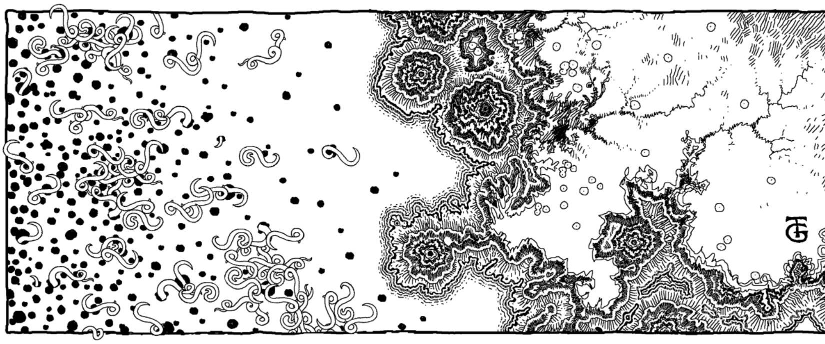


Chapter Thirteen

Worms and Disease

Human excrement has a bad reputation — unfairly so, because it's not the excrement that's bad; it's what we do with it that makes it bad. When we discard it as waste and pollution, we create health hazards. When we feed it to microbes and return it to the soil, we create health benefits. Although the former situation is well known, most people don't know anything about the latter.

In the late seventies when I first informed a friend that I intended to compost humanure and grow food with it, the response was predictable: "Oh my God, you can't do that!" she exclaimed.

"Why not?"

"Worms and disease!"

A young British couple was visiting me one summer after I had been composting humanure for about six years. One evening, as dinner was being prepared, the couple suddenly understood their horrible situation: The food they were about to eat was recycled shit. When this fact dawned on them, it seemed to set off an instinctive alarm, possibly inherited directly from Queen Victoria. "We don't want to eat shit!" they informed me, rather distressed (that's an exact quote), as if in preparing dinner I had simply set a turd on a plate in front of them with a knife and fork.

Fecaphobia is alive and well and running rampant. One common

misconception is that fecal material, when composted, remains fecal material. It does not. Humanure comes from the earth, and through the miraculous process of composting, is converted back into earth. When the composting process is finished, the end product is compost, not poop, and it is valuable for growing food. When you eat a piece of cherry pie and it's processed through your digestive system, is what comes out the other end cherry pie? Nope, it's poop. The cherry pie is gone. When microbes eat poop, they convert it to something else too. In a compost pile, the end product is compost. The poop is gone.

Humanure is not any more dangerous than the body from which it is excreted. The danger lies in what we do with the excrement, not in the material itself. A glass jar is not dangerous either, but if we smash it on the kitchen floor and walk on it with bare feet, we will be harmed. If we use a glass jar improperly and dangerously, we will suffer for it, but that's no reason to condemn glass jars. When we discard humanure as a waste material and pollute our soil and water supplies with it, we are using it improperly, and that is where the danger lies. When we constructively recycle humanure by composting, it enriches our soil, and, like a glass jar, actually makes life easier for us.

Not all cultures think of human excrement in a negative way. For example, swear words meaning excrement did not seem to exist in the Chinese language at one time. The Tokyo bureau chief for the New York Times explains why: *I realized why people [in China] did not use* *words for excrement in a negative way. Traditionally, there was nothing more valuable to a peasant than [humanure].*[1] Calling someone a "humanure head" just doesn't sound like an insult. "Humanure for brains" doesn't work, either. If you told someone he was "full of humanure," he'd probably agree with you. "Shit," on the other hand, is a substance that is widely denounced and has a long history of excoriation in the Western world. Our ancestors failed to responsibly recycle the substance and thereby caused monumental public health problems. Consequently, the attitude that humanure itself is terribly dangerous has been embraced and promulgated up to the present day.

For example, an American book on the topic of recycling "human waste" begins with the following disclaimer: "Recycling human waste can be extremely dangerous to your health, the health of your community and the health of the soil. Because of the current limits to general public knowledge, [we] strongly discourage the recycling of human waste on an individual or community basis at this time and cannot assume responsibility for the results that occur from practicing any of the methods described in this publication." The author adds, "Before experimenting, obtain permission from your local health authority since the health risks are great." The author then elaborates on a human "waste" composting methodology that includes segregating urine from feces, collecting the manure in thirty-gallon plastic containers, and using straw rather than sawdust as a cover material in the toilet.[2] All three of these procedures are ones I would discourage based on my forty plus years of humanure composting experience — there is no need to go to the bother of segregating urine; a thirty-gallon container is too big and heavy to be able to handle easily; and sawmill sawdust does, in fact, work beautifully in a compost toilet, much better than straw. These issues will be discussed in the next chapter.

I had to ask myself why an author writing a book on recycling humanure would "strongly discourage the recycling of human waste," which seems counterproductive, to say the least. If I didn't already know that recycling humanure was easy, simple, and beneficial, I might be totally petrified at the thought of attempting such an "extremely dangerous" undertaking after reading that book. And the last thing anyone wants to do is get the local health authorities involved. If there is anyone who knows little about composting, it's probably the local health authority, who likely receives no such training.

The "bio-dynamic" agricultural movement, founded by Dr. Rudolf Steiner, provides another example of fecaphobia. Dr. Steiner has quite some following around the world, and many of his teachings are followed almost religiously by his disciples. The Austrian scientist and spiritual leader had his own opinions about the recycling of humanure, based on intuition rather than on experience or science. He insisted that humanure must only be used to fertilize soil to grow plants to feed animals other than humans. The manure from those animals can then be used to fertilize soil to grow plants for human consumption. According to Steiner, humans must never get any closer to a direct human nutrient cycle than that. Otherwise, they will suffer "brain damage and nervous disorders." Steiner further warned against using "lavatory fluid," including human urine, which "should never be used as a fertilizer, no matter how well-processed or aged it is."[3] Steiner, quite frankly, was ill-informed, incorrect, and fecaphobic, and that fecaphobia has no doubt rubbed off on some of his followers.

History is rife with humanure misconceptions. At one time, doctors insisted that human excrement should be an important and necessary part of one's personal environment. They argued that, "fatal illness may result from not allowing a certain amount of filth to remain in [street] gutters to attract those putrescent particles of disease which are ever present in the air." At that time, toilet contents were simply dumped in the street. Doctors believed that the germs in the air would be drawn to the filth in the street and therefore away from the people. This line of reasoning so influenced the population that many homeowners attached their outhouses to their kitchens to keep their food germ-free and wholesome.[4] The results were just the opposite — flies made frequent trips between the toilet contents and the food table.

By the early 1900s the US government was condemning the use of humanure for agricultural purposes, warning of dire consequences, including death, to those who would dare to do otherwise. A 1928 US Department of Agriculture bulletin made the risks crystal clear:

> *Any spittoon, slop pail, sink drain, urinal, privy, cesspool, sewage tank, or sewage distribution field is a potential danger. A bit of spit, urine, or feces the size of a pin head may contain many hundred germs, all invisible to the naked eye and each one capable of producing disease. These discharges should be kept away from the food and drink of [humans] and animals. From specific germs that may be carried in sewage at any time, there may result typhoid fever, tuberculosis, cholera, dysentery, diarrhea, and other dangerous ailments, and it is probable that other maladies may be traced to human waste. From certain animal parasites or their eggs that may be carried in sewage there may result intestinal worms, of which the more common are the hookworm, roundworm, whipworm, eelworm, tapeworm, and seat worm.*
>
> *Disease germs are carried by many agencies and unsuspectingly received by devious routes into the human body. Infection may come from the swirling dust of the railway roadbed, from contact with transitory or chronic carriers of disease, from green truck [vegetables] grown in gardens fertilized with night soil or sewage, from food prepared or touched by unclean hands or visited by flies or vermin, from milk handled by sick or careless dairymen, from milk cans or utensils washed with contaminated water, or from cisterns, wells, springs, reservoirs, irrigation ditches, brooks, or lakes receiving the surface wash or the underground drainage from sewage-polluted soil.*

The bulletin continues, “In September and October 1899, 63 cases of typhoid fever, resulting in five deaths, occurred at the Northampton (Mass.) insane hospital. This epidemic was conclusively traced to celery, which was eaten freely in August and was grown and banked in a plot that had been fertilized in the late winter or early spring with the solid residue and scrapings from a sewage filter bed situated on the hospital grounds.”

And to drive home the point that human excrement is highly dangerous, the bulletin adds, "Probably no epidemic in American history better illustrates the dire results that may follow one thoughtless act than the outbreak of typhoid fever at Plymouth, Pa., in 1885. In January and February of that year the night discharges of one typhoid fever patient were thrown out upon the snow near his home. These, carried by spring thaws into the public water supply, caused an epidemic running from April to September. In a total population of about 8,000, 1,104 persons were attacked by the disease and 114 died." They could have thrown those night discharges into a compost pile where microbes would have eliminated the threat of disease, but they didn't know about this option at that time, and, ironically, neither do most government agencies today, nearly a century and a half later.

The US government bulletin insisted that the use of human excrement as fertilizer was "dangerous" and "disgusting." It warned that "under no circumstances should such wastes be used on land devoted to celery, lettuce, radishes, cucumbers, cabbages, tomatoes, melons, or other vegetables, berries, or low-growing fruits that are eaten raw. Disease germs or particles of soil containing such germs may adhere to the skins of vegetables or fruits and infect the eater." The bulletin added, "Never use [human] waste to fertilize or irrigate vegetable gardens." The fear of human excrement was so severe it was advised that the contents of collection toilets be burned, boiled, or chemically disinfected, then buried in a trench.[5]

This degree of fecaphobia, fostered and spread by government authorities and others who knew of no constructive alternatives to waste disposal, still maintains a firm grip on the Western psyche. It may take a long time to eliminate. A more constructive attitude is displayed by scientists with a broader knowledge of the subject of recycling humanure for agricultural purposes. They realize that the benefits of proper humanure *recycling* "far outweigh any disadvantages from the health point of view."[6]

It's already been mentioned that entire civilizations have recycled humanure for thousands of years. That should provide a fairly convincing testimony about the usefulness of humanure as an agricultural resource. You may have heard of the "Healthy Hunzas," a people in what is now a part of Pakistan who reside among the Himalayan peaks, and routinely live to be 120 years old. The Hunzas gained fame in the United States during the 1960s health food era when several books were written about the fantastic longevity of this ancient people. Their extraordinary health has been attributed to the quality of their overall lifestyle, including the quality of the natural food they eat and the soil it's grown on. Few people, however, realize that the Hunzas also recycled their humanure and used it to grow their food. They're said to have virtually no disease, no cancer, no heart or intestinal trouble, and they regularly live to be over a hundred years old while "singing, dancing, and making love all the way to the grave."

According to one account, "In their manuring, the Hunzakuts return everything they can to the soil: all vegetable parts and pieces that will not serve as food for humans or beast, including such fallen leaves as the cattle will not eat, mixed with their own seasoned excrement, plus dung and urine from their barns. Like their Chinese neighbors, the Hunzakuts save their own manure in special underground vats, clear of any contaminable streams, there to be seasoned for a good six months. Everything that once had life is given new to life through loving hands."[7]

Sir Albert Howard wrote in 1947, "The Hunzas are described as far surpassing in health and strength the inhabitants of most other countries; a Hunza can walk across the mountains to Gilgit sixty miles away, transact his business, and return forthwith without feeling unduly fatigued." Sir Howard maintains that this is illustrative of the vital connection between a sound agriculture and good health, insisting that the Hunzas have evolved a system of farming that is perfect. He adds, "To provide the essential humus, every kind of waste [sic], vegetable, animal and human, is mixed and decayed together by the cultivators and incorporated into the soil."[8]

McCarrison, former medical officer of the Gilgit Agency, described the health of the Hunzas: "During the period of my association with these people I never saw a case of asthenic dyspepsia, of gastric or duodenal ulcer, of appendicitis, of mucous colitis, of cancer . . . . Among these people the abdomen over-sensitive to nerve impressions, to fatigue, anxiety, or cold was unknown. Indeed, their buoyant abdominal health has, since my return to the West, provided a remarkable contrast with the dyspeptic and colonic lamentations of our highly civilized communities."[9]

Sir Howard adds, "The remarkable health of these people is one of the consequences of their agriculture, in which the law of return is scrupulously obeyed. All their vegetable, animal and human wastes [sic] are carefully returned to the soil of the irrigated terraces which produce the grain, fruit, and vegetables which feed them."[10]

The Hunzas recycled their organic material, incorrectly referred to as "waste" by Sir Howard, thereby enhancing their personal health and the health of their community. The US Department of Agriculture was unaware of the natural process of composting in 1928 when they described the recycling of humanure as "dangerous and disgusting." No doubt the USDA would have been scratching their heads about the Hunzas, who had for centuries safely and constructively engaged in such recycling.

Pathogens

Much of the information in this section is adapted from *Appropriate Technology for Water Supply and Sanitation*, by Feachem et al., World Bank, 1980. This comprehensive work cites 394 references and was carried out as part of the World Bank's research project on appropriate technology for water supply and sanitation.[11]

Clearly, even the primitive composting of humanure for agricultural purposes does not necessarily pose a threat to human health, as was made evident by the Hunzas. Yet fecal *contamination* of the environment certainly *can* pose a threat. Feces can harbor a host of disease organisms that can contaminate the environment to infect innocent people when infected human excrement is discarded as a waste material and pollutant. In fact, even a healthy person apparently free of disease can pass potentially dangerous pathogens through his or her feces, simply by being a carrier. The World Health Organization estimates that 80 percent of all diseases are related to inadequate sanitation and polluted water, and that half of the world's hospital beds are occupied by patients who suffer from water-related diseases.[12] Understanding how to compost humanure would certainly seem like a worthwhile undertaking worldwide.

Table 1: POTENTIAL PATHOGENS IN URINE

Healthy urine on its way out of the human body may contain up to 1,000 bacteria, of several types, per milliliter. More than 100,000 bacteria of a single type per milliliter signals a urinary tract infection. Infected individuals will pass pathogens in the urine that may include:

Bacteria	**Disease**
Salmonella typhi	Typhoid
Salmonella paratyphi	Paratyphoid fever
Leptospira	Leptospirosis
Yersinia	Yersiniosis
Escherichia coli	Diarrhea

Worms	**Disease**
Schistosoma haematobium	schistosomiasis

Source: Feachem et al., 1980; and Franceys, et al. 1992; and Lewis, Ricki. (1992). *FDA Consumer*, September 1992. p. 41.

Table 2: MINIMAL INFECTIVE DOSES For Some Pathogens and Parasites

Pathogen	**Minimal Infective Dose**
Ascaris	1-10 eggs
Cryptosporidium	10 cysts
Entamoeba coli	10 cysts
Escherichia coli	1,000,000-100,000,000
Giardia lamblia	10-100 cysts
Hepatitis A virus	1-10 PFU
Salmonella spp.	10,000-10,000,000
Shigella spp.	10-100
Streptococcus fecalis	10,000,000,000
Vibrio cholerae	1,000

Pathogens have various degrees of *virulence*, which is their potential for causing disease in humans. The minimal infective dose is the number of organisms needed to establish infection.

Source: Bitton, Gabriel. (1994). Wastewater Microbiology. New York: Wiley-Liss, Inc., p. 77-78. and *Biocycle*, September 1998, p. 62.

The following information is not meant to be alarming. It's included for the sake of thoroughness, and to illustrate the need to compost humanure, rather than to discard it as waste or to use it raw for agricultural purposes. When the composting process is side-stepped, and pathogenic waste is dispersed into the environment, various diseases and worms can infect the population living in the contaminated area. This fact has been widely documented.

Consider the following quote: *"The use of night soil [raw human fecal material and urine] as fertilizer is not without its health hazards. Hepatitis B is prevalent in Dacaiyuan [China], as it is in the rest of China. Some effort is being made to chemically treat [humanure] or at least to mix it with other ingredients before it is applied to the fields. But chemicals are expensive, and old ways die hard. Night soil is one reason why urban Chinese are so scrupulous about peeling fruit, and why raw vegetables are not part of the diet. Negative features aside, one has only to look at satellite photos of the green belt that surrounds China's cities to understand the value of night soil."*[13]

On the other hand, "worms and disease" are not spread by properly prepared compost, nor by healthy people. There is no reason to believe that the manure of a human being is dangerous unless allowed to accumulate in the environment, pollute water with intestinal bacteria, or breed flies and rats, all of which are the results of negligence. The breath one exhales can also be the carrier of dangerous pathogens, as can one's saliva and sputum. The issue is confused by the notion that if something is *potentially* dangerous, then it is *always* dangerous, which is not true. It is generally not understood that the composting of humanure converts it into a sanitized agricultural resource. No other system of fecal material recycling or disposal can so effectively achieve this without the use of dangerous chemical poisons or a high level of technology and energy consumption.

Even urine, usually considered sterile, can contain disease germs (Table 1). Urine, like humanure, is valuable for its soil nutrients. It is estimated that one person's annual urine output contains enough soil nutrients to grow grain to feed that person for a year.[14] Therefore, it is just as important to recycle urine as it is to recycle humanure, and com-

Table 3: POTENTIAL VIRAL PATHOGENS IN FECES

Virus	Disease	Can Carrier Be Symptomless?
Adenoviruses	varies	yes
Coxsackievirus	varies	yes
Echoviruses	varies	yes
Hepatitis A	Infectious hepatitis	yes
Polioviruses	Poliomyelitis	yes
Reoviruses	varies	yes
Rotaviruses	Diarrhea	yes

Rotaviruses may be responsible for the majority of infant diarrheas. Hepatitis A causes infectious hepatitis, often without symptoms, especially in children. Coxsackievirus infection can lead to meningitis, fevers, respiratory diseases, paralysis, and myocarditis. Echovirus infection can cause simple fever, meningitis, diarrhea, or respiratory illness. Most poliovirus infections don't give rise to any clinical illness, although sometimes infection causes a mild, influenza-like illness which may lead to virus-meningitis, paralytic poliomyelitis, permanent disability, or death. It's estimated that almost everyone in developing countries becomes infected with poliovirus, and that one out of every thousand poliovirus infections leads to paralytic poliomyelitis.

Source: Feachem et al., 1980

Table 4:
POTENTIAL BACTERIAL PATHOGENS IN FECES

Bacteria	Disease	Symptomless Carrier?
Campylobacter	Diarrhea	yes
E. coli	Diarrhea	yes
Salmonella typhi	Typhoid fever	yes
Salmonella paratyphi	Paratyphoid fever	yes
Other *Salmonellae*	Food poisoning	yes
Shigella	Dysentery	yes
Vibrio cholerae	Cholera	yes
Other *Vibrios*	Diarrhea	yes
Yersinia	Yersiniosis	yes

Source: Feachem et al., 1980

posting provides an excellent means for doing so.

The pathogens that can exist in humanure can be divided into four general categories: viruses, bacteria, protozoa, and worms (helminths).

Viruses

First discovered in the 1890s by a Russian scientist, viruses are among the simplest and smallest biological entities. Many scientists don't even consider them to be organisms. They are much smaller and simpler than bacteria and the simplest form may consist only of an RNA molecule. By definition, a virus is an entity that contains the information necessary for its own replication but does not possess the physical elements for such replication — they have the software but not the hardware. To reproduce, therefore, viruses rely on the hardware of the infected host cell, which is re-programmed by the virus to reproduce viral nucleic acid. Viruses cannot reproduce outside their cellular host.[15]

There are more than 140 types of viruses worldwide that can be passed through human feces, including polioviruses, coxsackieviruses (causing meningitis and myocarditis), echoviruses (causing meningitis and enteritis), reovirus (causing enteritis), adenovirus (causing respiratory illness), infectious hepatitis (causing jaundice), and others (Table 3). During periods of infection, one hundred million to one trillion viruses can be excreted with each gram of fecal material.[16]

Bacteria

Of the pathogenic bacteria, the genus *Salmonella* is significant because it contains species causing typhoid fever, paratyphoid, and gastrointestinal disturbances. Another genus of bacteria, *Shigella*, causes dysentery. Myobacteria cause tuberculosis (Table 4 lists some of the bacteria). However, according to Gotaas, pathogenic bacteria in compost "are unable to survive temperatures of [131°-140°F] 55° to 60°C for longer than 30 minutes to one hour."[17]

Protozoa

The pathogenic protozoa include *Entamoeba histolytica* (causing amoebic dysentery), and members of the Hartmanella-Naegleria group (causing meningo-encephalitis). The cyst stage in the life cycle of protozoa is the primary means of dissemination as the amoeba die quickly once outside the human body. Cysts must be kept moist to remain viable for any extended period.[18] See Table 5.

Parasitic Worms

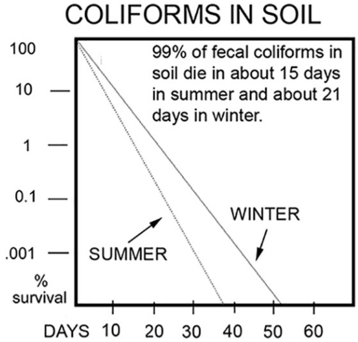
A number of parasitic worms pass their eggs in feces, including hookworms, roundworms (*Ascaris*), and whipworms (Table 6). Various researchers have reported 59 to 80 worm eggs in sampled liters of

Table 5:
POTENTIAL PROTOZOAN PATHOGENS IN FECES

Protozoa	Disease	Symptomless Carrier?
Balantidium coli	Diarrhea	yes
Entamoeba histolytica	Dysentery, colonic ulceration, liver abscess	yes
Giardia lamblia	Diarrhea	yes

Source: Feachem et al., 1980

SURVIVAL TIMES OF FECAL COLIFORMS IN SOIL



Source: Recycling Treated Municipal Wastewater and Sludge Through Forest and Cropland. Edited by William E. Sopper and Louis T. Kardos. 1973. p. 82. Based on the work of Van Donsel, et al., 1967.

Table 7:
AVERAGE DENSITY OF FECAL COLIFORMS EXCRETED IN 24 HOURS
(millions/100 ml)

Human	13.0
Duck	33.0
Sheep	16.0
Pig	3.3
Chicken	1.3
Cow	0.23
Turkey	0.29

Source: Agricultural Waste Management Field Manual. United States Soil Conservation Service. August 1975. P.16-12.

Table 6:
POTENTIAL WORM PATHOGENS IN FECES

Note: hum. = human; intes.=intestinal; Chin.=Chinese; Vietn=Vietnam

Common Name	Pathogen	Transmission	Distribution
1. Hookworm	*Ancylostoma doudenale* *Necator americanus*	Hum.-soil-human.	Warm, wet climates
2. ----------	*Heterophyes heterophyes*	Dog/cat-snail-fish-hum.	Mid. East/S. Eur./Asia
3. ----------	*Gastrodiscoides*	Pig -snail- aquatic vegetation-hum.	India/Bangla./Vietn./ Philippines
4. Giant intes. fluke	*Fasciolopsis buski*	Human/pig-snail- aquatic vegetation-human	S.E. Asia/China
5. Sheep liver fluke	*Fasciola hepatica*	Sheep -snail - aquatic vegetation -human	Worldwide
6. Pinworm	*Enterobius vermicularis*	Human-human	Worldwide
7. Fish tapeworm	*Diphyllobothrium latum*	Human/animal-copepod - fish-human	Mainly temperate
8. Cat liver fluke	*Opisthorchis felineus* *O. viverrini*	Animal-aquatic snail- fish-human	USSR/Thailand
9. Chin. liver fluke	*Chlonorchis sinensi*	Animal/human-snail-fish- human	S.E. Asia
10. Roundworm	*Ascaris lumbricoides*	Human-soil-human	Worldwide
11. Dwarf tapeworm	*Hymenolepsis* spp.	Human/rodent-human	Worldwide
12. ----------	*Metagonimus yokogawai*	Dog/cat-snail-fish-hum.	Jap./Kor./Chi./ Taiw./Siberia
13. Lung fluke	*Paragonimus westermani*	Animal/human-snail - crab/crayfish-human	S.E. Asia/Africa/ S. America
14. Schistosome, bil.	*S. haematobium*	Human-snail-human	Africa, M. East, India
----------	*Schistosoma. mansoni*	Human-snail-human	Afr., Arabia, Ltn. Amer.
----------	*S. japonicum*	Animal/hum.-snail-hum.	S.E. Asia
15. Threadworm	*Strongyloides stercoralis*	Hum.-hum. (dog-hum.?)	Warm, wet climates
16. Beef tapeworm	*Taenia saginata*	Human-cow-human	Worldwide
Pork tapeworm	*T. solium*	Human-pig-human or human-human	Worldwide
17. Whipworm	*Trichuris trichiura*	Human-soil-human	Worldwide

Source: Feachem et al., 1980

sewage. This suggests that billions of pathogenic worm eggs may reach a wastewater treatment plant daily in some parts of the world. These eggs tend to be resistant to environmental conditions because of their thick outer covering,[19] and they are extremely resistant to the sludge digestion process common in wastewater treatment plants. Three months' exposure to anaerobic sludge digestion processes appears to have little effect on the viability of Ascaris eggs; after six months, 10 percent of the eggs may still be viable. Even after a year in sludge, some viable eggs may be found.[20] In 1949 an epidemic of roundworm infestation in Germany was directly traced to the use of raw sewage to fertilize gardens. The sewage contained 540 Ascaris eggs per 100 ml; over 90 percent of the population became infected.[21]

If there are 59 to 80 worm eggs in a liter sample of sewage, then we could reasonably estimate that there are 70 eggs per liter, or 280 eggs per gallon to get a rough average. That means approximately 280 pathogenic worm eggs per gallon of wastewater could enter wastewater treatment plants in infected localities. A plant serving a population of eight thousand people and collecting about 1.5 million gallons of wastewater daily could have 420 million worm eggs entering the plant each day and settling into the sludge. In a year's time, over 153 billion parasitic eggs can pass through a small-town wastewater facility. Let's look at the worst-case scenario: All the eggs survive in the sludge because they're resistant to the environmental conditions at the plant. During the year, thirty tractor-trailer loads of sludge are hauled out of a facility of that size. Each truckload of sludge could theoretically contain over 5 billion pathogenic worm eggs, en route to maybe a farmer's field, but probably to a landfill.

As already mentioned, roundworms co-evolved over millennia as parasites of the human species by taking advantage of the long-standing human habit of defecating on soil. Since roundworms live in the human intestines but require a period in the soil for their development, their species is perpetuated by our excretory habits. If we humans never allowed our excrement to come in contact with soil, and if we instead composted it, the parasitic species known as *Ascaris lumbricoides*, a parasite that has plagued us for perhaps hundreds of thousands of years, would soon become extinct. Otherwise, we will continue to be outsmarted by the parasitic worms that rely on our ignorance and carelessness for their own survival.

Indicator Pathogens

Indicator pathogens are those whose detection in soil or water serves as evidence that fecal contamination exists.

The astute reader will have noticed that many of the pathogenic worms listed in Table 6 are not found in the United States. Of those that are, the *Ascaris lumbricoides* (roundworm) is the most persistent and can serve as an indicator for the presence of pathogenic helminths in the environment.

A single female roundworm may lay as many as twenty-seven million eggs in her lifetime.[22] These eggs are protected by an outer covering that is resistant to chemicals and enables the eggs to remain viable in soil for long periods of time. The egg shell is made of five separate layers: an outer and inner membrane, with three tough layers in between. The outer membrane may become partially hardened by hostile environmental influences.[23] The reported viability of roundworm eggs (*Ascaris* ova) in soil ranges from a couple of weeks under sunny, sandy conditions[24] to two and a half years,[25] four years,[26] five and a half years,[27] or even ten years[28] in soil, depending on the source of the information. Consequently, the eggs of the roundworm seem to be the best indicator for determining if parasitic worm pathogens are present in compost. In China, current standards for the agricultural reuse of humanure require an *Ascaris* mortality of greater than 95 percent.

Ascaris eggs develop at temperatures between 60° and 95°F (15.5°C and 35°C), but the eggs disintegrate at temperatures above 100.40° F (38°C).[29] The temperatures generated during thermophilic composting can easily exceed levels necessary to destroy roundworm eggs.

Although it's extremely unlikely that cured compost would be contaminated with *Ascaris* eggs, you can have a stool analysis done at a local hospital to check yourself. Such an analysis is relatively inexpensive. I subjected myself to three stool examinations over a period of twelve years as part of the research for earlier editions of this book. I had been composting humanure for fourteen years at the time of the first testing, and twenty-six years at the time of the third. I had used all of the compost in my food gardens. Hundreds of other people had also used my toilet over the years, potentially contaminating it with *Ascaris*. Yet, all stool examinations were completely negative. As of this writing, four decades have passed since I began gardening with compost made from humanure. During those years, I have raised several healthy children. Our toilets have been used by countless people, including many strangers from around the world. All of the toilet material has been composted and the compost used for gardening purposes.

There are indicators other than roundworm eggs that can be used to determine fecal contamination of water, soil, or compost. Indicator *bacteria* include fecal coliforms, which reproduce in the intestinal systems of warm-blooded animals (Table 7). If one wants to test a water supply for fecal contamination, then one looks for fecal coliforms, usually *Escherichia coli*, which is one of the most abundant intestinal bacteria in humans; over two hundred specific types exist. Although some of them can cause disease, most are harmless.[30] The absence of *E. coli* in water indicates that the water is free from fecal contamination.

Water tests often determine the level of *total coliforms* in the water, reported as the number of coliforms per 100 ml. Total coliform counts give a general indication of the sanitary condition of a water supply. Total coliforms include bacteria that are found in the soil, or in water influenced by surface water, and in human or animal excrements. Most coliform bacteria do not cause disease, but some rare strains of *E. coli*, particularly the strain 0157:H7, can cause serious illness. However, *E. coli* 0157:H7 rarely contaminates drinking water supplies.[31]

Fecal coliforms do not multiply outside the intestines of warm-blooded animals, therefore their presence in water is unlikely unless there is fecal pollution. Since fecal coliforms survive for a shorter time in natural waters than the coliform group as a whole, their presence indicates relatively recent pollution. In domestic sewage, the fecal coliform count is usually 90 percent or more of the total coliform count, but in natural streams, fecal coliforms may only contribute 10 to 30 percent of the total coliform density. Almost all natural waters have a presence of fecal coliforms, since all warm-blooded animals excrete them. Most states in the US limit the fecal coliform concentration allowable in waters used for water sports to two hundred fecal coliforms per 100 ml. Contrast this to the polluted Yamuna river in India, which contains twenty-two *million* fecal coliforms per 100 ml.[32] You don't want to be swimming in *that* water!

Bacterial analyses of drinking water supplies are routinely provided for a small fee by agricultural supply firms, water treatment companies, or private labs.

Persistence of Pathogens in Soil, Crops, Manure, and Sludge

In Soil

Survival times of pathogens in soil are affected by soil moisture, pH, type of soil, temperature, sunlight, and organic matter. Although fecal coliforms can survive for several years under optimum conditions, a 99 percent reduction is likely within twenty-five days in warm climates. Salmonella bacteria may survive for a year in rich, moist, organic soil, although fifty days would be a more typical survival time. Viruses can survive up to three months in warm weather and up to six months in cold. Protozoan cysts are unlikely to survive for more than ten days. Roundworm eggs can survive for several years.

The viruses, bacteria, protozoa, and worms that can be excreted in humanure all have limited survival times outside of the human body. Tables 8 through 12 reveal their survival times in soil.

Table 8:
SURVIVAL OF ENTEROVIRUSES IN SOIL

Viruses - These parasites, which are smaller than bacteria, can only reproduce inside the animal or plant they parasitize. However, some can survive for long periods outside of their host.

Enteroviruses - Enteroviruses are those that reproduce in the intestinal tract. They have been found to survive in soil for periods ranging between 15 and 170 days. The following chart shows the survival times of enteroviruses in various types of soil and soil conditions.

Soil Type	pH	% Moisture	Temp. (C)	Days of Survival (less than)
Sterile, sandy	7.5	10-20%	3-10	130-170
		10-20%	18-23	90-110
	5.0	10-20%	3-10	110-150
		10-20%	18-23	40-90
Non-sterile, sandy	7.5	10-20%	3-10	110-170
		10-20%	18-23	40-110
	5.0	10-20%	3-10	90-150
		10-20%	18-23	25-60
Sterile, loamy	7.5	10-20%	3-10	70-150
		10-20%	18-23	70-110
	5.0	10-20%	3-10	90-150
		10-20%	18-23	25-60
Non-sterile, loamy	7.5	10-20%	3-10	110-150
		10-20%	18-23	70-110
	5.0	10-20%	10	90-130
		10-20%	18-23	25-60
Non-sterile, sandy	5	air dried	18-23	15-25

Source: Feachem et al., 1980

Table 9:
SURVIVAL OF E. HISTOLYTICA PROTOZOA IN SOIL

Protozoa	**Soil**	**Moisture**	**Temp (C)**	**Survival**
E. histolytica	loam/sand	Damp	28-34	8-10 days
E. histolytica	soil	Moist	?	42-72 hrs.
E. histolytica	soil	Dry	?	18-42 hrs.

Source: Feachem et al., 1980

Table 10: SURVIVAL TIMES OF SOME BACTERIA IN SOIL

Bacteria	Soil	Moisture	Temp.(C)	Survival
Streptococci	Loam	?	?	9-11 weeks
Streptococci	Sandy loam	?	?	5-6 weeks
S. typhi	various soils	?	22	2 days-400 days
Bovine tubercule bacilli	soil & dung	?	?	less than 178 days
Leptospires	varied	varied	summer	12 hrs-15 days

Source: Feachem et al., 1980

Table 11: SURVIVAL OF POLIOVIRUS IN SOIL

Soil Type	Virus	Moisture	Temp.(C)	Days Survival
Sand dunes	Poliovirus	dry	?	Less than 77
Sand dunes	Poliovirus	moist	?	Less than 91
Loamy fine sand	Poliovirus I	moist	4	90% red. in 84
Loamy fine sand	Poliovirus I	moist	20	99.999% reduction in 84
Soil irrigated w/ effluent, pH=8.5	Polioviruses 1, 2 & 3	9-20%	12-33	Less than 8
Sludge or effluent irrigated soil	Poliovirus I	180 mm total rain	-14-27	96-123 after sludge applied
			-14-27	89-96 after effluent applied
		190 mm total rain	15-33	less than 11 after sludge or effluent applied

Source: Feachem et al., 1980

Table 12:
SURVIVAL TIMES OF SOME PATHOGEN WORMS

Soil	Moisture	Temp. (C)	Survival
HOOKWORM LARVAE			
Sand	?	room temp.	< 4 months
Soil	?	open shade, Sumatra	< 6 months
Soil	Moist	Dense shade	9-11 weeks
		Mod. shade	6-7.5 weeks
		Sunlight	5-10 days
Soil	Water covered	varied	10-43 days
Soil	Moist	0	< 1 week
		16	14-17.5 weeks
		27	9-11 weeks
		35	< 3 weeks
		40	< 1 week
HOOKWORM OVA (EGGS)			
Heated soil with night soil	water covered	15-27	9% after 2wks
Unheated soil with night soil	water covered	15-27	3% after 2wks
ROUNDWORM OVA			
Sandy, shaded		25-36	31% dead after 54 d.
Sandy, sun		24-38	99% dead after 15 d.
Loam, shade		25-36	3.5% dead after 21 d.
Loam, sun		24-38	4% dead after 21 d.
Clay, shade		25-36	2% dead after 21 d.
Clay, sun		24-38	12% dead after 21 d.
Humus, shade		25-36	1.5% dead after 22 d.
Clay, shade		22-35	more than 90 d.
Sandy, shade		22-35	less than 90 d.
Sandy, sun		22-35	less than 90 d.
Soil irrigated w/sewage		?	less than 2.5 yrs.
Soil		?	2 years

Source: Feachem et al., 1980; d.=days; <=less than

Table 13:
PARASITIC WORM EGG DEATH

Eggs	Temp.(C)	Survival
Schistosome	53.5	1 minute
Hookworm	55.0	1 minute
Roundworm	-30.0	24 hours
Roundworm	0.0	4 years
Roundworm	55.0	10 minutes
Roundworm	60.0	5 seconds

Source: Compost, Fertilizer, and Biogas Production from Human and Farm Wastes in the People's Republic of China, (1978), M. G. McGarry and J. Stainforth, editors, International Development Research Center, Ottawa, Canada. p. 43.

Bacteria and viruses are unlikely to penetrate undamaged vegetable skins. Furthermore, pathogens are unlikely to be taken up in the roots of plants and transported to other portions of the plant,[33] although some research indicates that pathogenic *E. coli* can enter lettuce plants through the root systems and travel throughout the edible portions of the plant, when the plants are fertilized using contaminated manure and irrigation water.[34]

Some pathogens can survive on the surfaces of vegetables, especially root vegetables, although sunshine and low air humidity will promote their death. Viruses can survive up to two months on crops but usually live less than one month. Indicator bacteria may persist several months, but usually less than one month. Protozoan cysts usually survive less than two days, and worm eggs usually last less than one month. In studies of the survival of Ascaris eggs on lettuce and tomatoes during a hot, dry summer, all eggs degenerated enough after twenty-seven to thirty-five days to be incapable of infection.[35] Of course, who wants to wait thirty-five days to eat lettuce and tomatoes?

Lettuce and radishes in Ohio sprayed with sewage containing Poliovirus I had a 99 percent reduction in pathogens after six days; 100 percent after thirty-six days. Radishes grown outdoors in soil containing fresh typhoid-contaminated feces four days after planting showed a pathogen survival period of less than twenty-four days. Tomatoes and lettuce contaminated with roundworm eggs showed a 99 percent reduction in eggs in nineteen days and a 100 percent reduction in four weeks.[36] Contaminated crops can be composted to remove residual pathogens.

Pathogen Survival in Sludge and Feces/Urine

Viruses can survive up to five months, but usually less than three months in sludge and human excrement. Indicator bacteria can survive up to five months, but usually less than four. Salmonellae survive up to five months, but usually less than one. Tubercle bacilli survive up to two years, but usually less than five months. Protozoan cysts survive up to one month, but usually less than ten days. Worm eggs vary depending on species, but roundworm eggs may survive many months.

PATHOGEN TRANSMISSION THROUGH VARIOUS TOILET SYSTEMS

It is evident that human excrement possesses the capability to transmit numerous diseases. For this reason, it should also be evident that the composting of humanure should not be done in a frivolous, careless, or haphazard manner. On the other hand, composting is not difficult. Simple practical procedures as outlined in this book will maximize sanitary efficiency. I am amazed when a "health authority" concludes that it's too dangerous for someone to compost humanure, then they drive off in a three-thousand-pound steel machine and race down the road at sixty miles an hour passing oncoming cars head-on only feet away on the other side of the road. There are many things people do every day that are infinitely more dangerous than making compost. Yet there is no proven, natural, low-tech, beneficial method for destroying human pathogens in organic material that is as successful and accessible to the average human as composting.

But what happens when the compost is not well managed? How dangerous is the undertaking when those involved don't make an effort to ensure that the compost maintains adequate temperatures? In fact, this is usually what happens in most owner-built and commercial dry toilets. Composting does not occur in most dry toilets because the correct blend of ingredients and the environment needed for such microbial activity does not exist. In the case of most commercial dry toilets, composting is not even intended. Instead, the toilets are designed to be dehydrators rather than composters.

On several occasions, I have seen compost toilet systems in which the compost collected from the toilet was simply dumped in an outdoor pile, not in a bin, and not covered with clean organic material such as straw or grass, kind of like my first compost pile. These piles most likely never became thermophilic, but since their temperatures were never checked, there is no way of knowing. People who are not responsibly working with and managing their compost often let the compost sit for years before use, if they use it at all. If they are combining their humanure with a carbonaceous cover material and letting it biologically degrade for at least a year, they are unlikely to be creating health problems. What happens to these ignored and neglected compost piles? After a couple of years, they turn into a pile of soil, and if left entirely alone, they will simply become covered with green vegetation, eventually disappearing back into the earth.

A different situation exists when humanure from a highly pathogenic population is being composted. Such a population would be the residents of a hospital in an underdeveloped country, for example, or any residents in a community where certain diseases or parasites are endemic, such as the German community in 1949. In that situation, the composter must make every effort necessary to ensure thermophilic composting, adequate retention time, and adequate pathogen elimination. Dedicated gloves, boots, tools, even coveralls and a dust mask would be recommended in these circumstances.

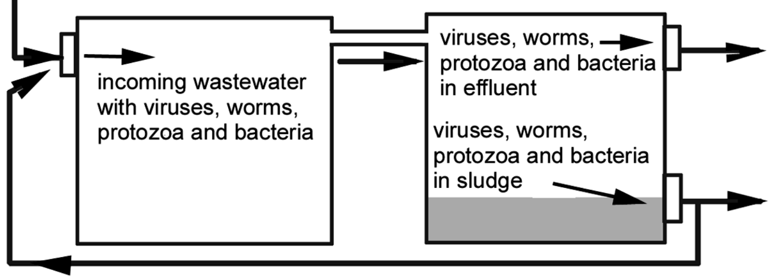
The following information illustrates the various waste treatment methods and composting methods commonly used today and shows the transmission of pathogens through the individual systems.

Outhouses and Pit Latrines

Outhouses have odor problems, breed flies and mosquitoes, and pollute groundwater. However, if the contents of a pit latrine have been filled over and left for a minimum of one year, there should be no sur-

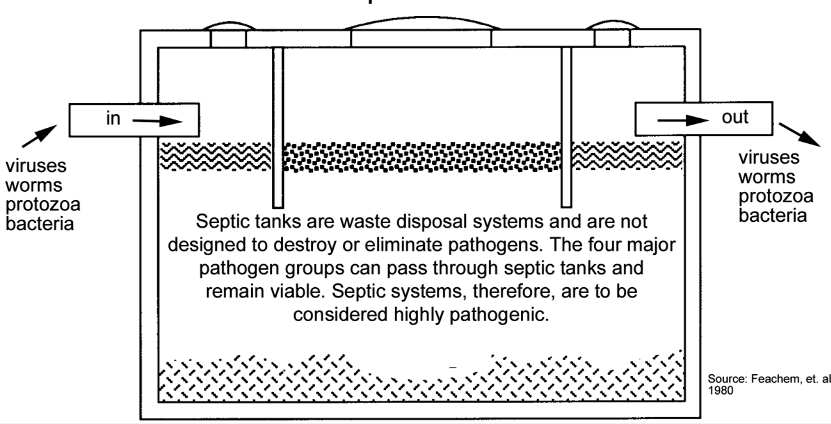
TRANSMISSION OF PATHOGENS THROUGH WASTEWATER PLANTS, SEPTIC TANKS AND WASTE STABILIZATION PONDS

Wastewater Plants

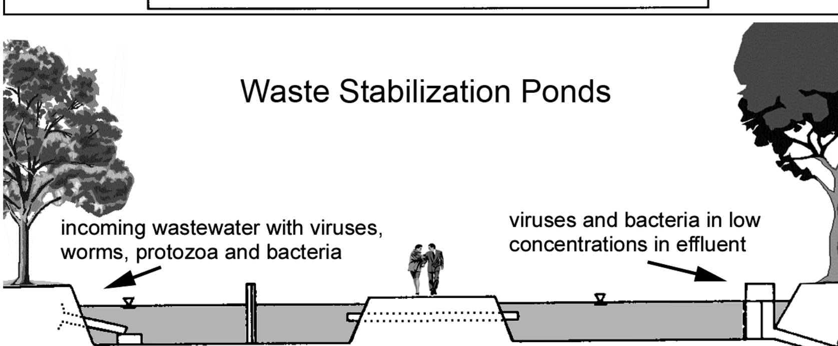


Conventional wastewater treatment plants allow the transmission of pathogens. Consequently, the effluent is commonly treated with chemicals such as chlorine and the sludge is often buried in landfills.

Septic Tanks



Source: Feachem, et. al., 1980



viving pathogens except for the possibility of roundworm eggs, according to Feachem. This risk is small enough that the contents of pit latrines, after twelve months burial, can be used agriculturally. Franceys et al. state, *"Solids from pit latrines are innocuous if the latrines have not been used for two years or so, as in alternating double pits."* [37]

Septic Tanks

It is safe to assume that septic tank effluents and sludge are highly pathogenic. Viable viruses, parasitic worm eggs, bacteria, and protozoa can be emitted from septic tank systems.

Conventional Sewage Treatment Plants

The only sewage digestion process producing a guaranteed pathogen-free sludge is batch thermophilic digestion in which all the sludge is maintained at 122°F (50°C) for thirteen days. Other sewage digestion processes will allow the survival of worm eggs and possibly pathogenic bacteria. Typical sewage treatment plants instead use a continuous process whereby wastewater is added daily or more frequently, thereby guaranteeing the survival of pathogens.

I took an interest in my local wastewater treatment plant in Pennsylvania when I discovered that the water in the creek below the wastewater discharge point had ten times the level of nitrates that unpolluted water has, and three times the level of nitrates acceptable for drinking water.[38] In other words, the water being discharged from the water treatment plant was polluted. We had tested the water for nitrates, but we didn't test for pathogens or chlorine levels. Despite the pollution, the nitrate levels were within legal limits for wastewater discharges.

Waste Stabilization Ponds

Waste stabilization ponds, or lagoons, large shallow ponds widely used in North America, Latin America, Africa, and Asia, involve the use of both beneficial bacteria and algae in the decomposition of organic waste materials. Although they can breed mosquitoes, they can be designed and managed well enough to yield pathogen-free waste water. However, they typically yield water with low concentrations of both pathogenic viruses and bacteria.

Compost Toilets and Dry Toilets

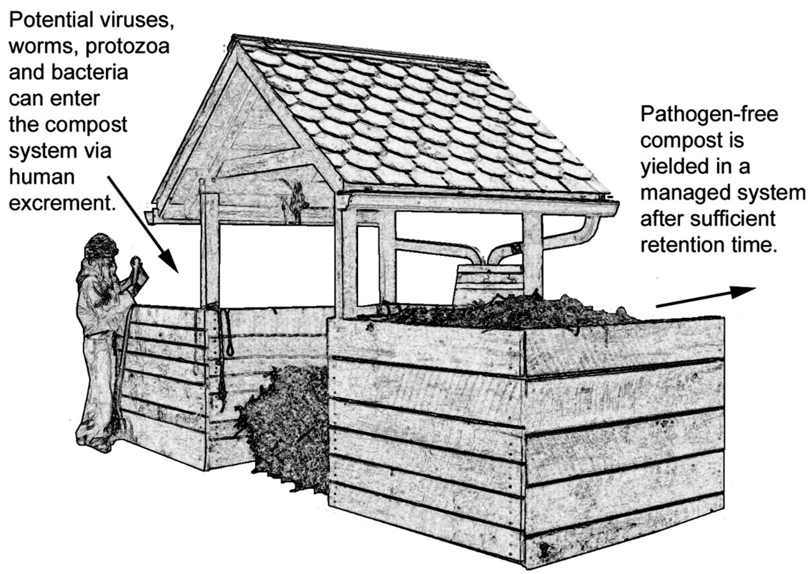
Most commercial dry toilets decompose organic material at a low temperature. According to Feachem, a minimum retention time of three months produces septage free of all pathogens except possibly some intestinal worm eggs. The septage obtained from these types of toilets can theoretically be composted again in a thermophilic pile and rendered suitable for food gardens (Table 14). Otherwise, the septage can be moved to an outdoor compost bin; moistened, if needed; covered with straw, weeds, or leaves; then left to age for an additional year or two to eliminate lingering pathogens. Over time, microbial activity and earthworms will aid in the sanitation of the compost.

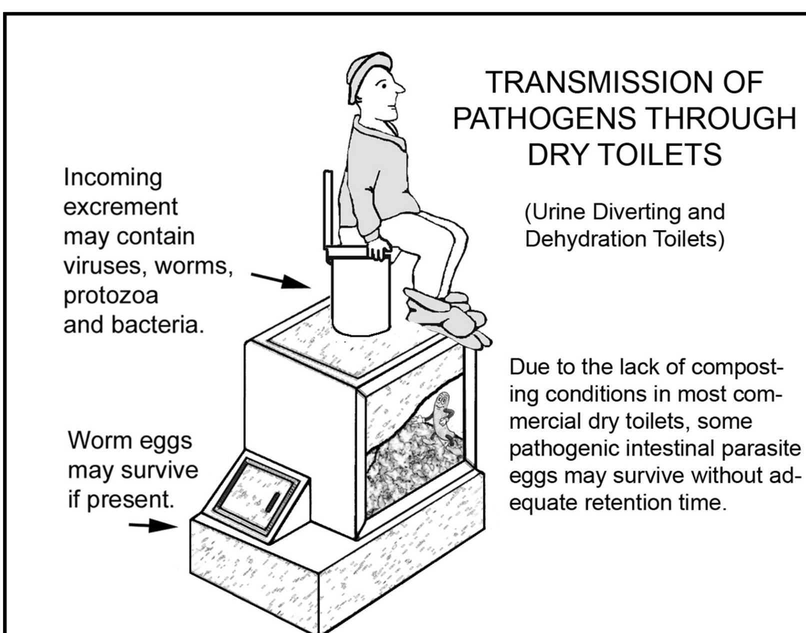
Composting

Complete pathogen destruction is guaranteed by arriving at a temperature of 143.6°F (62°C) for one hour, 122°F (50°C) for one day, 114.8°F (46°C) for one week, or 109.4°F (43°C) for one month. It appears that no excreted pathogen can survive a temperature of 149°F (65°C) for more than a few minutes. A compost pile may rapidly rise to a temperature of 131°F (55°C) or above or will maintain a temperature hot enough for a long enough period of time to destroy human pathogens beyond a detectable level.

The United States Environmental Protection Agency publishes requirements for the safe reuse of sewage sludge (biosolids) and domestic septage (such as from a dry toilet). The EPA states, "Composting creates a marketable end product that is easy to handle, store, and use. It is usually a 'Class A' material without detectable levels of pathogens

TRANSMISSION OF PATHOGENS THROUGH WELL-MANAGED COMPOST





that can be applied to gardens, food and feed crops, and rangelands. Biosolids compost is safe to use and generally has a high degree of acceptability by the public. Thus, it competes well with other bulk and bagged products available to homeowners, landscapers, farmers, and ranchers." They add, "Domestic septage is a form of sewage sludge. Domestic septage applied to a public contact site, lawn, or home garden must meet the same requirements as treated sewage sludge . . . .(Class A requirements)."[39]

EPA requirements for "Class A" sewage sludge compost include the following time/temperature requirements:

(1) Aerated static pile or in-vessel: 131°F (55°C) for at least 3 days.

(2) Windrow: 131°F (55°C) for at least 15 days with 5 turns.[40]

Prions

According to the EPA, "Can biosolids carry the pathogen that causes mad cow disease? It has been found that Bovine Spongiform Encephalopathy (BSE), or Mad Cow disease, is caused by a prion protein, or the resistant beta form of protein. The pathway for transmission is through the ingestion of tissue from infected animals. There has been no evidence that the BSE prion protein is shed in feces or urine. The primary route for infection, the use of animal carcasses in animal feed, is banned in [the US]. Thus there should be no risk of BSE exposure from biosolids."[41]

HIV

Also from the EPA: "Is there any risk of HIV infection from biosolids? The HIV virus is contracted through contact with blood or other body fluids of an infected individual. Feces and urine do not carry the HIV virus. Class A biosolids makes it virtually impossible that biosolids would contain the HIV virus."[42]

Table 14:
PATHOGEN SURVIVAL BY COMPOSTING OR SOIL

Pathogen	Soil Application	Unheated Anaerobic Digestion	Dry Toilet (Three mo. min. retention time)	Composting
Enteric viruses	May survive 5 mo	Over 3 mo.	Probably elim.	Killed rapidly at 60C
Salmonellae	3 mo. to 1 yr.	Several wks.	Few may surv.	Dead in 20 hrs. at 60C
Shigellae	Up to 3 mo.	A few days	Prob. elim.	Killed in 1 hr. at 55C or in 10 days at 40C
E. coli	Several mo.	Several wks.	Prob. elim.	Killed rapidly above 60C
Cholera vibrio	1 wk. or less	1 or 2 wks.	Prob. elim.	Killed rapidly above 55C
Leptospires	Up to 15 days	2 days or less	Eliminated	Killed in 10 min. at 55C
Entamoeba histolytica cysts	1 wk. or less	3 wks or less	Eliminated	Killed in 5 min. at 50C or 1 day at 40C
Hookworm eggs	20 weeks	Will survive	May survive	Killed in 5 min. at 50C or 1 hr. at 45C
Roundworm (*Ascaris*) eggs	Several yrs.	Many mo.	Survive well	Killed in 2 hrs. at 55C, 20 hrs. at 50C, 200 hrs. at 45C
Schistosome eggs	One mo.	One mo.	Eliminated	Killed in 1 hr. at 50C
Taenia eggs	Over 1 year	A few mo.	May survive	Killed in 10 min. at 59C, over 4 hrs. at 45C

Source: Feachem et al., 1980

Table 15:
THERMAL DEATH POINTS FOR COMMON PARASITES AND PATHOGENS

PATHOGEN	THERMAL DEATH
Ascaris lumbricoides eggs	Within 1 hour at temps over 50C
Brucella abortus or *B. suis*	Within 1 hour at 55C
Corynebacterium diptheriae	Within 45 minutes at 55C
Entamoeba histolytica cysts	Within a few minutes at 45C
Escherichia coli	One hr at 55 C or 15-20 min. at 60C
Micrococcus pyogenes var. *aureus*	Within 10 minutes at 50C
Mycobacterium tuberculosis var. *hominis*	Within 15 to 20 minutes at 66C
Necator americanus	Within 50 minutes at 45C
Salmonella spp.	Within 1 hr at 55C; 15-20 min. at 60C
Salmonella typhosa	No growth past 46C; death in 30 min. 55C
Shigella spp.	Within one hour at 55C
Streptococcus pyogenes	Within 10 minutes at 54C
Taenia saginata	Within a few minutes at 55C
Trichinella spiralis larvae	Quickly killed at 55C

Source: Gotaas, Harold B. (1956). Composting - Sanitary Disposal and Reclamation of Organic Wastes. p.81. World Health Organization, Monograph Series Number 31. Geneva.

Pinworms

Pinworms are fairly common among school-age kids. These unpleasant parasites are spread from human to human by direct contact and by inhaling eggs. The pinworm life cycle does not include a stage in soil, compost, or manure.

Pinworms (*Enterobius vermicularis*) lay microscopic eggs at the anus of a human being, its only known host. This causes itching at the anus which is the primary symptom of pinworm infection. The eggs can be picked up almost anywhere. Once in the human digestive system, they develop into the tiny worms. Some estimate that pinworms infest or have infested 75 percent of all New York City children in the three to five-year age group, and that similar figures exist for other cities.[43]

Infection is spread by the hand-to-mouth transmission of eggs resulting from scratching the anus, as well as from breathing airborne eggs. In about one-third of infected children, eggs may be found under the fingernails.

A worm's life span is thirty-seven to fifty-three days; an infection would self-terminate in this period, without treatment, in the absence of reinfection. The amount of time that passes from ingestion of eggs to new eggs being laid at the anus ranges from four to six weeks.[44]

In 95 percent of infected persons, pinworm eggs aren't found in the feces. Transmission of eggs to feces and to soil isn't part of the pinworm life cycle, which is one reason the eggs aren't likely to end up in feces or compost. Even if they do, they quickly die outside the human host.[45]

Hookworms

Hookworm species in humans include *Necator americanus*, *Ancylostoma duodenale*, *A. braziliense*, *A. caninum*, and *A. ceylanicum*.

These small worms are about a centimeter long (less than half an inch); humans are almost the exclusive host of *A. duodenale* and *N. americanus*. A hookworm of cats and dogs, *A. caninum*, is an extremely rare intestinal parasite of humans.

The eggs are passed in the feces and mature into larvae outside the human host under favorable conditions. The larvae attach themselves to the bottom of your foot when they're stepped on, then enter your body through pores, hair follicles, or even unbroken skin. They tend to migrate to the upper small intestine where they suck their host's blood. Within five or six weeks, they'll mature enough to produce up to twenty thousand eggs per day. Don't walk barefoot around pit latrines!

Hookworms are estimated to infect five hundred million people throughout the world, causing a daily blood loss of more than one million liters, which is as much blood as can be found in all the people in the city of Erie, Pennsylvania, or Austin, Texas. An infection can last two to fourteen years. Light infections can produce no recognizable symptoms, while a moderate or heavy infection can produce an iron deficiency anemia. Infection can be determined by a stool analysis.

These worms tend to be found in tropical and semi-tropical areas and are spread by defecating on the soil. Both the biological temperatures of composting and the freezing temperatures of winter will kill the eggs and larvae (Table 16). Drying is also destructive.[46]

Table 16:
HOOKWORMS

Hookworm larvae develop outside the host and favor a temperature range of 23°C to 33°C (73°F to 91°F).

	Survival Time of:	
Temperature	Eggs	Larvae
45°C (113°F)	Few hours	less than 1 hour
0°C (32°F)	7 days	less than 2 weeks
-11°C (12°F)	?	less than 24 hours

Both thermophilic composting and freezing weather will kill hookworms and eggs.

Source: Brown, H. W., and F. A. Neva. (1994). Basic Clinical Parasitology, 6th ed. Appleton-Century-Crofts: Norwalk, CT. pp. 129.

Whipworms

Whipworms (*Trichuris trichiura*) are usually found in humans but may also be found in monkeys or hogs. They're usually under two inches long; the female can produce three thousand to ten thousand eggs per day. Larval development occurs outside the host, and in a favorable environment (warm, moist, shaded soil), first stage larvae are produced from eggs in three weeks. The lifespan of the worm is usually considered to be four to six years.

Hundreds of millions of people worldwide, as much as 80 percent of the population in certain tropical countries, are infected with whipworms. In the US, whipworms are found in the South where heavy rainfall, a subtropical climate, and feces-contaminated soil provide a suitable habitat.

Persons handling soil that has been defecated on by an infected person risk infection by hand-to-mouth transmission of the eggs. Light infections may not show any symptoms. Heavy infections can result in anemia and death. A stool examination will determine if there is an infection. Cold winter temperatures of 18° to 10°F (-8° to -12°C) are fatal to the eggs, as are the high temperatures of composting.[47]

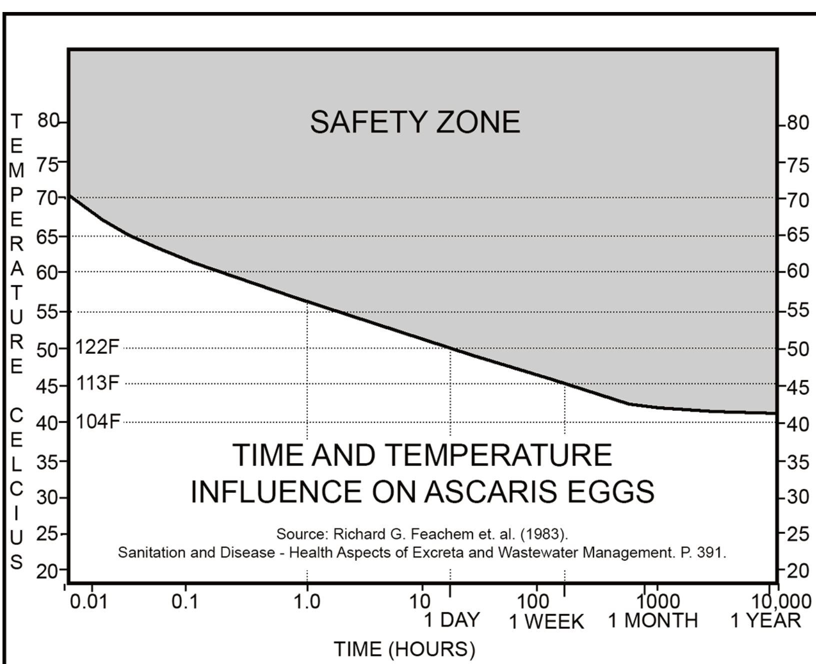
Roundworms

Roundworms (*Ascaris lumbricoides*) are fairly large worms (ten inches in length) that parasitize the human host by eating semi-digested food in the small intestine. The females can lay two hundred thousand eggs per day for a lifetime total of roughly twenty-six million. Larvae develop from the eggs in soil under favorable conditions (70°-86°F [21°C - 30°C]). Above 99°F (37°C), they cannot fully develop.

Approximately nine hundred million people are infected with roundworms worldwide, one million in the United States. The eggs are transmitted hand to mouth by people, usually children, who have come into contact with the eggs in their environment. Infected persons usually complain of a vague abdominal pain. Diagnosis is by stool analysis.[48] An analysis of four hundred thousand stool samples throughout the US by the Centers for Disease Control and Prevention found *Ascaris* in 2.3 percent of the samples, with a wide fluctuation in results depending on the geographical location of the people sampled. Puerto Rico had the highest positive sample frequency (9.3 percent), while samples from Wyoming, Arizona, and Nevada showed no incidence of Ascaris at all.[49] In moist tropical climates roundworm infection may afflict 50 percent of the population.[50]

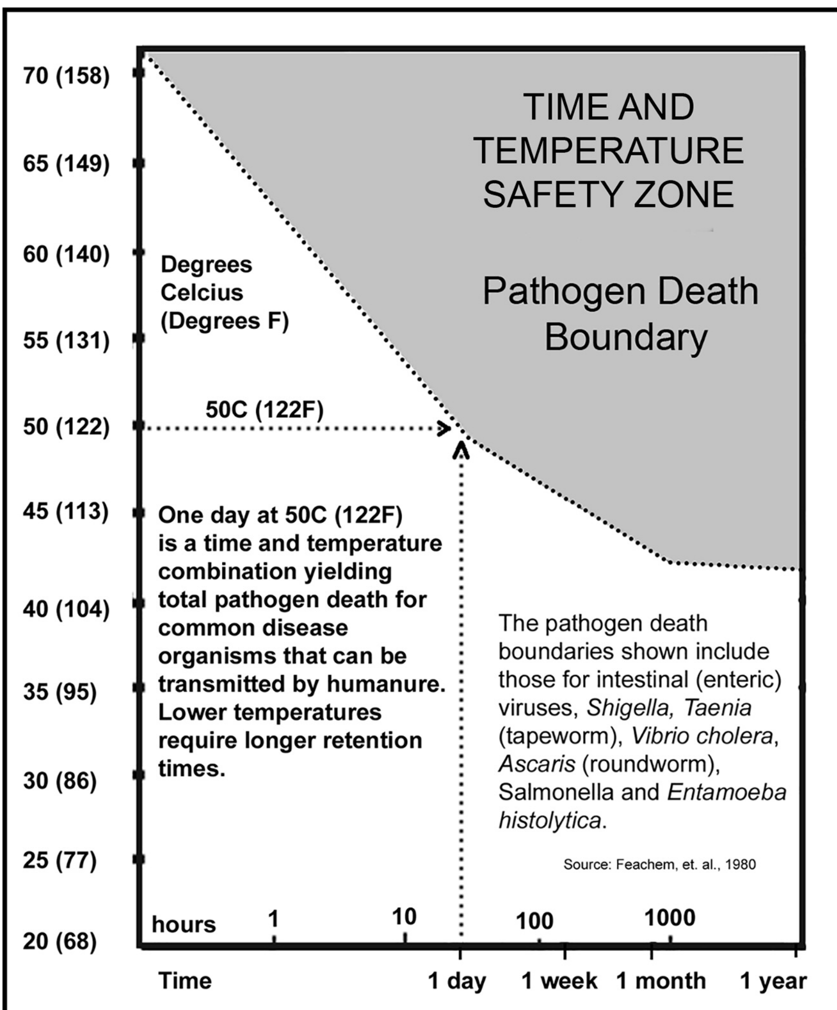
Eggs are destroyed by direct sunlight within fifteen hours and are killed by temperatures above 104°F (40°C), dying within an hour at 122°F (50°C). The eggs are resistant to freezing , chemical disinfectants, and other strong chemicals, but composting will kill them.

Roundworms, like hookworms and whipworms, are spread by fecal contamination of soil. Much of this contamination is caused and spread by children who defecate outdoors within their living area. One sure way to eradicate fecal pathogens is to conscientiously compost all fecal material. Therefore, it is important when composting humanure to be



certain that all children use a toilet facility and do not defecate on the soil. When changing soiled diapers, scrape the fecal material into a compost toilet with toilet paper or another biodegradable material (yeah, we parents actually used cloth diapers back in the last century). It's up to adults to keep an eye on kids and make sure they understand the importance of always using a toilet facility and never defecating on the ground.

Fecal environmental contamination can also be caused by using raw fecal material for agricultural purposes. Proper composting is es-



sential for the eradication of pathogens. And don't forget to wash your hands after feeding your compost pile and before feeding yourself!

After reading this section on intestinal parasites and their need to have some time in soil for their life cycle to be complete, it should be clear now why the Earth Closet, which used soil to cover feces, was not such a good idea, especially in warmer climates.

Temperature and Time

Two primary factors lead to the death of pathogens in humanure. The first is temperature. A compost pile that is properly managed will destroy pathogens with the heat and biological activity it generates.

The second factor is time. The lower the temperature of the compost, the longer the retention time needed for the destruction of pathogens. Given enough time, the wide biodiversity of microorganisms in the compost will destroy pathogens by antagonism, competition, consumption, and antibiotic inhibition provided by the beneficial microorganisms. Feachem et al. state that three months retention time will kill all the pathogens in a dry toilet except worm eggs, although Table 14 indicates that some additional pathogen survival may occur.

A thermophilic compost pile will destroy pathogens, including worm eggs, quickly, possibly in a matter of minutes. Lower temperatures require longer periods of time, possibly hours, days, weeks, or months, to effectively eliminate pathogens. One need not strive for extremely high temperatures in a compost pile to feel confident about the destruction of pathogens. It may be more realistic to maintain lower temperatures in a compost pile for longer periods of time, such as 122°F (50°C) for twenty-four hours, or 115°F (46°C) for a week. According to one source, "All fecal [pathogenic] microorganisms, including enteric viruses and roundworm eggs, will die if the temperature exceeds 114.8°F (46°C) for one week."[51] Other researchers have drawn similar conclusions, demonstrating pathogen destruction at 122°F (50°C), which produced compost "completely acceptable from the general hygienic point of view."[52]

A good approach to pathogen destruction when composting humanure is to compost the toilet material, then allow the compost to sit, undisturbed, for a lengthy retention time to allow the compost to thoroughly age or cure. The biodiversity of the compost will aid in the destruction of pathogens as the compost ages. If one wants to be particularly cautious, one may allow the compost to age for two years after the pile has been completed, instead of the approximately one year that is normally recommended.

In the words of Feachem, *"The effectiveness of excreta treatment methods depends very much on their time-temperature characteristics. The effective processes are those that either make the excreta warm (55°C/131°F), hold it for a long time (one year), or feature some effective combination of time and temperature."*

The US Environmental Protection Agency requires three days at 131°F (55°C) for pathogen elimination in a static compost pile. Our compost piles in Haiti, California, and elsewhere maintain temperatures above 131°F for many months. These are unturned piles, insulated on top and around the sides with cover material such as straw, or sugarcane bagasse. The temperatures are incredibly uniform throughout the piles, even maintaining pathogen destroying temperatures right up to the edges.

Conclusions

Humanure is a valuable resource suitable for agricultural purposes and has been recycled for such purposes by large segments of the world's population for thousands of years. However, humanure contains the potential for harboring human pathogens and thereby can contribute to the spread of disease when improperly managed or when discarded as a waste material. Yet, when humanure is composted, human pathogens are destroyed and the humanure is converted into a hygienically safe form suitable for human food production.