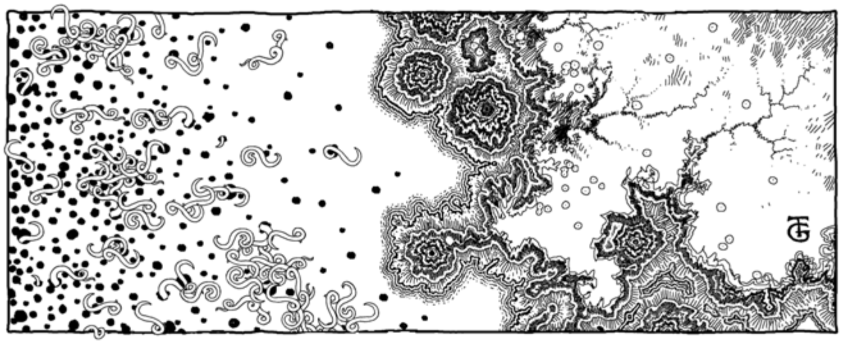

WORMS AND DISEASE

I well remember in early 1979 when I first informed a friend that I intended to compost my own manure and grow my own food with it. *"Oh my God, you can't do that!"* she cried.

"Why not?"

"Worms and disease!"

Of course.

A young English 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 the horrible reality of their situation: the food they were about to eat was *recycled human shit*. When this fact abruptly dawned upon 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 steaming turd on a plate in front of them with a knife, fork and napkin.

Fecophobia 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 humus, not crap, and it is useful in growing food. My friends didn't understand this and despite my attempts to clarify the matter for their benefit, they chose to cling to their misconceptions. Apparently, some fecophobes will always remain fecophobes.

Allow me to make a radical suggestion: humanure is not dangerous. More specifically, it is not any more dangerous than the body from which it is excreted. The danger lies in what we *do* with humanure, not in the material itself. To use an analogy, a glass jar is not dangerous either. However, 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 do not seem to exist in the Chinese language. 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 they were "full of humanure," they'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 ancestor's historical failure to responsibly recycle the substance caused monumental public health headaches. Consequently, the attitude that humanure *itself* is terribly dangerous has been embraced and promulgated up to the present day.

For example, a recently published 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 upon a human "waste" composting methodology which includes segregating urine from feces, collecting the manure in 30 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 30 years of humanure composting experience — there is no need to go to the bother of segregating urine; a 30 gallon container is much too big and heavy to be able to handle easily; and *sawmill* sawdust does, in fact, work beautifully in a composting 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 and simple, 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 nothing about composting humanure, it's probably the local health authority, who receives no such training.

The "Bio-Dynamic" agricultural movement, founded by Dr. Rudolf Steiner, provides another example of fecophobia. 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 fecophobic, and that fecophobia 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 people. This line of reasoning so influenced the population that many homeowners built their outhouses attached to their kitchens in order 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 U.S. 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 U.S. 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 waste 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."

The U.S. government bulletin insisted that the use of human excrement as fertilizer was both "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 summed it up by stating, *"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 fecophobia, 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]

THE HUNZAS

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. Many people 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 compost their humanure and use 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 Tompkins (1989), *"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 [emphasis mine], *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 which 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; the law of return is obeyed, the unseen part of the revolution of the great Wheel is faithfully accomplished."* [8] Sir Howard's view is that soil fertility is the real basis of public health.

A medical professional associated with the Hunzas claimed, *"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."*

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."* [9]

The Hunzas composted their organic material, thereby recycling it. This actually enhanced their personal health and the health of their community. The U.S. Department of Agriculture was apparently unaware of the effective natural process of composting in 1928 when they described the recycling of humanure as "dangerous and disgusting." No doubt the USDA would have confused the Hunzas, who had for centuries safely and constructively engaged in such recycling.

PATHOGENS*

Clearly, even the primitive composting of humanure for agricultural purposes does not necessarily pose a threat to human health, as evidenced by the Hunzas. Yet, fecal *contamination* of the environment certainly *can* pose a threat to human health. Feces can harbor a host of disease organisms which can contaminate the environment to infect innocent people when human excrement is discarded as a waste material. In fact, even a healthy person apparently free of disease can pass potentially dangerous pathogens through their fecal material, simply by being a carrier. The World Health Organization estimates that 80% 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.[11] As such, the composting of humanure would certainly seem like a worthwhile undertaking worldwide.

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 try 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.

For example, consider the following quote from Jervis (1990): *"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."*[12]

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 healthy person is dangerous unless left to accumulate, pollute water with intestinal bacteria, or breed flies and/or rats, all of which are the results of negligence or bad custom-

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*Much of the information in this section is adapted from Appropriate Technology for Water Supply and Sanitation, by Feachem et al., World Bank, 1980.[10] This comprehensive work cites 394 references from throughout the world, and was carried out as part of the World Bank's research project on appropriate technology for water supply and sanitation.

Table 7.1

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 7.2

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.

ary habits. It should be understood that 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. Furthermore, it is generally not understood that the carefully managed thermophilic composting of humanure converts it into a sanitized agricultural resource. No other system of fecal material and urine recycling or disposal can 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 (see Table 7.1). 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.[13] Therefore, it is just as important to recycle urine as it is to recycle humanure, and composting 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 of life forms. Many scientists don't even consider them to be organisms. They are much smaller and simpler than bacteria (some viruses are even parasitic to bacteria), and the simplest form may consist only of an RNA molecule. By definition, a virus is an entity which 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. In order to reproduce, therefore, viruses rely on the hardware of the infected host cell which is re-programmed by the virus in order to reproduce viral nucleic acid. As such, viruses cannot reproduce outside the host cell.[14]

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 (see Table 7.3). During periods of infection, one hundred

Table 7.3

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 7.4

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

million to one trillion viruses can be excreted with each gram of fecal material.[15]

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 (see Table 7.4). However, according to Gotaas, pathogenic bacteria *"are unable to survive temperatures of 55^0-60^{0}C for longer than 30 minutes to one hour."* [16]

PROTOZOA

The pathogenic protozoa include *Entamoeba histolytica* (causing amoebic dysentery), and members of the Hartmanella-Naegleria group (causing meningo-encephalitis — see Table 7.5). 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 in order to remain viable for any extended period.[17]

PARASITIC WORMS

Finally, a number of parasitic worms pass their eggs in feces, including hookworms, roundworms (*Ascaris*) and whipworms (see Table 7.6). Various researchers have reported 59 to 80 worm eggs in sampled liters of sewage. This suggests that billions of pathogenic worm eggs may reach an average wastewater treatment plant daily. These eggs tend to be resistant to environmental conditions due to a thick outer covering,[18] and they are extremely resistant to the sludge

Table 7.5

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

Table 7.6

POTENTIAL WORM PATHOGENS IN FECES

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

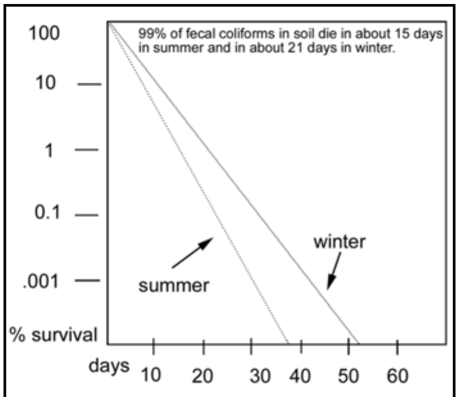
Common Name	Pathogen	Transmission	Distribution
1. Hookworm	*Ancylostoma doudenale* *Necator americanus*	Hum.-soil-human.	Warm, wet climates
2. ----------	*Heterophyes heterophyes*	Dog/cat-snail-fish-hum.	Mid. East/S. Eur./Asia
3. ----------	*Gastrodiscoides*	Pig -snail- aquatic vegetation-hum.	India/Bangla./Vietn./ 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

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% of the eggs may still be viable. Even after a year in sludge, some viable eggs may be found.[19] 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, and over 90% of the population became infected.[20]

If there are about 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. My local wastewater treatment plant serves a population of eight thousand people and collects about 1.5 million gallons of wastewater daily. That means there could be 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 my local 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, 30 tractor-trailer loads of sludge are hauled out of the local facility. 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.

It is interesting to note that 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 bad 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 lumbricoide*s, a parasite that has plagued us for perhaps hundreds of thousands of years, would soon become extinct. The human species is finally evolving to the extent that we are beginning to understand compost and its ability to destroy parasites. We need to take that a step further and entirely prevent our excrement from polluting the environment. Otherwise, we will continue to be outsmarted by the parasitic worms that rely on our ignorance and carelessness for their own survival.



Survival Times of Fecal Coliforms in Soil

Figure 7.1 — 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 7.7
AVERAGE DENSITY OF FECAL COLIFORMS EXCRETED IN 24 HOURS
(million/100ml)

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

INDICATOR PATHOGENS

Indicator pathogens are pathogens 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 7.6 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 27 million eggs in her lifetime.[21] 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.[22] The reported viability of roundworm eggs (*Ascaris* ova) in soil ranges from a couple of weeks under sunny, sandy conditions,[23] to two and a half years,[24] four years,[25] five and a half years,[26] or even ten years[27] 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%.

Ascaris eggs develop at temperatures between 15.5^{0}C (59.90° F) and 35^{0}C (95^{0}F), but the eggs disintegrate at temperatures above 38^{0}C (100.40° F).[28] The temperatures generated during thermophilic composting can easily exceed levels necessary to destroy roundworm eggs.

One way to determine if the compost you're using is contaminated with viable roundworm eggs is to have a stool analysis done at a local hospital. If your compost is contaminated and you're using the compost to grow your own food, then there will be a chance that you've contaminated yourself. A stool analysis will reveal whether that is the case or not. 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 this book. I had been composting humanure for fourteen years at the time of the first testing, and 26 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, nearly three decades have passed since I began gardening with humanure compost. During those years, I have raised several healthy children. Our toilet has been used by countless people, including many strangers. All of the toilet material has been composted and used for gardening purposes in our home garden.

There are indicators other than roundworm eggs that can be used to determine contamination of water, soil or compost. *Indicator bacteria* include fecal coliforms, which reproduce in the intestinal systems of warm blooded animals (see Table 7.7). If one wants to test a water supply for fecal contamination, then one looks for fecal coliforms, usually *Escherichia coli*. *E. coli* is one of the most abundant intestinal bacteria in humans; over 200 specific types exist. Although some of them can cause disease, most are harmless.[29] 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. Such a test measures *all* species of the coliform group and is not limited to species originating in warm-blooded animals. Since some coliform species come from the soil, the results of this test are not always indicative of fecal contamination in a stream analysis. However, this test can be used for ground water supplies, as no coliforms should be present in ground water unless it has been contaminated by a warm-blooded animal.

Fecal coliforms do not multiply outside the intestines of warm-blooded animals, and their presence in water is unlikely unless there is fecal pollution. They survive for a shorter time in natural waters than the coliform group as a whole, therefore their presence indicates relatively recent pollution. In domestic sewage, the fecal coliform count is usually 90% or more of the total coliform count, but in natural streams, fecal coliforms may contribute 10-30% 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 U.S. limit the fecal coliform concentration allowable in waters used for water sports to 200 fecal coliforms per 100 ml.

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

According to Feachem et al. (1980), the persistence of fecal pathogens in the environment can be summarized as follows:

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% reduction is likely within 25 days in warm climates (see Figure 7.1). *Salmonella* bacteria may survive for a year in rich, moist, organic soil, although 50 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 7.8 through 7.12 reveal their survival times in soil.

SURVIVAL OF PATHOGENS ON CROPS

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,[30] although research published in 2002 indicates that at least one type of *E. coli* can enter lettuce plants through the root systems and travel throughout the edible portions of the plant.[AA]

Some pathogens can survive on the surfaces of vegetables, especially root vegetables, although sunshine and low air humidity will promote the death of pathogens. 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 27 to 35 days to be incapable of infection.[31]

Lettuce and radishes in Ohio sprayed with sewage inoculated with Poliovirus I showed a 99% reduction in pathogens after six days; 100% were eliminated after 36 days. Radishes grown outdoors in soil fertilized with fresh typhoid-contaminated feces four days after planting showed a pathogen survival period of less than 24 days. Tomatoes and lettuce contaminated with a suspension of roundworm eggs showed a 99% reduction in eggs in 19 days and a 100% reduction in four weeks. These tests indicate that if there is any doubt about pathogen contamination of compost, the compost should be applied to long-season crops at the time of planting so that sufficient time ensues for the pathogens to die before harvest.

Pathogen Survival In Sludge and Feces/Urine

Viruses can survive up to five months, but usually less than three months in sludge and night soil. Indicator bacteria can survive up to five months, but usually less than four months. Salmonellae survive up to five months, but usually less than one month. 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 for many months.

PATHOGEN TRANSMISSION THROUGH VARIOUS TOILET SYSTEMS

It is clearly evident that human excrement possesses the capability to transmit various diseases. For this reason, it should also be evident that the composting of humanure is a serious undertaking and should not be done in a frivolous, careless or haphazard manner. The pathogens that may be present in humanure have various survival periods outside the human body and maintain varied capacities for re-infecting people. This is why the *careful management* of a ther-

Table 7.8

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	0-20%	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 7.9

SURVIVAL TIME 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 7.10

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 7.11

SURVIVAL OF POLIOVIRUSES 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 7.12

SURVIVAL TIME OF SOME PATHOGENIC WORMS IN SOIL

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 7.13

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.

mophilic compost system is important. Nevertheless, there is no proven, natural, low-tech method for destroying human pathogens in organic refuse that is as successful *and* accessible to the average human as well-managed thermophilic composting.

But what happens when the compost is not well-managed? How dangerous is the undertaking when those involved do not make an effort to ensure that the compost maintains thermophilic temperatures? In fact, this is normally what happens in most owner-built and commercial composting toilets. Thermophilic composting does not occur in owner-built toilets because those responsible often make no effort to create the organic blend of ingredients and the environment needed for such a microbial response. In the case of most commercial composting toilets, thermophilic composting is not even intended, as the toilets are designed to be dehydrators rather than thermophilic composters.

On several occasions, I have seen simple collection toilet systems (humanure toilets) in which the compost was simply dumped in an outdoor pile, not in a bin, lacking urine (and thereby moisture), and not layered with the coarse organic material needed for air entrapment. Although these piles of compost did not give off unpleasant odors (most people have enough sense to instinctively cover odorous organic material in a compost pile), they also did not necessarily become thermophilic (their temperatures were never checked). People who are not very concerned about working with and managing their compost are usually willing to let the compost sit for years before use, if they use it at all. Persons who are casual about their composting tend to be those who are comfortable with their own state of health and therefore do not fear their own excrement. As long as they are combining their humanure with a carbonaceous material and letting it compost, thermophilically or not, for at least a year (an additional year of aging is recommended), they are very unlikely to be creating any health problems. What happens to these casually constructed compost piles? Incredibly, after a couple of years, they turn into humus and, if left entirely alone, will simply become covered with vegetation and disappear back into the earth. I have seen it with my own eyes.

A different situation occurs 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. In that situation, the composter must make every effort necessary to ensure thermophilic composting, adequate aging time and adequate pathogen destruction.

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 possibly 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 will be no surviving 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."* [32]

SEPTIC TANKS

It is safe to assume that septic tank effluents and sludge are highly pathogenic (see Figure 7.3). Viruses, parasitic worm eggs, bacteria and protozoa can be emitted from septic tank systems in viable condition.

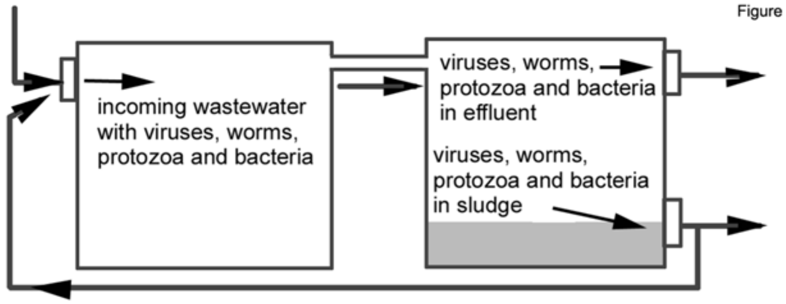
CONVENTIONAL SEWAGE TREATMENT PLANTS

The only sewage digestion process producing a guaranteed pathogen-free sludge is batch thermophilic digestion in which all of the sludge is maintained at 50°C (122°F) for 13 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 where wastewater is added daily or more frequently, thereby guaranteeing the survival of pathogens (see Figure 7.2).

I took an interest in my local wastewater treatment plant when I discovered that the water in our local 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.[33] In other words, the water being discharged from the water treatment plant was polluted. We had tested the water for

Transmission of Pathogens Through Wastewater Plants

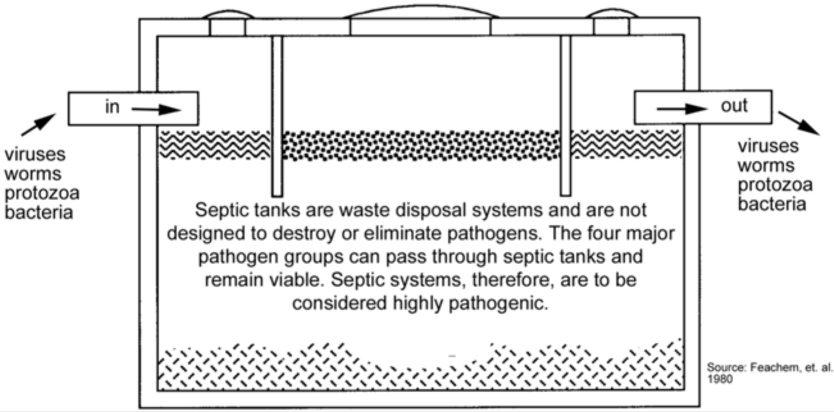
Figure 7.2



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.

Transmission of Pathogens Through Septic Tanks

Figure 7.3

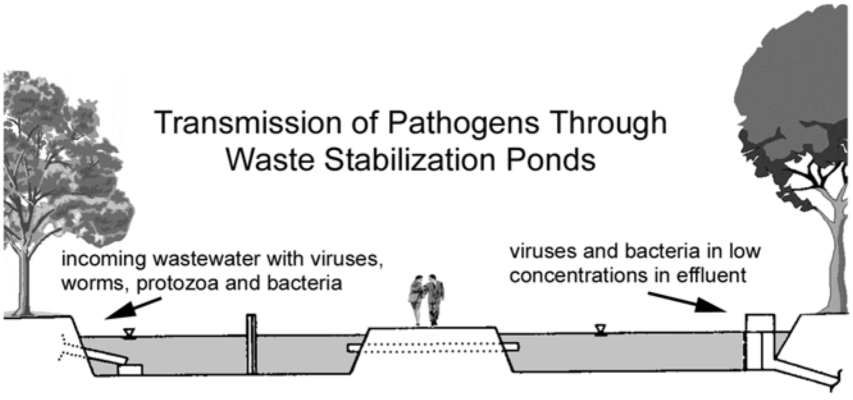


Septic tanks are waste disposal systems and are not designed to destroy or eliminate pathogens. The four major pathogen groups can pass through septic tanks and remain viable. Septic systems, therefore, are to be considered highly pathogenic.

Source: Feachem, et. al., 1980

Figure 7.4

Transmission of Pathogens Through Waste Stabilization Ponds



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 (see Figure 7.4).

Composting Toilets and Mouldering Toilets

Most mouldering and commercial composting toilets are relatively anaerobic and compost at a low temperature. According to Feachem et al., a minimum retention time of three months produces a compost free of all pathogens except possibly some intestinal worm eggs. The compost obtained from these types of toilets can theoretically be composted again in a thermophilic pile and rendered suitable for food gardens (see Figure 7.5 and Table 7.14). Otherwise, the compost can be moved to an outdoor compost bin, layered and covered with straw (or other bulky organic material such as weeds or leaf mould), moistened, and left to age for an additional year or two in order to destroy any possible lingering pathogens. Microbial activity and earthworms will aid in the sanitation of the compost over time.

Well-managed Thermophilic Composting System

Complete pathogen destruction is guaranteed by arriving at a temperature of 62°C (143.6°F) for one hour, 50°C (122°F) for one day, 46°C (114.8°F) for one week or 43°C (109.4°F) for one month. It appears that no excreted pathogen can survive a temperature of 65°C (149°F) for more than a few minutes. A compost pile containing entrapped oxygen may rapidly rise to a temperature of 55°C (131°F) or above, or will maintain a temperature hot enough for a long enough period of time to destroy human pathogens beyond a detectable level (see Figure 7.6). As pathogen destruction is aided by microbial diversity, as discussed in Chapter 3, excessively heating a compost pile, such as by forcing air through it, can be counter-productive.

Table 7.14 indicates survival times of pathogens in a) soil, b) anaerobic decomposition conditions, c) composting toilets and d) thermophilic compost piles.

MORE ON PARASITIC WORMS

This is a good subject to discuss in greater detail as it is rarely a topic of conversation in social circles, yet it is important to those who are concerned about potential pathogens in compost. Therefore, let's look at the most common of human worm parasites: pinworms, hookworms, whipworms and roundworms.

PINWORMS

A couple of my kids had pinworms at one time during their childhood. I know exactly who they got them from (another kid), and getting rid of them was a simple matter. However, the rumor was cir-

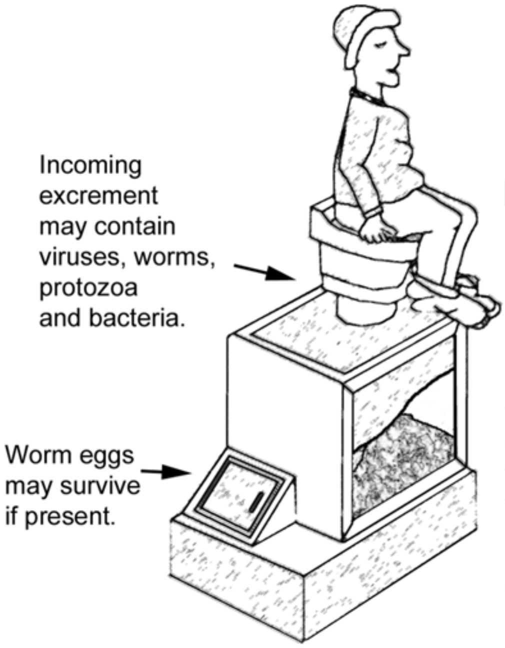


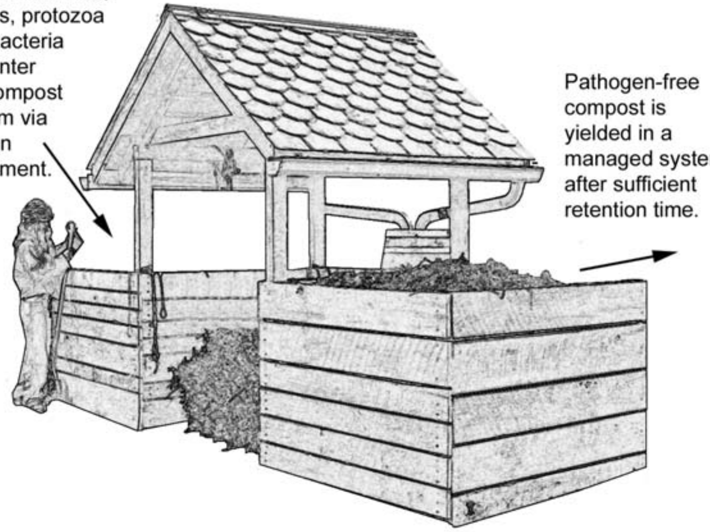
Figure 7.5

Transmission of Pathogens Through Low-Temperature Composting Toilets

Due to the low composting temperatures of most commercial composting toilets and mouldering toilets, the eggs of some intestinal parasites, if present, may survive the "composting" process.

Figure 7.6

Transmission of Pathogens Through Well-Managed Thermophilic Compost



Potential viruses, worms, protozoa and bacteria can enter the compost system via human excrement.

Pathogen-free compost is yielded in a managed system after sufficient retention time.

culated that they got them from our compost. We were also told to worm our cats to prevent pinworms in the kids (these rumors allegedly originated in a doctor's office). Yet, the pinworm life cycle does not include a stage in soil, compost, manure or cats. These unpleasant parasites are spread from human to human by direct contact, and by inhaling eggs.

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 infestation. 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% of all New York City children in the three to five year age group, and that similar figures exist for other cities.[34]

These worms have the widest geographic distribution of any of the worm parasites, and are estimated to infect 208.8 million people in the world (18 million in Canada and the U.S.). An Eskimo village was found to have a 66% infection rate; a 60% rate has been found in Brazil, and a 12% to 41% rate in Washington D.C.

Table 7.14

PATHOGEN SURVIVAL BY COMPOSTING OR SOIL APPLICATION

Pathogen	Soil Application	Unheated Anaerobic Digestion	Composting Toilet (Three mo. min. retention time)	Thermophilic 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 40^0 C
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 45^{0}C
Schistosome eggs	One mo.	One mo.	Eliminated	Killed in 1 hr. at 50^{0}C
Taenia eggs	Over 1 year	A few mo.	May survive	Killed in 10 min. at 59^{0}C, over 4 hrs. at 45^{0}C

Source: Feachem et al., 1980

Table 7.15

THERMAL DEATH POINTS FOR COMMON PARASITES AND PATHOGENS

PATHOGEN	THERMAL DEATH
Ascaris lumbricoides eggs	Within 1 hour at temps over 50^{0}C
Brucella abortus or *B. suis*	Within 1 hour at 55^{0}C
Corynebacterium diptheriae	Within 45 minutes at 55^{0}C
Entamoeba histolytica cysts	Within a few minutes at 45^{0}C
Escherichia coli	One hr at 55^{0}C or 15-20 min. at 60^{0}C
Micrococcus pyogenes var. *aureus*	Within 10 minutes at 50^{0}C
Mycobacterium tuberculosis var. *hominis*	Within 15 to 20 minutes at 66^{0}C
Necator americanus	Within 50 minutes at 45^{0}C
Salmonella spp.	Within 1 hr at 55C; 15-20 min. at 60^{0}C
Salmonella typhosa	No growth past 46C; death in 30 min. 55C
Shigella spp.	Within one hour at 55^{0}C
Streptococcus pyogenes	Within 10 minutes at 54^{0}C
Taenia saginata	Within a few minutes at 55^{0}C
Trichinella spiralis larvae	Quickly killed at 55^{0}C

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

Infection is spread by the hand to mouth transmission of eggs resulting from scratching the anus, as well as from breathing airborne eggs. In households with several members infected with pinworms, 92% of dust samples contained the eggs. The dust samples were collected from tables, chairs, baseboards, floors, couches, dressers, shelves, window sills, picture frames, toilet seats, mattresses, bath tubs, wash basins and bed sheets. Pinworm eggs have also been found in the dust from school rooms and school cafeterias. Although dogs and cats do not harbor pinworms, the eggs can get on their fur and find their way back to their human hosts. In about one-third of infected children, eggs may be found under the fingernails.

Pregnant female pinworms contain 11,000 to 15,000 eggs. Fortunately, pinworm eggs don't survive long outside their host. Room temperature with 30% to 54% relative humidity will kill off more than 90% of the eggs within two days. At higher summer temperatures, 90% will die within three hours. Eggs survive longest (two to six days) under cool, humid conditions; in dry air, none will survive for more than 16 hours.

A worm's life span is 37-53 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.[35]

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

One of the worst consequences of pinworm infestation in children is the trauma of the parents, whose feelings of guilt, no matter how clean and conscientious they may be, are understandable. However, if you're composting your manure, you can be sure that you are not thereby breeding or spreading pinworms. Quite the contrary, any pinworms or eggs getting into your compost are being destroyed.[36]

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, and 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 in favorable conditions. The larvae attach themselves to the human host usually at the bottom of the foot when they're walked on, then enter their host 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 20,000 eggs per day.

Hookworms are estimated to infect 500 million people throughout the world, causing a daily blood loss of more than 1 million liters, which is as much blood as can be found in all the people in the city of Erie, PA, or Austin, TX. 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 high temperatures of composting and the freezing temperatures of winter will kill the eggs and larvae (see Table 7.16). Drying is also destructive.[37]

WHIPWORM

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 3,000 to 10,000 eggs per day. Larval development occurs outside the host, and in a favorable envi-

Table 7.16

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.

ronment (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% of the population in certain tropical countries, are infected by whipworms. In the U.S., 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. Infection results from ingestion 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 -8^{0}C to -12^{0}C (17.6^{0}F to 10.4^{0}F) are fatal to the eggs, as are the high temperatures of thermophilic composting.[38]

ROUNDWORMS

Roundworms (*Ascaris lumbricoides)* are fairly large worms (10 inches in length) which parasitize the human host by eating semi-digested food in the small intestine. The females can lay 200,000 eggs per day for a lifetime total of 26 million or so. Larvae develop from the eggs *in soil* under favorable conditions (21^{0}C to 30^{0}C/69.8^{0}F to 86^{0}F). Above 37^{0}C (98.6^{0}F), they cannot fully develop.

Approximately 900 million people are infected with roundworms worldwide, one million in the United States. The eggs are usually 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.[39] An analysis of 400,000 stool samples throughout the U.S. by the Center for Disease Control found *Ascaris* in 2.3% of the samples, with a wide fluctuation in results depending on the geographical location of the person sampled. Puerto Rico had the highest positive sample frequency (9.3%), while samples from Wyoming, Arizona, and Nevada showed no incidence of *Ascaris* at all.[40] In moist tropical climates, roundworm infection may afflict 50% of the population.[41]

Eggs are destroyed by direct sunlight within 15 hours, and are killed by temperatures above 40^{0}C (104^{0}F), dying within an hour at 50^{0}C (122^{0}F). Roundworm eggs are resistant to freezing temperatures, chemical disinfectants and other strong chemicals, but thermophilic 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 collect and thermophilically compost *all* fecal material. Therefore, it is very important when composting humanure to be certain that *all* children use the toilet facility and do not defecate elsewhere. When changing soiled diapers, scrape the fecal material into a humanure toilet with toilet paper or another biodegradable material. It's up to adults to keep an eye on kids and make sure they understand the importance of *always using a toilet facility.*

Fecal environmental contamination can also be caused by using raw fecal material for agricultural purposes. *Proper thermophilic composting of all fecal material is essential for the eradication of fecal pathogens.*

And don't forget to wash your hands before eating!

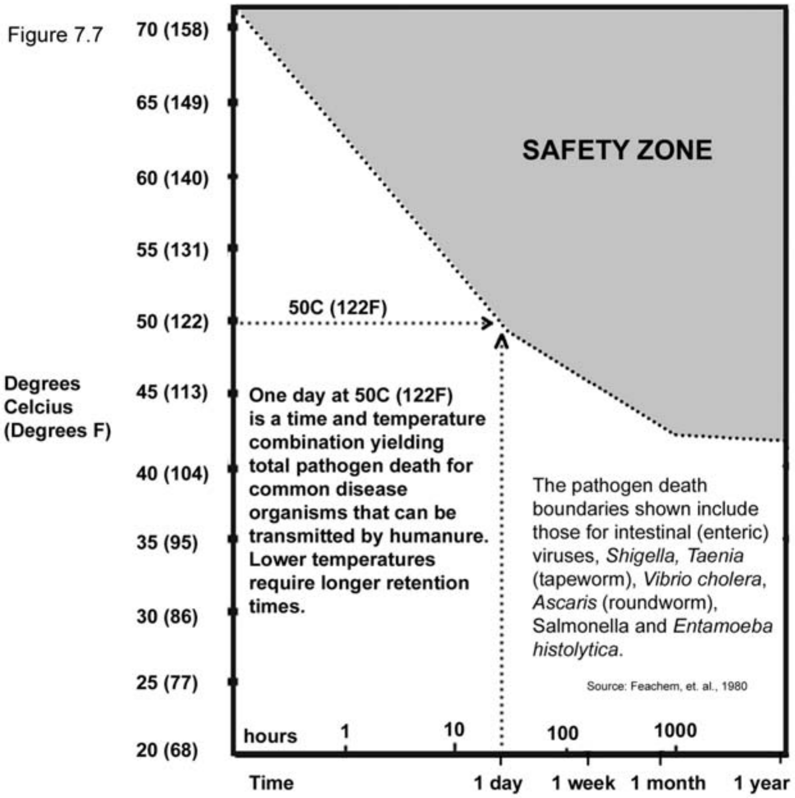
TEMPERATURE AND TIME

There are two primary factors leading 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 subsequent retention time needed for the destruction of pathogens. Given enough time, the wide biodiversity of microorganisms in the compost will destroy pathogens by the antagonism, competition, consumption and antibiotic inhibitors provided by the beneficial microorganisms. Feachem et al. state that three months retention time will kill all of the pathogens in a low-temperature composting toilet except worm eggs, although Table 7.14 (also from Feachem) 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 destroy pathogens. One need not strive for extremely high temperatures such as 65°C (150°F) in a compost pile to feel confident about the destruction of pathogens. It may be more

Figure 7.7



One day at 50C (122F) is a time and temperature combination yielding total pathogen death for common disease organisms that can be transmitted by humanure. Lower temperatures require longer retention times.

The pathogen death boundaries shown include those for intestinal (enteric) viruses, *Shigella, Taenia* (tapeworm), *Vibrio cholera*, *Ascaris* (roundworm), Salmonella and *Entamoeba histolytica*.

Source: Feachem, et. al., 1980

realistic to maintain lower temperatures in a compost pile for longer periods of time, such as 50^{0}C (122^{0}F) for 24 hours, or 46^{0}C (115^{0}F) for a week. According to one source, *"All fecal microorganisms, including enteric viruses and roundworm eggs, will die if the temperature exceeds* 46^{0}*C (114.8*^{0}*F) for one week."* [42] Other researchers have drawn similar conclusions, demonstrating pathogen destruction at 50^{0}C (122^{0}F), which produced compost "completely acceptable from the general hygienic point of view." [43]

A sound approach to pathogen destruction when composting humanure is to thermophilically compost the toilet material, then allow the compost to sit, undisturbed, for a lengthy period of time after the thermophilic heating stage has ended. 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 one year that is normally recommended.

In the words of Feachem et al., *"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^{0}C/131^{0}F), hold it for a long time (one year), or feature some effective combination of time and temperature."* The time/temperature factor of pathogen destruction is illustrated in Figure 7.7.

In short, the combined factors of temperature and time will do the job of turning your turds into tomatoes — so you can eat them.

CONCLUSIONS

Humanure is a valuable resource suitable for agricultural purposes and has been recycled for such purposes by large segments of the world's human population for thousands of years.

However, humanure contains the potential for harboring human pathogens, including bacteria, viruses, protozoa and parasitic worms or their eggs, and thereby can contribute to the spread of disease when improperly managed or when discarded as a waste material. When pathogenic raw humanure is applied to soil, pathogenic bacteria may continue to survive in the soil for over a year, and roundworm eggs may survive for many years, thereby maintaining the possibility of human reinfection for lengthy periods of time.

However, when humanure is composted, human pathogens are destroyed and the humanure is thereby converted into a hygienically safe form suitable for soil applications for the purpose of human food production.

Thermophilic composting requires no electricity and therefore no coal combustion, no acid rain, no nuclear power plants, no nuclear waste, no petrochemicals and no consumption of fossil fuels. The composting process produces no waste, no pollutants and no toxic by-products. Thermophilic composting of humanure can be carried out century after century, millennium after millennium, with no stress on our ecosystems, no unnecessary consumption of resources and no garbage or sludge for our landfills. And all the while it will produce a valuable resource necessary for our survival while preventing the accumulation of dangerous and pathogenic waste.

Back to Chapter 6 Go to next chapter.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