water and presence and concentrations of pathogenic bacteria in fish organs.From all fish organs tested, the muscles showed lowest bacterial recoveries. Bacterial concentrations ranged highest in DTC, but did not change significantly by exposing the fish to the pond water. At SPC (std. plate counts) of 10^3-10^5/ml (= 10^5-10^7/100 ml) of pond water, muscle recoveries at harvest ranged from 20-90 SPC/g. Viruses were once isolated from Carp kidneys. No Salmonella, Bacteriophages or viruses were found on fish surfaces. Bacteria were detected in Tilapia muscle still after eight weeks of depuration in clean water. High bacterial concentrations in DTC and intraperitoneal fluid are considered as potential risks for the transmission of pathogens through fish handlers and those cleaning the fish before cooking.

Reference	Purpose/type of study	Aquaculture system	Fish			Indicators and pathogens tested	Results
			Species studied	Stocking density	Duration of exposure		
Phelps (1984?)[1]	Testing suitability of tertiary wastewater ponds for aquaculture regarding fish yield and pathogen contents in fish	Ponds receiving secondarily treated wastewater[2]	Silver carp	10,000/ha	5 months	*Salmonella*, *faecal coliforms* (FC), feacal streptococci (FS)	Fish cultured in the ponds contained FC, FS and *Salmonella*. However, counts were similar as in non-wastewater cultured fish after the fish had been processed. *Salmonella* was confined to the intestine, none was found in mucous or flesh. Bacterial flora in fish had little relationship with bacterial contents in pond water.
Nupen (1983)	Assessment of potential health risks associated with fish reared in sewage maturation ponds	Ponds receiving settled sewage[2]	*Oreochromis mosambicus*	?	6 months (?)	Faecal coliforms (FC), salmonellas	No FC or salmonellas were isolated from sterily prepared fillets or from fish blood.
		Ponds receiving algae stabilisation pond effluent after algae flotation[2]	*Oreochromis mosambicus*	?	6 months (?)	FC, salmonellas	No FC or salmonellas isolated from fillets.
		Control pond receiving tap water[2]	*Oreochromis mosambicus*	?	6 months (?)	FC, salmonellas	No FC or salmonellas isolated from fillets
		"Sewage ponds" (receiving supplementary algae pellet feed)[2]	*Oreochromis mosambicus*			FC, salmonellas, *Clostridium perfringens*	Fish fillets contained on average 17-26 FC/100 g. No salmonellas were found in 23 fish samples. In a separate survey of catfish processing *Salmonellae* were found in 49 % of the processed fish flesh products; improved processing (hygiene ?) reduced this rate to 0 %.

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[1] Summary of a project executed on behalf of US - E.P.A.

[2] Concentrations of indicator organisms or pathogens in ponds not reported

Fish

Reference	Purpose/type of study	Aquaculture system	Species studied	Stocking density	Duration of exposure	Indicators and pathogens tested	Results
Baker, Smitherman, McCaskey (1983)	Quantification of S. typhimurium survival in wastewater ponds, and determination of longevity of Salmonella in fish	Field experiments with pools fertilized with 35 kg (dry weight) of fresh swine manure/ha, day; inoculation of S. typhimurium at start of experimental period	Tilapia aurea	20,500/ha	1 month approx.	Salmonella typhimurium	S. typhimurium concentration in pools was 10^5 /100 ml upon inoculation and decreased to 10/100 ml in 2 days. S. was not detectable in pool water 32 days after inoculation. Average water temperature was 29° C (!) Except for day 8 post S. inoculation into pools, S. was not isolated from Tilapia flesh during the 32 days experimental period. After 16 days, only 50 % of the viscera samples were positive for S.. 32 days post-inoculation S. could not be isolated neither from flesh, viscera nor from epithelium. Disappearance of S. from pond water, and from epithelium and viscera was correlated. The authors conclude that a period of 16-32 days is required for an inoculum of 10^5 S. typhimurium cells/100 ml of pool water to become undetectable in fish organs and pond water. Consumption of wastewater-cultured fish may not represent a health risk as S. does not invade the fish flesh. S. transmission risks are, however, associated with fish cleaning and processing.
Baker and Smitherman (1983)	To determine the immune response of a fish to a human pathogenic bacterium	(Inoculation/injection of pathogen to fish grown in freshwater	Tilapia aurea		15 and 30 days response periods	Salmonella typhimurium	S. typhimurium was isolated from viscera of the fish 15 days but not 30 days post-inoculation of viable organisms. The antibody titer in these fish increased 8-fold in 15 days, and was still elevated 5 x over normal levels after 30 days when no more viable S. were detected. Fish injected heat-killed S. developed a 6-fold increase of antibody titer in 15 days and a 9-fold increase in 30 days. Thus, elevated antibody titers may result from presence of viable bacterial cells or non-infective antigenic material, or may indicate a titer decline after clearance of antigenic material.

Reference	Purpose/type of study	Aquaculture system	Species studied	Fish		Indicators and pathogens tested	Result
				Stocking density	Duration of exposure		
Hejkal, Gerba, Henderson, Freeze (1983)	To determine efficiency of wastewater aquaculture in removing pathogens, and to determine their distribution in water, sediment and fish	Six ponds (total surface area 10.2 ha) in series receiving settled sewage; total detention time = 72 days; ponds 3-6 stocked with fish; pond temperatures ranging from 9-30° C	Silver carp, bighead carp	S.carp: 13'000-5'200 (ponds 3 - 6)	19 - 24 months	Faecal coliforms (FC), faecal streptococci (FS), Salmonella spp., enteric viruses	Average microbial levels in wastewater were: Influent: FC 10^4/100 ml, FS > 10^5/100 ml, Salmonella spp. 0.4 and 2.3 MPN/100 ml in 2/4 samples, enteric viruses 7.5-20 PFU/l; In pond 6: FC > 10^1/100 ml, FS > 10^3/100 ml, S. not detectable, ent. viruses not detectable. Average FC and FS levels in fish digestive tract (DT) were higher than in ponds, and FC and FS levels on fish skin were lower than in gut. FC and FS varied from 10^2 - 10^4/100 g each in DT and skin, concentrations in fish from pond 6 being only insignificantly lower than from pond 4. Fish dissected by "normal" fillet procedure exhibited sporadically high FC and FS levels ($\leqslant$ 22,000 MPN FS/100 g) in the muscle tissue (contamination from skin?). By sterile procedure, 3/9 muscle tissue samples had low levels of FC and FS (< 25 MPN/100 g from a fish with 1.4 x 10^5 MPN FS/100 g in DT). There was some correlation between FC and FS in water vs. FC and FS in fish skin and DT. Correlations of FC and FS in water or sediment vs. FC and FS in fish flesh were very weak. Except for 2/4 influent and one pond-2-samples no Salmonella spp. were detected from ponds, sediment or fish. No viruses were detected in water from ponds 3 - 6 nor in any of 45 fish samples The authors conclude that muscle tissue is relatively safe from bacterial penetration, even at rel. high levels in the DT. However, there is risk of muscle tissue becoming contaminated during fish processing. If virus levels in pond water were higher (i.e. also more representative of a "normal" sewage) the fish might have accumulated more viruses. Altogether the public health riks may not be greater than from fish harvested from waters receiving sewage treatment plant effluents, the authors argue.

				Fish			
Reference	Purpose/type of study	Aquaculture system	Species studied	Stocking density	Duration of exposure	Indicators and pathogens tested	Results
Cloete, Toerien, Pieterse (1984)	To compare potential health risks of waste-grown fish with risks from naturally-grown fish; evaluation of a full-scale plant	Cattle feedlot waste treatment system consisting of an aerated high-rate algal pond followed by a fish pond; freshwater impoundment as control system	Silver carp, Grass carp, Common carp	?	6 and 12 months	Coliforms, presumptive *Salmonellae*, presumptive *Clostridia* (="total anaerobic bacteria")[1]	Levels of mircroorganisms in fish pond were: tot.anaerobes 10^7-10^8/100 ml, coliforms 10^4-10^6/100 ml, pres. *Salmonellae* 8 x 10^3 - 5 x 10^4/100 ml. *Salmonellae* were found in all fish, including those which grew in the freshwater impoundment (control). Highest bacterial numbers occurred in the intestines (10^2-10^9/intestine). At the fish skin levels ranged from < 50 - > 10^5/cm² of skin. Concentrations in blood were < 10^2/ml and in tissue < 10^2/g. Levels in organs of naturally grown fish were not distinctly different than in pond-grown fish. The relative levels of anaerobes, coliforms and *Salmonellae* in the pond water showed some correlation with relative levels on skin, in gills and intestines of the fish. Results indicate that the feeding pattern of fish - bottom - vs. filter-feeding - may play a role in the bacterial content of fish, as aerobic bacteria were higher in bottom-feeders (common carp) than in filter-feeders (silver carp). The authors conclude that their results confirm previous researchers' findings which suggest that muscle tissues of waste-grown fish remain sterile though fish skin, gills and intestines may contain large bacterial populations. They postulate that the microbial quality of naturally-grown fish be used to assess the health risk of waste-grown fish.

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[1] The limit for detectability in bacterial analysis was 10^2/sample

Fish

Reference	Purpose/type of study	Aquaculture system	Species studied	Stocking density	Duration of exposure	Indicators and pathogens tested	Results
Feachem, Garelick, Slade (1981)	Literature review	Fish and shellfish growing in marine and estuarine waters which receive human wastes (experimental set-ups and assessment of natural systems)	Molluscs (e.g. oysters, clams) and crustacea (e.g. crab, lobsters, shrimps)		Varied with study	Enteroviruses	Results from studies reveal that shellfish, being filter feeders, accumulate viruses in their digestive system. In molluscs virus concentrations > 100-fold higher than in the surrounding water are reached. Similar phenomena are observed in crustacea. Human enteroviruses do not multiply in shellfish. Most documented viral disease outbreaks associated with shellfish are viral gastroenteritis transmissions. For enterovirus isolation, techniques are more advanced than for hepatitis A and rotavirus. In one experiment oysters within 2 days accumulated 10^4 polioviruses/g of meat in seawater containing 1.9×10^7 poliov./l. 30 viruses/100 g of flesh were found in clams growing in seawater containing as few as 2 viruses/l. Depuration of viruses from shell fish is a mechanical process. It takes place at the rate of 2-4 orders of magnitude within a few days if the shellfish is at a high feeding activity i.e. at warm temperature, optimal salinity and in flowing water. Even after cooking a residual risk remains that viable viruses may be found in some of the cooked shellfish.

Fish

Reference	Purpose/type of study	Aquaculture system	Species studied	Stocking density	Duration of exposure	Indicators and pathogens tested	Results
Noé M., N. et al. (1984)	To evaluate potential public health risks from growing fish in maturation ponds of the waste stabilization pond system at San Juan de Miraflores, Lima, Peru; field/full scale experiments as part of UNDP Integrated Resource Recovery (Health Effects Studies) Project GLO/80/004	Two parallel series of ponds (Series 1: Primary = facultative + sec. + tert. + quat., and Series 2: p. + s. + t. + quat. + quintenary) receiving raw municipal sewage from South-Lima. Theoretical hydr. retention times in primary + secondary + tertiary ponds = 6 + 9 + 8 and 11 + 10 + 17 days, respectively; true retention time = 60 % of theoretical ret. time; quat. and quint. ponds batch-operated	Tilapia, Big Belly Carp, Mirror Carp, freshwater prawn	?	6-7 months	Total and faecal coliforms (MPN), std. plate counts (SPC), Salmonella in water and fish of t., quat. + quint. ponds; protozoal cysts + helminth eggs in fish and sediments; fish organs tested: DTC (digestive tract content), PF (peritoneal fluid), muscle	Fish grown in tertiary ponds: . water: 10^4 FC/100 ml (geom. mean) 10^3-$10^{4.5}$SPC/ml (range) . DTC : 10^3-10^8/100 ml (range) 10^5 /100 ml (g. m.) . PF : 0-10^2 SPC/ml (range) . muscle: 0 FC/100 ml 0-$10^{2.6}$ SPC/ml (range) Fish grown in quintenary ponds: . water: 10^2 FC/100 ml (g.m.) 10^2-10^4 SPC/ml (range) . DTC : 10^3-10^6/100 ml (range) 10^5 /100 ml (g.m.) . PF : $10^{2.5}$ SPC/ml (mean) . muscle: 0 FC/100 ml $10^{2.5}$ SPC/ml (mean) Depuration for 80 hours and one week, respectively, did not yield conclusive results regarding reduction of indicator bacteria.