Future Fertility

Transforming Human Waste Into Human Wealth

by JOHN BEEBY

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, the author and Ecology Action 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. It is the author's hope that this publication will increase the reader's understanding of the challenges and necessity of recycling human waste, so that one day soon we can return our urine and manure to the soil in a way that is safe and beneficial to the environment, the soil and each of us.

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A Brief Note on the Title

Future Fertility: Transforming Human Waste into Human Wealth describes the necessity of properly recycling human waste to maintain the fertility of food-producing soils. No agriculture system can be considered sustainable if the nutrients in human waste are not returned safely and effectively to the soil from which they came. Chemical fertilizers have served to replenish some, but far from all, of the nutrients lost to the soil when human waste is not recycled properly. These fertilizers are becoming increasingly expensive, less effective and, for many people, scarce. According to a May 1995 article in *Pacific Coast Nurseryman and Garden Supply Dealer*, United States is the largest importer of anhydrous ammonia, a chemical nitrogen fertilizer that is increasingly scarce on the world market. Furthermore, China, India and the United States, with their increasingly large populations, are all importers of chemical fertilizers. Organic fertilizers, in contrast to chemical fertilizers, generally contain a wider range of nutrients. However, chemical fertilizers and other products from nonrenewable petroleum are usually used to grow the crops and/or animals from which most organic fertilizers are produced. The fertilizer of the future, if we are to maintain fertile soils to grow our food, is the fertilizer we all possess -- human waste.

The title of this publication was originally *The Tao of Poo: Transforming Human Waste into Human Wealth*, but it has been changed because of legal considerations. Tao means the Way. Taoism, an ancient oriental philosophy, sees the universe as filled with opposites (day / night, good / bad, assertiveness / receptiveness, and so on). The Tao is the fluid, ever-changing balance between these opposites. By bringing the opposites into harmony in one's mind, one can see the true nature of things and live in balance with oneself, others and the environment as a whole. A. A. Milne's Winnie-the-Pooh seems to live these ideals, always in perfect balance with himself and whatever is going on around him. Poo (human manure), too, has its opposites, and hopefully soon we will recognize not only its negative aspects (smelly and full of disease-causing organisms) but its positive aspects as well (nutrient-rich, life-sustaining and soil-enhancing). By acknowledging its negative side and valuing its positive side, we Bears With Some Brains will hopefully learn to return our wastes simply and safely to the soil and live in healthy balance with the Earth.

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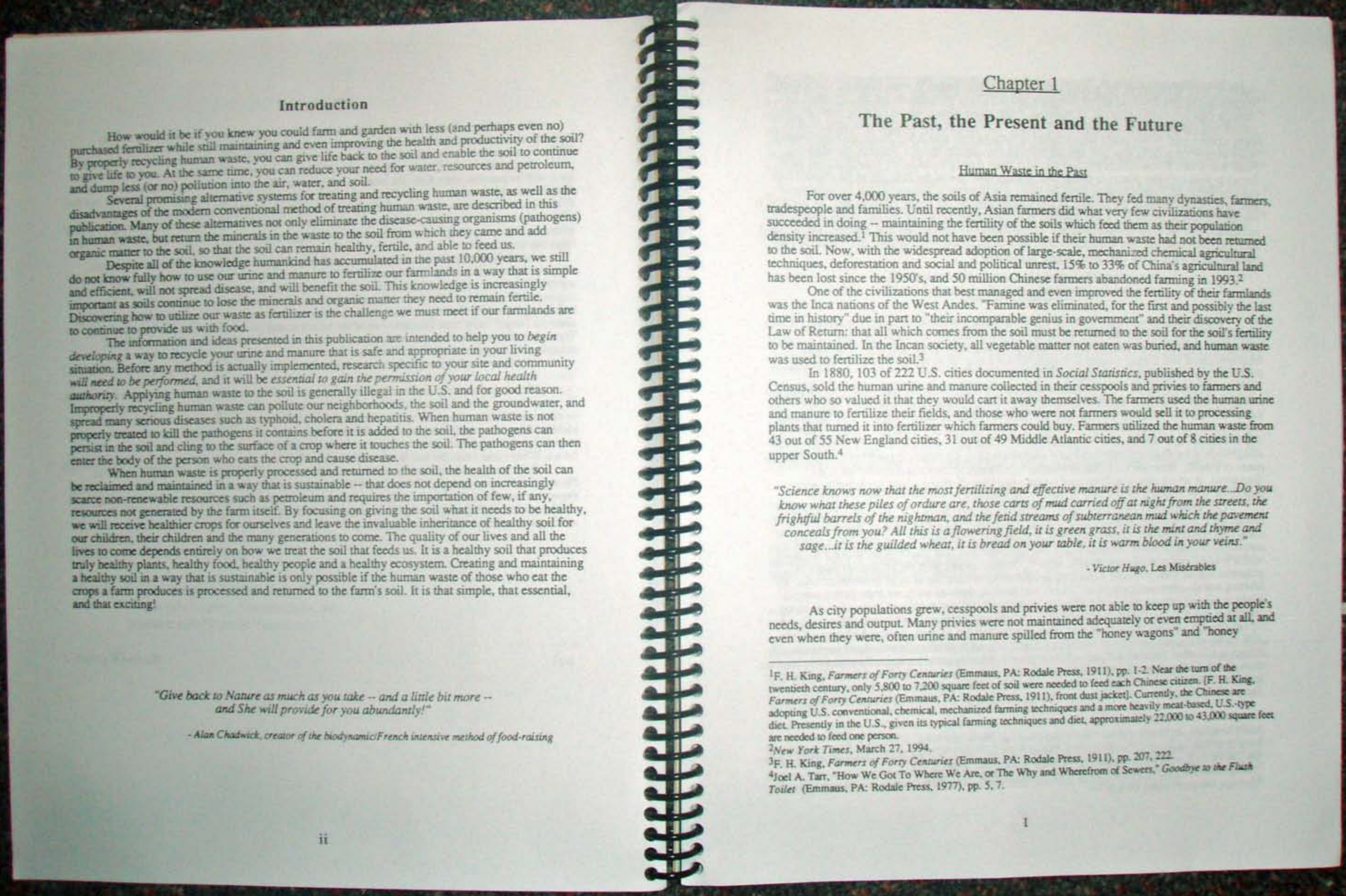

Introduction

How would it be if you knew you could farm and garden with less (and perhaps even no) purchased fertilizer while still maintaining and even improving the health and productivity of the soil? By properly recycling human waste, you can give life back to the soil and enable the soil to continue to give life to you. At the same time, you can reduce your need for water, resources and petroleum, and dump less (or no) pollution into the air, water, and soil.

Several promising alternative systems for treating and recycling human waste, as well as the disadvantages of the modern conventional method of treating human waste, are described in this publication. Many of these alternatives not only eliminate the disease-causing organisms (pathogens) in human waste, but return the minerals in the waste to the soil from which they came and add organic matter to the soil, so that the soil can remain healthy, fertile, and able to feed us.

Despite all of the knowledge humankind has accumulated in the past 10,000 years, we still do not know fully how to use our urine and manure to fertilize our farmlands in a way that is simple and efficient, will not spread disease, and will benefit the soil. This knowledge is increasingly important as soils continue to lose the minerals and organic matter they need to remain fertile. Discovering how to utilize our waste as fertilizer is the challenge we must meet if our farmlands are to continue to provide us with food.

The information and ideas presented in this publication are intended to help you to *begin developing* a way to recycle your urine and manure that is safe and appropriate in your living situation. Before any method is actually implemented, research specific to your site and community *will need to be performed*, and it will be *essential to gain the permission of your local health authority*. Applying human waste to the soil is generally illegal in the U.S. and for good reason. Improperly recycling human waste can pollute our neighborhoods, the soil and the groundwater, and spread many serious diseases such as typhoid, cholera and hepatitis. When human waste is not properly treated to kill the pathogens it contains before it is added to the soil, the pathogens can persist in the soil and cling to the surface of a crop where it touches the soil. The pathogens can then enter the body of the person who eats the crop and cause disease.

When human waste is properly processed and returned to the soil, the health of the soil can be reclaimed and maintained in a way that is sustainable -- that does not depend on increasingly scarce non-renewable resources such as petroleum and requires the importation of few, if any, resources not generated by the farm itself. By focusing on giving the soil what it needs to be healthy, we will receive healthier crops for ourselves and leave the invaluable inheritance of healthy soil for our children, their children and the many generations to come. The quality of our lives and all the lives to come depends entirely on how we treat the soil that feeds us. It is a healthy soil that produces truly healthy plants, healthy food, healthy people and a healthy ecosystem. Creating and maintaining a healthy soil in a way that is sustainable is only possible if the human waste of those who eat the crops a farm produces is processed and returned to the farm's soil. It is that simple, that essential, and that exciting!

> *"Give back to Nature as much as you take -- and a little bit more --*
> *and She will provide for you abundantly!"*
>
> *- Alan Chadwick, creator of the biodynamic/French intensive method of food-raising*

Chapter 1

The Past, the Present and the Future

Human Waste in the Past

For over 4,000 years, the soils of Asia remained fertile. They fed many dynasties, farmers, tradespeople and families. Until recently, Asian farmers did what very few civilizations have succeeded in doing -- maintaining the fertility of the soils which feed them as their population density increased.[1] This would not have been possible if their human waste had not been returned to the soil. Now, with the widespread adoption of large-scale, mechanized chemical agricultural techniques, deforestation and social and political unrest, 15% to 33% of China's agricultural land has been lost since the 1950's, and 50 million Chinese farmers abandoned farming in 1993.[2]

One of the civilizations that best managed and even improved the fertility of their farmlands was the Inca nations of the West Andes. "Famine was eliminated, for the first and possibly the last time in history" due in part to "their incomparable genius in government" and their discovery of the Law of Return: that all which comes from the soil must be returned to the soil for the soil's fertility to be maintained. In the Incan society, all vegetable matter not eaten was buried, and human waste was used to fertilize the soil.[3]

In 1880, 103 of 222 U.S. cities documented in *Social Statistics*, published by the U.S. Census, sold the human urine and manure collected in their cesspools and privies to farmers and others who so valued it that they would cart it away themselves. The farmers used the human urine and manure to fertilize their fields, and those who were not farmers would sell it to processing plants that turned it into fertilizer which farmers could buy. Farmers utilized the human waste from 43 out of 55 New England cities, 31 out of 49 Middle Atlantic cities, and 7 out of 8 cities in the upper South.[4]

> *"Science knows now that the most fertilizing and effective manure is the human manure...Do you know what these piles of ordure are, those carts of mud carried off at night from the streets, the frightful barrels of the nightman, and the fetid streams of subterranean mud which the pavement conceals from you? All this is a flowering field, it is green grass, it is the mint and thyme and sage...it is the guilded wheat, it is bread on your table, it is warm blood in your veins."*
>
> *- Victor Hugo*, Les Misérables

As city populations grew, cesspools and privies were not able to keep up with the people's needs, desires and output. Many privies were not maintained adequately or even emptied at all, and even when they were, often urine and manure spilled from the "honey wagons" and "honey

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[1] F. H. King, *Farmers of Forty Centuries* (Emmaus, PA: Rodale Press, 1911), pp. 1-2. Near the turn of the twentieth century, only 5,800 to 7,200 square feet of soil were needed to feed each Chinese citizen. [F. H. King, *Farmers of Forty Centuries* (Emmaus, PA: Rodale Press, 1911), front dust jacket]. Currently, the Chinese are adopting U.S. conventional, chemical, mechanized farming techniques and a more heavily meat-based, U.S.-type diet. Presently in the U.S., given its typical farming techniques and diet, approximately 22,000 to 43,000 square feet are needed to feed one person.

[2] *New York Times*, March 27, 1994.

[3] F. H. King, *Farmers of Forty Centuries* (Emmaus, PA: Rodale Press, 1911), pp. 207, 222.

[4] Joel A. Tarr, "How We Got To Where We Are, or The Why and Wherefrom of Sewers," *Goodbye to the Flush Toilet* (Emmaus, PA: Rodale Press, 1977), pp. 5, 7.

buckets" used to cart away the privies' contents. As people began to view diseases, specifically cholera and yellow fever, as social problems and not God's punishment for sin, demands for sanitary improvements increased. In response, many cities connected the existing water closets (which had replaced cesspools and privies) to their network of gutters and pipes used to carry away storm water. While storm water could run through city streets and be dumped into nearby waterways without difficulty, raw sewage running through city gutters polluted the cities and rivers into which it was discharged and spread disease among those living nearby. Cities were forced to look for other places to dump their sewage, and one of the first places they found was outlying farmland. Liquid sewage from the cities was dumped at one end of the "sewage farm" and, as it trickled through the sloping fields, was purified by the fields' crops so that, by the time it reached the end of the fields, it was claimed to be drinkable. However, by the 1890s, chemical, mechanical and bacterial sewage treatment technologies were developed that required less land and seemingly involved less risk to public health. As a result, sewage farms and other methods that returned the sewage to the land were largely abandoned.[5]

Human Waste Today

The flush toilet was born from the knowledge that human waste can cause disease. Unlike the Incans, we did not consider the Law of Return important, so, in general, we have not extensively pursued how to return the nutrients in human waste to the soil from which they originally came. We simply wanted to dispose of our waste. Only recently have we begun to realize the real costs of this short-sightedness.

After each flush of 1 to 7 gallons of drinkable water[6], our urine and manure move into the sewage system where they are purified to "primary", "secondary", and sometimes "tertiary" standards. Primary standards are met after the floatable trash has been removed from the sewage and the solids have settled out from the liquid as sludge. Secondary standards are met when the liquid is aerated and broken down by aerobic bacteria and then chlorinated to kill pathogens. The sludge undergoes anaerobic decomposition and generally is not further treated but dumped into an ocean or landfill. State law may require that the liquid meet tertiary standards before it is discharged, in which case it is floculated (vigorously stirred), filtered, and subjected to ozone, ultraviolet light, chlorine or bromine before it is discharged.[7]

Our sewage systems receive most everything we consider waste. This includes not only human urine and manure, but also toxic and cancer-causing chemicals such as pesticides, herbicides and fungicides that are carelessly dumped down the toilet or sink and heavy metal-containing industrial waste. Human waste, once a potentially rich source of fertility for the soils which feed us, is rendered toxic to soils once it has been mixed with the poisonous slurry of industrial toxins, heavy metals, pesticides and the other wastes our sewage systems contain. By labeling human urine and manure as "waste" and treating them as such, we transform potential assets to the soil into poisons and problems. Both the sludge and the liquid, even after meeting secondary and tertiary standards respectively, can still contain heavy metals and other toxic and cancer-causing substances, such as pesticides and herbicides, as well as some pathogens. Only 20% of the *sludge* we produce in the United States is used to fertilize farmlands or garden soils[8], though it still often contains dangerously high levels of heavy metals (especially cadmium, copper, zinc, nickel, lead and mercury) and other toxins that can endanger the health of the soil, the crops and those who consume the crops. The other 80% that is too poisonous for the soil usually is dumped into a landfill, in which case a wilderness and all of the creatures whose lives depend on

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[5] Carol H. Stoner, ed., *Goodbye to the Flush Toilet* (Emmaus, PA: Rodale Press, 1977), pp. 4-16.

[6] 40% of the pure water we use in our homes is flushed down the toilet (The Earth Works Group, *50 Simple Things You Can Do To Save the Earth* [Berkeley, CA: Earth Works Press, 1989], p. 48).

[7] Sewage plant personnel of Willits, CA, personal communication, April 1993.

[8] *Garbage*, January/February 1990, p. 31.

the health of that ecosystem may be destroyed, or into an ocean[9], in which case millions of sea creatures are poisoned with the toxins that find their way into sewage systems and are not removed by conventional treatment. All of the *liquid* produced from conventional treatment of our sewage is discharged into our rivers and oceans, along with the soluble toxins that conventional treatment could not remove. So despite being expensive, energy-inefficient, and sometimes malfunctioning and discharging nearly raw sewage into rivers and oceans, our most "advanced" sewage treatment plants, even when functioning properly, are unable to remove many toxins from sewage. And this is the least of their shortfalls!

The most important shortfall of modern sewage treatment is that it is depleting our soils -- it is agriculturally insustainable. Despite the increased popularity of the word "sustainability" in agriculture, we often forget that no system is truly sustainable if we take more from it than we give back. This simple guideline will help us evaluate the effect modern sewage treatment has on the sustainability of the soils that feed us.

Regardless of the method of human waste treatment,
the soil loses minerals and humus when it grows crops.

As crops grow in soil, they extract the minerals they need from the soil and incorporate them into their bodies. When the crops are harvested, the minerals they contain are removed from the soil. When we consume the crops, the minerals enter our bodies. Except when our bodies are growing, almost all of these minerals eventually pass out of our bodies in our urine and manure (and, to a much lesser extent, in our hair, nails, sweat, secretions and exhalations).[10] In order to maintain the fertility of the soil that produces our food, the minerals must be returned to the soil. They are essential for the metabolic processes and health of the various soil-dwelling creatures, which are in a large part responsible for the vitality and fertility of the soil.

Besides minerals, when soil is cultivated and/or the microbial life in the soil is active, the soil also loses humus. To understand what humus is, why it is so important and why it must be replenished, we need first to differentiate *humus* from *organic matter* and *cured compost*.

What is organic matter? Organic matter is any naturally occurring plant or animal matter once living that is now dead. A compost pile, in short, is simply a pile of organic matter possibly mixed with a little soil and water. After the pile is built, with the right amount of air and water, the microbes in the pile begin to decompose the organic matter. During the process of decomposition, the compost pile will cure to 1/2 to 1/3 its initial volume.[11] When the original material is fully decomposed and mature, it is called cured compost. Cured compost is what is added to the soil to restore and maintain its fertility.

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[9] The Ocean Dumping Ban Act of 1988 prohibits U. S. cities from dumping their sewage sludge (but not the liquid) into the ocean. Worldwide, however, only a small percentage of the sewage even enters sewage systems where treatment is possible, and the rest, raw and teeming with pathogens, simply goes directly into rivers, ponds, oceans or onto the land. So even if all conventional treatment plants were improved so that they could consistently remove all toxins and pathogens from sewage, most of the human waste generated worldwide would still continue to enter and pollute rivers, oceans and groundwater (The World Resources Institute, *World Resources 1990-91* [New York: Oxford University Press, 1990], p. 183).

[10] Dan Hemenway, "To Pee or Not to Pee," *The Permaculture Activist*, August 1992, p. 48.

[11] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 42) and John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7. Current data from compost piles made at the Common Ground Biointensive Research Mini-Farm indicate some piles may decompose to *as little as* 1/6 their original size. Two conditions will result in less cured compost produced from the same volume of initial compost: 1) The initial carbon-to-nitrogen ratio is less than 30 to 1; and/or 2) if the pile is turned more than once to speed decomposition.

What makes cured compost so essential for soil fertility? Not only is the organic matter decomposed as the compost pile matures, but some of it is actually transformed into a new substance called humus. Like alchemy, "lead" (organic matter) is turned into "gold" (humus) by the action of decomposing organisms such as bacteria, fungi and worms. Not all organic matter is transformed, so not all cured compost is humus, but it is humus that makes cured compost so valuable and essential to the health of the soil.

What is humus? Humus is a complex *synthesis* of living and dead microorganisms, decomposed organic matter, and minerals in an inorganic state.

Why is humus important? Humus is essential for the fertility of the soil.

1) Humus is an *energy source* for soil microbes which are able to improve the soil's structure and indirectly make unavailable nutrients available to plants.
2) Humus *adds nitrogen and other important major and minor minerals* to the soil.
3) Humus *prevents* those minerals already in the soil, especially nitrogen, from leaching out.
4) Humus *holds water* like a sponge, increasing the amount of water the soil can store, which in effect decreases the amount of irrigation water the soil needs to produce healthy crops.
5) Humus *releases the minerals and water slowly*, making them available to the plants over a relatively long period of time.
6) Humus *buffers the pH of the soil*, allowing acid-loving plants to grow in slightly alkaline soil and alkaline-loving plants to survive in slightly acidic soil.[12]

Humus is constantly being lost from the soil over time. To maintain and improve the health of the soil, humus in the form of cured compost must be added to agricultural soil at least annually. In order to generate enough humus, the inedible portions of crops and our urine and manure must be allowed to decompose and be transformed into humus. Ideally, when the cured compost is added to the soil, the minerals and humus lost from the soil will be replenished. This will be expanded upon on pages 12-19.

Instead of returning the minerals that are contained in our urine and manure to the soil, we currently dump the minerals along with our waste into the ocean, a landfill or simply a hole in nonagricultural soil. Not only are the minerals not returned to the soil from which they came, but they also cannot be composted and transformed into life-giving humus for the soil upon whose fertility our lives depend. We break the cycle of giving and receiving that life requires for its continuation. We cannot continue to live on this planet if we do not recycle and reuse the planet's precious resources. What comes from our farms must be returned to them if we want our farms and ourselves to survive.

The way that we break the Law of Return and the consequences we suffer for doing so are worthy of a closer look. We use scarce water, resources, energy and money to transport, process and get rid of our manure and urine which contain nutrients that originated in the soil. Rather than returning these nutrients to the soil, we throw them away, and in the process, we throw away the past and future fertility of our soils. Then, after throwing away our natural fertilizers containing a wide range of nutrients and trace minerals, we use more resources, energy and money to make incomplete chemical fertilizers from increasingly scarce fossil fuels that are unable to fully replenish the soil's supply of minerals and humus. A lot of time and energy is spent to create a system that is not sustainable. The dependence on a nonrenewable, increasingly scarce, and environmentally-polluting source of energy like petroleum is, in itself, enough to warrant our search for alternative, sustainable ways to process our sewage.

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[12] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 45.

> *"If I urinated and defecated into a pitcher of drinking water and then proceeded to quench my thirst from the pitcher, I would undoubtedly be considered crazy. If I invented an expensive technology to put my urine and feces into my drinking water, and then invented another expensive (and undependable) technology to make the same water fit to drink, I might be thought even crazier. It is not inconceivable that some psychiatrist would ask me knowingly why I wanted to mess up my drinking water in the first place.*
>
> *"The 'sane' solution, very likely, would be to have me urinate and defecate into a flush toilet, from which the waste would be carried through an expensive sewerage works, which would supposedly treat it and pour it into the river -- from which the town downstream would pump it, further purify it, and use it for drinking water."*
>
> *- Wendell Berry, Introduction to* The Toilet Papers *by Sim Van der Ryn*

Human Waste in the Future

Once our waste is properly processed and purified of the pathogens it may contain, we can safely use it to fertilize our farmlands. We can turn the problems we have created into the solutions for sustainable soil fertility. On the basis of its mineral content, the fertilizing potential of human waste is substantial (see Table 1 on page 9). When we consider that the minerals in human waste can be used to produce mineral-containing humus for the soil, we can see the key role properly recycling human waste plays in maintaining the sustainability of the soil. Human waste no longer is something to get rid of as quickly as possible; it is a key to the continuation of humankind.

Although our cities are cleaner, and our life spans on average have increased largely as a result of improved sanitation and developments in sewage treatment technology, there are means other than the construction and operation of a conventional sewage treatment plant that can better realize these important social achievements. Alternative treatment processes exist that require fewer resources, no landfills and no poisonous chemicals, and they may be able to increase rather than decrease the fertility of our agricultural soils. Rather than spending money to discard our waste, we can earn money from selling this processed waste to increase the fertility of the soil. This soil, in turn, will produce more and healthier food for market. As we create healthier soil that produces healthier food, we can not only maintain but *improve* our present level of sanitation and health. Most importantly, we can pass on healthy soil and the knowledge and skill necessary to keep it healthy to our children and the generations to come.

If towns and cities need to upgrade or expand their sewage treatment facilities, the adoption of sustainable, environmentally-sound methods to treat and recycle human waste needs to be encouraged over the construction of larger conventional treatment plants (see pages 44-45 which describe the alternative system which the people of Arcata, California, encouraged and which was finally approved by the state). If no alternative system seems appropriate for your living situation and climate, you can begin considering and designing one that is. Returning human waste to the soil, by a method described in this booklet or by any other method, is generally and understandably *not legal* on an individual or community basis due to the general lack of public knowledge about the health risks involved and the skill required to overcome them. But once we fully develop safe, easy ways to fertilize the soil sanitarily with processed human urine and manure, we may find it necessary to change the laws in order that we can maintain the fertility of the soil sustainably.

Human Waste Recycling and the Appropriateness of Biointensive Food-Raising

Probably Sufficient Nutrients Are Present in One Person's Human Waste to Sustain Soil Fertility if High Biointensive Yields Are Obtained -- As shown in Table 1, the amounts of nitrogen, phosphorus, potassium and calcium that are contained in human urine and manure, if applied at the *low* application rates with additional cured compost, if necessary, can be nearly or totally sufficient to fertilize the approximate area needed to grow all the food (calories; see Note for Table 2 on page 9) needed by one person annually in a way that maintains the fertility of the soil if *high* (*How To Grow More Vegetables*, pages 70-97, column E, third figure) Biointensive yields can be produced (see Table 2). *This is a remarkable and significant correlation which seems to suggest the appropriateness of scale of Biointensive food-growing.*

Insufficient Nutrients Are Present in One Person's Human Waste to Sustain Soil Fertility When Conventional Agricultural Techniques Are Used -- If, instead of Biointensive techniques, commercial, chemically-dependent, mechanized agricultural techniques are used to grow a vegetarian diet that includes all of the calories one person needs for all year, 2.5 to 5 times more area is needed.[13] There are *not* enough nutrients in the urine and manure to maintain the fertility of the additional land needed. So even if human urine and manure are recycled in full, if commercial techniques are employed, the farm still would require purchased fertilizer and be dependent on petroleum or the fertility of another farm's soil (see page 24).

Possibly Sufficient Nutrients with Mid-Range Biointensive Yields -- If *high* Biointensive yields are not obtained, it is still possible that the fertilizing ability of human urine and manure, with additional cured compost, if necessary, is sufficient for the area needed to grow one person's diet when *mid-range* Biointensive yields are produced, for three reasons. *First*, the fertilizer application levels listed in Table 1 are needed for *conventional chemical* agriculture, which usually relies on a large amount of added nutrients for productivity. Further, *conventional chemical* agriculture does not add sufficient cured organic matter to the soil for the most effective pick-up of nutrients by the plants and for the retention of surplus nutrients in the soil. Organic matter is essential for holding nutrients in the soil and allowing the soil to act as a nutrient reservoir for crops. If insufficient amounts of cured organic matter are added to the soil, the soil can hold fewer nutrients, and more nutrients must be added annually to ensure crop production. With Sustainable Biointensive Mini-Farming, the soil becomes a deep nutrient reservoir, and less fertilizer can be added annually while crop yields are maintained and increased.

Second, yields produced by Sustainable Biointensive Mini-Farming generally increase steadily over time until a maximum level is reached even though the quantities of fertilizers applied annually stay the same or decrease. (The maximum yield level depends on the type and fertility of the soil, the climate, the resources available and the plants being grown.) This increase occurs because as the organic matter level of the soil is increased: 1) fewer nutrients are lost from the soil, and 2) the nutrients in the soil are utilized by the plants more efficiently. Therefore, the soil's fertility may be increased, so that eventually high yields can be produced, assuming the proper climate and sufficient water for the crops being grown.

Third, if the growing climate is such that even the increased soil fertility only allows for the production of *mid-range* Biointensive yields, more land will be needed to grow one person's diet compared to the amount of land needed when high Biointensive yields are produced. If more land is needed, then the nutrients from human waste must be spread over a greater area, and may be insufficient to maintain yields and soil fertility. However, if mid-range Biointensive yields are produced, the nutrients contained in one person's urine and manure may be sufficient to maintain soil productivity if the crops grown for the diet are selected to reduce the amount of land needed.

The amount of land needed to grow one person's diet can be *reduced* through the use of potatoes and/or sweet potatoes in addition to grains in the diet. Potatoes and sweet potatoes generally produce many more calories per unit of area than grains. (See David Duhon's *One Circle* for more details.) However, these crops (and root crops in general) do not produce organic material that can be composted and returned to the soil. Therefore, approximately one to two times the area growing potatoes and/or sweet potatoes is needed to grow sufficient carbonaceous crops in order to maintain the organic matter level of the soil that grows the root crops *and* the soil that grows the carbonaceous crops. The total amount of land needed when some potatoes and/or sweet potatoes and sufficient carbonaceous crops are grown is less than the amount needed when only grains are produced. When the amount of land needed to grow one person's food is reduced, the amount of nutrients from human waste that can be added per unit of area increases, so that the fertilizing potential of the person's urine and manure may be adequate to maintain the health and productivity of the soil.

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[13] 10,000 square feet are needed to grow a vegan diet for one person with conventional agriculture (Kenneth E. F. Watt, *The Titanic Effect* [Stamford, CT: Sinaur Associates, 1974], p. 41). 2,000 to 4,000 square feet are needed when the Biointensive method is used.

Lack of experience, an unimproved, less fertile soil, and/or difficult climatic conditions can result in the production of *low/beginning* Biointensive yields. The nutrients in one person's annual output of urine and manure are generally insufficient to adequately fertilize and maintain the fertility of the additional land (approximately double that needed when mid-range yields are produced) needed to grow one person's annual diet when low/beginning Biointensive yields are produced. However, returning the nutrients in human waste safely and efficiently to the soil from which they came will ensure that these nutrients (except those lost through leaching and/or gasification) will be available for future crops. Further, with the production of compost crops and cured compost, the nutrients in human waste can improve the fertility and productivity of the soil over time, which can allow the annual diet to eventually be raised in a smaller area. Generally, in most soils and under most climatic conditions, mid-range Biointensive yields can be produced in a reasonable amount of time after one's skill and soil have improved.

In conclusion, *Biointensive mini-farming has the potential to transform scarcity into abundance*. With conventional farming practices, there are not enough nutrients in one person's human waste to maintain the fertility of the soil needed to grow that person's food because the nutrients are spread over too large an area and insufficient amounts of organic matter are added to the soil. With Biointensive practices, there can be enough nutrients in one person's human waste to maintain the fertility of the soil needed to grow that person's food. *Less becomes more* depending simply on *how* the land is used. From this perspective, it is no wonder that the Chinese for at least 4,000 years, and many generations of other peoples around the world, chose to farm using techniques very similar to modern Biointensive techniques and were able to sustain the soil and themselves.

With Biointensive mini-farming, the same amount of nutrients in human waste can be sufficient even though they are insufficient when conventional agricultural techniques are used. Similarly, with Biointensive mini-farming, the amount of arable land in the world can be enough to feed us in situations where there is not enough land when conventional food-growing techniques are used. Biointensive mini-farming makes possible 2 to 6 times the yield per unit of area compared to conventional chemical and organic agriculture, dramatically reducing the amount of land needed to feed us. As the amount of arable land available per capita decreases worldwide as population and land degradation increase (see Appendix D: The Circle Chart on pages 159-160), the ability to grow one's food and other agricultural needs on a small area becomes increasingly important.

What Is Sustainable Biointensive Mini-Farming?

Sustainable Biointensive Mini-Farming is a method of growing food, based on sophisticated principles dating back 4,000 years in China, 2,000 years in Greece, and 300 years in Europe. Sustainable Biointensive Mini-Farming was developed from a system called "the Biodynamic/French intensive method," which was synthesized and brought to the United States by the English master horticulturalist, Alan Chadwick, in 1967. Ecology Action has simplified this approach and termed the method Sustainable Biointensive Mini-Farming. The most important aspects of the method are:

Double-Dug, Raised Beds

In Sustainable Biointensive Mini-Farming, crops are planted in beds that are "double-dug" – loosened to the depth of 24 inches, which creates a "raised-bed" effect. This loose soil enables plant roots to penetrate easily and allows air, the most important element for healthy plant growth, to enter the soil. Moisture is retained without "waterlogging", weeding is simplified because of the looseness of the soil, and erosion is minimized.

Intensive Planting

Seeds or seedlings are planted in 3- to 5-foot-wide beds using a hexagonal spacing pattern. Each plant is placed the same distance from all plants nearest to it so that when the plants mature, their leaves touch. This provides a "mini-climate" under the leaves which retains moisture, protects the valuable microbiotic life of the soil, retards weed growth, and provides for higher yields. The method avoids the problems encountered when planting in narrow rows.

Composting

The high yields made possible by intensive planting would not be sustainable without a way of recycling all of the soil's nutrients and maintaining the soil's organic matter level. Chemical fertilizers, derived from increasingly scarce and expensive petroleum, generally do not replenish all of the nutrients lost from the soil when crops are grown, leading to a loss of quality and nutritional value of future crops grown. Also, chemical fertilizers have been shown to be less effective over time, damaging soil structure, soil microbial life and long-term soil fertility.

Sustainable Biointensive Mini-Farming avoids these problems through the composting and recycling of organic materials such as crop residues, manure and vegetation produced by the mini-farm and farmer themselves. When these materials are properly composted, they are transformed into humus which provides the elements necessary to maintain the fertility of agricultural soil (as described on page 4).

Companion Planting

Research has shown that many plants grow better when near certain other plants. Green beans and strawberries, for instance, thrive when they are grown together. Some plants are useful in repelling pests, while others attract beneficial insect populations. Borage, for example, helps control tomato worms while its blue flowers attract bees. Also, many wild plants have healthy effects on the soil; for example, their deep roots loosen the subsoil and bring up previously unavailable trace minerals and nutrients.

A Whole Food-Raising Method

Sustainable Biointensive Mini-Farming is a *whole system*, and the components of the method must all be used together for the optimum results. Merely spacing crops closer together, for example, is not enough. Farmers experimenting with such intensive spacing in Europe, while not using deep soil preparation and companion planting and still employing chemical fertilizers, find themselves beset with decreasing productivity and soil fertility.

Sustainable Biointensive Mini-Farming, used as a whole system, is able to maintain and even increase the health of the soil, while producing yields that are generally 2 to 6 times those of mechanized chemical or organic agriculture and using 67% to 88% *less* water, 50% to 100% *less* purchased fertilizer and 99% *less* energy.

For more information on Sustainable Biointensive Mini-Farming, see:

- John Jeavons. *How To Grow More Vegetables*. Berkeley, CA: Ten Speed Press, 1991, 175 pp.
- John Jeavons and Carol Cox. *Lazy-Bed Gardening*. Berkeley, CA: Ten Speed Press, 1992, 118 pp.

and write for a catalog to:

- Bountiful Gardens, 18001 Shafer Ranch Road, Willits, CA 95490.

Table 1
The Fertilizer Potential of Human Waste

Pounds Produced Per Person Per Year[14]

	Nitrogen	Phosphorus	Potassium	Calcium
Urine	7.5	1.6	1.6	2.3
Manure	2.8	1.9	0.8	2.0
Total	10.3	3.5	2.4	4.3

Range of Pounds a Garden Requires Per Year Per 100-Square-Foot Bed[15]

Nitrogen	Phosphorus	Potassium	Calcium
0.1 - 0.5	0.2 - 0.6	0.15 - 0.5	0.2 - 0.8

Range of Square Feet One Person's Urine and Manure Can Fertilize Each Year

	Nitrogen	Phosphorus	Potassium	Calcium
Urine	1,500 - 7,500	266 - 800	320 - 1,067	287 - 1,150
Manure	560 - 2,800	316 - 950	160 - 533	250 - 1,000
Total	2,060 - 10,300	582 - 1,750	480 - 1,600	537 - 2,150
	(20.6 to 103 beds)	(5.8 to 17.5 beds)	(4.8 to 16 beds)	(5.4 to 21.5 beds)

Table 2
Approximate Area Needed with Biointensive Yields to Grow...

	a Complete Diet for One Person	a Complete Diet for One Person - *and* Maintain the Fertility of the Area's Soil Sustainably by Producing Enough Humus for the Area on a "Closed System" Basis (described in Chapter 2)
Low/Beginnning Yields	4,000 sq. ft. (40 beds)	8,000 sq. ft. (80 beds)
Mid-Range Yields	2,000 sq. ft. (20 beds)	4,000 sq. ft. (40 beds)
High Yields	1,000 sq. ft. (10 beds)	2,000 sq. ft. (20 beds)

Note for Table 2: Calories are the most difficult nutritional requirement to grow in a small space[16]; in general, once the caloric requirement is met, the protein requirement will also be met for that person.[17] All of the vitamins and minerals one person needs annually can be typically grown in a single Biointensively managed bed.[18] Since a person's caloric requirement is the most difficult one to meet in a small area, the extent to which this requirement is met by each of the food-raising systems described in this book will be discussed.

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[14] Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956), p. 35; and Philip L. Altman and Dorothy Dittmer, eds., *The Biology Data Book Vol. 3*, 2nd ed. (Bethesda, MD: American Societies for Experimental Biology, 1974), pp. 1496-1503. The exact quantities of minerals in human urine and manure can vary more than two-fold between individuals due to differences in their diets and lifestyles. The above figures are based on the average amounts of minerals in human urine and manure.

[15] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 23. Adapted from 1978 La Motte soil test instructions. This range is a broad generalization. The exact amount needed depends on the condition of the soil. See Appendix C: Further Discussions #1 and #3.

[16] David Duhon, *One Circle* (Willits, CA: Ecology Action, 1985), p. 32.

[17] Exceptions to this rule of thumb are diets that consist of only one or possibly two staples for calories.

[18] Based on data from actual field-produced yields presented by John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 70-97.

Chapter 2

The Four Goals of Recycling Human Waste

1) Purification
2) Production of Sufficient Humus
3) Return of Minerals
4) Proper Nitrogen Application

For any method of food-raising to be sustainable, human waste must be returned to the soil producing the food in a way that achieves these four goals. The goals are listed in order of importance, but all must be achieved if the soil is to remain fertile.

Goal #1

Purification of Human Waste

Human manure generally contains more human pathogens than human urine. Pathogens are extremely small life-forms such as bacteria, viruses and parasitic worms that cause cholera, typhoid, hepatitis and many other diseases when they are able to live within a human body. Most pathogens cannot be removed through any method of filtration or sifting. The following agents can be used to destroy pathogens:

- Heat
- Desiccation
- Lack of air
- Competition / consumption by other organisms
- Time outside of the human body
- Chemicals

While 100% destruction of the pathogen population is ideal before human waste is handled and returned to food-raising soil, some percentage less than 100% may be acceptable depending on the method of returning the processed waste to the soil, the resistance of the person handling the processed waste, the ability of the pathogens to survive and multiply in the soil, and the number of pathogens necessary to cause disease.[19] *An actual percentage can only be determined through extensive scientific testing of the processed waste, a procedure that is generally unavailable to most people in the world. In the later chapters on recycling human urine and manure, the scientifically proven and accepted criteria are given that must be met before the processed waste can be considered safe to handle and add to food-producing soil. (Domestic cat and dog waste may contain human pathogens and must be treated to meet the same purification requirements that human waste must meet before it should be added to soil producing food for humans.)*

It is often supposed that the waste from a person who eats a vegetarian diet (which includes eggs and dairy products), a vegan diet (which includes no animal products) or a raw foods diet (which may or may not be vegetarian but includes no cooked food) contains fewer pathogens than the waste from one who eats an average American diet, and therefore does not need to be subjected to the same rigorous processes of purification. While there are many benefits to the diets mentioned above, it is unlikely that one of those benefits is the production of "clean" urine and manure. Strict adherence to the purification of all waste before adding it to food-raising soil (regardless of the diet of the person who produced it) is essential to avoid risking the health of yourself, your family, your community and the soil.

If none of the above agents are used to destroy the pathogens in human waste, adding unprocessed human waste to the soil producing human food is a sure way to spread disease. Although human urine and manure account for one-third of China's fertilizers and have been used for many centuries to fertilize China's farmlands, they are often applied *fresh* to the soil. As a result, many diseases which are transmitted through human waste are common in China. Local people may acquire immunity or tolerance to some of the pathogens, but many of the other diseases transmitted through human waste cause severe debilitation and even death.[20]

Two methods, "Trees" and "Grains and Perennials," are described in this book in which human manure is added fresh to the soil and purified with time and the action of soil organisms. While the soil could eventually be worked safely, it might be that the crops produced still are not safe to eat. It has been shown that plants can take in the nutrients they need by directly absorbing large molecules, a process called endocytosis.[21] However, according to Dr. Lawrence Fowke, a cell biologist and professor in the Department of Biology at the University of Saskatchewan who has extensively researched the endocytotic pathway in plants, and Dr. Lewis Feldman, a professor in the Department of Plant Biology at the University of California, Berkeley, it is unlikely that organisms as large as even the smallest human pathogens, viruses, are able to pass through the cell walls of plants.[22]

The crops also may not be safe to eat if the human waste has been mixed with heavy metals and other toxins before it is applied to the soil. The heavy metals can be taken up by the crops, making the crops poisonous to humans. Progress on purifying human waste of these contaminants has been made through the use of water plants, though further research is needed before these systems are fully sustainable (see pages 44-49).

Even if the human waste is purified of its pathogens and free of industrial or household toxins, Dr. Rudolf Steiner, the Austrian scientist, philosopher and mystic and the originator of the biodynamic method of farming, felt that human waste still should not be used to directly fertilize crops for human consumption. Since the source of Steiner's information on human waste was his intuition, scientific proof for his statements is currently unavailable. While many of Steiner's statements have been proven accurate, this publication considers that human urine is valuable and usable for food-raising soil despite Steiner's warning. Furthermore, Steiner's criterion for human manure purification is not included in the criteria this book recommends that human manure must meet before it can be safely applied to soil growing human food.[23]

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[19] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage [Grey water] Management -- A State of the Art Review* (Washington, D.C.: World Bank, 1981), pp. 33-39.

[20] H. I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* (Washington, D.C.: World Bank, 1981), p. i.

[21] Dr. Lawrence C. Fowke, et al., "Ultrastructure of the endocytotic pathway in plants," *Endocytosis, Exocytosis and Vesicle Travel in Plants*, ed. C. R. Hawes, et al., Society for Experimental Biology Seminar Series 45 (New York: Cambridge University Press, 1991); more references, electron microscopy photographs and a detailed explanation in support of the endocytotic process in plants in Bargyla and Gylver Rateaver, *The Organic Method Primer*, Update Special Edition (San Diego, CA: The Rateavers, 1993), pp. 21-27.

[22] Dr. Lawrence C. Fowke, personal communication, November 24, 1993; and Dr. Lewis Feldman, personal communication, December 13, 1993.

[23] According to Steiner, the pathway through which the nutrients in human manure must travel is: "human - plant - animal - plant - human." In other words, human manure should be used to fertilize soil that grows food for animals.

Any system of human waste processing must prevent flies, mosquitoes and other vectors (animals, often insects, that transmit infection from person to person or from animal to person) from contacting the human waste and spreading disease. Therefore, in all systems, the human waste storage container must be sealed so that no insects can enter. When human waste is composted, creating a barrier between the vectors and the compost pile is necessary and is described in more detail in the section, "Composting Human Urine".

The entire process of returning human waste to the soil, including its collection and transportation, must be done sanitarily in order to prevent the transmission of disease, since pathogens from the waste of one person can enter the mouth of another *before*, as well as after, the waste is added to the soil. While improving sanitation conditions within a community generally causes a decrease in the incidence of human waste-transmitted diseases, it can also cause some surprising and severe repercussions. As an example, in a community with poor sanitation, almost all of its members are exposed to certain diseases early in childhood and acquire immunity against these pathogens. With improved sanitation, it is possible that fewer people will acquire immunity and may suffer more serious effects if they become infected later in life. Poor sanitation is certainly not the best way to acquire immunity and ensure the health of the community, but it is important to acknowledge and weigh all of the possible effects a change in sanitation practices may bring.

Goal #2

Production of Enough Humus with the Nutrients in Human Waste to Replenish the Supply Lost from the Soil

As described earlier, humus is essential for the fertility of soil. Enough humus must be generated with the nutrients in human urine and manure so that the humus can be added to the soil to fully replenish the soil's supply and maintain its fertility.

It would seem that if we properly process our human waste and return it to the soil, all of the minerals and humus lost from the soil when our food crops were grown would be replenished. While this may be true in terms of minerals, it is not true in terms of the humus.

Carbon and nitrogen are essential for the production of humus. If all of the nitrogen and carbon that we consumed remained in our waste, then we might be able to generate enough humus to fully replenish the soil's supply by simply allowing our waste to decompose and be transformed into humus. *However, we breathe.* Because we breathe, most of the carbon in the food does not appear in our waste. Rather, it escapes into the air as carbon dioxide with every exhalation we make. Furthermore, organisms in the soil and compost pile, as well as the roots of plants, also exhale carbon dioxide. So continuously, carbon, in the form of carbon dioxide, is being lost from the soil.

If a system is to be sustainable, nothing can be lost and not replenished. The way this carbon can be reclaimed and returned to the soil is by growing plants. Plants absorb carbon dioxide from the air in the process of photosynthesis and incorporate some of the carbon in their bodies.

The manure from these animals then could be used to grow crops for human consumption. (Rudolf Steiner, *Spiritual Foundations for the Renewal of Agriculture: A Course of Lectures Held at Koberwitz, Silesia, June 7 to June 16, 1924* [Kimberton, PA: Bio-Dynamic Farming and Gardening Association, 1993], p. 250.) If human manure does not travel through this pathway (or perhaps a more complex pathway if farm animals are unavailable) but is used directly to fertilize crops for humans, Steiner believed that later generations of those who eat the crops may have brain damage and nervous disorders. An example of an animal that naturally avoids eating crops fertilized with its own manure is the cow. Though the grass fertilized by the cow's manure may be greener, the cow will avoid it. (Dr. William A. Albrecht, *The Albrecht Papers*, Charles Walters, Jr., ed. [Raytown, Missouri: Acres U.S.A., 1975], p. 170.) The reason for this avoidance may be due in part to the grass containing toxic levels of nitrate.

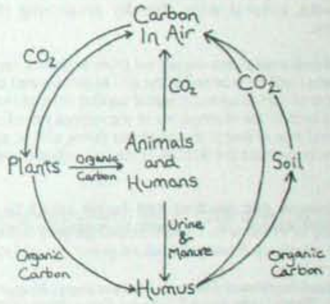
According to Steiner, lavatory fluid [which includes human urine] should never be used as a fertilizer, no matter how well processed or aged it is. (Dr. Rudolf Steiner, *Agriculture*, "Supplement" [London: Bio-Dynamic Agriculture, 1974], p. 167, and Craig Siska, personal communication, September 23, 1993.)

When the plants are composted, some of the carbon in their bodies is transformed into humus (some is also returned to the air as carbon dioxide from the exhalations of the organisms in the compost pile, as mentioned above).

Plants that are especially productive storers of carbon are wheat, rye, corn and amaranth, among others. Carbonaceous plants usually are tall with rigid stems when they are mature. Look at the wild and cultivated plants around you to discover which might be good candidates for carbonaceous compost material.

Figure 1

The Carbon Cycle Simplified



The most important plants we can grow with the nutrients in human waste are plants which are carbonaceous. In order to achieve *Goal #2, the production of sufficient humus with the nutrients in human waste,* we need to produce carbonaceous plants that can be combined with the nitrogen-rich human waste so that they can decompose together and produce enough humus to fully replenish the humus lost by the soil when it grew food. *If we do not grow carbon, the soil upon which our lives depend will become depleted of organic matter and humus.* Consequently, the soil will be less able to retain nutrients and support a healthy population of soil microorganisms, and will be more vulnerable to wind and water erosion. If the overall health of the soil is allowed to decline, the soil will produce less healthy food and we who depend on the soil's vitality will become less healthy.

In fact, depletion of the organic matter of soils worldwide has occurred and continues to occur. This is especially true for soils of farms managed with commercial U.S. agricultural techniques -- such soils often have an organic matter level as low as 0.5 to 1% (4 to 6% is the goal for optimum soil and plant health). Over the past 100 years, 50% of the organic matter originally in

Midwestern soil has been lost.[24] Declines in soil organic matter levels were largely the cause of the tragic American Dust Bowl in the 1930's. Preventable soil loss through erosion that results from a lack of soil organic matter continues today. Alarmingly, the amount of soil lost annually to erosion in the United States today is approximately *six pounds for every one pound of caloric food produced.*[25] One estimate stated that, by 1989, the United States had lost 75% of its agricultural topsoil.[26]

A major reason for the loss of organic matter is that sufficient amounts of cured compost have not been produced or added to farmland soil, because the size of the farm has made it economically unfeasible. To grow all of our own food, income and compost with Sustainable Biointensive Mini-Farming techniques, we need only approximately one-quarter of the land compared to that needed when chemical, mechanized agricultural techniques are employed.[27] When we need only one quarter the land, we can give the land the care and attention it needs to remain fertile sustainably. With small farms ("mini-farms"), growing carbonaceous crops and producing sufficient cured compost, which is **essential for the revitalization and sustainable management of the soil's fertility, becomes economically feasible. Furthermore, if only one-quarter of the land is needed, three-quarters can be left or returned to its wild, natural state, thereby preserving the land's natural plant and animal diversity.**

How many carbonaceous plants should we grow to ensure enough carbon (in the form of cured compost and humus) will be returned to the soil to sustain and even improve its health?

The exact amount of carbonaceous material needed to be grown to recycle human urine and manure will be given in each of the descriptions of the various recycling methods included in this book. However, a general rule of thumb to ensure our farms will be able to produce enough compost for themselves to maintain the fertility of the soil, whether we are recycling human waste or not, is:

70% of the area in our gardens and farms needs to grow carbonaceous crops, called "compost crops", if we want to maintain the fertility of the soil sustainably.[28]

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[24] David Pimental, et al., "Land Degradation: Effects on Food and Energy Resources," *Science*, October 8, 1976, p. 150; and Barry Commoner, "Nature Under Attack," *Columbia Forum*, Spring 1978, Vol. 11, No. 1.

[25] *Tri-City Herald*, Washington State, July 14, 1994, based on 1992 USDA data published in 1994 with amplification by John Jeavons and Ecology Action.

[26] Robin Hur, "Six Inches From Starvation: How and Why America's Topsoil is Disappearing," *Vegetarian Times*, March 1985, pp. 45-47.

[27] Biointensive yields are generally 2 to 6 times those produced with chemical, mechinized agricultural techniques (based on yields obtained in the field presented by John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 70-97).

[28] See Appendix B: Detailed Calculation #2 for a description of how to calculate what percentage of a farm is used for growing compost crops, food crops and income crops.

70% of the farm should be used for growing compost crops to sustain the fertility of the soil. Of the remaining 30% of the farm area, approximately 20% can grow non-carbonaceous food crops for those on the farm (whose human manure and urine can be processed -- perhaps composted with the carbonaceous crops grown on 70% of the farm -- and added to the soil growing their food). 10% of the farm area or less can be marketed. The reason that so little of a sustainable farm is marketed is because none of the nutrients contained in the marketed crops will generally be returned to the farm. Therefore, the area of the farm used for marketing will slowly lose minerals. If the soil's minerals are not replenished, the soil will eventually become infertile.

If some arrangement is made so that all of the manure and urine of those who buy and consume the farm's crops are processed and returned to the farm's soil, then the soil's minerals will be returned. However, the amount of carbon in human manure and urine is low compared to the amount contained in the crops which were consumed. *Even if human waste is processed and returned to the farm's soil, not enough humus can be generated from the waste alone to fully replenish the soil's supply. Unless enough of the farm is used to grow carbonaceous crops that can be composted to generate humus, the humus supply of the soil could diminish to unhealthy levels over time.* Therefore,

Using 70% of the farm for carbonaceous crop production is really not as difficult as it might appear. All grain crops are excellent carbonaceous crops that provide food for humans as well as food for the soil (when the crop residues are converted into humus), and in temperate climates they grow during the winter when few other crops thrive. Assuming your climatic year can be divided into roughly 6 months of warm weather and 6 months of cool weather, if grains are grown during the colder 6 months of the year on the entire farm, already 50% of the farm's time and area are used to grow carbonaceous crops, and only 20% of the farm in the warmer 6 months needs to grow carbonaceous crops like corn, grain amaranth, millet and quinoa in order to produce approximately enough humus to maintain the fertility of the farm's soil.[29] See Detailed Calculation #2 for two methods of determining the percentage of the farm in compost, food and income crops.

While carbonaceous crops can be bought or received for free from those who do not yet know their value, as more and more people understand the value of compost, these materials may become increasingly difficult to obtain. For this reason, *the most important step we can take toward achieving Goal #2 is to* ***"grow" carbon*** *in the form of carbonaceous crops whose non-edible portion can be decomposed to generate humus.*

> *"Nightsoil [human urine and manure]...was so highly prized [by Indian farmers] as to be called sonkhat, that is, manure as valuable as gold."*
>
> - *Winin Pereira,* Tending the Earth: Traditional, Sustainable Agriculture in India

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even when a farmer has taken the important step of reclaiming the nutrients in his or her consumers' manure and urine, she or he must still use about 70% of the farm to produce carbonaceous crops for composting and generating humus in order to improve and sustain the fertility of the soil.

[29] See John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #14: The Complete 21-Bed Biointensive Mini-Farm* (Willits, CA: Ecology Action, 1987), pp. 4-15 for the derivation of the 70%, 20%, 10% guideline for sustainability.

Maximizing the Humus Produced from the Carbon You Grow - Aerobic and Anaerobic Composting Compared

Once we have enough carbonaceous and nitrogenous materials, and in the right proportion, how do we turn them into humus? Humus is the "product" of aerobic (with air) or anaerobic (without air) decomposition. The advantages and disadvantages of each method are given below:

Advantages of aerobic composting:

1) Less time is needed to decompose the organic matter and produce humus.

2) Temperatures hot enough to kill most human pathogens (and weed seeds) can be generated in the center of an aerobic compost pile.

Disadvantage of aerobic composting:

1) 40% to 90% of the nitrogen in animal manure can be lost when it is aerobically decomposed.[30] Since organic nitrogen is essential for humus production,[31] less humus may be produced compared to that produced through anaerobic decomposition. However, adding sufficient carbonaceous organic matter to the manure to increase the initial carbon-to-nitrogen ratio to approximately 30 to 1 may enable as much as 99.5% of the original nitrogen to be retained in the final cured compost (see footnote #152).

Advantage of anaerobic composting:

1) Only 2% to 10% of the nitrogen in animal manure is typically lost when it is anaerobically decomposed in a closed pit.[32] Since organic nitrogen is essential for humus build-up, more humus may be generated compared with that produced through aerobic decomposition.

Disadvantages of anaerobic composting:

1) It may be difficult to find an efficient, simple and sustainable way that does not rely on plastic to exclude air from the pile.

2) It can smell bad and attract insects and animals.

3) Compounds toxic to plants are produced through anaerobic decomposition and may remain in the cured compost.[33]

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[30] J. I. Rodale and staff, *The Complete Book of Composting* (Emmaus, PA: Rodale Books, 1960), p. 63.

[31] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 44.

[32] J. I. Rodale and staff, *The Complete Book of Composting* (Emmaus, PA: Rodale Books, 1960), p. 63.

[33] David E. Chaney, et al., *Organic Soil Amendments and Fertilizers*, Publication 21505 (Oakland, CA: University of California, 1992), p. 18.

How much humus must we generate to consider Goal #2 achieved?

Humus is an ever-changing, difficult-to-define substance, making it nearly impossible to determine exactly how much humus is actually present in cured compost, how much of the humus that is added to soil is retained in the soil, and how much is lost annually from the soil. Despite this, *a rough goal for temperate-climate growers is to generate enough cured compost that is 50% soil by volume so that each growing bed[34] (a "bed" is 100 square feet throughout this publication) can receive a minimum of 2.4 to 3.3 cubic feet* (2.4 cubic feet if the cured compost is made, in part, from human manure as described on pages 62-72; 2.7 if it is made, in part, from human urine as described on pages 27-33; and 3.3 if it is made from no human waste[35]) and a maximum of 8 cubic feet per year[36]. This application rate of cured compost should achieve Goal #2 and be able to produce over time and maintain a soil organic matter level of roughly 4% to 6% in most soils and under most temperate climatic conditions.

One of the properties of humus, as described on page 4, is its ability to prevent nutrients that are essential for healthy plant growth from leaching out of the soil. When the organic matter level is below 4%, some of these beneficial nutrients will more readily leach from the soil over time, and the soil will slowly lose its fertility. So even if all of the minerals in human waste are returned to the soil, they may not be available for the next year's crops if there is not enough humus in the soil to prevent them from leaching. All four goals of recycling human waste must be met, including the creation of sufficient humus through the growing of additional carbon crops, for the fertility of the soil to be maintained. In other words, achieving Goal #3, the return of the minerals in human waste to food-producing soil, which will be discussed next, depends in part on achieving Goal #2, the production of sufficient humus.

In the tropics, with generally increased soil temperature and possibly moisture, the soil organisms are much more active, consuming soil organic matter much more rapidly, and this makes it difficult to maintain a soil organic matter level above 3%. More plant biomass is produced per day in the tropics, allowing the farmer to produce more cured compost, but the amount of soil organic matter that is lost per day is also greater. In general, the farmer's goal should be to produce enough cured compost on the farm so that 8 cubic feet of cured compost (that is 50% soil by volume) can be applied per 100 square feet of soil per growing season. To prevent the soil's nutrients from leaching out of the soil, it is essential that plants are growing in the soil whenever possible to take up the nutrients that would otherwise be lost.[37]

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[34] In Biointensive Mini-Farming, crops are grown in beds. Except for narrow paths between the beds, the entire farm is growing crops for compost, food and income, and there is very little exposed soil that can be filled with weeds. When crops are grown in rows, there is much more exposed, unplanted soil that nature often fills with weeds and that is vulnerable to erosion, compaction, drying out, humus oxidation and nutrient loss.

[35] See Appendix B: Detailed Calculation #1.

[36] See Appendix C: Further Discussion #1.

[37] For more information on composting in tropical climates, see Overseas Members, *Composting for the Tropics* (England: Henry Doubleday Research Association, 1963). This publication is currently being reprinted and sold by Ecology Action by the kind permission of the Henry Doubleday Research Association.

Goal #3

Return of the Nutrients in Human Waste to Food-Raising Soil

With the modern resource-, energy- and capital-consumptive method of treating human waste, all of the minerals extracted from the soil by the plants and consumed by flush toilet-using humans are sent into the sewage system and buried at the bottom of a landfill or ocean. They are not returned to the soil. In order to keep the soils that feed us fertile sustainably and without reliance on nonrenewable resources, we must return the minerals contained in our waste to those soils.

It may seem odd that returning the minerals contained in human waste is only the third most important goal of the four mentioned above. This is not meant to suggest that returning the minerals in our waste is not important, only that it is less important than the first two goals. In order of importance, soil needs air, water, humus and minerals to be fertile. Minerals are listed last not only because minerals are the least important of the four elements necessary for healthy soil, but also because there are many minerals in the soil that are unusable by plants. They are bound with other minerals and cannot be absorbed by the plants' roots. Some of these minerals can become available when they are consumed and excreted by soil organisms (such as earthworms) and/or when there is a change in the soil's pH (level of acidity). Both of these events may be encouraged when humus is added to the soil. So some unavailable minerals can be made available in the soil slowly, but continually, as the soil becomes healthier. Still, if a soil is deficient in one or more of the minerals essential for plant growth, the soil's productivity is usually impaired so that fewer crops and less carbon are produced. Soils worldwide are currently depleted of many minerals, especially trace minerals that are essential to soil and plant health but needed in very small amounts. This is one reason theorized by John Hamaker, a scientist who has studied the periodic changes in the world's climatic patterns and soil compositions, for the decline in the world's biomass and the increase in atmospheric carbon dioxide levels.[38] Returning the minerals in our waste to the soils that feed us is one way to begin to reverse these dangerous trends.

If the soil is deficient in some mineral, the food produced by that soil will be deficient in that mineral. If we eat only the crops produced by that soil, we too will be deficient in that mineral as will be our waste. When we add our waste to the soil that feeds us or cured compost generated from plants the soil grew, **neither the waste nor the cured compost contains any minerals the soil did not already have, and the soil will remain deficient.** Therefore, the soil must first have the proper amount and balance of minerals before the human waste and cured compost generated from the crops the soil grew can be the only fertilizers used to maintain the soil at a maximum level of health. In order to balance the soil minerals, have the soil analyzed by a reputable laboratory[39] that can advise you on the type and quantity of organic fertilizers to add to the soil.[40]

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[38] John D. Hamaker and Donald A. Weaver, *The Survival of Civilization* (Potterville, MI: Hamaker-Weaver Publishers, 1982).

[39] An excellent laboratory, Timberleaf Farm, 5569 State Street, Albany, Ohio, 45710, is run independently by Steve Rioch who is able to recommend organic fertilizers to balance the soil and greatly enhance its productivity and health.

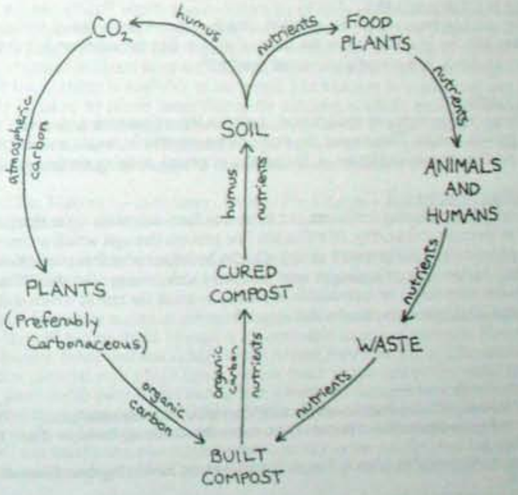
[40] If any organic fertilizers or amendments need to be added to the soil to help balance the soil's minerals, they should be added to the surface of the soil before the cured compost is added. After both the fertilizers and compost are applied evenly over the surface of the bed, mix them into the top 2 to 3 inches of the soil with a digging fork. Fertilizers should only be added after a thorough soil test has been done, and the amount of each fertilizer per 100 square feet has been recommended by a knowledgeable soil scientist. *A warning should be written on the sample bag and on the information sent to the soil testing center if the sample contains soil enriched with human manure that was not first processed (and thus may contain human pathogens) as described in the "Trees" and "Grains and Perennials" sections on pages 74-82 and 83-109 respectively.* If no soil test is available or the minerals in the soil are balanced, simply add cured compost each year and mix it into the top 2 to 3 inches of soil. If the soil has been

Table 1 on page 9 shows the average amounts of nitrogen, phosphorus, potassium and calcium in human urine and manure, and describes their fertilizing potential assuming all of the nutrients needed for good plant growth in your climate and soil are present in the soil and in the proper amounts, and all of the nutrients originally contained in the waste are returned to the soil. However, the amount of nitrogen which is finally added and remains in the soil can be substantially less than the amount contained in the fresh waste, as suggested in the above comparison of aerobic and anaerobic decomposition of animal manures. Still, the amount of nitrogen remaining in aerobically prepared compost may be more than enough for growing all of one person's food, compost and income each year.

Achieving Goal #2 and Goal #3 is interdependent. Goal #2 must be achieved so that there is enough humus in the soil to prevent the minerals that are returned to the soil in the human waste from leaching. For Goal #2 to be achieved, all of the minerals and nutrients in the human waste must be conserved so that they can be converted into humus. Therefore, if either goal is not achieved, probably the other goal will not be fully achieved.

Figure 2

The Humus and Nutrient Cycle



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enriched with human manure and may contain pathogens, the fork used to mix in the compost should be reserved for that purpose and no other.

Goal #4

Proper Nitrogen Application

When we return human waste to the soil, we want to add it in a quantity that does not add too much nitrogen. There are five possible detrimental effects on soil, plant, animal and human health if too much nitrogen is added to the soil:

1) Nitrate toxicity of the crops

Adding excessive amounts of nitrogen in a highly soluble and active chemical form, as in the case of common chemical nitrogen fertilizers, effectively force-feeds the plants nitrogen by causing them to take in more nitrogen than they can convert into protein. The excess nitrogen in the plant accumulates as either free amino acids, which makes the plants susceptible to insects and disease[41], or as nitrate or nitrite, both of which are deadly poisonous to animals and people even in very small dosages. While the risk is highest when chemical nitrogen fertilizers are used, the same problem can occur when excessive amounts of raw or only partially decomposed manures are added to the soil, since manures contain inorganic nitrogen (which is more rapidly converted into nitrite and nitrate) as well as organic nitrogen. It may be for this reason that cattle and other animals do not eat the grass growing around their manure, although it is much greener than the grass they prefer.[42]

2) Nitrate in the groundwater

When the soil receives excess nitrogen, much of the nitrogen that is not taken up by the plants leaches into the groundwater in the form of nitrate. Nitrate, whether it is in the plants we eat or the water we drink, is extremely toxic and deadly.[43]

3) Crop lodging

With excessive nitrogen applications, a plant's leaves become dark green, and excessive vegetative growth occurs. This causes the stems of the plant to be weak, and the plant tends to lodge (fall over) with rain and/or wind. In the case of grains, lodging severely reduces the yield.[44]

4) Acidification of the soil

"Ammonia-containing fertilizers and those that form ammonia upon reacting in the soil have a tendency to increase soil acidity. Nitrification [the process through which ammonia is converted into nitrite and nitrate in the presence of air] releases hydrogen ions that become adsorbed on the soil colloids." An increase of hydrogen ions makes the soil more acidic (the pH is lower)[45] which can cause some minerals to be unavailable to plants, increase the rate at which soil humus is destroyed and inhibit the growth of some crops.[46]

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[41] Frank von Steensel, "Healthy Plants Don't Get Sick," *Soil & Health*, December/January 1993-94, pp. 18-19, originally from Francis Chaboussou, *Santé des Cultures, une Révolution Agronomique* (Paris: Flammarion, La Maison, 1985).

[42] Dr. William A. Albrecht, *The Albrecht Papers*, Charles Walters, Jr., ed. (Raytown, Missouri: Acres U.S.A., 1975), p. 170.

[43] Judith D. Soule and Jon K. Piper, *Farming in Nature's Image* (Covelo, CA: Island Press, 1992), p. 33.

[44] Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. (New York: Macmillan Publishing Company, 1984), pp. 284-285.

[45] Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. (New York: Macmillan Publishing Company, 1984), p. 311. Also, see Appendix C: Further Discussion #3 on the increased loss of soil humus due to soil acidification.

[46] Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. (New York: Macmillan Publishing Company, 1984), p. 206.

5) Excessive loss of soil humus

There are many differing opinions on the existence and possibility of this danger, and more research is needed before a conclusion can be drawn. Summaries of the differing views that the author has encountered can be found in Appendix C: Further Discussion #3.

The degree to which an application of nitrogen fertilizer can cause the above effects depends on: **a)** the percentage of the fertilizer's nitrogen that is immediately available (in a water-soluble form); and b) the quantity of fertilizer that is applied. These two variables, **a)** and **b)**, are discussed separately below.

a) The amount of nitrogen immediately available in a fertilizer is the amount of nitrogen that is in the form of ammonia (NH_3) or nitrate (NO_3^-). Because most of the nitrogen in a chemical synthetic nitrogen fertilizer is already in one of these forms (for example, anhydrous ammonia, ammonia nitrate and ammonia sulfate), most of the nitrogen applied is immediately available. This is the reason why chemical fertilizers are often called "hot" and "unstable." There is generally less nitrogen that is immediately available in organic fertilizers than there is in chemical fertilizers, and thus more of the nitrogen is released gradually over time.

Another way to estimate the rate at which nitrogen is released from any nitrogen fertilizer is based on the carbon-to-nitrogen ratio of the fertilizer. A fertilizer that has little carbon compared to the amount of nitrogen it contains tends to release its nitrogen more quickly than a fertilizer that has a lot of carbon compared to the amount of nitrogen it contains.[47] Much of the nitrogen in organic fertilizers is not in the ammonia or nitrate form, but in organic forms such as proteins, cell wall constituents and nucleic acids[48] which also contain a lot of carbon. Since the nitrogen in these organic forms needs to be converted to ammonia or nitrate before it can be utilized, it is available more slowly over a longer period of time compared to the nitrogen in chemical nitrogen fertilizers. But even among organic fertilizers there are differences between the carbon-to-nitrogen ratios and the rates at which the nitrogen is available to the crops. The nitrogen in blood meal and human waste is generally taken up by plants faster than is the nitrogen in alfalfa meal, soybean meal and cottonseed meal. Compared to animal manures, human manure is less hot (has a smaller percentage of nitrogen in the ammonia or nitrate form and a larger percentage in organic forms) than chicken manure, equal to pig and sheep manure, and hotter than horse and cow manure.[49]

Horse / Cow Manure -----> Human / Sheep / Pig Manure -----> Chicken Manure
Least Hot --> Hottest

All forms of nitrogen fertilizers become less hot after they are composted since most of the nitrogen is converted into an organic form once it has been consumed by the microorganisms in the compost pile.

Humus is an important source of nitrogen that, unlike chemical or organic fertilizers, can be produced by the farm or garden itself. Humus is a sustainable source of nitrogen. However, there are two types of humus, *labile and non-labile*, which release their nitrogen at different rates. Carbonaceous plant material with a high lignin content (such as sawdust or any wood product) tends to produce more stable (non-labile) humus that releases its nitrogen very slowly compared to the humus produced from plant material with less lignin. Some of the labile humus can become non-labile humus in the soil as it develops resistance to microbial attack. Depending on environmental and soil conditions, non-labile humus can stay in the soil for decades, centuries and even millenia with minimal degradation, all the while enhancing the soil's tilth and fertility.[50]

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[47] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 77.

[48] E. A. Paul and F. E. Clark, *Soil Microbiology and Biochemistry* (New York: Academic Press, Inc., 1989), p. 133.

[49] L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973), p. 15.

[50] Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), p. 45.

b) The amount of total nitrogen that can be applied without endangering the health of the soil or crops is approximately 0.1 to 0.5 pound per garden bed (100 square feet) per year depending on the amount of nitrogen in the soil and the percentage of available nitrogen in the fertilizer used.[51] Therefore, throughout this book, if no more than 0.5 pound of nitrogen is added per 100 square feet of soil, Goal #4 is considered achieved. In terms of cured compost, this will be considered to be equivalent to 8 cubic feet of cured compost that is 50% soil by volume. See Appendix C: Further Discussion #1 for a more thorough discussion of this guideline for applying cured compost and achieving Goal #4.

It is often supposed that manure must be composted before it is added to soil in order to avoid the five dangers described above. From 1958 to 1976, the Scandinavian Research Circle tested and observed the effects of various fertilizers on the physical, chemical and biological characteristics of the soil. Among the fertilizers that were tested were raw manure from unspecified barnyard animals, composted manure from unspecified barnyard animals, raw manure and chemical fertilizers, and chemical fertilizers alone. They were applied at rates so that the amount of *available* nitrogen would be similar -- about 0.07 pound per 100 square feet.[52] Throughout the 18 years of this experiment, the topsoil and the subsoil of the plot fertilized with *raw* barnyard manure had the highest amounts, or compared closely with the plots with the highest amounts, of pore volume, carbon and nitrogen levels, biological activity and percentage of total humus, and had the lowest bulk density. Even the yields produced from the plot fertilized with raw manure were highest. In conclusion, the authors state: "Fresh farmyard manure has had favorable effects on both yields of crop and various soil traits. With the addition of inorganic-NPK [chemical fertilizers] to the manure the yields have increased further but humus content diminished, especially in the subsoil, followed with a worsening of soil structure and biological reactions."[53]

The nitrogen in fresh human manure appears to contain an average amount of readily available nitrogen compared to the manure of various farm animals. Since the animal manure used in the above study was from unspecified barnyard animals, it probably contained an average and not unusually low amount of available nitrogen. Therefore, applying no more than 0.5 pound of total nitrogen per 100 square feet per year in the form of fresh or composted human manure is probably safe for the soil in terms of the five possible dangers listed above, and most likely beneficial.

In most cases, when human waste is processed for recycling, some of the nitrogen it contains will be lost. Depending on the processing technique, the loss can range from approximately 0% to 100%.[54] Since not all of the nitrogen will be returned, slowly the nitrogen supply in the soil will decrease unless additional nitrogen is added. How can this be added to the soil in a way that is sustainable and does not depend on nonrenewable resources or the fertility of another farm's soil as in the case of chemical and organic fertilizers? We can do this by growing legumes and other plants with which "nitrogen-fixing" bacteria associate. These bacteria are able to transform nitrogen in the air (atmospheric nitrogen, N_2) into a form (ammonia, NH_3, or nitrate, NO_3^-) that is usable by plants. In order for the plant-bacteria association to add nitrogen to the soil, legumes should be harvested when 10% to 50% of their flowers are in bloom. Annual legumes should be harvested about 1 to 1.5 inches above ground level, leaving the roots, which contain the nitrogen, in the soil, and perennial legumes should be harvested 1 to 1.5 inches above the growing crown of the plant. When 10% to 50% of the legumes' flowers are in blossom, legumes contain the maximum amount of nitrogen, most of which will be concentrated in their roots. If they continue to blossom and produce seeds, the nitrogen is transported from the roots into the developing seeds. So if legumes are harvested later, much of the nitrogen will have left the roots, and very little will remain to feed the soil.

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[51] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 23. Adapted from 1978 La Motte soil test instructions. This broadly generalized guideline for the maximum amount of nitrogen that should be applied to a given area of soil will vary with the climate, precipitation, soil and form of nitrogen in the fertilizer.

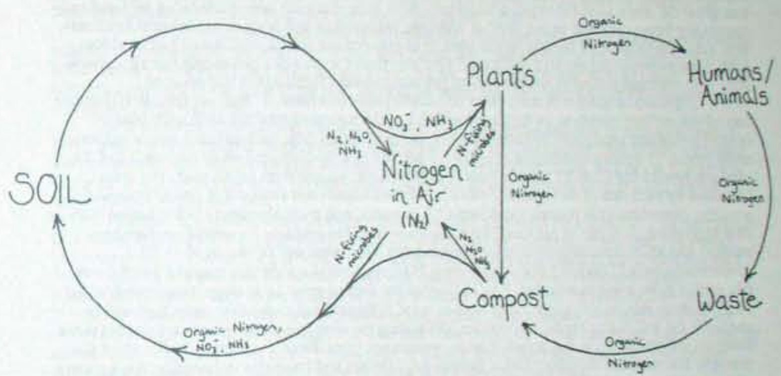
[52] Available fraction of the total nitrogen is 35% for manure and 70% for inorganic fertilizers, based on standard literature values (B. D. Pettersson and E. v. Wistinghausen, *Effects of Organic and Inorganic Fertilizers on Soils and Crops* [Temple, ME: Woods End Agricultural Institute, 1979], p. 10).

[53] B. D. Pettersson and E. v. Wistinghausen, *Effects of Organic and Inorganic Fertilizers on Soils and Crops* (Temple, ME: Woods End Agricultural Institute, 1979), p. 10.

[54] See footnotes #76 and #152.

Figure 3

The Nitrogen Cycle Simplified



The following two chapters describe many different methods by which human urine and manure can be safely and effectively processed and returned to the soil. Each of the methods will be appraised on its success in achieving the four goals of recycling human waste described above, as well as its appropriateness in various climates and living situations. While some methods meet all four goals, others do not since their creators may have had different, as well as similar, goals in mind. Nevertheless, each of the alternative methods discussed is a vast improvement over the conventional method of treating and discarding human waste, and has the potential to greatly benefit the planet, the soil and ourselves.

Chapter 3

Recycling Human Urine

"By the year 2000, 25% of all the energy consumed in the world in 1973 will be required just to produce nitrogen fertilizer, if all of the food in the world were grown with U.S.-type agricultural techniques."[55] If chemical synthesis of nitrogen fertilizers is not a viable long-term source of supplementary nitrogen for agricultural soils, what about organic fertilizers such as alfalfa, cottonseed and blood meals? Almost all of the plants and animals used to produce organic fertilizers are grown or raised chemically or raised on chemically grown plants, so we are *still* dependent on scarce petroleum to grow our food. We are also dependent on the fertility of the soils that grow the crops used for organic fertilizers. With their nutrients constantly being sold and only marginally being returned in the form of nitrogen, phosphorus and potassium chemical fertilizers, how long will these soils remain fertile enough to produce the alfalfa, cottonseed and food for cattle used to create our organic fertilizers? One alternative source that can supply our agricultural soils with nitrogen that need not depend on petroleum-based fertilizers is human urine.

Typically, a garden or mini-farm bed (throughout this book, a "bed" represents 100 square feet of soil surface) needs to be fertilized with 0.1 to 0.5 pound of total nitrogen each year to remain fertile and productive.[56] Depending on the application rate, each person's yearly output of urine (about 91 gallons containing roughly 7.5 pounds of total nitrogen) could provide all of the nitrogen needed for 15 to 75 garden beds (1,500 to 7,500 square feet) for all year. The urine produced by each one of us each year can also contain significant amounts of phosphorus (1.6 pounds), potassium (1.6 pounds), calcium (2.3 pounds), and trace elements.[57] One person may be able to produce all of her or his food (for a complete diet that contains no animal products) and income, and all of the compost crops needed to keep the garden soil fertile, in 20 to 50 Biointensive beds (2,000 to 5,000 square feet).[58] (Commercial agriculture requires 2 to 5 times this area to grow a vegetarian diet, 9 to 22.5 times the area to grow an average American diet and 18 to 45 times this area to grow a diet high in meat.[59] Regardless of the diet, more land will be needed if the soil is less fertile.) Therefore, depending on what minerals the soil lacks and if those minerals are contained in the person's urine, we can see from Table 1 (see page 9) that all of the nitrogen and much of the phosphorus, potassium, calcium and trace elements one person's garden needs each year may be obtained from only that person's yearly output of urine![60] However, for reasons that will be described later, it is likely that the person's manure will also need to be processed and returned to the soil in order to maintain the soil's fertility.

The challenge is to find the simplest, safest and most effective way to recycle human urine with a method that meets all four goals of recycling human waste. However, since fertilizing with human urine is generally *not legal* and can endanger your health and that of others, as well as the health of the soil if it is not used properly, obtain permission from your local health authority before you begin utilizing human urine in your garden.

The easiest way to avoid the human health risks involved in using human urine as fertilizer, and in effect achieve *Goal #1, purification of the urine*, is to not use the urine of anyone with typhoid, urinary schistosomiasis or leptospirosis.[61] Time and the difficulty of living outside of the human body will eventually kill the pathogens, but the lengths of time, depending on the environmental conditions, are unknown to the author at the time of this writing. Pathogens in the urine will also be destroyed by the heat generated during composting as described below, but again the minimum time and temperature necessary are unknown to the author at this time. Since other diseases may need to be included in this list, at this point, *it is safest not to utilize the urine of anyone who is sick.*

Composting human urine is the easiest way to accomplish *Goal #2, the production of humus from the nutrients contained in the urine.* Since the carbon-to-nitrogen ratio of urine is 0.8 to 1, the urine must be added to carbonaceous material (such as straw) in order to produce the maximum amount of humus from nutrients contained in the urine.

When urine is stored in a sealable glass container, all of the minerals in human urine can be retained and returned to the soil from which they came, with the exception of nitrogen.[62] Nitrogen is the element most easily lost from human urine. As we better understand how to return the nitrogen contained in the urine to the soil, we will be better able to achieve *Goal #3, conservation and return of the nutrients.*

It is important to understand how nitrogen is lost from urine and how to minimize such a loss if we expect to retain enough nitrogen to fertilize 1,500 to 7,500 square feet of soil with only the composted urine each of us produces each year. If, as is quite possible, half of the nitrogen in our urine is lost before the urine is composted and added to soil, we *may* have enough nitrogen for only 750 to 3,750 square feet.

Nitrogen is lost from urine through a process called ammonia volatilization. The nitrogen in fresh urine is in the form of urea which is quickly consumed by microorganisms and converted into ammonia. Ammonia is a gas which will escape into the air, and much of the urine's nitrogen will be lost. This is also true for animal urine. For example, the urine of American bison contributes relatively little to the fertility of the grasslands compared to the manure they produce.[63] In order to minimize the production of ammonia and reduce the amount of nitrogen lost after the urine is discharged but before it is added to soil and composted, the urine can be kept in a sealed jar and covered with a thin layer of oil.[64] However, it takes a lot of land and much labor-intensive processing to produce oil, and oil is slow to break down in a compost pile.

A simpler way to prevent ammonia volatilization is to add the urine while it is still fresh to a 5-gallon bucket partially filled with straw and soil. This procedure is described in detail below. The straw and soil absorb the urine. When the microorganisms begin converting the urea to ammonia, the humus and clay particles in the soil are able to hold on to the ammonia and reduce the amount

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[55] Amory Bloch Lovins, "Energy in the Real World," *Stockholm Conference ECO*, San Francisco, December 13, 1975, p. 9.

[56] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 23. Adapted from 1978 La Motte soil test instructions.

[57] Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956), p. 35; and Philip L. Altman and Dorothy Dittmer, eds., *The Biology Data Book Vol. 3*, 2nd ed. (Bethesda, MD: American Societies for Experimental Biology, 1974), pp. 1496-1503.

[58] Based on models created by the author using field-produced data from John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 70-98.

[59] Kenneth E. F. Watt, *The Titanic Effect* (Stamford, CT: Sinaur Associates, 1974).

[60] The exact quantities of minerals in human urine, as well as human manure, vary according to the diet and lifestyle of the individual. The above figures are based on the *average* amounts of minerals in human urine.

[61] Determined by the author from data presented by R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management – A State of the Art Review* (Washington, D.C.: World Bank, 1981), p. 24. The worms responsible for urinary schistosomiasis, once inside the body, can live for years and even decades (Feachem, p. 26). **Hepatitis A** virus, the causative agent of infectious hepatitis, is excreted in the manure, not the urine, of those infected. "In **cystitis and other urinary infections**, coliform and other bacteria may be numerous in the urine, but they are no risk to others. In **venereal infections**, also, the microbial agents will reach the urine, but they are so vulnerable to conditions outside the body that [manure and urine] are unimportant as vehicle[s] of transmission." (Feachem, p. 24).

[62] The loss of nitrogen from urine that is exposed to the air is accelerated by sunshine. The sun's warmth stimulates the microorganisms that converted the urine's nitrogen into ammonia and increases evaporation. When urine is stored indoors and covered, as much as 92% of the original nitrogen can be retained. (Viet Chy, *Human Faeces, Urine and Their Utilization* [Environmental Sanitation Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand, 1978], pp. 32-33.)

[63] Judith D. Soule and Jon K. Piper, *Farming in Nature's Image* (Covelo, CA: Island Press, 1992), p. 92.

[64] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 44.

that escapes, until the urine-containing soil and straw are composted and the nitrogen is stabilized.[65]

Goal #4, the proper application of nitrogen, can be achieved by this method of composting urine simply by returning the cured urine-enriched compost at a rate equivalent to no more than 0.5 pound of nitrogen per 100 square feet. *2.7 cubic feet of human urine-enriched cured compost produced as described on pages 24-31 contains approximately 0.5 pound of cured nitrogen* (see Appendix B: Detailed Calculation #1).

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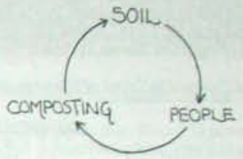
[65] Dr. Robert Parnes, personal communication, February 18, 1993.

COMPOSTING HUMAN URINE



To create a compost pile by this method, you need only urine, straw, soil and water. In order to maximize the amount of *cured* compost you generate, each urine/straw/soil compost pile should have an initial carbon-to-nitrogen ratio of about 30 to 1, the same as a compost pile not containing human urine. At this ratio, the microorganisms in the compost pile will consume nitrogen and carbon equally efficiently and stabilize both elements in their bodies. When the ratio is much greater than or less than 30 to 1, a significant portion of the nitrogen and/or carbon originally contained in the compost pile is not incorporated into the bodies of the microorganisms and retained in the final cured compost but escapes into the air and is lost.

However, most of us gardeners and farmers who grow a wide variety of food crops have too much nitrogenous plant residue and too little carbonaceous plant residue to create a compost pile that has a carbon-to-nitrogen ratio of 30 to 1. Because of this, we may not be producing enough humus to replenish the soil's supply. *Growing carbonaceous compost crops and composting them to generate enough humus for the soil is essential, if we are to improve rather than deplete the soil's fertility.*

Since human urine alone has a carbon-to-nitrogen ratio of 0.8 part carbon to 1 part nitrogen, in order to increase the carbon-to-nitrogen ratio to 30 to 1 for the maximum and most efficient production of humus, roughly 733 pounds of dry carbonaceous material are needed to compost all of the urine one person produces each year.[66] By sowing winter grains, such as oats, barley, wheat or rye, you can generate that amount of straw from about *24.4 beds grown Biointensively with mid-range Biointensive yields (which are, in general, twice the average U.S. yield).*[67] If 24.4 beds seems like a lot, remember that it is possible to grow all of the calories you need for all year *as well as* all of your straw needed to recycle your yearly output of urine, as well as your manure, with 24.4 beds or less (see Chapter 5, Example #1)!

733 pounds of straw, with soil and urine, is enough material to create about 10, 3-foot-wide, 3-foot-long and 3-foot-high compost piles.[68] These 10 compost piles, if properly built and

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[66] Carbon-to-nitrogen ratios for urine and straw, as well as manure, vary from source to source. 733 pounds of carbonaceous material is based on the data for wheat straw (50.9% carbon, 0.62% nitrogen) presented by Frank B. Morrison, *Feeds & Feeding*, 21st ed. (Ithaca, NY: Morrison Publishing Co., 1949), pp. 1086-1109. See Appendix B: Detailed Calculation #3 for the derivation of the amount of wheat straw needed.

[67] All "straw" production figures in this book include both the weight of the chaff and the weight of the straw from the grain-producing plant. Chaff, like straw, is carbonaceous and ideal for composting with human urine and manure. At mid-range Biointensive yields, one bed produces about 30 pounds of wheat straw and chaff (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], p. 82.). So 24.4 beds (733 / 30 = 24.4) are needed to produce this amount of total straw and chaff.

[68] Based on data from compost piles built at the Common Ground Biointensive Research Mini-Farm in Willits, CA. See Appendix B: Detailed Calculation #4.

The minimum size of a compost pile is 3 feet wide by 3 feet long by 3 feet high for successful and efficient decomposition and production of humus (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 41-42). Piles that are 4 feet by 4 feet or 5 feet by 5 feet could be 4 feet high. 4-foot-high piles tend to decompose better than 3-foot-high piles as they are better insulated and maintain a more constant moisture level maintained as described below, will generate about 98.8 cubic feet of *cured* compost that is 68.6% soil by volume. This is enough cured compost to apply 4.3 to 12.7 cubic feet (equivalent in terms of nitrogen and humus to 2.7 to 8 cubic feet of cured compost that is 50% soil by volume -- the guideline mentioned earlier) per bed per year for 7.8 to 23 beds (see Appendix B: Detailed Calculation #5). *Goal #2, production of sufficient humus*, is then achieved for those beds.

Equivalent Quantities of Cured Compost in Terms of Nitrogen and Organic Matter

% Soil	Volume (ft^3)
50	2.7 - 8
68.6	4.3 - 12.7

In order to achieve *Goal #3, the return of the minerals*, all of the beds that grew the complete diet for the person producing the urine should receive an equal portion of urine-enriched cured compost, since each of the beds contributed some of the minerals contained in the urine and the urine-enriched compost. Spread equally over 24.4 beds, 98.8 cubic feet of cured compost that is 68.6% soil by volume is enough for each bed to receive only 4 cubic feet per year (less than the minimum of 4.3 necessary to achieve Goal #2). Therefore, more organic material will need to be grown on these 24.4 beds in order to produce enough compost to achieve both Goal #2 and Goal #3. If Goal #2 is not achieved, not enough carbon and nitrogen in the form of humus will be added to the food-producing soil to hold the minerals that *are* returned.

Growing more organic matter for the compost pile is possible in two ways: 1) by interplanting the wheat with another crop, such as vetch that can be pulled out when it is 10% to 50% in flower (leaving most of the roots in the soil, thereby adding some of the nitrogen which was fixed from the air)[69]; and/or 2) by growing a second or third crop (depending on the number of growing seasons you have) as described below that produces a lot of carbonaceous biomass.

Goal #4, proper nitrogen application, is achieved when the cured compost is added to no less than 7.8 beds, and possibly more (see Appendix C: Further Discussion #3).

If you have two growing seasons annually, it is easy to grow more carbonaceous biomass and produce more compost for your garden or farm. In the winter, the 24.4 beds can grow wheat that will provide food for you and straw to compost with your urine. In the summer, the 24.4 beds can be used to grow additional food or income crops, or they can grow "dual-purpose" crops like millet and amaranth which provide not only food, but also the carbonaceous material that is essential for a successful compost pile. Summer "compost crops" (crops that produce compost material, and especially carbonaceous compost material) will allow you to grow fewer beds in the winter and still obtain all the straw you need to compost your urine. You then need fewer total beds both to be self-sufficient in food *and* to return the nutrients in your waste to the soil and maintain its fertility.

If you decide to try this method and *have obtained permission from your local health authority*, reserve a set of clothing, at least 2, 5-gallon buckets with covers, a spading fork, a

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and a more stable environment for decomposition. In the case of urine-enriched compost piles, the larger piles may also allow less urine to leach out. Piles higher than 4 feet tend to either fall over or compress, which reduces the amount of air in the pile and encourages anaerobic decomposition.

[69] For more examples of interplanted combinations that yield large quantities of carbonaceous compost material, see John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #14: The Complete 21-Bed Biointensive Mini-Farm: Fertility, Nutrition and Income* (Willits, CA: Ecology Action, 1987), pp. 12-15; J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #15: One Basic Mexican Diet*, "Supplement" (Willits, CA: Ecology Action, 1988); Patrick Wasike, *Ecology Action's Self-Teaching Mini-Series Booklet #25: One Basic Kenyan Diet* (Willits, CA: Ecology Action, 1991), pp. 15-16; and Carol Cox and Staff, *Ecology Action's Self-Teaching Mini-Series Booklet #26: Learning to Grow All Your Own Food* (Willits, CA: Ecology Action, 1991), pp. 3-5.

spade and a pitchfork for the tasks of building, turning and maintaining the urine-containing compost piles *and use them for no other purposes*. It is probably best to start by creating only 1 or 2 compost piles until you have gained some experience. The method is experimental, and through observation, you may discover modifications that need to be made.

Choosing and Preparing an Appropriate Site for Composting Human Urine

In order to create the 10 compost piles from 733 pounds of straw, all of the urine produced by one person in a year and soil, as outlined above, you will need an area at least 3 feet wide and 30 feet long (90 square feet), plus an additional area that is 3 feet wide and 6 feet long to provide space into which you can turn the piles. (In general, to ease the task of turning the piles once they are partially decomposed, an *additional area equal to the initial length and width of your largest compost pile* should be provided for every *4 to 5* built compost piles. After you turn the first partially decomposed pile into this space, the space the turned pile occupied can be used to turn the next pile once it is ready, and so on.) The total area needed is about 108 square feet (a little more than the area of one garden bed). You will also need space for a 209-cubic-foot storage bin (approximately 3 bins that are 3.5 feet high, 4 feet wide and 5 feet long, for example)[70] to keep the straw dry throughout the year. Less storage space is needed if straw-producing crops are grown during the summer and winter. Since the straw is used continuously to build compost, as described below, no more than about half of the straw needed throughout the year will need to be stored at any point in time.

The 3-foot-by-36-foot site for your urine-containing compost piles should be downhill and at least 150 feet away from any source of water or living habitat. For the first few years of composting your urine, you should monitor the amount of urine that leaches from the pile by building the pile on a pallet or frame raised above the ground and collecting the urine that leaches out in a pan, for example. While the leachate is generally free of pathogens, it could contaminate the groundwater. How deep the groundwater beneath the urine-composting site must be to avoid contamination will depend on the amount of leachate and the texture and structure of the soil beneath the piles. If the groundwater is at least 6 feet below the soil surface (5 feet below the bottom of the loosened soil) at the wettest time of the year, there will be no risk of groundwater contamination.

To test the groundwater level, dig a hole 3 feet square and 3 feet deep in the center or lowest part of the site. Then, dig a 3-foot-deep hole in the bottom of the first hole with a posthole digger before the rainy season. Build a berm (as described in the sections on composting human urine and manure) around its perimeter and cover the hole and berm with plastic to prevent rainfall and surface runoff from entering the hole. Use an 8-foot-long, 1-inch-by-1-inch pole to test if water appears at the bottom of the post hole. If water is detected at any time during the year, a new site or a new method of recycling human waste should be chosen. Be sure to verify from that year's precipitation that the year you checked was a representatively wet one. If not, be sure to recheck the site before using it. Also, the site must not receive severe runoff that could erode your site and carry pathogens downhill and into a source of water where it could spread disease.

The site should never be situated above fissured rock or other highly permeable rock formations which would allow excessive leaching of nutrients and pathogens in the urine into the groundwater. Sandy soils are generally suitable so long as the depth of the water table is 5 feet or more at the wettest time of the year. If there is a time when the groundwater is normally higher than this, it may be best to store your urine and use it to build compost when the water table has dropped.

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[70] *Loosely packed* straw weighs 3.5 to 4.5 pounds *per cubic foot* (University of Wisconsin, Special Bulletin #4) [2.3 to 3.0 pounds *per 5-gallon bucket*]. The lower figure of 3.5 pounds per cubic foot is used throughout this book to estimate the straw storage space needed. (733 / 3.5 = 209 ft^3).

If possible, choose a site that is shaded, ideally by a deciduous tree that will contribute its leaves to the piles. The piles should be far enough from the trunk to prevent insect infestations and far enough from the dripline so that the feeder roots of the tree will not be damaged when the soil is loosened (see step #2 of "A Method" below) and will not be able to steal nutrients from the piles. The shade will keep the moisture and temperature levels of the compost piles more constant and allow the piles to decompose more efficiently.

You may also want to situate your compost piles on unused garden beds to enrich them with the nutrients that may leach from the piles.

A Method

1) Measure out the area you will need for the number of compost piles you plan to build.

2) Loosen the soil of the area for one compost pile to the depth of 1 foot with a garden fork. (When you are ready to build your second pile, loosen that area. If both areas are loosened at the same time, the second area may compact before the second pile is built, which will decrease its drainage.)

3) Add a 3- to 4-inch layer of branches and twigs over the loosened soil. Steps #2 and #3 create the foundation for your pile and will help keep the pile well-drained and aerated.[71]

Collecting and Preparing Your Urine

4) Collect your day's urine in a glass container that can be sealed after each addition of urine; metal ones will corrode, and plastic ones will dissolve over time and contaminate the urine.[72] (An alternative storage system which can also store manure is shown in Figure 6 on page 64.) *The storage container's seal must be tight enough to prevent flies, mosquitoes and other vectors from entering the storage container, contacting pathogens and causing disease. This requirement is essential for all human waste storage and recycling systems.*

One person generates about 1 quart of urine per day.[73] Take all precautions necessary to prevent the glass container from breaking or the contents from spilling. An alternative is to prepare buckets as described below and urinate directly into the prepared, sealable bucket.

5) Place 2 pounds of straw or other dry, carbonaceous material into two 5-gallon buckets (1 pound in each). • Straw *very loosely packed* into a *5-gallon bucket* weighs about 2 pounds, • *loosely packed* about 2.3 pounds, and • *tightly packed* about 3.0 to 3.4 pounds.[74]

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[71] While the loosened soil and layer of branches are essential for ensuring the piles decompose aerobically, they also allow some of the nutrients in the urine that leach out of the compost piles. One way to minimize the amount of nutrients that are lost is by planting comfrey around the bottom edges of the compost piles. "Unlike most plants, [comfrey] is not burned by very strong doses of concentrated nutrients, such as urine or chicken manure, but consumes them voraciously. Its ability to scavenge nutrients in this way makes it particularly suitable for preventing leaching around compost piles..." (Peter Harper, *The Natural Garden Book* [NY: Simon & Schuster, 1994], p. 105.) The leaves and stems of comfrey, a perennial, can then be periodically harvested (cut the plants at a point 2 to 3 inches above the soil) and added to the urine-containing compost pile, thereby returning some of the urine's nutrients that would otherwise have been lost.

[72] Dan Hemenway, "To Pee or Not To Pee," *The Permaculture Activist*, August 1992, p. 48.

[73] Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956), p. 35; and Sim Van der Ryn, *The Toilet Papers* (Santa Barbara, CA: Capra Press, 1978), p. 33. The amount of urine produced daily depends greatly on the amount of liquid that is consumed. While one may produce more than 1 quart of urine each day, the total amount of minerals contained in the urine generally is not greatly affected, only diluted.

[74] If a person's diet contains less protein than the diet consumed by people in industrialized nations, the person's annual production of urine can have as much as 40% less nitrogen than the 7.5 pounds annually shown in Table 1. (J. R. Snell, "Anaerobic Digestion of Undiluted Human Excreta," *Sewage Works Journal*, July 1943, pp. 679-680.)

6) Add 1/8 of a 5-gallon bucket of soil (about 4 to 5 pounds) to each bucket of straw. After a garden bed has been double-dug (see Jeavons and Cox, *Lazy-Bed Gardening* [Berkeley, CA: Ten Speed Press, 1993], pp. 27-32), the soil removed from the first trench can be stored and used for this purpose.[75] It is best if the soil is dry and crumbled into a powder to increase its surface area and ability to absorb ammonia, thereby decreasing the loss of nitrogen.[76]

7) Mix the soil and straw together in the bucket.

8) Add the urine you produced in one day equally to the 2 buckets of soil and straw. When the urine is added to two buckets of soil and straw rather than one, the straw and soil will have more surface area with which to absorb the urine. Urine should be added to the buckets of soil and straw as fresh as possible to minimize the amount of nitrogen that is converted into ammonia and lost.

9) Cover the buckets with tight-sealing lids, and let the soil and straw absorb the urine for about 24 hours. *Since most 5-gallon buckets are plastic, urine (combined with straw and soil) should not be left in the bucket for more than 24 hours to prevent it from corroding the plastic. Wash the bucket with a little water after the urine, straw and soil are added to a compost pile as described below and pour the waste water over a urine-containing compost pile.*

Building a Urine-Enriched Compost Pile

10) Spread the 2 buckets of straw, soil and urine as evenly as possible over the branches and twigs prepared in step #3. In compost piles that do not include urine, each layer of compostable material must be watered after it is added to the pile. In the case of urine-enriched compost piles, the layers do not need to be watered since they are already sufficiently moist. However, *after the*

If you consume a low-protein diet (generally vegetarian in which grains, beans and nuts are not overly consumed) and urinate less than 1 quart per day, you may want to add less straw to each bucket.

[75] 91, 5-gallon buckets of soil are needed per year to compost the urine one person annually produces. Since 7, 5-gallon buckets of soil are removed from each 5-foot-wide garden bed in the process of double-digging, 13 double-dug beds could provide the amount of soil needed for urine composting. Soil removed from other beds in the garden can be used in other compost piles.

[76] Experimental data indicates that if no soil is added to the urine, almost all of the nitrogen contained in the urine can be lost. However, 30%, 45%, 70%, 80% and 85% of the nitrogen can be retained if 1, 2, 3, 4 and 5 parts of soil (dry and crumbled into a powder) are added to 1 part of urine (by volume), respectively. (Viet Chy, *Human Faeces, Urine and Their Utilization* [Environmental Sanitation Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand, 1978].) It may be that more soil could be added without hindering the decomposition process.

It is important to note that if 85% of the nitrogen is retained, the 15% that is lost can be replaced by growing nitrogen-fixing leguminous crops. In fact, a 15% annual loss of nitrogen from the urine-containing compost piles generated with one person's urine and 733 pounds of wheat straw as described above equals 1.725 pounds (11.5 pounds [7.5 pounds from the urine and 4 pounds from the straw] x 0.15) of nitrogen. This amount of nitrogen can be added to the soil by interplanting the straw-producing beds with cool weather fava beans and vetch as described in detail in John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #14: The Complete 21-Bed Biointensive Mini-Farm: Fertility, Nutrition and Income* (Willits, CA: Ecology Action, 1987), pp. 4-15. The above ground biomass of the fava beans and vetch contains 0.53 pound of nitrogen per bed. If 15% of this nitrogen is lost when the fava beans and vetch are harvested and composted, 0.45 pound per bed will be available in the cured compost. Since a total of 1.725 pounds are needed, only 3.8 beds of the 24.4 beds producing wheat need to be so interplanted to produce the 1.725 pound of nitrogen that is lost.

85% of the original nitrogen in the urine was retained when only soil was added. Adding carbonaceous crop residues to the urine and soil will increase the amount of nitrogen that is retained. The goal is 100% retention, and it may be possible to approximate this with experience. However, from the above calculation, any nitrogen that is lost can be easily replenished through interplanting some grain-producing beds with compatible nitrogen-fixing crops.

Composting urine with acidic soil and/or aerating the compost pile will prevent the loss of nitrogen through denitrification (Dr. Robert Parnes, personal communication, January 3, 1995). However, turning the pile more than once tends to oxidize and encourage the loss of carbon from the compost pile, which may indirectly encourage the loss of nitrogen, since carbon combines with and holds nitrogen in the bodies of microorganisms in the compost pile.

pile is completed, it should be watered in order to keep the pile about as moist as a wrung-out sponge.

11) After each addition of human urine, straw and soil to the compost pile, the pile must be sealed so that no flies, mosquitoes or other vectors can contact pathogens in the human urine and spread disease. One simple way of achieving this is by building a wooden frame and covering it with a tight netting such as mosquito netting. A tarp or a thick layer of available materials (palm fronds or sticks, for example) may also be effective but will generally reduce the amount of air entering and exiting the pile and may encourage anaerobic decomposition. There shoould be no space between the bottom edges of the barrier and the soil, in order to prevent insects from entering. If flies do enter the pile, the pile should be turned to prevent them from breeding. Fly larva cannot survive temperatures above 124°F (51°C).[77]

If the pile attracts curious animals or neighbors' complaints, covering the pile with a light tarp that is anchored to the ground with stones or heavy sticks may be helpful. Be sure to remove the tarp and air the pile occasionally to prevent the pile from decomposing anaerobically. From the author's experience, very little odor is detectable even when standing next to the pile.

12) Continue adding to your pile until it is at least 3 feet high. If it is not convenient to add to your compost pile every day, you could store your buckets and add them every few days to the pile. When the pile is completed, add 1, 5-gallon bucket of soil to cap it off (to help hold in the ammonia).

Repeat the sequence above for building all subsequent urine-enriched compost piles.

Note: Undiluted urine is toxic to the creatures that live in the soil. Therefore, those who recommend adding urine directly to the soil rather than composting it recommend to first dilute urine with at least 5 to 10 parts water to 1 part urine, effectively detoxifying it. In the method of composting urine described here, adding the urine to the soil and straw and watering the compost pile after it has been built will probably dilute, decompose and detoxify the urine enough so that it does not need to be diluted with water before it is added to the buckets of soil and straw. (See "The Risk of Increasing Soil Salinity Through the Use of Urine-Enriched Cured Compost in the Garden", page 33) Diluting the urine before adding it to straw and soil would require a tremendous and impractical amount of straw and soil to absorb the additional liquid.

Maintaining the Compost Pile

13) Once the water in the urine begins to evaporate, you will probably need to water the pile as often as you water the rest of your garden, unless it is covered with a tarp, in which case you could water it less often. *Keep the pile about as moist as a wrung-out sponge.*

To keep the pile from becoming too moist and avoid anaerobic decomposition and the nutrients from excessively leaching out, protect the pile from rain with available materials, wood or plastic. However, anaerobic decomposition can also be encouraged by covering the pile with a tarp, since the tarp can exclude air from entering and exiting the pile. If you detect a sour odor and discover the pile is very wet, it is probably decomposing anaerobically, which in general produces a lower quality of cured compost (see the comparison of aerobic and anaerobic composting on page 16). Turn the pile immediately to allow some of the moisture to evaporate. Do not water the pile, and, if you have been covering it with a tarp, try to keep the tarp off until the pile no longer smells, which indicates it is once again decomposing aerobically.

14) Generally, after a compost pile is built, its temperature will increase until it reaches 120° to 140°F.[78] After a week or two, its temperature will begin to drop. *"When the decrease exceeds 20 degrees below its peak, it is time to turn the pile."*[79] However, since a urine-enriched compost pile constructed by this method will not be built at once but over a period of time, the pile's temperature may not peak and fall once but have several mini-peaks and mini-falls. If this is the case, turn the pile when the straw near the center of the pile smells musty, is yellowish-brown and is partially decomposed so that it is difficult to tell what it is. Turning a compost pile involves making a new pile with the decomposing material so that the material on the outside of the old pile is on the inside of the new pile. This will allow the undecomposed material on the outside of the old pile to decompose. The rate at which a pile decomposes depends on the outside temperature and how quickly the pile was built, so it may take 2 to 6 weeks after the pile was completed before it is ready to be turned.

15) After this soil-containing pile has completely decomposed, it will be 1/2 to 1/3 its original size.[80] A compost pile built of urine, soil and straw will decompose and transform into rich, cured compost and humus in about 3 months, with a range of 2 to 12 months depending on the size and density of the carbonaceous material in the pile, the number of turnings (turning more than once will speed the decomposition process but will also increase the amounts of nitrogen and carbon lost from the pile), the outside temperature, and the size of the pile.[81]

This cured compost can be used immediately. If you prefer to store it, break apart the pile and allow it to dry to 15% to 20% moisture optimally.[82] The dried cured compost can then be stored in a bin that protects it from the rain, snow and intense sunlight.

The Risk of Increasing Soil Salinity through the Use of Urine-Enriched Cured Compost in the Garden

When urine composted with straw is added to the soil, it contains most of the salts (any dissolved substances) originally contained in the urine. If these salts are not eventually leached from the soil or taken up by plants at an equal or greater rate than they are added, they could accumulate in the uppermost regions of the soil. The possible results are:

1) *Increased soil salinity*. The danger of increasing the salinity of the soil depends on the amount of total salts added to the soil through fertilization (the addition of cured compost and/or fertilizers) and irrigation, and the amount of salts lost through leaching and plant uptake. Increased soil salinity can make it more difficult for crops to extract water from the soil, which could slow or reduce their growth.The electrical conductivity (EC) of the irrigation water is used to predict the likelihood of the irrigation water increasing the soil's salinity level over time.

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[77] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], p. 108.

[78] We are not relying on killing pathogens in a human urine-containing compost pile with extreme heat generated from the pile. Therefore, we do not need to allow or encourage the pile to generate pathogen-killing temperatures (generally 160°F and above). The disadvantage of very hot piles is that less cured compost is produced, as more of the compost pile's initial organic matter is burned off in the pathogen-destroying heat. When we compost human manure, however, we do want sufficient heat to be generated in the center of the pile to kill pathogens. We must consider the disadvantage of burning up our cured compost as well as our pathogens when deciding the most appropriate method to use to recycle human manure.

[79] Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), p. 90.

[80] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 42) and John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7. Current data from compost piles made at the Common Ground Biointensive Research Mini-Farm indicate some piles may decompose to *as little as* 1/6 their original size. Two conditions will result in less cured compost produced from the same volume of initial compost: 1) The initial carbon-to-nitrogen ratio is less than 30 to 1; and/or 2) if the pile is turned more than once to speed decomposition.

[81] See Steve Rioch, Ecology Action's Self-Teaching Mini-Series, *Booklet #23: Biointensive Composting* (Willits, CA: Ecology Action, March 1990) for the various signs that indicate a compost pile is completely mature.

[82] Steve Rioch, Ecology Action's Self-Teaching Mini-Series, *Booklet #23: Biointensive Composting* (Willits, CA: Ecology Action, March 1990), p. 9. To determine the compost's moisture level, see the same page of the same publication.

2) *Decreased soil permeability.* The danger of decreasing the permeability of the soil depends on four factors:

a) the amount of total salts added to the soil through fertilization and irrigation, and the amount of salts the soil loses through leaching and plant uptake. Irrigation water that has few salts can reduce a soil's permeability because of the water's ability to extract calcium and other soluble minerals from the soil;

b) the amount of sodium relative to the amounts of calcium and magnesium that are added to the soil through fertilization and irrigation;

c) the amounts of carbonates and bicarbonates that are added. The combined effects of these first three factors -- a), b) and c) -- can be predicted by calculating the "adjusted Sodium Adsorption Ratio" (adj. SAR). The adj. SAR, as well as the electrical conductivity of the irrigation water, is used to predict the danger of the irrigation water decreasing the soil's permeability over time;

d) the dominant type of clay in the soil. Shrinking-swelling clays (such as montmorillonite) are more adversely affected than are non-swelling clays (such as illite-vermiculite and kaolinite). Decreased soil permeability reduces the amount of air and water (the two most important elements for fertile soil) that can enter the soil, and reduces crop vigor.

3) *Salt toxicity* (most commonly boron, chlorine and sodium). The danger of accumulating toxic levels of certain minerals in the soil depends on the difference between the amounts of these minerals added to the soil through fertilization and irrigation and the amounts lost through leaching and plant uptake.[83]

As shown in Appendix B: Detailed Calculation #6, when the urine one person produces each day is composted and added to 24 garden beds,[84] it has little effect on the salinity, permeability or salt toxicity of the soil. The more important determining factor is the quality of the water used to irrigate the soil and crops.

Human urine (as well as manure) has been used for many centuries by ancient Andean peoples[85] and, for the past 4,000 years, by the Chinese[86] to fertilize their fields. The Andeans and the Chinese (until recently when they adopted conventional mechanized chemical agricultural techniques), unlike most human civilizations before and after them (including our own), generally succeeded in maintaining and even improving the fertility of their soils. So, on the basis of these histories and the calculations shown in Appendix B: Detailed Calculation #6, it seems extremely unlikely that properly composted and applied human urine would compromise the health of the soil.

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[83] R. S. Ayers and D. W. Westcot, *Water Quality in Agriculture, Irrigation and Drainage Paper #29* (Rome: Food and Agriculture Organization of the United Nations, 1976), pp. 2-4, 7.

[84] While 24.4 beds are needed in the winter to grow the straw needed to compost all of the urine one person produces annually, fewer beds are needed if additional carbonaceous compost crops are grown in the summer as well. Two examples of systems to grow all of one's food (calories) and recycle all of one's waste (urine and manure) are given in Chapter 5 of this publication. Example #1 requires 24 beds and Example #2 requires 35 beds. In any sustainable system, all of the urine-enriched cured compost should be added to *all* of the beds growing the person's diet in order to maintain the soil's fertility and meet the four goals of recycling human waste. However, the fewer the beds that receive the given amount of urine-enriched cured compost that one person can generate annually, the greater the risk of increasing the soil's salinity. Therefore, the lower number of beds, 24 in Example #1, is used to determine the risk of increasing soil salinity by adding the annual production of urine-enriched cured compost. If no risk is found, increasing the number of beds that receive the annual production of urine-enriched cured compost will not change this prediction.

[85] Edward Hyams, *Soil & Civilization* (New York, NY: Harper & Row, 1976), p. 222.

[86] F. H. King, *Farmers of Forty Centuries* (Emmaus, PA: Rodale Press, 1911), pp. 193-205.

Other Uses

Other reported uses of human urine in the garden are to deter deer from the garden (presumably by sprinkling it around the perimeter of the garden "to mark human territory") and as an herbicide in specific, limited cases: for example, fresh urine sticks to the leaves of buttercups and scorches them, but runs off the leaves of onions. Undiluted human urine is toxic to soil organisms.[87] The rate at which the urine can be applied, so that it is effective but not toxic to soil organisms, will depend on soil and climatic conditions and must be determined through careful experimentation.

When urine is added undecomposed to a garden, much of the nitrogen and other nutrients it contains are lost. The cost of this loss of nutrients from the urine and the possible increased rate of humus loss seems a large price to pay to avoid weeding by hand.

For more information, read:

1. R. G. Feachem, et al. *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review.* Washington, D.C.: World Bank, 1981. (Free of charge!)
2. Elaine Myers, "Pee on the Garden," *The Permaculture Activist*, May 1992, pp. 21-22.
3. Dr. William S. Peavy, "An Analysis of Plant Nutrients in Urine," *Maine Organic Farmer & Gardener*, November / December 1993, p. 18.

> *"The taking of food from the topsoil and failing to return it in compost is suicidal. Western man has been undermining his very existence since the introduction of chemical manures and water sanitation. He has been raping the earth, taking from it crops of every kind, and has failed to recognize the law of return and fair play. Few people realize that every ton of wheat grain represents four fifths of a ton of earth...In so far as this produce is fed to livestock, it may be returned to the land as farmyard manure; but the great majority of food consumed by city dwellers eventually leaves their bodies in the form of solid and liquid waste and is lost to the land, owing to modern sewage."*
>
> *- Richard St. Barbe Baker*, Green Glory

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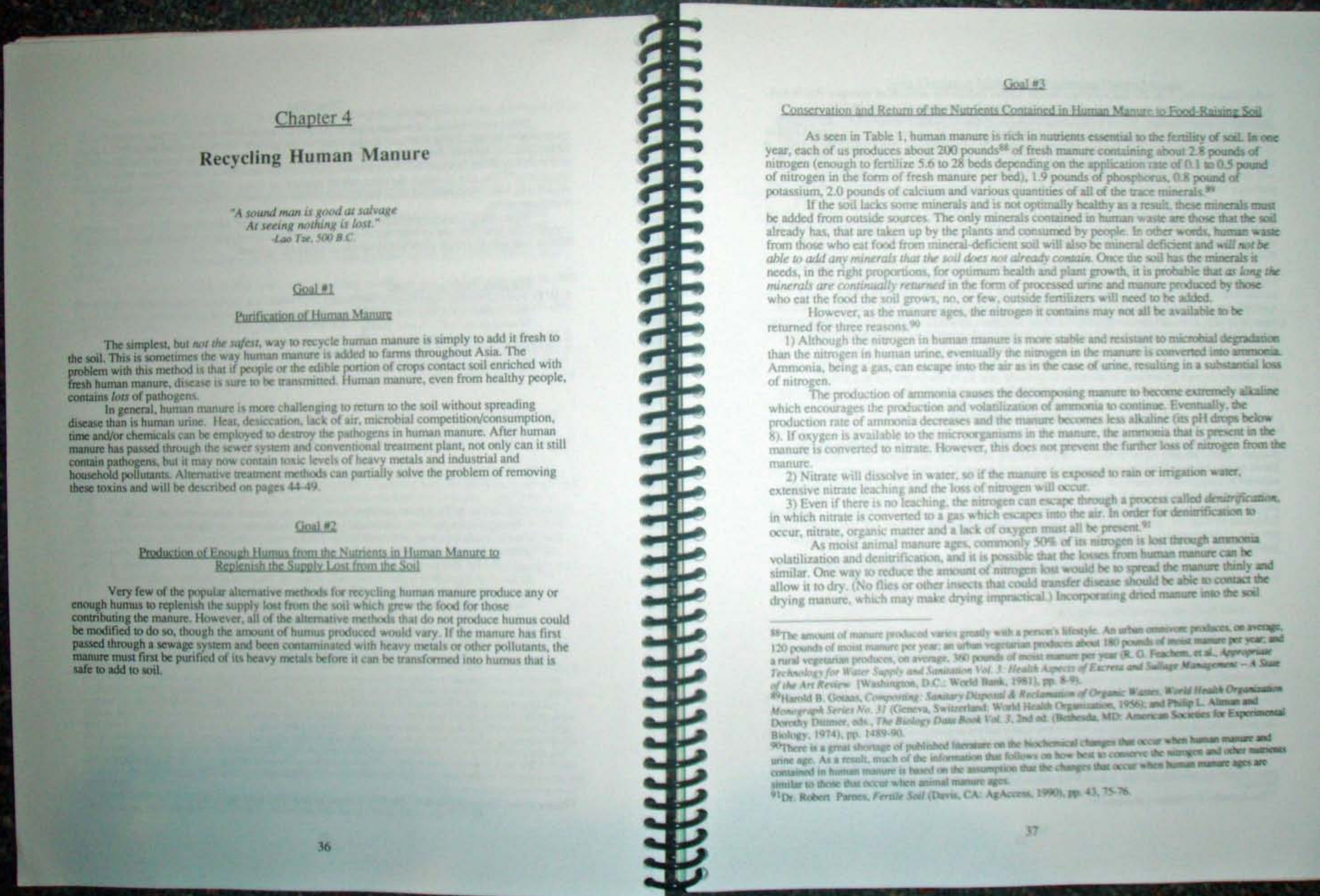
[87] Elaine Myers, "Pee on the Garden," *The Permaculture Activist*, May 1992, pp. 21-22.



Chapter 4

Recycling Human Manure

"A sound man is good at salvage
At seeing nothing is lost."
-Lao Tse, 500 B.C.

Goal #1

Purification of Human Manure

The simplest, but *not the safest*, way to recycle human manure is simply to add it fresh to the soil. This is sometimes the way human manure is added to farms throughout Asia. The problem with this method is that if people or the edible portion of crops contact soil enriched with fresh human manure, disease is sure to be transmitted. Human manure, even from healthy people, contains *lots* of pathogens.

In general, human manure is more challenging to return to the soil without spreading disease than is human urine. Heat, desiccation, lack of air, microbial competition/consumption, time and/or chemicals can be employed to destroy the pathogens in human manure. After human manure has passed through the sewer system and conventional treatment plant, not only can it still contain pathogens, but it may now contain toxic levels of heavy metals and industrial and household pollutants. Alternative treatment methods can partially solve the problem of removing these toxins and will be described on pages 44-49.

Goal #2

Production of Enough Humus from the Nutrients in Human Manure to Replenish the Supply Lost from the Soil

Very few of the popular alternative methods for recycling human manure produce any or enough humus to replenish the supply lost from the soil which grew the food for those contributing the manure. However, all of the alternative methods that do not produce humus could be modified to do so, though the amount of humus produced would vary. If the manure has first passed through a sewage system and been contaminated with heavy metals or other pollutants, the manure must first be purified of its heavy metals before it can be transformed into humus that is safe to add to soil.

Goal #3

Conservation and Return of the Nutrients Contained in Human Manure to Food-Raising Soil

As seen in Table 1, human manure is rich in nutrients essential to the fertility of soil. In one year, each of us produces about 200 pounds[88] of fresh manure containing about 2.8 pounds of nitrogen (enough to fertilize 5.6 to 28 beds depending on the application rate of 0.1 to 0.5 pound of nitrogen in the form of fresh manure per bed), 1.9 pounds of phosphorus, 0.8 pound of potassium, 2.0 pounds of calcium and various quantities of all of the trace minerals.[89]

If the soil lacks some minerals and is not optimally healthy as a result, these minerals must be added from outside sources. The only minerals contained in human waste are those that the soil already has, that are taken up by the plants and consumed by people. In other words, human waste from those who eat food from mineral-deficient soil will also be mineral deficient and *will not be able to add any minerals that the soil does not already contain.* Once the soil has the minerals it needs, in the right proportions, for optimum health and plant growth, it is probable that *as long the minerals are continually returned* in the form of processed urine and manure produced by those who eat the food the soil grows, no, or few, outside fertilizers will need to be added.

However, as the manure ages, the nitrogen it contains may not all be available to be returned for three reasons.[90]

1) Although the nitrogen in human manure is more stable and resistant to microbial degradation than the nitrogen in human urine, eventually the nitrogen in the manure is converted into ammonia. Ammonia, being a gas, can escape into the air as in the case of urine, resulting in a substantial loss of nitrogen.

The production of ammonia causes the decomposing manure to become extremely alkaline which encourages the production and volatilization of ammonia to continue. Eventually, the production rate of ammonia decreases and the manure becomes less alkaline (its pH drops below 8). If oxygen is available to the microorganisms in the manure, the ammonia that is present in the manure is converted to nitrate. However, this does not prevent the further loss of nitrogen from the manure.

2) Nitrate will dissolve in water, so if the manure is exposed to rain or irrigation water, extensive nitrate leaching and the loss of nitrogen will occur.

3) Even if there is no leaching, the nitrogen can escape through a process called *denitrification*, in which nitrate is converted to a gas which escapes into the air. In order for denitrification to occur, nitrate, organic matter and a lack of oxygen must all be present.[91]

As moist animal manure ages, commonly 50% of its nitrogen is lost through ammonia volatilization and denitrification, and it is possible that the losses from human manure can be similar. One way to reduce the amount of nitrogen lost would be to spread the manure thinly and allow it to dry. (No flies or other insects that could transfer disease should be able to contact the drying manure, which may make drying impractical.) Incorporating dried manure into the soil

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[88] The amount of manure produced varies greatly with a person's lifestyle. An urban omnivore produces, on average, 120 pounds of moist manure per year; an urban vegetarian produces about 180 pounds of moist manure per year; and a rural vegetarian produces, on average, 360 pounds of moist manure per year (R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], pp. 8-9).

[89] Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956); and Philip L. Altman and Dorothy Dittmer, eds., *The Biology Data Book Vol. 3*, 2nd ed. (Bethesda, MD: American Societies for Experimental Biology, 1974), pp. 1489-90.

[90] There is a great shortage of published literature on the biochemical changes that occur when human manure and urine age. As a result, much of the information that follows on how best to conserve the nitrogen and other nutrients contained in human manure is based on the assumption that the changes that occur when human manure ages are similar to those that occur when animal manure ages.

[91] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), pp. 43, 75-76.

rather than leaving it on the soil's surface would further reduce the amount of nitrogen that is lost. A third way to decrease the amount of nitrogen lost from human manure would be to let it decompose anaerobically. When animal manure is decomposed in the absence of air, the organic acids produced reduce the amount of ammonia produced. Little of the ammonia that is produced is converted to nitrate since this process requires oxygen. To anaerobically decompose the manure, it should be kept slightly moist -- too dry and it will let in air and produce ammonia; too wet and it will putrify and emit offensive odors, which may attract flies and animals.[92] A fourth way, and probably the most practical way, to decrease the amount of nitrogen lost is to compost the manure with plenty of soil and carbonaceous plant material for the reasons described in "Composting Human Urine." Composting human manure is described in detail on pages 61-73. Even if 50% of the nitrogen in human manure is lost, all of the lost nitrogen can be returned from the air to the soil by growing leguminous crops that fix atmospheric nitrogen. (For a more detailed discussion of this, see pages 71-72.)

Nitrogen is the element most easily lost from human waste, but it may not be its most important constituent. Unlike the phosphorus in many inorganic fertilizers, the phosphorus in animal manure (and possibly human manure) is readily available and usable by plants. Trace minerals are inconvenient to add in inorganic form, but both human urine and manure are rich in trace minerals. Also, the microorganisms and the enzymes, vitamins, hormones and other organic molecules in human manure could increase soil fertility and crop vigor in ways not entirely understood.[93]

Goal #4

Proper Nitrogen Application

The percentage of available nitrogen contained in human manure is lower than all fowl manure, approximately equal to sheep and pig manure, and higher than horse and cow manure. Based on the 18-year Scandinavian study which found unspecified raw barnyard manure equal or superior to composted manure for improving the health of soil (see page 22 of this publication), human manure, even in the raw state, is beneficial to soil and crop health (though it could be a danger to human health, depending on the way that it is added to the soil) so long as no more than 0.5 pound of total nitrogen is added in the form of processed human manure per 100 square feet per year. Conservatively, human manure never needs to be added fresh; it can always be aged before it is returned to the soil.[94]

2.4 cubic feet of human manure-enriched cured compost produced as described on pages 62-72 contain 0.5 pound of cured nitrogen.[95]

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[92] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), pp. 44-45.

[93] Extrapolated to human manure from information on animal manures by Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 44.

[94] A customary practice is to use rotted [animal] manure on fast-growing crops and fresh manure on slower ones, though the flavor of some crops is tainted when fertilized with fresh manure (Dr. Robert Parnes, *Fertile Soil* [Davis, CA: AgAccess, 1990], pp. 44, 46).

On the other hand, when Chinese farmers switched from fertilizing with human, animal and plant waste to chemical synthetics, they "complained that the rice was 'harder and not as good to eat,' saying 'if you use only family fertilizer, it is better to taste.'" (Michael Ableman, *From the Good Earth* (New York: Harry N. Abrams, Inc., 1993), p. 58.

In either case, one must be absolutely sure that the manure used to fertilize soil that will grow root or leaf crops has met the strict requirements described throughout Chapter 4 to ensure the pathogens it contains have been destroyed.

[95] See Appendix B: Detailed Calculation #1.

Nine Alternative Methods for Processing Human Manure

Nine alternative methods for processing human manure[96] are described in this chapter, most of which use fewer resources and less energy and require less capital than the conventional method of treatment with massive sewage systems and treatment plants. An even more important advantage to these alternative methods is that, unlike conventional treatment, they are able to achieve some or all of the four goals of recycling human waste. The alternative methods are:

1) Aquaculture
2) Human-Designed Wetlands
3) "Solar Aquatics Sytems"
4) An Algal Regenerative System
5) Pelletization
6) Solar Heating
7) Composting
8) Trees
9) Grains and Perennials

All of the alternative methods described in this book for recycling human manure that do not produce cured compost could be modified to do so, in order that the soil's supply of humus is replenished. *Because none of the methods require that more than 0.5 pound of total nitrogen be added to 100 square feet per year, Goal #4 is assumed to be achieved by all methods, will not be further discussed and is not used to compare the methods in Table 3.*

Table 3 is a comparison of all nine alternative methods of processing human manure that are discussed in this book. The ratings given to each method assume that the method is a part of a sustainable food-raising system. Therefore, if the method of purifying manure does not also produce food for the people generating the waste, as well as food (in the form of nutrients and compost) for the soil growing the people's food, the rating reflects the additional land, water and resources that would be needed.

> *In the 1960's, Chinese farmers began using chemical fertilizers instead of human waste on their farms. Now farmers complain "that the rice [is] 'harder and not as good to eat,' saying 'if you use only family fertilizer, it is better to taste.'"*
>
> - ***Michael Ableman***, From The Good Earth

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[96] Of the nine methods listed below, aquaculture, human-designed wetlands, "solar aquatics systems", and an algal regenerative system simultaneously process human urine and manure.

Table 3

The Methods Compared

	Goal#1: Human Waste Purified?[A]	Goal #2: Enough Humus Produced?	Goal #3: Minerals Returned to Food-Producing Soil ?	Land Required[E]	Energy & Resources Required	Water Required[M]	Usable by One Person or Family ?	Usable in Cold Climates?
Aquaculture	Often No	No[C]	Possibly	Low	Very Low	High	Yes	No
Human-Designed Wetlands	Yes-Chemical	No[C]	Possibly[D]	High[F]	High[J]	Very High	No	No
Solar Aquatics Systems	Yes-Chemical	No[C]	Possibly[D]	Medium[G]	Medium[K]	High	Possibly	Yes
Algal Regenerative System	Possibly[B]	No[C]	Yes	High[H]	Medium[L]	Very High	Yes	Unlikely
Pelletization	Yes-Heat	No	Possibly[D]	Medium[I]	Very High	High[N]	No	Yes
Solar Cooking	Yes-Heat	No	Yes	Low[I]	Low	Low	Yes	Possibly
Composting	Yes-Heat	Yes	Yes	Low	Very Low	Low	Yes	Yes
Trees	Yes-Time	Yes	Yes	Low	Very Low	Low	Yes	Yes
Grains and Perennials	Yes-Time	Yes	Yes	Very Low	Very Low	Low	Yes	Yes

Notes for Table 3

A) "Chemical", "Heat", etc. refer to the principal method used to remove the pathogens. Removal of toxic contaminants is not considered here.

B) What is to be applied to food-raising soil as fertilizer may not have been exposed to anaerobic conditions long enough to kill worms of the genus *Ascaris* and other parasitic worms that may be common in the community. Parasitic worms of the genus *Ascaris* can cause mechanical obstruction in the human digestive tract and a reduction in food absorption and utilization.[97] *Ascaris* is found worldwide.[98]

C) Enough humus could be produced only if composting was incorporated into the system and the plants did not accumulate excessive amounts of toxins in their bodies.

D) Since the method generally requires a sewage system to bring the waste to the treatment site, whether the nutrients in the waste could be returned to the soil would depend on the amount of toxic contaminants in the waste before it is processed. In the case of methods which use water plants, if excessive toxins were in the waste, the plants could take up and accumulate a level of toxins that would remain in their bodies when they decompose and cause the compost that is generated to be too toxic to add to soil.

E) The rating given to each method takes into account the amount of additional land that would be required to grow the food for the people generating the urine and manure. The land required by some of the systems to sustainably recycle human waste may not be available for many people in the world currently or in the future. For further information on the average amount of land available per capita currently and in the future, see Appendix D: The Circle Chart.

F) About 87 square feet are required per person to treat a community's waste, but the method does not produce food for that community.

G) Although as little as 6 square feet per person are required to treat a community's waste, additional land may be needed to transport the sewage from the homes to the treatment facility and to grow the food for the people generating the sewage.

H) Rating is due to the system's reliance on livestock.

I) Since very little humus is produced and much of the carbon and nitrogen in the waste is lost, additional land is needed to produce enough compost to keep the food-growing soil fertile.

J) The method uses a conventional treatment plant for final purification of the sewage water.

K) SAS use ozone to purify the waste of its pathogens and take place within greenhouses, which may need to be heated during the winter for the method to work properly.

L) This rating could change depending on the method used to further purify the sludge produced from anaerobically decomposing the waste since it may still contain pathogens.

M) The rating given to each method takes into account the amount of additional water that would be required to grow the food for the people generating the urine and manure.

N) Pelletization currently depends on sewage systems that require large amounts of water to transport the waste to the processing plant.

The first four alternative methods that will be described all use water plants to remove the toxins which conventional sewage treatment methods cannot. They are all designed to be usable by communities, towns and cities, though some may be less appropriate for individuals and families. All four systems are less expensive and consume much less energy and fewer resources than conventional systems to purify the same amount of wastewater, and do not require highly-trained personnel to operate.

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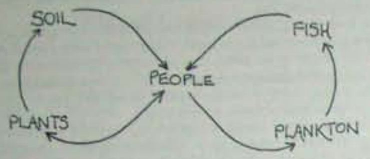
[97] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], pp. 21,65.

[98] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], p. 22.

AQUACULTURE



For many centuries and up to the present, people living where water is plentiful year round have often situated their privies above ponds. The nutrients contained in the waste feed the plankton which feed the fish which feed the people who produce more urine and manure to feed the plankton and continue the cycle. The nutrients also feed the plants in the pond which can be periodically harvested and either eaten or composted and added to the farmlands.

One challenge with aquaculture systems is that *Goal #1, the purification of the manure*, is difficult to achieve. Since the manure is fresh and unprocessed when it enters the pond, all of the pathogens it contains must be destroyed in the pond in order for disease not to be spread when the fish and water plants are consumed. However, some human manure-transmitted pathogens, including parasitic worms, not only are not destroyed but thrive in ponds. For example, part of the reproduction cycle of the worm responsible for urinary schistosomiasis takes place in an intermediate aquatic host, and one egg can give rise to thousands of larvae.[99] Hookworm larvae can survive as long as 1.5 years in water.[100] Some viruses, such as the one responsible for polio, can be found three to five months or more after they have entered and polluted a water source.[101] If fish or plants from the pond are consumed before sufficient time has passed to kill the pathogens in the waste that entered the pond, the pathogens could survive to cause disease. In order to ensure these pathogens are destroyed before produce from the pond is consumed, two ponds could be used: only one pond receives human waste for 1.5 years (assuming hookworm is prevalent in the community). For the next 1.5 years, the second pond receives human waste while the organisms in the first pond have time to destroy the pathogens that were introduced. A further complication is that ponds can serve as breeding grounds for insects like mosquitoes that transfer many deadly diseases and often cannot be eliminated by simply improving sanitation conditions. If these are dangers you may face, it may be safest to choose another means to purify and recycle your waste.

One advantage to most aquaculture systems is that the human waste never enters a sewage system but goes directly into a pond, so the waste is not contaminated with the heavy metals and other toxins that a sewage system typically contains.

While the fish, when sufficiently cooked to kill any pathogens within or on the outside of it, may be a valuable source of nutrition and calories, vegetables are needed for a complete and balanced diet. While all of the water plants can be composted, if they do not contain enough carbon, not enough humus will be generated to replenish the humus supply of the soil growing the

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[99] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], p. 52.

[100] W. Nicoll, "Observations on the Influence of Salt and Other Agents in Modifying the Larval Development of the Hookworms *Ancylostoma duodenale* and *Necator americanus*," *Parasitology*, Vol. 9, 1917, pp. 157-189.

[101] A. J. Rhodes, et al., "Prolonged Survival of Human Poliomyelitis Virus in Experimentally Infected River Water," *Canadian Journal of Public Health*, Vol. 41, 1950, pp. 146-149; and N. A. Clarke, R. E. Stevenson, and P. W. Kabler, "Survival of Coxsackie Virus in Water and Sewage," *Journal of the American Water Works Association*, Vol. 48, 1956, pp. 677-682.

vegetable crops. Therefore, in order for an aquaculture system to achieve *Goal #2, production of sufficient humus*, additional land would be required to grow carbonaceous crops that could be composted to generate humus and replenish the soil's supply.

Since the vegetables, grains and other crops contain minerals derived from the soil, if those minerals (most of which are contained in the urine and manure of those who consume the crops) are returned to the pond and not eventually to the soil, eventually the soil will be depleted of certain minerals. Therefore, for the aquaculture system to be sustainable and achieve *Goal #3, return of the minerals to food-raising soil*, the minerals taken up by the crops and consumed by the people must return to the farm's soil by either: 1) flowing out of the pond and onto the land growing the remainder of the diet; or 2) being taken up by the plants growing in the pond. The plants must then be composted and returned to the soil as cured compost. If there is not sufficient water and nutrient outflow or plant nutrient uptake and the soil's nutrients accumulate on the bottom of the pond, the nutrient-rich bottom mud must be occasionally removed and added to the soil growing the food crops. This is possible if a boat equipped with a silt pump is available with which the mud can be removed, or more simply, if the pond is dry during a part of the year or can be drained so that the bottom mud can be removed and added to the farm's soil.[102] Still, 70 to 80% of the nitrogen in the manure may be lost as it breaks down in the pond.[103] Analyzing the soil periodically can help determine if the soil's minerals are being replenished or depleted.[104]

The amount of nitrogen applied to the soil should be no more than 0.1 to 0.5 pound per 100 square feet per year in order to achieve *Goal #4, proper application of nitrogen*. The amount of nitrogen that can be safely added to a pond would depend on a number of factors such as the pond's surface area and depth, the annual outflow, the needs and tolerances of the various pond organisms and plants and the downstream uses of the water.

Further research is needed to know how to add our waste to a pond in ways that will benefit the entire pond ecosystem of which we are a part.

For more information, read:

- The New Alchemy Institute. *The Journal of New Alchemists* (any issue). Woods Hole, MA: New Alchemy Institute, Inc.
- R. G. Feachem, et al. *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review*. Washington, D.C.: World Bank, 1981. (Free of charge!)
- G. A. Rohlich, et al. *Food, Fuel, and Fertilizer from Organic Wastes*. Washington, D.C.: National Academy Press, 1981.

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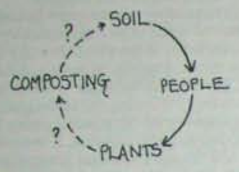
[102] Food and Agriculture Organization of the United Nations, *China: Recycling of Organic Wastes in Agriculture*, FAO Soils Bulletin #40 (Rome: Food and Agriculture Organization of the United Nations, 1977), pp. 9-10.

[103] Extrapolated to human manure from animal manure data presented by David E. Chaney, et al., *Organic Soil Amendments and Fertilizers*, Publication 21505 (Oakland, CA: University of California, 1992), p. 16.

[104] For a thorough soil analysis, contact Steve Rioch, Timberleaf Farm, 5569 State Street, Albany, Ohio, 45710.

HUMAN-DESIGNED WETLANDS



Arcata System

When the discharge from the sewage treatment plant in Arcata, California no longer met government standards, Dr. Bob Gearheart, an environmental engineering professor at Humboldt State University, Dr. George Allen, a fisheries professor at Humboldt, and Frank Klopp, the public works director of Arcata, teamed up to devise a solution. Sparked by a suggestion from a "C-minus student who slept all the time" of Allen's,[105] the trio went to work and eventually came up with a cheaper, more environmentally sound alternative to the state's proposed regional treatment plant. It was called human-designed wetlands. With the support of the people of Arcata and the perseverance of Gearheart, Allen and Klopp, the construction of the wetlands was reluctantly approved by the state. In 1986, the wetlands were completed and have been purifying Arcata's sewage water to *tertiary* standards (see page 2) ever since.[106]

In Arcata's wetlands system, Arcata's sewage first goes to a conventional treatment plant where it is treated to meet primary standards. The sewage is then pumped into oxidation ponds where it is treated to secondary standards. After the suspended solids have settled to the bottom, the liquid flows through a series of three 2.5-acre marshes for two days, feeding the cattails, bulrushes and other marsh-loving plants with the nutrients it contains.[107] Roughly 90% of the sewage's heavy metals are removed by the plants and microbes living in the marshes which take up and incorporate the heavy metals into their bodies. The plants and microbes are also able to break down pesticides, industrial solvents and other toxins in the sewage water,[108] but they are unable to remove all of the pathogens. In order to fully achieve *Goal #1, the purification of the waste*, the sewage water is pumped back to the treatment plant where it is chlorinated, to kill any remaining pathogens, and then dechlorinated and discharged into Humboldt Bay.[109] The discharged water is actually cleaner than the bay itself, and pure enough to raise salmon.[110] The plants, having accumulated industrial toxins, are harvested and burned to prevent the toxins from accumulating and damaging the wetlands.[111]

Arcata's wetlands system has at least three advantages over conventional sewage treatment plants. First, it is a much cheaper way for a town to purify its sewage water to tertiary standards. Arcata estimates its wetlands system has saved it $2 million in capital costs over the state-advocated regional treatment plant.[112] Second, Gearheart estimates that the cattails grown in the marshes could be harvested and converted into fuel to provide 10% of the fuel used by Arcata's police force.[113] Third, the wetlands have transformed an eyesore of a landfill locally called Mount Trashmore, as well as other neighboring abandoned lands, into beautiful habitats that teem with almost 200 species of birds, mammals, amphibians and other wildlife, and attract locals and visitors alike.[114] Despite redwood forests and dramatic, secluded beaches nearby, Arcata's natural sewage treatment plant is often the preferred place to spend free time.[115]

For illustrations of such a system, see:
Will Browne, "From Waste to Wealth," *Resurgence*, January/February 1994, pp. 18-19.

Wolverton and Microbial Rock Plant Filter Systems

Dr. B.C. Wolverton, formerly with NASA and now heading Wolverton Environmental Services, has designed several natural sewage treatment plants that are currently used in several towns in the U.S. In his system, the town's sewage is pumped into an oxidation pond where it is decomposed by aerobic and anaerobic microorganisms for about three months. The wastewater then moves through a rock-reed filter where it is further decomposed by microorganisms that associate with the roots of water plants such as reeds, African calla lilies, water irises and arrowheads. Virtually identical to Wolverton's system is the Microbial Rock Plant Filter (MRPF) which has been promoted by the EPA as a viable, low-cost alternative to a conventional sewage treatment plant for small communities.

Existing sewage treatment facilities do not have to be abandoned with the establishment of a Wolverton or MRPF system but can be incorporated into the system to pre-treat the sewage. Costing 1/30th the price of a conventional sewage treatment plant to create, a Wolverton or MRPF system is a much cheaper *and* more environmentally benign alternative than a conventional sewage treatment plant to improve the quality of the wastewater discharged into our waterways.

One disadvantage with the system in Arcata and the Wolverton and MRPF systems is that they require more land than a conventional system -- about 20 to 60 acres for every 10,000 people[116] -- which may restrict other towns from adopting such a system. *Where winters are cold enough to inhibit the biological activity of the plants and microbes in the wetlands, additional land may be required to store the sewage until warmer weather allows the wetlands to properly purify the waste.*[117] For further information on the average amount of land available per capita currently and in the future, see Appendix D: The Circle Chart.

One disadvantage to Arcata's wetlands system specifically is that it still relies in part on an expensive, energy- and resource-consumptive conventional treatment plant to purify its sewage and achieve *Goal #1, the purification of the waste*. The Wolverton and MRPF systems do not require a conventional sewage treatment plant, but they only clean to secondary standards and it is probable that pathogens remain in the treated wastewater. Furthermore, all three systems, like aquaculture, have the potential to serve as breeding grounds for mosquitoes that transmit malaria and snails that carry schistosomes, the parasites that cause liver damage.[118] However, it may be that the predators of mosquitoes and snails could also be a part of the wetlands ecosystem and would keep them in

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[105] James Willwerth, "A Swamp Makes Waste To Be Sweet Again," *Time*, March 20, 1989; and J. William Price, "The Marsh That Arcata Built," *Sierra*, May/June 1987, p. 52.

[106] *Garbage*, January/February 1990, p. 29; and Susan Dillingham, "Letting Nature Do The Dirty Work," *Insight*, January 16, 1989, p. 50.

[107] Susan Dillingham, "Letting Nature Do The Dirty Work," *Insight*, January 16, 1989, p. 50.

[108] Bruce E. Goldstein, "Sewage Treatment, Naturally," *Worldwatch*, July/August 1988, p. 5.

[109] Susan Dillingham, "Letting Nature Do The Dirty Work," *Insight*, January 16, 1989, p. 50.

[110] J. William Price, "The Marsh That Arcata Built," *Sierra*, May/June 1987, p. 53.

[111] Bruce E. Goldstein, "Sewage Treatment, Naturally," *Worldwatch*, July/August 1988, pp. 5-6.

[112] Susan Dillingham, "Letting Nature Do The Dirty Work," *Insight*, January 16, 1989, p. 50.

[113] J. William Price, "The Marsh That Arcata Built," *Sierra*, May/June 1987, p. 53.

[114] J. William Price, "The Marsh That Arcata Built," *Sierra*, May/June 1987, p. 53.

[115] *Garbage*, January/February 1990, p. 28.

[116] Susan Dillingham, "Letting Nature Do The Dirty Work," *Insight*, January 16, 1989, p. 51; and *Garbage*, January/February 1990, pp. 28-29.

[117] Christopher Hallowell, "Plants That Purify: Nature's Way to Treat Sewage," *Audubon*, January-February 1992, pp. 76-80.

[118] Bruce E. Goldstein, "Sewage Treatment, Naturally," *Worldwatch*, July/August 1988, p. 6.

check. These predators may be, in part, the fish living in the pond. Before the fish are eaten, they must be thoroughly cooked in order to kill any pathogens the fish may have consumed.

Another disadvantage to Arcata's wetlands system is that by using oxidation ponds to treat the sewage to secondary standards, some of the nutrients and most of the less soluble nutrients that settle to the bottom of the ponds are lost and very difficult to remove and return to agricultural lands. Therefore, *Goal #3, the return of the nutrients in the waste to food-raising soil*, and, consequently, *Goal #2, production of sufficient humus*, may not be achieved.

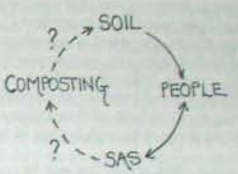
Further challenges we face when using human-designed wetlands to achieve Goals #2 and #3 are identical to those faced when Solar Aquatics Systems are employed, and are described in the following section.

An advantage of these systems is that they are gaining in popularity and have proven themselves effective in cleaning effluent under various climatic conditions. To gain approval for the installation and use of a wetlands system, first contact your county's health department representative responsible for such approvals. If the representative is not knowledgeable about wetlands systems, contact the United States Environmental Protection Agency's Small Flows Clearinghouse. This agency will send an appropriate Environmental Protection Agency manual to your health representative which describes how wetlands work and how to inspect and approve them.

For more information, contact:

- United States Environmental Protection Agency's Small Flows Clearinghouse (800) 624-8301

SOLAR AQUATICS SYSTEMS



"Solar Aquatics Systems" (SAS), developed by Dr. John Todd, formerly the Director of the New Alchemy Institute and now heading Ocean Arks International (OAI), require no more land than conventional systems, are cheaper to construct, and, unlike conventional systems, are modular and easily expandable. Unlike human-designed wetlands, *SAS can function in cold climates* and can serve big cities as well as small communities. SAS use bacteria, algae and higher plants, snails and other mollusks, and fish to purify wastewater to tertiary standards, and ozone is used to destroy any remaining pathogens. According to OAI, by-products such as trees, plants, soil amendments and bait fish can be produced to offset the costs of the system.

Dr. Todd and OAI are also developing a water treatment system that "is extremely low cost, easily transported and installed, and requires little maintenance and no skilled operation." This could be extremely important in "disaster areas, in countries where funds for water treatment are extremely limited and in places where water-born diseases get out of control."[119]

One limit of SAS is that they rely on ultraviolet radiation or ozone to remove the pathogens from sewage and achieve Goal #1. Both technologies are fairly expensive and would be difficult to obtain and maintain for many people in the world. Also, unlike chlorine (which is not an optimal means of killing sewage pathogens because it is converted into poisonous, cancer-causing compounds when it mixes with other chemicals in sewage), ozone is not able to kill pathogens that may enter the water *after* it has been discharged from the system.

One of the end-products of conventional sewage treatment is sludge, and finding somewhere to put all of the sludge we produce has always been a problem. The problem has intensified in the U.S. ever since Congress banned the practice of dumping sewage sludge into oceans in 1988 and continues to intensify as the remaining possible sites for landfills decrease and public opposition to landfills increases. In 1992, New York City alone produced 710,000 pounds of *dry* sludge each day! [120]

Another advantage to SAS, human-designed wetlands and the Wolverton/MRPF system is that instead of producing mountains of sludge, the three alternative systems produce plants, as well as the other by-products mentioned above, which have grown from the nutrients contained in the sewage. The plants, which have taken in carbon from the air, can increase the amount of carbon available to the system that can be converted into cured compost for the soil. While each of the systems may need to be modified so that the plants are composted and not burned or discarded, the systems that grow plants will produce more compost than a conventional system modified so that the sludge is composted and will better achieve *Goal #2, the production of sufficient humus*, and *Goal #3, return of the minerals to food-raising soil*. However, if the plants and other by-products are sold, the nutrients they contain would also be sold. If the nutrients are discarded and/or not

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[119] Quoted from the information packet on SAS available from The Center at OAI, 1 Locust St., Falmouth, MA, 02540.

[120] Teresa Austin, "From Sludge to Brokered Biosolids," *Civil Engineering*, August 1992, pp. 32-35. NYC officials now see promise in pelletizing and selling their sludge for land application/reclamation, lawn care, gardening and golf course/recreation cover. See "Pelletization" (page 58) for a discussion and analysis of this method.

returned to the soil from which they came, neither Goal #2 nor Goal #3 may be adequately achieved.

An important disadvantage to most systems that employ water plants to purify the waste is that generally not enough carbon is produced to fully achieve Goal #2. (See discussion of Goal #2 on pages 12-17.) In general, water plants, like most of our common vegetable plants, are comparatively low in carbon and high in nitrogen, with notable exceptions being reeds (which are produced in Wolverton's system), cattails, bulrushes and others. Since we need to grow carbonaceous crops to produce enough cured compost to maintain the fertility of the soil that feeds us, we can modify water plant systems to include *carbonaceous water plants* (reeds, cattails and bulrushes, among others) in order to produce enough humus to maintain the fertility of the soil growing our food.

Even if the nutrients are composted, it may still not be possible to use the cured compost on the soil from which the nutrients originally came if the sewage initially was contaminated with heavy metals and other toxins from industrial and/or household wastes. In each of the systems that utilize plants to purify sewage of toxins, the plants take up and concentrate the sewage's heavy metals and toxins in their bodies. Compost created from these plants would still contain most of these toxins, perhaps at levels which would harm the soil and severely reduce its ability to grow healthy crops, animals and people.

According to the USDA,[121] the amounts of four heavy metals that agricultural soils can "safely" accumulate (in kilograms per hectare) per year are:

Cadmium	5-20
Zinc	250-1000
Copper	125-500
Nickel	50-200

Stated a different way, sludge may be safe to apply to food-raising soil if it contains no more than 25 parts per million (ppm) of cadmium (sludge with 50 ppm of cadmium has been found acceptable to apply to ornamentals and trees). No data on the acceptable levels (in ppm) of the other heavy metals was given, nor was data given on the acceptable levels of lead or mercury, other heavy metals that can poison the soil and its crops. The sludge should not contain more than 10 ppm of either PCB or PBB, common industrial chemicals that are extremely toxic.

The above USDA guidelines appear to be extremely high since heavy metals tend to accumulate in the soil and do not readily leach out of the soil through irrigation. More research seems needed on what level of toxic heavy metal contamination is safe to apply to soil.

Another guideline to gauge the toxicity of sewage sludge is its cadmium-to-zinc ratio. If the cadmium-to-zinc ratio is less than or equal to 100, the zinc will act as a safety switch if there is toxic level of cadmium in the sludge. That is, if there is an excessive level of cadmium in the sludge that would render the crops toxic, there would be enough zinc in the sludge to kill off the plants before they could mature. So crops that would have contained toxic levels of cadmium cannot be consumed. However, if this results, *it would be very destructive to the soil;* lime would need to be added to the soil in order to increase the soil's pH and make the heavy metals less available, though this would also make other important nutrients, such as phosphorus, less available.[122] The soil would then need to be analyzed, preferably by someone experienced in revitalizing soils with toxic levels of heavy metals, to determine the next step to help restore the soil's health.

Before using any sewage sludge (which is best composted before it is used, to allow some of the organic toxins and pathogens to be destroyed) in your garden or farm, be sure that the levels of lead, mercury, cadmium, zinc, copper and nickel, as well as PCB and PBB, are considered safe

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[121] Jerry Minnich, et al., *The Rodale Guide to Composting* (Emmaus, PA: Rodale Press, 1979), p. 364.

[122] Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. (New York: Macmillan Publishing Company, 1984), p. 206.

for crop production (though these levels may not be safe for the long-term health of the soil, as discussed below). Then determine the cadmium-to-zinc ratio. If *any* of this information is not available from the supplier of the sludge, *do not use the sludge to fertilize any soil.*[123]

Rather than focusing on the possibility of *crop* toxicity, we need to focus on the possibility of *soil* toxicity. While the plants grown on soil fertilized with sludge whose levels of heavy metals are considered "safe," we could still be endangering *the long-term health of the soil.* Most heavy metals stay in the soil. If heavy metal-contaminated sludge is used continuously, these heavy metals will accumulate and eventually destroy the soil's health and ability to grow healthy crops. The use of contaminated human waste is necessarily a temporary measure: if we continue to use it, we will eventually toxify the soil. If we do not find a way not to contaminate our waste, our soils will continue to be depleted until they no longer can support us.

In order to safely return to the soil the nutrients in sewage, we can work to:

- *Decrease the amount of toxins we produce* by 1) finding ways to reuse them rather than discard them. For example, "A circuit board manufacturer (Aeroscientific) invests in ion-exchange columns to reclaim heavy metal wastes and ends up with an income from the recycled metals, a much reduced water bill and lower liability insurance,"[124] and/or 2) finding alternative chemicals that are more environmentally benign.
- *Prevent the toxins we do discard from entering our sewage systems* and contaminating our manure and urine.

For more information, read:

- *Garbage*, January/February 1990, pp. 28-35 [a good discussion and comparison of conventional sewage treatment and water plant-utilizing alternatives].
- Christopher Hallowell, "Plants That Purify: Nature's Way to Treat Sewage," *Audubon*, January-February 1992, pp. 76-80.
- Tom Crane and John Todd, Ph.D., "Solar Aquatics: Nature's Engineering," *Pollution Engineering*, May 15, 1992, pp. 50-53.

and write: The Center at OAI, 1 Locust St., Falmouth, MA, 02540

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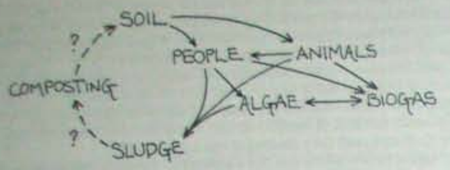
[123] Jerry Minnich, et al., *The Rodale Guide to Composting* (Emmaus, PA: Rodale Press, 1979), pp. 364-6.

[124] Donella H. Meadows, et al., *Beyond the Limits* (Post Mills, VT: Chelsea Green Publishing Company, 1992), p. 96.

AN ALGAL REGENERATIVE SYSTEM



In 1973, Dr. Clarence. G. Golueke, then research biologist and lecturer with the Sanitary Engineering Research Laboratory at the University of California, Berkeley, and Dr. William S. Oswald, then professor with the Department of Civil Engineering and School of Public Health at the University of California, Berkeley, designed a model of a small-scale algal regenerative system for single-family farms and homesteads.[125] The system includes housing for four people, one dairy cow and 50 chickens, an algal pool, an anaerobic digester and a solar still. The humans, cow and chickens all live in the circular building whose interior is divided by heavy walls, not only to support the algal pool which is on the roof, but to provide the humans privacy and quiet from the animals. The food scraps and waste from the people and animals are used to produce fuel for the people and animals, fertilizer for the soil and food for the algae. Excess algae are either fed to the animals, added to the anaerobic digester or sold. A gross annual income of $250 to $1,000 (estimated at 1973 prices) can be earned by selling the surplus milk and/or milk products, eggs, and dried algae.

In order to produce fuel and fertilizer, the food scraps, waste and excess algae enter the digester and undergo anaerobic decomposition. The gas which is produced (called "biogas") contains 50 to 70% methane and can be burned for fuel.[126] The liquid produced from the process enters a 16,250-liter (4,276-gallon) pool which grows algae. From 1 to 2.5 kilograms (2.2 to 5.5 pounds) dry weight of algal protein can be produced by this system per day. The solids, in the form of sludge, produced from the process of anaerobic decomposition are generally 2 to 4% nitrogen and, once they are composted, could be used to fertilize garden and farm soils. *No industrial wastes enter this system so heavy metals and other toxins do not need to be removed.*

The liquid from the digester passes through the algal pool, into a solar still, and becomes drinkable water. By placing the digester and algal pool on the roof of the home of the people, cow and chickens, the entire system occupies only 100 square meters (1,076 square feet). Since the pool weighs about 17 tons, the roof would need to be heavily reinforced.

The benefit of using this algal regenerative system is that no longer are the nutrients being removed from the land at the rate they are when conventional treatment is employed. Also, the system generates useful by-products such as algae and biogas for the people and animals, and sludge that can be composted and added to the soil.

However, there are five difficulties to the algal regenerative system designed by Golueke and Oswald. **First**, Goal #1 may not be consistently achieved. It is unclear how long the pathogens in the human waste would be subjected to anaerobic conditions before the sludge is removed and applied to food-raising soil. Viruses and bacteria are destroyed virtually 100% after

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[125] C. G. Golueke and W. J. Oswald, "An Algal Regenerative System for Single-Family Farms and Villages," *Compost Science*, May-June 1973, pp. 12-15.

[126] Biogas also contains 30-50% carbon dioxide and small amounts of nitrogen, hydrogen, carbon monoxide, oxygen and hydrogen sulfide gases (L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* [Santa Barbara, CA: L. John Fry, 1973], p. 17).

being subjected to anaerobic conditions for 80 days. However, the eggs of many human-parasitic worms can survive for up to a year, the eggs of worms in the genus *Ascaris* can survive up to 15 months and hookworm larva can survive up to 18 months under anaerobic conditions.[127] In order to produce pathogen-free sludge that could be applied to food-raising soil, the system would have to be modified so that the anaerobic digester does not continually accept human waste and the sludge can age. If the system included two or more digesters (or as many as necessary so that each could age up to 18 months, depending on the pathogens prevalent in the community), one digester could be filled and its contents could age while another digester receives the fresh waste.

The **second** difficulty is that if methane accidently mixes with air, it becomes highly explosive. A considerable amount of caution and experience would be needed before one could safely generate, store and use the methane-containing biogas. Even then, a leak could go undetected and cause the digester to explode.

The **third** difficulty is that biogas has a relatively low fuel value so a lot more biogas, and a lot more storage space, are needed to obtain the same amount of energy compared to other fuels such as natural gas and propane.[128] To minimize the amount of space required to store fuel, most fuels are stored as liquids. However, 5,000 pounds per square inch (psi) are required to liquify biogas which is a lot more than most fuels (250 psi for propane). Therefore, biogas requires more energy or more storage space (if it is stored as a gas instead of a liquid) compared with most other fuels.

The **fourth** difficulty is that the system requires a lot of land if the system is to be sustainable, and even then the amount of energy the system produces is small. Although the algal pool, the digester, the animals and the people all fit into only 1,076 square feet, at mid-range Biointensive yields, approximately an additional 44,310 to 69,310 square feet (1.0 to 1.6 acres) are needed to grow the food required by the four people, the cow and 50 chickens living in this system.[129] With land prices increasingly restrictive and the amount of arable land available per person decreasing as world population and desertification increase, it is possible that by the year 2014, only 9,000 square feet (slightly more than 1/5 of an acre) of arable land will be available for each person living in a developing nation.[130]

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[127] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], pp. 201-215. To determine whether *Ascaris* is prevalent in your community, ask your local physician.

[128] Neither natural gas nor propane is renewable, and therefore is not a sustainable, long-term energy solution. Managed properly, wood can be a renewable resource. One cord (128 cubic feet) of dry beech wood burned in an average heater (50% efficient) produces as many units of heat (BTU) as 20,000 cubic feet of natural gas (which can be burned at a higher average efficiency of 70%). (John Vivian, *The New Improved Wood Heat* [Emmaus, PA: Rodale Press, 1978], p. 23.)

[129] With land producing crops at mid-range Biointensive yields, 1000 square feet are needed per laying hen (500 square feet if they are allowed to forage in the garden) (John Jeavons, et al., *Backyard Homestead Mini-Farm & Garden Log Book* [Berkeley, CA: Ten Speed Press, 1983], p. 6); about 3,000 square feet (less if the milk and eggs are consumed) are needed to grow a complete and balanced vegetarian diet per person (based on models the author has created using mid-range Biointensive yields which have been regularly obtained in the field in John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], p. 96); and 7,310 square feet are needed to feed one Jersey dairy cow 8 pounds of alfalfa and 20 pounds of corn silage every day (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], p. 82; J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #15: One Basic Mexican Diet*, "Supplement"[Willits, CA: Ecology Action, 1988]); and Clarence H. Eckles, *Dairy Cattle & Milk Production*, 3rd ed. [New York: Macmillan, 1939], p. 281). Less area would be needed to feed the cow if the algae provide a significant amount of calories for the cow.

[130] Based on the population growth of developing nations remaining at 2.1%; land degradation to continue linearly to result in a loss of production of 30% in the next 25 years, as predicted by P. Buringh, "Availability of Agricultural Land for Crop and Livestock Production," in D. Pimentel and C.W. Hall, eds., *Food and Natural Resources* (San Diego: Academic Press, 1989), pp. 69-83, as noted in Dr. David Pimentel, et al., "Natural Resources and an Optimum Human Population," *Population and Environment: A Journal of Interdisciplinary Studies*, Vol. 15, No. 5, May 1994; as well as UN/FAO data, Worldwatch data and other information.

Although the inclusion of animals increases the area this system requires to be sustainable, animals are a part of this system for two reasons:

1) More energy is produced and available for human usage. Because the amount of energy needed by the cow and chickens is very low, most of the fuel generated by anaerobically decomposing their manure can be used by humans. If no animals were included in the system, the amount of biogas that could be generated by anaerobically decomposing the urine and manure one person produces in a year is only enough to meet less than 4% of the individual's yearly energy need. This is enough energy to run a 2- to 4-inch burner for, at most, 17 minutes (hardly enough to cook one meal for one person each day) *or* an average light bulb for 1 hour each day, with no energy left over to heat the home or the water, or power any appliances.[131] Even with the animals, the algal regenerative system would produce only about 25% the energy required by the average North American (who may not be an ideal role model since she or he consumes 40 times as much energy as the average person in a developing country[132]). The system minimizes the amount of energy required by the people and animals by housing them in a single, though divided, unit.

2) With the exception of water plants such as algae and water hyacinths, all crops used for biogas production (most often grain and forage crops) are usually first fed to animals before they are anaerobically decomposed (in the form of manure). The gas produced by the manure is richer in methane, containing more energy per volume and requiring less storage space than gas produced from placing raw plant material into the biogas digester.[133] Also, when manure rather than raw plant material is used to produce biogas, less sludge accumulates in the digester, and the digester does not need to be cleaned out as often.

But herein lies the **fifth** difficulty, and a disadvantage of all systems which produce biogas for fuel. The carbon in the manure used to produce biogas is not converted into humus to replenish the supply of the soil that grew the plants consumed by forage animals (such as cattle, whose manure is commonly used to generate biogas), but is burned up and escapes into the air. The only carbon that remains after the manure is anaerobically digested is the carbon in the sludge.[134] As seen in Figure 4, this is not an adequate amount of carbon to generate the humus needed to sufficiently replenish the amount of humus lost from the soil that grew the crops for the forage animals. Therefore, a sufficient amount of humus cannot be generated from the sludge remaining from the production of biogas from forage animal manure. If Goal #2 is not achieved, the soil's organic matter and humus levels will eventually be so depleted that the soil will not be able to produce healthy crops or healthy people.

There are at least two different ways of avoiding this and achieving Goal #2:

1) For every bed growing forage crops that are fed to animals, approximately one additional bed could grow carbonaceous crops. These crops could then be combined with the sludge that is produced in order to generate a sufficient amount of humus.

2) Rather than producing biogas by anaerobically decomposing the manure of forage animals, manure from animals (chickens, for example) that can subsist primarily on grains could be used.

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[131] From data presented by L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973), pp. 14, 19, 23. See Appendix B: Detailed Calculation #7. Biogas may be a practical source of energy where there is a large concentration of people, such as a hospital or library, where the energy expended could meet the needs of many people simultaneously (for example, when biogas is used to power lighting).

[132] Ged R. Davis, "Energy for Planet Earth," *Scientific American*, September 1990, p. 55. An average American uses the equivalent of 60 ft^3 of biogas every day, approximately the same amount produced by anaerobically decomposing the manure produced by 1 dairy cow and 50 chickens (L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* [Santa Barbara, CA: L. John Fry, 1973], pp. 14, 19, 23).

[133] S. Klein, "Anaerobic Digestion of Solid Wastes," *Compost Science Journal*, February 1972, pp. 6-11; and R. Laura and M. Idnai, "Increased Production of Biogas from Cowdung by Adding Other Agricultural Waste Materials," *Journal of the Science of Food and Agriculture* #22, April 1971, pp. 164-167.

[134] Golueke and Oswald's system channels the biogas after it is burned through the algal pool. The extent to which this would overcome the loss of carbon as a result of burning biogas depends on the amount of carbon that is trapped in the algal pool, and the resulting amount of additional algal growth and carbon dioxide that is converted and contained in algal bodies.

The grain could be fed to the chickens, and the stalks could be composted along with the sludge from producing biogas by anaerobically decomposing the chicken manure. In this way, both the humus and the nutrients lost from the soil that grew the grains could be returned. (Some of the nitrogen will have escaped into the air during anaerobic and aerobic decomposition and could only be returned to the soil through the action of nitrogen-fixing bacteria.) One Biointensively managed bed growing corn in the summer and an interplanted combination of wheat, rye, fava beans and vetch in the winter produces enough compost material to generate 4 cubic feet of cured compost that is 50% soil by volume which could be applied to the soil growing the grains for the chickens.

If the chickens are fed crops that produce very little carbonaceous compost material, to achieve Goal #2 for the beds growing the food for the chickens, the beds must be used to produce sufficient carbonaceous compost crops in a second growing season during the year. If no season exists, you should consider changing the diet grown for the chickens.

Similarly, it is possible to grow all of the food (assuming a grain-based diet that includes no animal products and only minute amounts of sugar and oil) for the four humans on 12,000 square feet of soil, including all of the carbonaceous compost material needed to keep the soil fertile sustainably. If the sludge generated from anaerobically decomposing the human waste and food scraps were combined and processed with the carbonaceous material grown, all four goals of recycling human waste could be achieved (though the cured compost may not contain all of the nitrogen that was lost from the soil, as described in the discussion on producing biogas from chicken manure above).

The difficulty with growing food for a cow (or any animal which cannot survive on a diet that heavily emphasizes grains) is that straw is not a by-product. In order to produce the carbonaceous compost material needed to generate humus and maintain the fertility of the soil, additional land beyond that needed to feed the cow is required. By comparing the amount of land that can be maintained by the humus generated from composting the cow's manure to the amount of land needed to feed the cow, we can determine how much additional land growing carbonaceous compost crops is needed to maintain the humus level of the entire farm. This determination is shown in Figure 4 and the discussion that follows.

Figure 4

Does the Algal Regenerative System Achieve Goal #2?

One 2-year-old Jersey dairy cow grows well on 2,920 lbs. alfalfa hay (90.5% dry matter) and
7,300 lbs. corn silage (26% dry matter) per year.[135]
Beds needed to grow corn at mid-range Biointensive yields = 36.6[136]
Beds needed to grow alfalfa at mid-range Biointensive yields = 36.5
Total area needed to grow food crops for cow = 7,310 square feet

Total carbon in feed = 2,386 lbs.
|
Fed to animals----> approx. **53% of carbon lost** as carbon dioxide
|
V
1,117 lbs. of carbon in manure produced[137]
|
Digested to make biogas---->**27% of remaining carbon lost** from burning biogas
|
V
815 lbs. of carbon in sludge
|
Sludge aged 2-3 months[138]---->**50% of remaining carbon lost** as carbon dioxide
|
V
408 lbs. of carbon or only 17% of the initial 2,386 lbs. of carbon can be returned to the soil. This is almost 3 times less than the amount of carbon that can be returned to the soil if the alfalfa and corn are simply composted aerobically.

See Appendix B: Detailed Calculation #8 for the derivation of the figures.

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[135] Clarence H. Eckles, *Dairy Cattle & Milk Production*, 3rd ed. (New York: Macmillan, 1939), p. 281. Dry matter percentages from Frank B. Morrison, *Feeds & Feeding*, 21st ed. (New York: The Morrison Publishing Co., 1949), pp. 1086, 1110.

[136] This assumes that there are no chemical or organic substances lost from the harvested corn other than water when it is fermented to make silage.

[137] This loss of carbon happens *whenever food crops, and especially forage crops in which the entire plant is consumed (such as clover and alfalfa, as well as lettuce and cabbage), are fed to animals and people.* Again, **we need to grow carbonaceous compost crops in 70% of our farms and gardens in order to sustainably maintain and improve the fertility of the soil.**

[138] Most of the nitrogen in the sludge produced by anaerobic decomposition is in the form of ammonia, whereas the nitrogen in compost produced by aerobic decomposition is mostly in the oxidized forms (nitrate and nitrite). Ammonia may be a more valuable nitrogen source since it is more apt to stay in the soil rather than leach out. However, sludge fresh from the biogas generator contains such a high concentration of ammonia that it may force-feed the plants nitrogen, much like a chemical fertilizer, and weaken their health (see pages 20-22). If the sludge is stored in an open or closed container for a few months before it is used, some of the ammonia will be converted into humus, which releases nitrogen much more slowly to the plants (L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* [Santa Barbara, CA: L. John Fry, 1973], p. 25).

408 pounds of cured carbon remains after the plants are fed to the cow, the manure is anaerobically digested, the gas is burned and the sludge is aerobically composted. 408 pounds of cured carbon is approximately enough cured carbon in the form of cured *compost* for 20.4 to 49.4 beds (depending on the application rate of 3.3 to 8 cubic feet per 100 square feet per year).[139] Since about 73.1, 100-square-foot beds are needed to produce the food for the cow, only a fraction of the cured compost that is needed to keep the soil fertile is generated.

One way to overcome this shortage of cured compost is to grow wheat or another grain crop that is suitable for growing after the corn each year. As shown in Appendix B: Detailed Calculation #8, this will provide only enough cured compost to minimally achieve Goal #2 and may not be enough cured compost to maintain the humus supply of soil in a very warm, humid climate.

One way to produce more biogas *and* increase the amount of carbon available to be returned to the soil, while still using the same amount of land, is to remove animals from the system. If the crops were not first fed to animals but added directly to the digester to produce gas, more carbon would be available to be converted into fuel, and as much as seven times the amount of gas could be produced.[140] This would require at least seven times the storage area, and the biogas produced would be richer in carbon dioxide. In other words, the energy contained per unit of volume of the biogas made from plant material is less than that of biogas produced primarily from manure. The total energy produced would be no more than twice the amount produced from the manure and probably less.[141] Since the plants are not first fed to animals, it is likely that the percentage of original carbon that could be returned to the soil as composted sludge would be greater than that which could be returned if the plants were first fed to animals. Assuming only 27% of the carbon originally contained in the plants is lost when the gas is burned and an additional 50% of the remaining carbon is lost when the sludge is composted,[142] only about 37% of the carbon initially contained in the plants could be returned to the soil. See Figure 5 on page 56. While the loss of carbon is still significant, *Goal #2, production of sufficient cured compost and humus* could be achieved. The energy which is produced from anaerobically digesting the plants directly may be enough to meet the basic survival needs of the four people living in the system.

However, one way to ensure that there will be sufficient carbon to produce the cured compost needed to maintain the fertility of the soil is by not producing biogas. If all of the alfalfa and corn that were processed and fed to the cow were instead aerobically composted, ***3 times the** cured compost that is produced when the plants are used to make biogas would be generated.* Applied at a rate of 3.3 to 8 cubic feet per 100 square feet, this would be enough cured compost to maintain the humus level of 60 to 145, 100-square-foot beds (see Appendix B: Detailed Calculation #9). It is then up to each of us to decide whether having one-third the possible cured compost and the additional labor involved in maintaining animals and 7,310 square feet of soil is worth the small amount of biogas we will generate. For many people, the additional amount of land needed will not be available in the future as populations increase and arable land decreases due to erosion and loss of fertility caused by insustainable farming practices. For further information on the average amount of land available per capita currently and in the future, see Appendix D: The Circle Chart.

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[139] See Appendix B: Detailed Calculation #8 and Appendix C: Further Discussion #1.

[140] Ram Bux Singh, *Bio-Gas Plant* (Ajitman, Etawah [U.P.], India: Gobar Gas Research Station, 1971); and Ram Bux Singh, *Some Experiments with Bio-Gas* (Ajitman, Etawah [U.P.], India: Gobar Gas Research Station, 1971).

[141] Using Figure 4 as a guide, if we feed 100 units of carbon to animals, 53 units are lost as carbon dioxide and 47 units remain in their manure. If we anaerobically decompose their manure, we produce about 12.7 units of carbon in the form of biogas, and the rest of the carbon remains in the sludge. If, instead, we convert 100 units of carbon into biogas directly, at a conversion efficiency of 27% (see Figure 4 and Appendix B: Detailed Calculation #8), we will still produce only 27 units of carbon in the form of biogas or a little more than 2 times the amount we produced when the plants were first fed to animals.

[142] The estimated loss of 50% of the carbon through aerobic composting is based on John Jeavons, Ecology Action's Self-Teaching Mini-Series, *Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7; and David E. Chaney, et al., *Organic Soil Amendments and Fertilizers*, Publication 21505 (Oakland, CA: University of California, 1992), p. 18.

Figure 5

Comparison of the Amount of Biogas Produced and Carbon Available to Be Returned to the Soil When Plants Are Digested Directly and When They Are First Fed to Animals

Gas Produced When Plants Are Fed To Animals

Total carbon in feed = 2,386 lbs.
Fed to animals----> approx. **53% of carbon lost** as carbon dioxide
1,117 lbs. of carbon in manure produced
Digested to make biogas---->**27% of remaining carbon lost** from burning bio-gas
815 lbs. of carbon in sludge
Aged 2-3 months---->**50% of remaining carbon lost** as carbon dioxide
408 lbs. of cured carbon can be returned to the soil, enough to achieve Goal #2 for only **20.4 to 49.4 beds**. 73.1 beds are needed to produce this amount of cured compost, so 52.7 to 23.7 beds will be depleted of organic matter and fertility over time.

Gas Produced When Plants Are Anaerobically Decomposed Directly

Total carbon in feed = 2,386 lbs.
Digested to make biogas---->**27% of remaining carbon lost** from burning bio-gas
1,742 lbs of carbon in sludge
Aged 2-3 months---->**50% of remaining carbon lost** as carbon dioxide
871 lbs. of cured carbon can be returned to the soil, enough to achieve Goal #2 for **43.7 to 106 beds**, or enough to maintain all 73.1 beds that are needed.

While the algal regenerative system designed by Golueke and Oswald does not fully achieve Goal #2, it probably achieves *Goal #3, the return of the minerals to the food-raising soil*, since all of the elements in the waste (with the exception of carbon and nitrogen[143]) would be returned to the soil when the cured sludge is added. So long as no more than 0.5 pound of nitrogen in the form of composted sludge is added to 100 square feet of soil per year, *Goal #4, the proper application of nitrogen*, would also be achieved.

Note: In 1973, Golueke and Oswald demonstrated that the components of the algal regenerative system, individually and integrally, were technologically feasible in laboratory and pilot studies.

For further information on the sustainable use and application of cow manure, see Appendix E: Sustainable Application of Composted Vegetable Matter, Composted Cow Manure and Organic Fertilizers.

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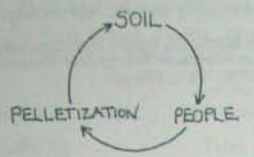
[143] If there is not an adequate amount of carbon to hold the nitrogen in the form of humus, the nitrogen in the waste will escape as a gas when it is composted.

For more information, read:
C. G. Golueke and W. J. Oswald, "An Algal Regenerative System for Single-Family Farms and Villages," *Compost Science*, May-June 1973, pp. 12-15.

For more information on alternative sources of energy, read:
Ken Darrow and Mike Saxenian, *Alternative Energy Sourcebook* (Volunteers in Asia, P.O. Box 4543, Stanford, CA 94305, 1986), 800 pp.

PELLETIZATION



BioGro Systems and other up-and-coming companies have developed a process to produce dry fertilizer pellets from the sludge generated from conventionally treating human waste. Because the sludge is dried at 212°F (100°C), the pellets are free of pathogens and could safely be applied to all food-growing soils *as long as the sludge was not contaminated with heavy metals and/or toxic waste*. Therefore, like the water plant systems, pelletization only partially achieves *Goal #1, purification of the waste*. The pathogens are killed but the toxic contaminants from industry and careless household dumping remain.

Pelletization also does not fully achieve *Goal #2, production of sufficient humus*: no humus is produced through the heating and drying of sewage sludge. Assuming the pellets do not contain toxic levels of contaminants and can be safely applied to soil, as the pellets break down, some of their nutrients will be converted into humus. More humus will be generated if the pellets are incorporated into the top two to three inches of soil and even more if the pellets are first composted with carbonaceous material before they are added to soil.[144] Still, it is unlikely that Goal #2 is achieved by this method for 2 reasons:

1) Only the nutrients from the human waste that enters the sewage system and remains in the sludge are contained in the pellets. The more soluble nutrients, including some forms of nitrogen, that are contained in the liquid portion of the sewage are still dumped into the ocean or nearby waterway. If some of the nitrogen is lost, less humus is produced.

2) When the sludge is heated and dried at 212°F, much of the carbon and nitrogen that remain in the sludge will escape as gas, reducing the humus-producing potential of the pellets. It is unlikely that enough carbon and nitrogen remain to produce enough humus to replenish the supply in the soil that grew the food for those generating the waste used to produce the pellets.

Due to the losses of carbon and nitrogen, and because only the minerals contained in the sludge are returned, pelletization is probably unable to adequately achieve *Goal #3, return of the nutrients*.

Another consideration is that the process of pelletizing sewage sludge requires large amounts of energy, resources and capital, making it an inaccessible and/or inappropriate final solution for most people of the world.

For more information, write:
BioGro Systems, 180 Admiral Cochrane Drive, Suite 305, Annapolis, MD, 21401.

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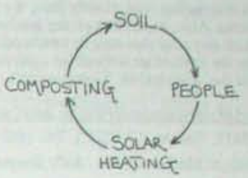
[144] "Incorporating the fertilizers into the top few centimeters of soil can reduce ammonia loss by 25 to 75% over levels found when the materials are applied to the surface" (Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. [New York: Macmillan Publishing Company, 1984], p. 299). With more of the pellets' organic nitrogen retained in the soil, more of it can combine with available carbon in the pellets and the soil to create more humus. By adding carbonaceous material to the pellets in a compost pile, the additional carbon will be able to trap more of the pellets' nitrogen and combine with it to produce more humus.

SOLAR HEATING



Another way to purify human manure is to cook the pathogens using the energy of the sun. The materials required to build a solar oven are inexpensive and accessible to nearly everyone, and the energy it uses is free, environmentally sound, and will not be exhausted in the foreseeable future. Solar ovens typically reach 250°F on warm, cloudless days. Human manure heated to this temperature will be pathogen-free in 30 minutes, after which it can be safely added to food-producing soil.[145] An example of such a system that receives both human manure and human urine is shown in *Earthship Volume III: Evolution Beyond Economics* by Michael Reynolds (Taos, NM: Solar Survival Architecture, 1993).

Since solar heating can be used by an individual (after approval has been granted by the health department), the human manure does not have to enter a sewage system and will not be contaminated with toxins. Therefore, unlike pelletization, solar heating can always achieve *Goal #1, purification of the waste*, completely.

Goal #2, the production of sufficient humus, is not directly achieved by this method, since no humus is produced in the process of heating the manure, but may be partially achieved when the heated and dried manure (especially if it is composted) is added to the soil. The nitrogen and carbon that remain in the dried manure can be consumed by soil microbes and eventually form humus in the soil. However, according to Reynolds, *"extreme temperatures (200° to 400°F) and direct sun simply fry the solids and evaporate the liquids." While this makes such a system very approachable and simple to use safely, it also causes most of the carbon and nitrogen originally contained in the manure (and urine) to be lost, burned up into the air*. Therefore, with such a system, it is unlikely that enough carbon and nitrogen would remain in the dried manure (described as "black ash" by Reynolds) to produce enough humus to replenish the supply in the soil that grew the people's food. In order to include solarization of human waste as part of a sustainable food-raising system, *additional land and labor* would be required in order to grow carbonaceous compost crops that could be used to generate enough cured compost and humus to replenish the supply of humus in the soil growing the food of those producing the manure and urine.

While the remaining ash will not contain much carbon or nitrogen to return to the soil, it may contain most of the other major and trace elements that the food originally contained, and should be returned to the soil producing the food in order to achieve, with exception in terms of carbon and nitrogen, *Goal #3, the return of the minerals contained in the waste to food-raising soil.* In order to achieve Goal #3 in terms of carbon, *additional* cured compost must be made from the crops grown on the additional land, as suggested for achieving Goal #2. In terms of nitrogen, additional cured compost must be produced, as well as leguminous or other crops with which

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[145] Determined by the author from data presented by R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* (Washington, D.C.: World Bank, 1981), p. 106; and C. G. Golueke and P. H. McGauhey, "Reclamation of Municipal Refuse," *Sanitary Engineering Research Laboratory Bulletin 9* (Berkeley, CA: University of California, Berkeley, June 1953), p. 73. One of the most heat-tolerant pathogens known to the author, the fungus *Candida albicans*, can survive at 175°F for only 30 minutes (B. B. Wiley and S. C. Westerberg, "Survival of Human Pathogens in Composted Sewage," *Applied Microbiology*, December 1969, pp. 994-1001).

nitrogen-fixing bacteria associate in order to bring nitrogen in the air into the soil and replenish the soil's supply of nitrogen.

Another consideration is that during cool, cloudy days, we would need to store moist human manure until the sun returns. Also, depending on the method of solarization used, we would need to find a way to reduce any odor that may be produced from heating the manure. One possibility is to channel and filter the emitted air through an aged compost pile, as was done in Beltsville, Maryland described in the next section, "Composting".

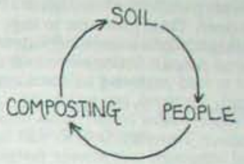
For more information and plans to construct a solar oven, write or call:

- Kerr Enterprises, P.O. Box 27417, Tempe, AZ 85285. Tel. (602) 968-3068
- Thomas P. "Pete" Pirotte, Spotlight Marketing, Inc., 4609 Seagraves, Joplin, MO 64804

and read:

- Michael Reynolds. *Earthship Volume III: Evolution Beyond Economics.* Solar Survival Architecture, P.O. Box 1041, Taos, NM 87571
- Beverly Blum, ed. *The Solar Box Cooker Manual: How to make, use and teach others about them.* Solar Box Cookers International, 1724 Eleventh St., Sacramento, CA 95814. Tel. (916) 444-6616.
- Joseph Radabaugh. *Heaven's Flame: A Guidebook to Solar Cookers*, 1991. Available from Home Power, Inc., P.O. Box 275, Ashland, OR 97520 for $10.00.
- Barbara Prosser-Kerr. *The Expanding World of Solar Box Cookers*, 1991. Available from Bountiful Gardens (a project of Ecology Action), 18001 Shafer Ranch Road, Willits, CA, 95490, or from Kerr-Cole Solar Box Cookers, P.O. Box 576, Taylor, AZ 85939 for $10.00.
- Hillel I. Shuval, et al. *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting.* World Bank, Washington, D.C., 1981.

COMPOSTING



One way to kill all of the pathogens in human manure and achieve *Goal #1, purification of the waste*, (assuming the manure has not been contaminated with toxins) is to heat it to at least 131°F (55°C) for at least 21 consecutive days[146] or 140° to 158°F (60° to 70°C) for 3 consecutive days[147] before adding it to the soil. These temperatures can generally be reached in the center of a properly maintained aerobic compost pile that is 4 feet wide, 4 feet long and 3 to 4 feet high, or larger. However, the outer layer of any compost pile is usually much cooler. So if human manure is added to a compost pile, any pathogen contained in the manure must eventually be turned into the center of the pile to be sufficiently heated and killed before the manure-containing compost can safely be added to a food-producing garden.

Composting Human Manure on a Municipal Level

In Beltsville, MD, compost piles of one part wood chips to two parts sewage sludge by weight[148] were built that consistently were able to heat-kill all of the pathogens in the sludge, even if the pathogens were near the surface of the piles. This was made possible by covering each pile with a 12-inch layer of cured, pathogen-free compost that acted as an insulator. Including insulation, the piles were 7.5 feet high, 15 feet wide, and of varying lengths. Air was drawn through the pile from the outside by 2 perforated, plastic pipes underneath the pile that were attached to a small electric fan. Both the fan and the wood chips increased air circulation in the pile and promoted aerobic decomposition. The air that passed through the pile was then channelled

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[146] Raymond P. Poincelot, *The Biochemistry and Methodology of Composting* (New Haven, Connecticut: The Connecticut Agricultural Experiment Station, 1975), p. 7: "*Bacillus anthracis* [seemingly the most heat-resistant human pathogen tested] was only destroyed by temperatures above 131°F (55°C) for 3 weeks or longer at 40% or more moisture. [The ideal moisture level for aerobic decomposition is 50 to 60%.]" Poincelot later states that some pathogenic fungi may be able to survive these conditions. In order to ensure complete purification, be sure that the temperature and duration requirements given in this booklet are met or exceeded during the processing of human waste.

[147] B. B. Wiley and S. C. Westerberg, "Survival of Human Pathogens in Composted Sewage," *Applied Microbiology*, December 1969, p. 994.

[148] The carbon-to-nitrogen ratio of the piles would be about 22 to 1 (assuming the carbon and nitrogen content of the wood chips was approximately equal to the average of rotted and raw sawdust, since the wood chips were reused in the process). A carbon-to-nitrogen ratio of 30 to 1 is more optimal and will be considered the goal when building a compost pile in this booklet. Dr. Robert Parnes suggests that 50 or 60 to 1 may trap more nitrogen and create more humus. Therefore, while *more total area is required* to produce a pile with an initial carbon-to-nitrogen of 60 to 1 compared to the amount needed to create a pile with an initial carbon-to-nitrogen of 30 to 1, more cured compost will probably be available per square foot of growing area. However, a carbon-to-nitrogen ratio of 30 to 1 encourages more biological activity that may more successfully decrease the number of pathogens in the manure (Dr. Robert Parnes, personal communication, November 1, 1993 and January 7, 1994). A pile that initially contains a carbon-to-nitrogen ratio of 60 to 1 will generally produce less heat and take considerably longer (perhaps as long as two years) to decompose.

through a small pile of mature compost, effectively eliminating the smell of the decomposing piles. The piles' temperatures consistently reached 140°F (60°C) and maintained this temperature for 5 to 10 days; sometimes a pile's temperature would reach as high as 176°F (80°C). Neither snow nor cold weather could slow the piles down. These piles were so large and well-aerated, and able to generate so much heat, that all of the pathogens tested for (viruses, bacteria and the heat-resistant eggs of intestinal worms of the genus *Ascaris*, among others) were sufficiently destroyed so that the compost could safely be added to food-producing soil even though the piles were never turned. While the pathogens were completely destroyed, any toxins contained in the sludge as a result of heavy metal industrial waste, pesticides or other contaminants would have remained in the compost and restricted its usability as a fertilizer. Therefore, Goal #1 may not have been fully achieved.

Since the Beltsville method composted only sewage sludge and not the wastewater, as is the case with pelletization and other methods of processing human waste, all of the soluble nitrogen and other nutrients in the liquid portion of the sewage were lost when the liquid was discharged into a waterway or ocean rather than composted. Of the nitrogen that remained in the sludge, up to half of it, as well as much of the carbon in the sludge, was converted into gas which escaped into the air and was lost due to the extreme heat generated by the pile.[149] *Since nitrogen, as well as carbon, is necessary to enable the microorganisms in the compost pile to generate humus, the loss of carbon and nitrogen will decrease the total amount of humus that can be produced.* Therefore, the Beltsville piles may not have produced enough humus to restore the amount lost from the soil which produced the food consumed by the contributors of the sewage sludge. In other words, the method may not have adequately achieved *Goal #2, production of sufficient humus to replenish the supply lost in the growing of crops from the food-raising soil.*

Another difficulty of the Beltsville system is that it required machinery costing $160,000 or more, and energy to run these machines, in order to assemble and manage its enormous compost piles.[150]

Composting Human Manure on a Smaller Scale

Composting human manure and achieving the four goals of recycling human waste take a considerable amount of experience and skill. The difficulty of achieving Goal #1 is that not only must the above temperature and duration requirements be met after the pile is initially built, but they must also be met after the pile is turned. Otherwise, *pathogens on the outside of the pile* may survive even if they end up in the center of the new pile once the pile is turned. And there is still a chance that some of the pathogens were not turned into the center of the pile but remained on the outer layers of the pile where it is generally not hot enough to kill them. In fact, *Salmonella*, the bacteria that commonly infects meat and causes intestinal problems, and other disease-causing bacteria that are not exposed to the killing heat in the center of the pile, can multiply in the cooler outer layers and throughout the pile as the temperature of the pile decreases.[151]

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[149] H. I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* (Washington, D.C.: World Bank, 1981), p. 57.

[150] H. I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* (Washington, D.C.: World Bank, 1981), pp. 73-74.

[151] *Salmonella* are destroyed when exposed to 149°F (65°C) for one day (K. H. Knoll, "Compost Preparation from the Hygienic Viewpoint," *Information Bulletin No. 7* [International Research Group on Refuse Disposal, 1959]; K. H. Knoll, "The Influence of Various Composting Processes on Non-Sporeforming Bacteria," *Information Bulletin No. 19* [International Research Group on Refuse Disposal, December 1963]; and K. H. Knoll, "Public Health and Refuse Disposal," *Compost Science*, 1961, pp. 35-40). *Salmonella* will be more likely destroyed in a compost pile that is frequently turned than one that is turned infrequently (H. I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* [Washington, D.C.: World Bank, 1981], p. 12. *Salmonella* will also be destroyed with time (R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World

Generally, in order for a compost pile to decompose aerobically and heat sufficiently to kill pathogens, it must:

- Be initially at least 3 feet long, 3 feet wide and 3 feet high, and built within a day in order to be sufficiently insulated when it decomposes to reach a peak temperature of 140° to 158°F and hold the temperature within that range for at least 3 days;
- Have a carbon-to-nitrogen ratio of about 30 to 1 (see footnote #148);
- Be kept about as moist as a wrung-out sponge.

If the temperatures generated in the pile to achieve Goal #1 are too high, it is possible that Goals #2 and #3 will not be fully achieved. The amount of nitrogen contained in cured compost ranges from 61.2% (when the initial carbon-to-nitrogen ratio of the pile is 20 to 1) to 99.5% (when the initial carbon-to-nitrogen ratio is 30 to 1) of the nitrogen that the pile originally contained.[152] The initial carbon-to-nitrogen ratio of the compost pile largely governs the peak temperature of the pile during decomposition -- within limits, the lower the carbon-to-nitrogen ratio, the hotter the pile will become. The hotter the pile becomes, the more carbon and nitrogen that are lost from the pile, which decreases the amount of cured compost and humus that result. Therefore, the temperature that the pile reaches during decomposition is critical, and the margin of error is relatively small -- too hot and less humus is produced, too cold and the pathogens are not killed. Still, *if the pile reaches but does not exceed 140°F for 3 consecutive days, and is allowed to mature as described below, Goals #1, #2 and #3 can all be achieved.*[153] If it exceeds 140°F for only a day or so, the losses of carbon and nitrogen probably will not be substantial. If a pile becomes excessively hot, you can decrease its temperature by opening the pile to let some of the heat out and adding additional carbonaceous material.

Bank, 1981], pp. 221-226. All temperature, duration and maturation requirements stated in this publication, when met, will ensure the destruction of *Salmonella* and all other known human pathogens.

[152] Based on data from compost piles containing no human waste presented by J. I. Rodale, *The Complete Book of Composting* (Emmaus, PA: Rodale Press, 1960), p. 647. Human manure composted only with ashes or soil (the initial carbon-to-nitrogen ratio, therefore, is much less than 30 and not optimal for nitrogen retention) can retain 15% or 95% respectively of its original nitrogen (Viet Chy, *Human Faeces, Urine and Their Utilization* (Environmental Sanitation Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok, Thailand, 1981), p. 23.

The goal for nitrogen retention of human manure containing compost pile is 99.5% to 100%. Since 99.5% is possible with non-human manure containing piles, it may be possible with human manure containing piles after a few years of experience, experiments, careful observations and ingenuity. However, until this goal is reached, a 35% loss of nitrogen (due to leaching or ammonification) from compost piles with an initial carbon-to-nitrogen ratio of 30 to 1 is *probable*. The nitrogen that is lost, even if it is more than 35%, can be returned to the soil by growing leguminous crops that fix nitrogen in the air into the soil. With a 35% loss of nitrogen, Appendix B: Detailed Calculation #15 shows that no additional beds of leguminous crops are needed and only a *fraction* of the grain-producing beds need to be interplanted with leguminous crops (that may have many secondary benefits, including increased grain yields) to replace the nitrogen that is lost. (see page 138). This calculation for the amount of nitrogen in the compost is based on either the ability to retain 100% of nitrogen initially contained in the compost pile or on the interplanting of sufficient grain-producing beds to replace all of the nitrogen that was lost. Even if 50% of the nitrogen in one person's annual production of human manure and 210 pounds of straw is lost (2 pounds of nitrogen lost per year), if all 7 beds are interplanted and the nodules as well as the above ground biomass of the favas and vetch are composted (0.61 pound of nitrogen added per bed for a total of 4.3 pounds of nitrogen for the 7 beds) and 50% is lost (2.15 pounds of nitrogen retained in the cured compost) more nitrogen than was lost (2 pounds) would be available to add to the soil.

[153] Alternatively, if the compost temperature instead reaches 131°F (55°C) for 18 to 21 consecutive days, the pathogens will be destroyed and more cured compost will be generated compared to the amount when hotter temperatures are reached. However, in meeting this condition for pathogen destruction, there is a greater chance, especially in colder climates, that the temperature will not be maintained for this length of time and some pathogens will remain infectious.

The method of storing and composting human manure described below will generally produce pathogen-free cured compost, so long as it is strictly followed and the temperature and duration requirements for purification are met. Before experimenting with your method, *obtain permission from your local health authority since the health risks are great.*

Capturing and Storing Your Manure

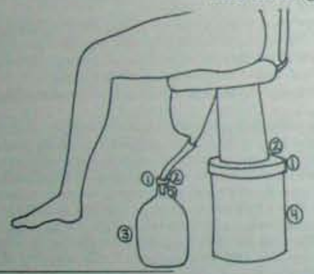
To create a compost pile all at once, you will need to store your manure until you have accumulated enough to construct your pile. In order to *prevent the manure from decomposing anaerobically*:

- Collect your manure and urine in *separate* containers. Urine in the manure storage drum will make the manure too wet. Also, the size of the storage drum needed, if enough soil and straw to absorb the urine and prevent its nitrogen from escaping were added, would be enormous and impractical (see "Composting Human Urine", pages 27-33, for an easier way to recycle urine).[154] One method to separate the urine from the manure is to have two different toilet seats in your composting privy -- one for manure and one for urine. Another method is to use a deflector plate as illustrated in Figure 6 below. Once the urine is captured, it can be composted as described in Chapter 3.

The seal between the storage container and privy must be tight enough to prevent flies, mosquitoes and other vectors from entering the storage container, contacting pathogens and causing disease. This requirement is essential for all human waste storage and recycling systems.

Figure 6

Sophisticated Low-Technology Urine and Manure Separator[155] and Storage Privy



FEATURES:

① Both storage containers are sealable

② Junction between lids and entry tubes must be tight enough to exclude flies.

③ Urine storage container is glass.

④ Manure storage container can be supported so that it can be raised and lowered without moving the entry tube or lid. Padding on the inside of the lid will ensure a good seal.

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[154] You may want to experiment with adding redworms (*Einsenia foetida*) to the storage drum to help break down the manure more quickly and perhaps trap more nitrogen that could be returned to the soil in the form of worm castings. Unlike the worms found in the deeper strata of soil, *E. foetida* are found in any aged, moist compost pile. You will probably need to reintroduce the worms to the drum after each dumping. Urine must not enter the manure storage drum as it will kill the worms.

Using worms to decompose human manure will not purify it of its pathogens since the temperatures attained will be too low (David E. Chaney, et al., *Organic Soil Amendments and Fertilizers*, Publication 21505 [Oakland, CA: University of California, 1992], p. 19). Further research is needed to determine the extent to which various pathogens are destroyed when they are consumed by worms that consume human manure.

[155] For another urine and manure separator design, see La Coordinación General del Programa IMSS Solidaridad, *Catálogo de Actividades de Acción Comunitaria* (México D.F.: México, IMSS, 1994), p. 85.

- Store the manure in 30-gallon plastic containers. Plastic containers are lighter and less apt to corrode and wear out than metal ones.
- Add 1 tightly packed 1/2-gallon can of wheat straw (the straw should weigh a little under 5 ounces) to the container once each day.[156] (See Appendix B: Detailed Calculation #10.) The straw should be broken into bits -- the smaller the better (see footnote #161).This is about half the straw that needs to be added to the manure to create a carbon-to-nitrogen ratio of approximately 30 parts carbon to 1 part nitrogen, which is the ideal for aerobic decomposition.[157] The other half will be added when the pile is built.[158]

Approximately *210 pounds of straw are needed to compost the manure generated by one person each year* at the optimal carbon-to-nitrogen ratio of 30 to 1 (see Appendix B: Detailed Calculation #10). At mid-range Biointensive yields, one bed can produce 30 pounds of wheat straw,[159] so you will need 7, 100-square-foot beds to grow 210 pounds of wheat straw (about 3,

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[156] Instead of or in addition to wheat straw, sawdust can also be used, but it may not be the best source of carbon. First, trees must be cut to produce sawdust, and there are too few trees in the world as it is -- China has lost 75% of its forest, Europe has no primary old-growth forests left, the U.S. has lost 85% of its forests and 50% of the world's original rainforest is gone (Donella H. Meadows, et al., *Beyond the Limits* [Post Mills, VT: Chelsea Green Publishing Company, 1992], pp. 57-58). Second, expensive, energy-consuming machinery is needed in order to produce the amount of sawdust each person would need to compost their manure each year. Third, sawdust tends to allow less air into the drum than straw and, when used exclusively, seems to encourage stronger odors to be produced, which may indicate anaerobic decomposition taking place. When only straw is added to the composting toilet at Ecology Action's Mini-Farm, much less odor is detected when its contents are buried in the orchard between the trees, which is far from the main garden which receives no human waste, compared to the odor when only sawdust is added. On the other hand, sawdust has more lignin (a form of carbon that, when composted, produces a more stable form of humus) than straw. To calculate the quantity of sawdust you will need, see Appendix A and use Detailed Calculation # 10 in Appendix B as a model.

[157] The quantity of toilet paper generally used only increases the carbon-to-nitrogen ratio minutely and so is not included in the total carbon-to-nitrogen ratio approximation. Since toilet paper production requires the cutting of trees and/or the use of a lot of energy, even in the case of recycled toilet paper, and requires a lot of time when it is produced sustainably, you may want to experiment with the soft leaves of arla (*Tithonia sp.*; seeds available from J. L. Hudson, Seedsman, P.O. Box 1058, Redwood City, CA 94064, USA), mullein and wooly lamb's ears plants. Mullein has wider and more practically-sized leaves. The leaves of these plants would also provide more readily available carbon and, therefore, allow more nitrogen to be retained (see footnote #161). If you are curious to discover which plants growing around you would work well, be sure first to identify them and make sure that they are not irritating or poisonous!

Throughout the Middle East, India and elsewhere, the left hand and water are used instead of toilet paper.

[158] Adding less than the total amount of straw needed to create a carbon-to-nitrogen ratio of 30 to 1 has been avoided up to this point in this book because of two possible disadvantages. The first possible disadvantage is an increased loss of nitrogen. Because only half of the optimal amount of carbonaceous material is added and stored with the manure, more nitrogen from the manure will escape as ammonia gas compared to the amount that will escape when the full amount of materials is added. The second possible disadvantage is the anaerobic decomposition of the manure, due to the wetness and tendency toward compaction of fresh human manure. From trials at Ecology Action, anaerobic decomposition when half the amount of straw is added to the storage container appears very unlikely.

On the positive side, adding only half of the straw to the storage container decreases the necessary volume of the container by half. Or, the storage container could be kept large and emptied less frequently. Also, the straw may be able to dry out the manure (which is roughly 70 to 85% water) below the ideal moisture level of 50 to 60% for aerobic decomposition and slow the decomposition of the manure until the manure can be used to construct a compost pile. However, now that you are conscious of the trade-offs involved, you may want to experiment with adding more or less straw to the manure storage container, observe the results, and decide which works best for you and the soil.

[159] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82. To create a total carbon-to-nitrogen ratio of 60 to 1 as suggested by Parnes (see footnote #148), 1,167 pounds of wheat straw are needed per person per year (see Appendix B: Detailed Calculation #10). At mid-range Biointensive yields, (1,167 / 30) 38.9 beds would need to grow wheat each year.

3-wire bales) annually. To store this straw, you will need a bin that will hold approximately 60 cubic feet of straw (see footnote #70). (The bin can be 3 feet high, 4 feet wide and 5 feet long, for example.)

If you obtain permission to compost human waste and decide to compost both your urine and your manure with straw, you will need 943 pounds of straw each year. At mid-range Biointensive yields, you will need about 25 beds during the winter to grow all of this straw (or fewer if straw-producing grains such as millet and quinoa are grown in the same beds in the summer as well) and about 269 cubic feet of storage space (approximately 3 bins that are 5 feet wide, 3 feet high and 6 feet long, for example.) If straw-producing crops are grown during the summer *and* the winter, as described in the section "Composting Human Urine", page 28, less storage space is needed. Since the total amount of straw needed will be divided between two harvests, each harvest will be less than that when all of the straw is grown in only one season. Each harvest is continually used to make compost piles, so that the amount being stored will diminish before the next harvest needs to be stored. See Chapter 5 for detailed descriptions of two systems to grow all of your calories and recycle all your waste for each year.

Choosing an Appropriate Site for Composting Your Manure

If you plan to compost all of the manure you generate each year, annually you will need an area that is 3.3 feet wide and 6.6 feet long to contain two piles that will each be about 3.3 feet wide and long and 3 feet high. Also, an additional space 3.3 feet wide and long is needed into which one of the piles can be turned. These compost piles will contain all of your year's manure, plus straw and soil.

The 3.3-foot-by-9.9-foot site for your compost piles should be downhill and at least 150 feet away from any source of water or living habitat. *The groundwater level under the entire composting area should be at least 5 feet below the depth to which the soil is loosened (or 6 feet below the surface of the soil),*[160] *since the water that leaches through the pile will likely contain pathogens. If the groundwater is at least 5 feet below the depth to which the soil is loosened, most of the pathogens will have died or been consumed by soil organisms before reaching the groundwater.* To test the groundwater level, dig a 6-foot-deep hole (using a posthole digger can make it easier after you have dug to 3 feet or so). Build a berm around its perimeter and cover the hole and berm with plastic to exclude rainfall and surface runoff. Use a long 1-inch-by-1-inch pole to test if water appears at the bottom of the hole. If water is detected at any time during the year, a new site should be chosen. Be sure to verify from that year's precipitation that the year you checked was a representatively wet one. If not, be sure to recheck the site before using it. Also, be sure that the site does not receive severe runoff that could erode your pile and transmit disease. If you are building the pile on a slightly inclined surface, you may want to build a berm around the entire composting site in order to prevent any pathogen-rich leachate from the pile from leaving the compost site and threatening the health of those nearby.

The site should not be above fissured rock or other permeable rock formations that would allow excessive leaching of the nutrients and pathogens from the manure into the groundwater. Sandy soils are usually suitable as long as the depth of the water table meets the requirements described above.

After you have chosen a site which meets the above requirements, present your site and proposal to your local health authority in order to obtain permission before you begin

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As a side note, 38.9 beds of wheat at mid-range Biointensive yields can provide 389 pounds of wheat seed, which, when ground, is enough whole wheat flour for 1.6, 1-pound loaves of bread each day of the year (2/3 pound of wheat flour combined with water, yeast and other ingredients makes a 1-pound loaf of bread). 389 pounds of wheat seed will provide one person 1,595 calories per day or approximately 66% of an average person's daily caloric need. Calories is the nutritional requirement that requires the most area to grow. For almost any diet worldwide, if a person's caloric requirement is met, all other requirements are generally met.

[160] Sim Van der Ryn, *The Toilet Papers* (Santa Barbara, CA: Capra Press, 1978), p. 48.

experimenting with composting your manure. Composting human manure is illegal and can be dangerous not only to your health but to the health of your community and the soil. *Do not begin composting your manure without first consulting and obtaining permission from your local health authority.*

Preparing the Site

Next, loosen the soil to a depth of 1 foot with a garden fork in the 3.3-foot-by-3.3-foot area that will contain your first pile, and add a layer of branches, twigs and/or stalks, as described in the section on composting urine. The loosened soil and twigs will allow the pathogen-containing leachate from the pile to sink into the soil and not run over the surface of the soil where it could spread disease. As in urine composting, loosen the area for your second pile only immediately before you need it instead of loosening it and then having it compact and need reloosening.

When you are ready to turn the first pile, as will be described later, loosen the new 3.3-foot-by-3.3-foot area and add a layer of sticks and twigs. If the entire composting area is loosened at once, the unused portion will tend to compact and need reloosening, which means extra work.

Reserve a set of clothing, a spading fork, a spade, a pitch fork, and a compost thermometer for the tasks of building, turning and maintaining the manure-containing compost pile *and use them for no other purposes.*

Creating the Pile

In order to create your pile all at once, you will need to store all of the manure you produced during the preceding year. Including the straw you have added to it, it will fill about 10, 30-gallon containers.[161] The contents of these containers, along with soil and additional straw, will form your manure-enriched compost.[162]

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[161] See Appendix B: Detailed Calculation #11. The number of 30-gallon containers needed will vary depending on the size of the straw that is added. If the straw is broken into small bits, not only will the container be able to hold more manure and straw, but more of the carbon in the straw will be available to the microorganisms. Since the surface area of the straw is increased when it is broken into bits, more of the straw is exposed and can be consumed by the microorganisms. With more of the straw's carbon readily available, the microbes will be able to capture more of the nitrogen that is converted into ammonia. For this reason, Dr. Robert Parnes, who has operated a commercial soil testing service for the last 10 years and holds a Ph.D. in physics from Ohio State University, suggests adding carbonaceous material whose carbon is more readily available than straw, such as the alternatives to toilet paper (see footnote #157) and any other fresh plant material (personal communication, November 1, 1993). However, most green plant material is not especially high in carbon. Exceptions to this are fresh alfalfa and other somewhat woody-stemmed plants as well as some grasses. Since they are both somewhat rich in carbon and their carbon is relatively more available, they may be better ingredients to add to the manure storage container. The disadvantage is that they have a lot of water in them, so the contents in the storage container will remain comparatively wet and will tend to decompose anaerobically. Also, these materials have a carbon-to-nitrogen ratio lower than 30 to 1, so adding them to the final compost piles you build will not increase the overall carbon-to-nitrogen ratio to 30 to 1 needed for maximum humus production. Therefore, depending on how much green plant material is added to the storage container, more than the 210 pounds of straw normally needed to increase the carbon-to-nitrogen ratio to 30 would need to be added to the final compost piles.

[162] If 10, 30-gallon containers are not available (and likely they will not be for many people in the world), you may want to simply use 1, 30-gallon container, fill it halfway and add it to your compost pile periodically. *However, building the pile on an ongoing basis is not optimal for maximum heat generation which is necessary to kill the pathogens.*

The Recipe

On top of the sticks, add the following layers in succession, and water each layer with roughly 1 to 2 quarts of water to thoroughly moisten the layer after it has been added:

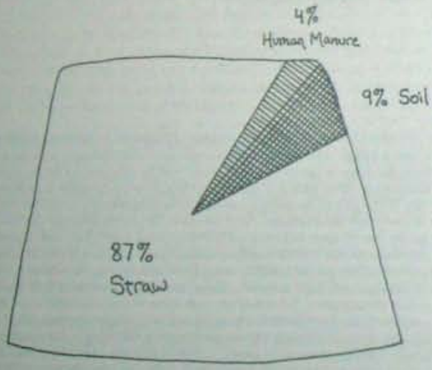
1) Two (2) tightly packed 5-gallon buckets of straw, weighing a total of about 5.25 pounds (creating a layer approximately 1 to 2 inches thick).
2) One-half of a 30-gallon container of human manure and straw[163] (a layer approximately 1 to 2 inches thick).
3) Slightly more than one-third (0.37) of a 5-gallon bucket of soil (a layer less than 1/4 of an inch thick).

Continue adding these layers in sequence and watering until 20 layers of each have been added (at which time you should also run out of your 210-pound supply of straw for the year). The pile, if it is built all at once, should be about 3 feet tall when it is completed. The very last layer of the pile should be 1, 5-gallon bucket of soil (0.67 cubic feet). See Appendix B: Detailed Calculation #12 for the derivation of this recipe.

Keeping good records of the amounts of materials you use and any that you run out of, as well as any observations and problems you have, will allow you to learn more quickly about the process and how to improve and simplify it for the next year.

Figure 7

Built Human Manure-Containing Compost Pile by Volume



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[163] If you find that a full 30-gallon container is too awkward to handle and add to the compost pile, you may want to use 20, 30-gallon containers and fill them only halfway.

When constructing a compost pile, it is always best to use a wide range of materials. The recipe above uses only straw, human manure and soil. If this recipe is followed, the pile you construct will consist of 4% human manure by volume (see Figure 7 and Appendix B: Detailed Calculation #13). A pile with more variety of compostable carbonaceous and nitrogenous materials (such as those with more available carbon) will probably decompose more efficiently, retain more nitrogen and contain more humus as long as the initial carbon-to-nitrogen ratio remains about 30 to 1. Furthermore, the more diversity that exists in a compost pile, the more diverse the populations of microorganisms in the compost. When the compost is added to the soil, diverse populations of microorganisms are added, encouraging a healthy balance of soil microorganisms that reduce the likelihood of pathogenic microorganisms from becoming dominant and causing plant and soil diseases.

If you want to experiment with different combinations of carbonaceous material, use a *total* of approximately 22 parts (tightly packed) dry to 1 part human manure by volume to achieve a carbon-to-nitrogen ratio of 30 to 1. If you want to experiment with adding fresh, green material or kitchen scraps to the pile, be sure to add *an additional* 1 part dry, carbonaceous material for every 1.25 parts green material added in order to maintain the carbon-to-nitrogen ratio of the pile at approximately 30 to 1.

Experimentation with the pile should probably only be done after you have *at least* three years of experience with composting human manure by the recipe above to minimize the number of variables and increase your ability to learn from each composting experience.

After a compost pile has been built with human manure, the pile must be sealed so that no flies, mosquitoes or other vectors can contact the pathogens in the human manure and spread disease. This can be achieved with a wooden frame supporting mosquito netting that entirely covers each human manure-containing pile. A tarp or a thick layer of available materials (palm fronds or woven straw, for example) may also work but will generally reduce the amount of air flowing into and out of the pile and may encourage anaerobic decomposition. Soil should be mounded against the bottom edges of the barrier in order to prevent insects from entering. If flies do enter the pile, the pile should be turned to prevent them from breeding. Fly larva cannot survive temperatures above 124°F (51°C).[164]

Protect your pile from the rain with a structure made out of available materials or clear plastic (black plastic may cause the pile to get too hot and result in the excessive loss of carbon and nitrogen) loosely draped to prevent anaerobic decomposition and/or the excessive leaching of nutrients and pathogens from the pile. *The goal is to keep the compost pile about as moist as a wrung-out sponge.* A roof structure that does not touch the top of the pile is preferable over simply covering the pile with plastic as it is less likely to exclude the passage of air and encourage anaerobic decomposition. A sheet of plastic tends to blow away in the wind if it is not properly anchored, or suffocate the pile and encourage anaerobic decomposition when it is properly anchored. Anaerobic decomposition can be kept in check by removing the sheet of plastic on clear days. An advantage to a firmly anchored sheet of plastic around the pile is that it may help keep animals and flies from the pile.

Turning and Maintaining the Pile and Storing the Compost

Organisms like bacteria, fungi, worms and sowbugs, among many others, are the creatures responsible for decomposition. In order for any compost pile to decompose efficiently, we must be sure the decomposers have what they need: air, water, food and warmth. Maintenance of the manure-enriched compost pile, and any compost pile, entails keeping these four items in balance and available to the decomposers. If there is too much air and too little water, the pile will be very slow at decomposing. If too much water is added to the pile, there will be too little air, and it will

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[164] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], p. 108.

decompose anaerobically. In order to add more air to the pile, the pile can be turned. The goal of turning the manure-enriched compost pile is the same as it is for a compost pile not containing human manure: to make all of the material on the outside of the existing pile end up on the inside of the new pile, and to make all of the material on the inside of the existing pile end up on or near the outside of the new pile.

By maintaining the proper air and water balance in the compost pile with turning, you will encourage efficient decomposition. Material on the outside of a compost pile is generally too dry to decompose efficiently. Turning ensures that no material remains on the outside and relatively undecomposed. When compost is made with human manure, making the outside of the existing pile the inside of the new pile is even more critical because we are concerned not only with decomposing the pile but also with killing all of the human pathogens contained in the pile. Pathogens have a much better chance of survival if they are not exposed to the heat-killing temperatures that can be generated *only* from the center of a properly built and managed compost pile, as mentioned earlier.

How often should the pile be turned? It should be turned at least once (to expose pathogens on the outside of the pile to the heat-killing temperatures at the center of the pile), but the fewer times it is turned, the better. *Frequent turning will increase the likelihood that all of the pathogens in the manure will be turned into the center of the pile and killed, but may reduce the amount of cured compost and humus the pile generates, since turning encourages the oxidation and loss of humus in the compost pile.* Robert Rodale recommended in *Organic Gardening* (February 1972) that a compost pile containing human manure should be turned "at least 3 times in the first few months, and then once every 3 months thereafter for a year." However, to obtain the maximum amount of humus and cured compost and still kill the pathogens in human manure, another option is **to turn the pile only once,** after the pile's temperature has peaked and then fallen 20 degrees or more below its peak,[165] as you would with a compost pile that does not contain human manure.

Whether the pile is turned three times or only once, the cured compost will be safe to apply to food-raising soil, even where *Ascaris* is present, 1 year after the pile was completed ***only if*** the pile maintained a temperature of at least 140°F for 3 consecutive days ***both*** after it was built ***and*** after it was first turned. A composting thermometer is invaluable for determining the peak temperatures of the pile.

In order to create piles that consistently meet these requirements, a considerable amount of experience and skill is needed, especially when the weather is cold and/or rainy. Give yourself time to learn.

If the temperature and duration requirements are not met both times, the pile should be allowed to mature for 2 years after it is completed, or 7 years if *Ascaris* infections are common in your community (*Ascaris* is found worldwide[166]). During this time, the pile should continue to be kept as moist as a wrung-out sponge in order to encourage a healthy population of decomposers that will eventually consume the human pathogens that are not as well suited for life in a compost pile. The main disadvantage of waiting this long is that the compost may become mineralized (when the decomposition process continues and the humus in the cured compost is degraded and transformed back into its mineral components).[167] If mineralization occurs to the extent that the final cured compost has very little humus, *Goal #2, production of sufficient humus to add to food-raising soil*, may not be achieved, especially if the presence of *Ascaris* requires a 7-year maturation period. Therefore, if we choose to recycle human manure through composting, we must allow ourselves time to develop our skill in order to consistently build and maintain a compost pile that meets the temperature and duration requirements for pathogen purification and will not be in danger

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[165] Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), p. 90.

[166] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* [Washington, D.C.: World Bank, 1981], p. 22.

[167] Steve Rioch, Ecology Action's Self-Teaching Mini-Series, *Booklet #23: Biointensive Composting* (Willits, CA: Ecology Action, March 1990), p. 1.

of mineralizing. Once our skill is honed, we can compost our manure and achieve all four goals of recycling human waste through composting.

After the human manure-enriched compost has matured sufficiently to kill the pathogens, the cured compost can be used immediately or stored. If you decide to store it, break apart the pile and allow it to dry to 15 to 20% moisture (see footnote #82). In this way, you halt the decomposition process and prevent mineralization of the humus. Store the dried cured compost in a bin[168] that protects it from the rain and snow (which could restart the decomposition process) and intense sun (which could make the cured compost very hard, resistant to absorbing water and difficult to apply evenly to the soil).

By composting your manure according to the recipe and guidelines above, you will be able to produce about 16.0 cubic feet of cured compost that is 40% soil by volume. This is enough cured compost to apply at a rate equivalent in terms of organic matter and nitrogen and minerals to 2.4 to 8 cubic feet per 100 square feet and maintain the humus supply of 2.4 to 8, 100-square-foot beds. (See Appendix B: Detailed Calculation #14.) Therefore, enough cured compost is generated to maintain the humus supply of the beds that grew the straw needed to compost the manure. However, it is likely that not enough cured compost is generated by composting one person's annual production of manure to achieve *Goal #2, the production of sufficient cured compost*, for all of the beds required to feed the person each year. The actual number of beds needed to Biointensively grow a complete diet for one person can vary from 10 to 40 beds (1,000 to 4,000 square feet) or more depending on the climate, soil, desired diet, and the experience of the gardener. Therefore, if more than 8 beds are needed to grow one person's food for all year, additional carbonaceous crops must be grown on the other food-raising beds to achieve Goal #2.

Can we generate enough cured compost to achieve Goal #2 for all of our food-raising beds if we compost both our manure and our urine?

The amount of cured compost we generate from composting our urine annually is enough to maintain the humus level of about 7.8 to 23 beds. The amount of cured compost we generate from composting our manure annually is enough to maintain the humus level of about 2.4 to 8 beds, for a total of 10.2 to 31 beds. Depending on the area needed to grow all of one person's food for all year, this may or may not be enough cured compost to achieve Goal #2. Remember:

Because we and the creatures in the soil and compost piles breathe, we need to grow carbonaceous crops in 70% of our gardens and farms if we want to maintain the fertility of the soil sustainably.

So, we may need to grow additional carbonaceous compost crops to generate enough cured compost and humus to fully achieve Goal #2.

Once Goal #2 is achieved, *Goal #3, the return of the minerals in our waste to the soil which produced our food*, may also be fully achieved: all of the minerals in the urine and manure, including a sufficient amount of carbon and nitrogen in the form of cured compost, may be returned to the soil which produces the person's food. The only exception may be nitrogen, since some of it may have been lost as the organic material decomposed and transformed into humus. To replenish the soil's supply of nitrogen, leguminous or other crops with which nitrogen-fixing bacteria associate can be grown, thereby bringing nitrogen that gasified into the air back down into the soil. If the goal of 100% retention of nitrogen is not achieved and a 35% loss of the nitrogen originally contained in the manure occurs[169], all of this nitrogen can be returned to the soil from the air by interplanting 4.2 of the 7 beds used to grow the wheat straw with cool weather fava beans and vetch as described in John Jeavons, *Ecology Action's Self-Teaching Mini-Series*

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[168] About 15 cubic feet of storage space is needed for every year's worth of manure-containing compost you plan to store.

[169] A loss of 35% of the original nitrogen through composting is based on an estimate for a compost pile that does not contain human manure by Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 56. See footnote #152.

Booklet #14: The Complete 21-Bed Biointensive Mini-Farm: Fertility, Nutrition and Income (Willits, CA: Ecology Action, 1987), pp. 4-15. The fava beans and vetch are harvested when 10% to 50% of their flowers are in bloom and composted. The additional nitrogen added and retained in the cured compost will fully replace the amount that was lost during the composting of human manure *and* the composting of the fava beans and vetch (see Appendix B: Detailed Calculation #15).

One advantage to composting is that, like solar heating, it can be done by an individual. The waste does not first have to travel through a sewage system, so Goal #1 can be fully achieved through composting. However, the killing of pathogens through solar heating requires no skill, whereas a significant level of experience and skill is required to be able to create compost piles that consistently reach and maintain a sufficient level of heat to kill the pathogens.

Composting Toilets

Instead of storing your manure and using it to build a compost pile, it could simply be left in the storage bin, and, over time, the pathogens it contains would be consumed by organisms more fit to survive in that environment and would be destroyed. This is how composting toilets can eventually produce pathogen-free cured compost: not with heat, but with the competition and consumption of organisms better fit to survive over time in that environment.

There are several commercially available composting toilets with various features and at various prices. No manufacturer guarantees the final compost will be safe to use on food-growing soil, since it is nearly impossible to ensure that the pathogens have been exposed to temperatures within the toilet hot enough to kill them. Some composting toilets are able to store large amounts of manure (up to 2 to 3 years' worth of manure produced by a family of four) and allow you to take material only from the bottom of the bin, to ensure that what is extracted is not fresh. However, unless you are sure the manure you are removing is at least 2 years old (7 years where *Ascaris* infections are prevalent), *the compost should not be added to soil that will be worked or used to produce food whose edible portion may contact the soil.*[170] Instead, allow what you remove from the composting toilet to age further, or compost it as described above.

Since the manure generally does not get as hot in a composting toilet as it would in an aerobic compost pile, at least as much, *if not more*, humus will be produced assuming an equal quantity of carbonaceous material is added. A little less than 10 ounces of wheat straw (or the appropriate amount of other carbonaceous material to create an initial carbon-to-nitrogen ratio of 30 to 1) should be added each day to the toilet so that 210 pounds of straw are added to the toilet each year for every person using the toilet. Most composting toilet manufacturers do not design their toilets to receive this amount of dry material. As a general guideline, *you will be adding about 20 to 30 times the volume that the designer predicted so if the manufacturer claims it will hold all the human waste produced by a family of four for 2 years, it will probably only hold one month's worth which will not be a sufficient amount of time for the manure to mature and be safe to handle.*

Two commercially available composting toilets deserve special attention: the Sun-Mar NE (non-electric) and the Phoenix. The two toilets are similar in conceptual design to insure proper composting and require very little maintenance. Both have handles that, when rotated, add air to the decomposing manure and encourage aerobic decomposition, and both generate cured compost that, *once sufficiently aged*, can be removed only from the bottom of the storage bin (to minimize the risk of contacting fresh manure) and added to food-raising soil.

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[170] Based on the author's analysis of data presented by R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* (Washington, D.C.: World Bank, 1981), pp. 193-200; and Jerry Minnich, et al., *The Rodale Guide to Composting* (Emmaus, PA: Rodale Press, 1979), p. 363. However, it may be possible to use human urine to kill parasitic worm eggs, including eggs from worms of the genus *Ascaris*. See Appendix C: Further Discussion #2.

There are two notable differences between these two finely-made toilets. The first difference is that the Phoenix has a greater storage capacity (up to 126 cubic feet compared to 13 cubic feet for the Sun-Mar). Using a Phoenix, one person could add enough straw to his/her manure (approximately 76 cubic feet if no soil was included[171]) to create a carbon-to-nitrogen ratio of 30 to 1. Using a Sun-Mar, only about 30 pounds of straw or 14% of the amount needed to create a carbon-to-nitrogen of 30 to 1 could be added. With less carbon present to combine with and trap the nitrogen, more of the manure's nitrogen would be lost.

The second difference is that the Phoenix is designed to store accumulated liquid away from the composting manure in order to encourage the manure to decompose aerobically. The liquid, in the form of urine and moisture from the manure, collects below and away from the composting manure in a storage tray. The liquid can then be removed and composted, or pumped and sprayed onto the composting manure and straw if they are dry, in order to maintain an optimal moisture content of 50 to 60% for aerobic decomposition. *Since the liquid may have picked up pathogens from the manure, if the liquid (which is primarily urine) is removed and composted as described in "Composting Urine," pages 27-33, it must meet the temperature and duration requirements described above for composting manure, or be sufficiently matured, in order to ensure complete pathogen destruction.*

In the Sun-Mar, most of the liquid from the urine and manure evaporates into the air through a vent, so much of the nitrogen and other water soluble nutrients in the waste are lost and cannot be returned to the soil.

Before pursuing any method of composting human manure, first get permission from your local health authority. *Storing your manure in a drum, using a composting toilet and composting human manure in a compost pile without permission from the health authority are generally illegal due to the potential risks to public health.*

For more information on composting toilets, write or call:

- Phoenix Toilet: Glenn Nelson, Advanced Composting Systems, 195 Meadows Rd., Whitefish, MT 59937 (406) 862-3854
- Sun-Mar Toilet: Real Goods Trading Corporation, 966 Mazzoni Street, Ukiah, CA 95482 Toll Free Orders (800) 762-7325, Technical Assistance (707) 468-9214, Business Office (707) 468-9292, Fax: (707) 468-0301.

For more information on composting human manure in general, read:

1. R. G. Feachem, et al. *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review.* Washington, D.C.: World Bank, 1981. (Free of charge!)
2. H. I. Shuval, et al. *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting*. Washington, D.C.: World Bank, 1981.
3. C. H. Stoner, ed. *Goodbye to the Flush Toilet*. Emmaus, PA: Rodale Press, 1977. (Out of print.)
4. Sim Van der Ryn. *The Toilet Papers*. Santa Barbara, CA: Capra Press, 1978. Distributed by Chelsea Green Publishing Co., Old Country Road South, RR 1, Box 95, Francestown, NH 03043

Note: References 1, 3 and 4 discuss site requirements and include plans for building your own composting toilet.

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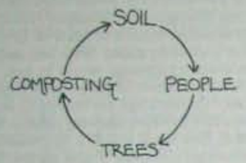
[171] Estimated packing density is 3.6 pounds per cubic foot (the same approximate density as that of dry material in a compost pile). 210 pounds of straw / 3.6 pounds / ft^3 = 58.3 ft^3 + 2.7 ft^3 of manure = 61 ft^3 total.

TREES



One way to purify manure and return the nutrients it contains to the soil that grows our food is known as *secondary recycling*. Rather than adding the nutrients directly to the soil which grows food-producing annual crops, we can first add the manure to soil that grows trees. When the trees eventually take up the nutrients in the manure and turn them into leaves, among other things, *some* of the leaves can be collected from mature trees. (Some of the leaves will need to be left under the tree to decompose and maintain the humus supply of the soil growing the tree.) Then, the collected leaves can be composted. When the composted leaves are added to the soil growing annual food crops, the soil's nutrients can be returned and its supply of humus may be replenished as well.

The length of time a pathogen will live depends, in part, on the environment in which it lives. When human manure is buried in soil, the pathogens will generally survive longer than if they were in a compost pile (see Table 7 on page 120). Therefore, in order to prevent the spread of disease, the soil between the trees that receives the manure should not be worked for 3.5 years after the manure is buried, or 7 years if our community has had incidence of *Ascaris* infections.[172] Eventually, the pathogens are unable to survive the hardships of living outside of the human body and are consumed by soil organisms. Since this method does not rely on a sewage system, the manure is not vulnerable to contamination by industrial and household wastes. Therefore, *Goal #1, the purification of the manure, can be fully achieved.*

There are *five challenges* we face in achieving Goals #2 and #3 when we use trees to recycle human manure. The **first challenge** is to avoid depleting the supply of humus of the soil supporting the trees. If we remove all of the fallen leaves of trees, we take away from the trees not only all of the minerals the leaves contain, but also all of the soil-enriching humus that the decomposing leaves could have potentially added. When we fertilize the trees with fresh human manure, we can replenish the supply of minerals in the soil, but not necessarily the soil's supply of humus. Since the carbon-to-nitrogen ratio of human manure is only about 7.5, as the manure decomposes in the ground, it does not contain enough carbon to use all of its nitrogen to produce humus, and Goal #2 may not be adequately achieved.[173] One way to overcome this humus deficiency may be to compost some of the fallen leaves and add the cured compost back to the trees. The success of this approach will depend mainly on the variety and age of the trees (which will govern the amount of leaves the tree produces), the texture and structure of the soil and the climate.

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[172] Based on the author's analysis of data presented by R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* (Washington, D.C.: World Bank, 1981), pp. 217-230; and Jerry Minnich, et al., *The Rodale Guide to Composting* (Emmaus, PA: Rodale Press, 1979), p. 363.

[173] This is similar to the difficulty we encountered in examining the algal regenerative system: whenever crops are fed to animals (in this case, humans), a substantial amount of the carbon in the crops does not end up in the animals' or humans' manure but escapes into the air with each exhalation of carbon dioxide of those who eat and metabolize the crops. Therefore, there may not be enough carbon in the animals' or humans' manure to generate enough humus to replenish the soil's supply.

Another way to increase the amount of humus generated from the buried manure is to add enough carbonaceous material such as straw to the manure before it is buried to create a total carbon-to-nitrogen ratio of 30 to 1. At this ratio, the carbon and nitrogen are used equally efficiently by the organisms responsible for decomposition, and the maximum amount of humus is produced from the given amount of undecomposed organic matter.

However, *burying* undecomposed carbonaceous material and manure (whose combined carbon-to-nitrogen ratio is 30 to 1) may make it more difficult for a tree (or any plant) to grow *next to or on top of* the buried undecomposed material. As the undecomposed material breaks down, the amount of nitrogen in the soil which is initially available to the tree and essential for its continued growth and health may be decreased in *two* ways:

1) Since undecomposed straw has a carbon-to-nitrogen ratio much greater than 30 to 1,[174] whenever the soil microorganisms consuming the straw have access to nitrogen in the soil and not nitrogen in the manure, they will consume nitrogen in the soil in a ratio of roughly 1 part of nitrogen for every 30 parts of carbon consumed. Therefore, less nitrogen and other nutrients will be available for the tree until the decomposition process is complete.[175]

2) If the carbonaceous material is added in an undecomposed and/or unstable state (available for microbial consumption), it may overly stimulate the aerobic soil organisms which will deplete the soil's supply of oxygen, resulting in anaerobic conditions in the soil and the onset of denitrification (when nitrogen in the soil is converted into a gaseous form and escapes into the air). Acidic soils are more susceptible to denitrification than neutral or alkaline soils, perhaps because the organic matter is less stable and more easily consumed by soil organisms.[176] Adding only enough carbonaceous material to the manure to increase the carbon-to-nitrogen ratio to 10 to 1, approximately equal to the carbon-to-nitrogen ratio of soil, will minimize both the competition between the microorganisms and the trees for soil nitrogen, and denitrification. At the same time, the extra carbon in the soil will combine with more of the nitrogen in the manure, and more humus is produced compared to the amount when no straw is added. Still, there will be less of the manure's nitrogen and carbon retained in the soil compared to the amount retained when the manure is composted at an initial carbon-to-nitrogen ratio of 30 to 1.

The **second challenge** in achieving Goals #2 and #3 in this method is that in order for the system to be balanced and sustainable, we must determine roughly how much manure should be given to the orchard and how many of the fallen leaves can be taken from the orchard and used for the garden. This will depend on: the amount of leaves the trees are producing; the mineral content of the soil, leaves and manure; the amount of minerals that leach from the soil; and the amount of humus and minerals the soil and the trees require to be healthy. Many of these factors cannot be known precisely, but periodic testing of the mineral and organic matter levels of both the garden and orchard soils is recommended to ensure the system is sustainable and the garden and orchard soils remain fertile.[177] If too much manure is added to the orchard soil, a toxic imbalance of minerals may eventually occur, and if too little manure is added and too many leaves are used, the orchard soil may eventually be depleted of its minerals and fertility.

The **third challenge** is to have enough area between the trees in our orchard into which the manure can be buried and remain undisturbed for 3.5 to 7 years. Since we are constantly producing more manure, the orchard would need to constantly expand, unless there was enough area between the trees (so that the feeder roots of the trees are not injured by digging) to receive at

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[174] Frank B. Morrison, *Feeds & Feeding*, 21st ed. (New York: The Morrison Publishing Co., 1949), pp. 1086-1099.

[175] In contrast to this, "where the ratio of carbon to nitrogen in the crop residues is 30/1 or less, no serious tie-up of the soil nitrogen occurs." Helmut Kohnke, *Soil Science Simplified*, 3rd ed. (Prospect Heights, IL: Waveland Press, 1966), p. 42. Therefore, there may only be a significant loss of available soil nitrogen and other nutrients when the carbon-to-nitrogen ratio is greater than 30 to 1.

[176] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 76.

[177] For a thorough soil analysis, contact Steve Rioch, Timberleaf Farm, 5569 State Street, Albany, Ohio, 45710; Fax: (614) 698-2216

least 3.5 years of manure (or 7 years if *Ascaris* is present in our community). The manure should be applied at a rate equivalent to no more than 0.5 pound of nitrogen per 100 square feet in order to achieve *Goal #4, the proper application of nitrogen to food-raising soil.* If 3.5 years (or 7 years, if necessary) of manure can be received by the orchard, then enough time will have passed to kill any pathogens in an area after it has received human manure and before it needs to be redug and receive more manure.

The **fourth challenge** with this method is that the total area required to recycle one person's human manure may not be available to some people in the world, especially if additional land is required to grow annual crops like grains, legumes and vegetables. In Examples #1 and #2, 4,349 to 10,270 square feet are needed to recycle the manure produced by one person annually. In 1988, China had only 9,300 square feet per capita, the Netherlands had 6,700 square feet per capita, Egypt had 5,300 square feet per capita, and Japan had 4,100 square feet per capita.[178] For further information on the average amount of land available per capita currently and in the future, see Appendix D: The Circle Chart.

How much area between the trees is needed? In 3.5 years, we produce about 9.7 pounds of nitrogen in our manure (19.4 pounds in 7 years). Applied at a rate of 0.5 pound per 100 square feet, we would need 1,932 square feet (in a community where *Ascaris* is not present) or 3,864 square feet (where *Ascaris* is present) of area between the trees in the orchard. As the feeder roots grow and extend their boundaries year after year, it may be more and more difficult to dig between the trees in the orchard without damaging roots. This difficulty can be overcome by planting the trees on spacings slightly larger than recommended to insure that there will always be enough area between the trees to dig. In Examples #1 and #2 of Figure 8, the recommended spacings of 40 feet and 15 feet have been increased to 45 feet and 20 feet respectively to accommodate the additions of human manure.

The **fifth challenge** with this method is that most trees take 4 to 12 years to mature.[179] Therefore, it will probably take several years for a tree to produce enough leaves for there to be an "excess" so that some of them could be used for garden compost. Currently, at Ecology Action's Mini-Farm, the garden does not receive any human waste, but the orchard, situated far from the garden, receives partially decomposed human manure. The orchard trees are beginning to produce a quantity of leaves sufficient so that some of them could be composted and added to the garden.

Site Requirements

The orchard that is to receive human manure must be downhill and 150 feet away from any water source, and the groundwater level must be at least 6 feet below the surface of the soil (or 5 feet below the bottom of the excavated sections described below) during the wettest time of the year. To estimate the depth of the groundwater under the orchard, dig a hole 3 feet square and 3 feet deep in the center or lowest part of the site. Standing in this hole, dig a 3-foot-deep hole with a posthole digger before the rainy season. Build a berm (as described in the sections on composting human urine and manure) around its perimeter, and cover the hole and berm with plastic to prevent rainfall and surface runoff from entering the hole. Use an 8-foot-long, 1-inch-by-1-inch pole to test if water appears at the bottom of the hole. If water is detected at any time during the year, a new site or a new method of recycling human waste must be chosen. Be sure to verify from that year's precipitation that the year you checked was a representatively wet one. If not, be sure to recheck the site before using it. Also, be sure that the site does not receive severe runoff that could erode your site and carry pathogens downhill and into a source of water where they could spread disease.

The areas that receive human manure cannot be situated above fissured rock or other extremely permeable rock formations as the nutrients and pathogens in the manure could leach into the groundwater. Sandy soils are generally suitable to receive human manure so long as the depth of the water table meets the requirements described above.

Digging the Holes

In general, a hole 6 inches to one foot deep that receives a layer of human manure equivalent to no more than 0.5 pound of nitrogen per 100 square feet and is filled in with soil will not attract animals. Per month, one person's output of manure contains approximately 0.23 pound of nitrogen, enough to fertilize approximately 46 square feet of soil. Therefore, each month, dig out an area that is 46 square feet to the depth of 1 foot, add one person's monthly output of manure (for a sophisticated low-technology urine and manure separator and storage privy, see Figure 6 page 64) and the appropriate amount of carbonaceous material, if you have not already (the hole may need to be deeper if large amounts of straw are added), and fill in the hole with soil. *The shaded areas in the example orchards in Figure 8 are the areas in which human manure can be added without overly damaging the feeder roots of the trees.*

In Example #1A of Figure 8, 5 trees are grown: 2 regular apple trees (for food or income), 2 English walnut trees (for calories, building material, fuel and/or income) and 1 chestnut tree (for calories, building material, fuel and/or income). The recommended spacing for all three types of trees is 40 feet,[180] but they are instead planted 45 feet apart. Then, when the trees are mature, there will be at least 5 feet between neighboring trees' driplines[181] that can be dug and receive manure. Each site will need to be carefully marked and recorded in order to be sure that the minimum 3.5 or 7 years have passed before the site is redug to receive more manure.

> *"Trees create micro-climates, reduce the speed of wind, lift the water table and increase the population of worms...If farmers knew how to harness worms, they could double their crops. Trees provide the answer...If you want to double your supplies of food, then you should devote twenty-two percent of your farm to trees, to strategically-planted shelter belts."*
>
> - *Richard St. Barbe Baker*, Man of the Trees

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[178] *FAO Production Yearbook*, Vol. 43 (Rome, Italy: Food and Agriculture Organization of the United Nations, 1990), pp. 47-58, 63-79.

[179] In the early years of the orchard, you may want to dig closer to the trees than is shown in the shaded areas in Figure 8 in order to ensure that the trees' feeder roots have access to the nutrients in the buried manure. Also, as the trees' feeder roots grow and extend the area they occupy, this closer area will not be able to be dug without injuring the feeder roots, so it may as well receive nutrient-rich human manure while it can.

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[180] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 90-91, 94-95.

[181] A tree's dripline is the approximate extent of the majority of its main feeder roots, though feeder roots can be found in an area with a diameter 2 to 3 times that of the tree's canopy.

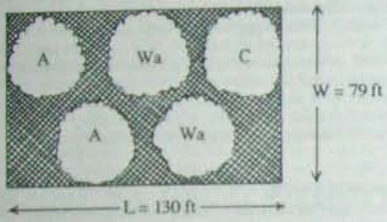
Figure 8

Recycling One Person's Manure with a Mature Orchard[182]

Example #1A: Using Full-Sized Trees

Where Ascaris Is Prevalent

Orchard Layout



A = apple, Wa = walnut, C = chestnut

No. of Trees	Type of Tree	Actual Spacing (Feet)[183]	Calories/Year Produced	Pounds/Day Consumed[184]
2	Regular Apple	45	455,928	5.16
2	English Walnut	45	241,538	0.23
1	Chestnut	45	123,281	0.20

Total = 820,747 Calories / Year
or approximately 94% of the calories
needed by one person annually.

Total Number of Trees = 5
Total Area Needed for Orchard = 10,270 square feet[185]
Area Available to Receive Manure = 3,990 square feet[185]

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[182] Figures for calories produced per year and pounds of produce (fruit or nuts) consumed per day are for when the orchard is mature and are derived from John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 90-97. All figures do not include refuse weight.

[183] Recommended spacing for these trees is 40 feet (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 90-91, 94-95). The trees are planted on 45-foot centers in order to provide soil that can receive human manure between the trees.

[184] This is the amount of fruits and nuts that could be consumed if only one person (the person whose manure is added to the orchard's soil) eats all of the orchard's annual harvest.

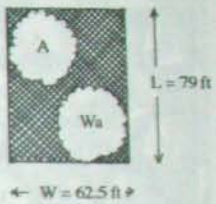
[185] See Appendix B: Detailed Calculation #16A.

Figure 8 (continued)

Example #1B: Using Full-Sized Trees

Where Ascaris Is Not Prevalent

Orchard Layout



A = apple, Wa = walnut

No. of Trees	Type of Tree	Actual Spacing (Feet)[183]	Calories/Year Produced	Pounds/Day Consumed[184]
1	Regular Apple	45	227,964	2.58
1	English Walnut	45	120,769	0.12

Total = 348,733 Calories / Year
or approximately 40% of the calories
needed by one person annually.

Total Number of Trees = 2
Total Area Needed for Orchard = 4,938 square feet[186]
Area Available to Receive Manure = 2,426 square feet[186]

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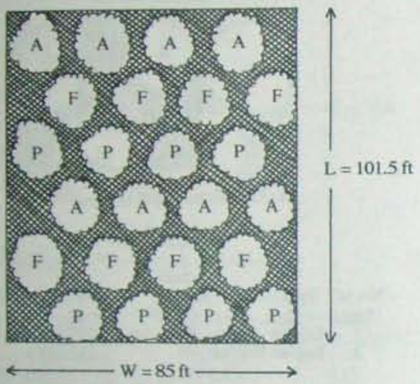
[186] See Appendix B: Detailed Calculation #16B.

Figure 8 (continued)

Example #2A: Using Semi-Dwarf-Type Trees

Where Ascaris Is Prevalent

Orchard Layout



A = apple, F = filbert, P = peach

No. of Trees	Type of Tree	Actual Spacing (Feet)[187]	Calories/Year Produced	Pounds/Day Consumed[184]
8	Semi-Dwarf Apple	20	256,424	2.90
8	Filbert (Hazelnut)	20	504,651	0.48
8	Regular Peach	20	108,779	1.99

Total = 869,854 Calories / Year
or approximately 99% of the calories
needed by one person annually.

Total Number of Trees = 24
Total Area Needed for Orchard = 8,628 square feet[188]
Area Available to Receive Manure = 4,390 square feet[188]

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[187] Recommended spacing for these trees is 15 feet (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 90-91, 94-95). The trees are planted on 20-foot centers in order to provide soil that can receive human manure between the trees.

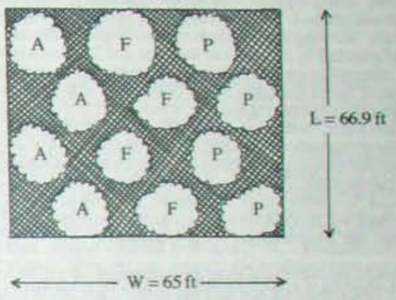
[188] See Appendix B: Detailed Calculation #16C.

Figure 8 (continued)

Example #2B: Using Semi-Dwarf-Type Trees

Where Ascaris Is Not Prevalent

Orchard Layout



A = apple, F = filbert, P = peach

No. of Trees	Type of Tree	Actual Spacing (Feet)[187]	Calories/Year Produced	Pounds/Day Consumed[184]
4	Semi-Dwarf Apple	20	128,212	1.45
4	Filbert (Hazelnut)	20	252,326	0.24
4	Regular Peach	20	54,389	0.99

Total = 434,927 Calories / Year
or approximately 50% of the
calories needed by one person
annually.

Total Number of Trees = 12
Total Area Needed for Orchard = 4,349 square feet[189]
Area Available to Receive Manure = 2,230 square feet[189]

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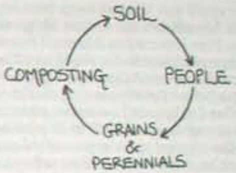
[189] See Appendix B: Detailed Calculation #16D.

Analysis and Comparison of the Two Examples

In selecting trees for recycling human manure, as seen in Examples #1 and #2, the smaller the recommended spacing of the trees, the more trees that are needed, in order to provide enough area in between the trees that can receive human manure. This would not necessarily be the case if trees recommended to be planted 15 feet apart were, for example, planted 40 feet apart, instead of 20 feet apart as in Example #2. However, the recommended spacing for each type of tree is designed so that, once the trees are mature, the trees' leaves, especially those nearest the ground, touch. This has the similar and beneficial effects of spacing other crops, whether they are lettuce, beans or wheat, closely together -- the touching leaves: 1) shade the ground, which minimizes weed growth and creates a *"moisture bubble"* by minimizing soil evaporation; 2) create a *"carbon dioxide bubble,"* allowing the maximum amount of carbon dioxide given off by the soil to be available and absorbed by the leaves of the trees; and 3) create a more stable mini-climate beneath the trees by minimizing wind and temperature fluctuations within the orchard and soil. If the trees are spaced much farther apart than about 25% to 30% of the recommended spacing, then none of these positive effects can be realized. There is more evaporation from the soil, causing the orchard to require more water; more weed growth in between the trees; less carbon dioxide readily available to the trees for photosynthesis and more carbon dioxide (one of the greenhouse gases) released into the already carbon dioxide-rich atmosphere; and a greater exposure to the elements which can slow growth and reduce yields. *Therefore, the larger the tree is that you use to recycle your manure, the fewer trees and less water, fertilizer/compost, time and labor you will need. Also, with larger trees, the orchard will produce the same or more calories per area, though fewer total calories, than if you use trees that are spaced more closely together.*

In conclusion, burying manure and using trees for secondary recycling, unlike composting, requires very little experience and skill and involves less health risk, since less handling of the manure is required. Also, trees can be excellent for preventing erosion and upgrading marginal soils. *Still, more research needs to be done to determine which deciduous trees grow best in manure-rich soil and produce the most leaves (as well as fruits or nuts) in the shortest amount of time.*

GRAINS AND PERENNIALS



Through the use of grain-producing crops and deep-rooted perennials, human manure can be purified of its pathogens and replenish the soil's supply of minerals and humus. *The method outlined below requires less skill and risk than composting and eliminates the waiting period and complications involved in using trees to recycle human manure.*

Goal #1, purification of the manure, is achieved with this method by shallowly burying human manure in the soil. Human pathogens, which are well suited for life inside a human body, are not so well suited for life in the soil. Still, some human pathogens in relatively sterile soil can live for 3.5 years, and eggs of the parasitic worm *Ascaris* can survive up to 7 years in the soil.[190] Therefore, in order to achieve Goal #1 by this method, the manure must be allowed to age sufficiently. Using a simple and yet efficient rotation system, only 18, 100-square-foot garden beds are needed on a continual basis to allow the manure annually produced from one person to age for 7 years (where *Ascaris* is prevalent) and only 12 beds are needed to allow the manure annually produced from one person to age for 3.5 years (where *Ascaris* infections are not prevalent in the community). Because these 18 or 12 beds can grow crops to provide human food and compost material while they are used to recycle human manure, it is possible to integrate the 18 or 12 beds into your current garden or farm so that no additional space is needed (except approximately 600 cubic feet of soil storage space) to grow all of your food, all of your compost material *and* return all of the manure you produce to the soil that feeds you.

Note: Ecology Action has had success with growing crops in specialized tests in soil that has received human manure, indicating the viability of this method. However, the method has yet to be implemented in its entirety due to the current legal guidelines that generally prevent the recycling of human waste on an individual or community basis. Therefore, the method as outlined below is still experimental.

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[190] Based on the author's analysis of data presented by R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review* (Washington, D.C.: World Bank, 1981), pp. 193-200; and Jerry Minnich, et al., *The Rodale Guide to Composting* (Emmaus, PA: Rodale Press, 1979), p. 363. However, it may be possible to use human urine to kill parasitic worm eggs, including eggs from worms of the genus *Ascaris*. See Appendix C: Further Discussion #2.

Choosing a Site

All 18 or 12 beds must be uphill and 150 feet away from any water source, and the groundwater level must be at least 7 feet below the surface of the soil (or 5 feet below the depth to which the excavated sections have been loosened as described below) during the wettest time of the year. To estimate the depth of the groundwater under the 18 or 12 beds, dig a hole 3 feet square and 4 feet deep in the center or lowest part of the site. Then, dig a 3-foot-deep hole in the bottom of the first hole with a posthole digger before the rainy season. Build a berm (as described in the sections on composting human urine and manure) around its perimeter, and cover the hole and berm with plastic to prevent rainfall and surface runoff from entering the hole. Use an 8-foot-long, 1-inch-by-1-inch pole to test if water appears at the bottom of the post hole. If water is detected at any time during the year, a new site or a new method of recycling human waste should be chosen. Be sure to verify from that year's precipitation that the year you checked was a representatively wet one. If not, be sure to recheck the site before using it. Also, the site must not receive severe runoff that could erode your site and carry pathogens downhill and into a source of water where they could spread disease.

The beds that receive human manure should not be situated above fissured rock or other extremely permeable rock formations as the nutrients and pathogens in the manure could leach into the groundwater. Sandy soils, in general, are suited to receive human manure so long as the depth of the water table meets the requirements described above.

If you have more beds in your garden than you need to recycle your waste, you probably should rotate which beds receive human manure. This will minimize the risk of any section of your garden losing or accumulating minerals which would imbalance and compromise the health of the soil. However, *if only certain sections of your garden meet the stipulations described above, only those sections should be used to recycle your manure by this method.* Further research is necessary before we can fully understand the extent of the risk of the manure imbalancing the mineral content of the soil and how best it can be overcome. In the meantime, if you have only 18 or 12 beds to recycle your manure, it may be best to recycle your manure by composting it (see pages 62-72) or by a method other than using grains and perennials.

Modifications to the method as it is described below are given on pages 108-109.

Collecting Your Manure

1) During each month, collect the manure you generate in a separate sealable container. *The container's seal and/or the seal between the storage container and privy must be tight enough to prevent flies, mosquitoes and other vectors from entering the storage container, contacting pathogens and causing disease. This requirement is essential for all human waste storage and recycling systems.* Each container must be at least 1 gallon in volume (a 5-gallon bucket, though it is larger than needed, may work well). Plastic containers are suitable for storing human manure (since human manure will not corrode them as human urine would) and are less likely to corrode than metal containers. If you have the proper clay available, you could fashion manure storage pots.

Other than manure and toilet paper (or arla, mullein or lamb's ears leaves; see footnote #157), no other material should be added to the container. At the end of the month, seal the storage container and record the date on it. Dating each container will allow you to dump them systematically to ensure that sufficient time passes after the manure is added to kill any pathogens it may contain and before the manure-enriched soil is reworked or used to plant crops whose edible portion touches the soil. Then, begin collecting your manure in another container.[191]

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[191] If you find that the storage container is odorous, the manure is probably decomposing anaerobically. If necessary, periodically open the container and stir the manure with a tool *that is used for no other purpose* in order to encourage aerobic decomposition until the container is emptied and the manure is added to soil.

Optimally, you will begin collecting and storing your manure in the fall for the reason discussed on page 92.

Preparing the Beds to Receive Human Manure

2) Remove the soil from 6 beds to a depth of at least 1 foot and store it in a separate bin. (You will need about a 600-cubic-foot storage capacity.) *Loosen and aerate the soil at the bottom of the excavated beds to a depth of 1 foot with a garden fork.* Divide each bed in half by staking string across the top of the beds. Number the *sections* 1 through 12 (a "section" is half of a 100-square-foot garden bed. The word "section" will be italicized to help you keep from confusing it with a "bed"). All 12 *sections* do not need to be dug at once, but you will need to dig out at least half of a bed each month for one year in order to have somewhere to put the manure you produce each month.

With 1 foot of soil removed, each dug-out bed is designed to receive 3 separate layers of stored manure, soil, seeds and more soil. Therefore, after you have dug out all 6 beds, you will not need to dig for the next 3 years, until a new set of 6 beds is needed.[192] In total, only 2 or 3 sets of 6 beds are needed to recycle all of the manure one person produces, as mentioned above.

To prevent the sides of the excavated beds from collapsing, a path at least 2 feet wide should separate the beds. Also, the beds should probably be no wider than 4 feet (and therefore 25 feet long so they remain 100 square feet and correlate to the guidelines and calculations mentioned below) to ease harvesting and minimize stress on the path and walls of the excavated beds.

Adding the Manure

3a) Where Crops Can Grow Year-Round

If you live where you can grow crops year-round, no storage of manure beyond one month is necessary. You do not need to record the date or have more than one manure storage container on hand. After the first month, simply spread the manure you collected over *Section* 1. After the second month, spread the manure you collected during that month over *Section* 2, spread the next month's worth of manure over *Section* 3, and so on. You can then cover the manure and sow seeds as described in Steps 4 and 5 below.

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[192] Each person excretes about 2.8 pounds of nitrogen per year in her or his manure or about 0.23 pound per month. A nitrogen-deficient soil will generally benefit by receiving about 0.5 pound of nitrogen per 100 square feet per year; more than this could result in nitrogen toxicity in the crops and groundwater, crop lodging, soil acidification and possibly a loss of soil humus as described on pages 20-22. The manure produced by one person in 2 months, therefore, contains 0.46 pound, slightly less than 0.5 pound, of nitrogen. *So, no more manure than is generated by one person in approximately 2 months should be added to a bed.*

In this method, each of the 6 beds that are to receive the manure produced by one person during the year is divided into 2 *sections*, for a total of 12 *sections*. Each *section* receives the manure generated by one person in one month once a year so that each bed receives 2 months' worth or slightly less than 0.5 pound of nitrogen per year. *Goal #4, the proper application of nitrogen*, is then achieved.

If, instead of adding human manure to the beds at a rate of 0.5 pound of nitrogen per 100 square feet per year, it is added at a rate of 0.1 pound of nitrogen per 100 square feet per year, where *Ascaris* is prevalent, 84 beds are needed to recycle one person's manure. (2.8 pounds of nitrogen are produced per year, enough to fertilize [2.8 / 0.1] 28 beds at an application rate of 0.1 pound per 100 square feet per year. To ensure that the manure cures sufficiently to be pathogen-free, 3 sets of 28 beds are needed for a total of [28 x 3] 84 beds where *Ascaris* is prevalent.) Where *Ascaris* is not prevalent, (2.8 / 0.1) 28 beds are used per year, and 2 sets of 28 beds, for a total of [28 x 2] 56 beds per person, are required before a manure-enriched bed is pathogen-free and can be reused. See Figures 11 and 13 on pages 94 and 101 respectively for further clarification.

To determine whether or not *Ascaris* is prevalent in your community, ask your local physician.

3h) Where There Are One or Two Growing Seasons

If, however, you live where there are only one or two growing seasons, you will need to store your manure in separate containers until the beginning of the next growing season.[193] Each manure storage container should be dated at the end of the month after it is filled and sealed. *At the beginning of the first growing season (optimally in the spring, for reasons which will be explained later)*, put the manure you collected during Month 1 into *Section* 1, the manure you collected during Month 2 into *Section* 2, Month 3 into *Section* 3, and so on until you run out of stored manure. It is essential that the manure be added in this systematic manner in order to minimize the amount of area you need and to know when the manure has aged sufficiently and the soil can be safely worked.

If you have only one growing season per year, you will need 12 manure storage containers for this method.[194] You can choose to collect *two* months' worth of manure per container, in which case you will need only 6 containers per person. The manure in each container would then be spread over *two* excavated *sections* (the entire bed) rather than over one *section*. The disadvantage of this is that the more manure you have to spread over a larger area, the more difficult and time-consuming it is to spread the manure evenly, and spreading manure is not a task you will generally want to take much time.

As with human urine and manure composting, reserve a set of clothing and a spade for dumping, spreading and covering the manure, *and use them for no other purposes*.

4) Cover the manure with a layer of soil about 2 inches thick.[195] You can use the soil that you removed when you dug the beds. If you find that animals are attracted to the buried manure, use more soil to cover the manure, construct a barrier around the perimeter of the *sections* containing manure, or cover the excavated *sections* with light netting (flagged so it is visible to animals) to exclude them. If you are not going to sow seed immediately into the *section* as described below and do not need the *section* to receive sunlight, a plywood cover may also be used to keep animals out. A sheet of translucent plastic over the bed will effectively turn the excavated bed into a sunken greenhouse.

It is possible that covering the manure with soil will encourage the manure to decompose anaerobically and inhibit plant growth. However, this has never been observed in Ecology Action's preliminary experiments with this method of recycling human manure, and in fact quite the opposite.

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[193] Instead of storing the manure in containers, an alternative to this method is to spread it over a *section* each month and cover it with a layer of soil just as you would if you could grow crops year-round. Then, at the beginning of the next growing season, sow seed. The disadvantages to this method are that some of the nutrients in the manure may leach out before the seeds that are sown are mature enough to use them. Also, the bare soil will not deter many animals from unearthing the manure whereas growing plants may.

[194] For a family of four, a single container with a volume of at least 4 gallons may be used to store the manure the family generates each month, but it will need to be added to 4 times the area (or as many times as there are family members but less if some of the members are very young and produce less manure) each month and in a sequential pattern like the one described in the text above and shown in Figures 11 and 13 on pages 94 and 101 respectively.

[195] "Incorporating the fertilizers into the top few centimeters of soil can reduce ammonia loss by 25 to 75% over levels found when the materials are applied to the surface" (Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. [New York: Macmillan Publishing Company, 1984], p. 299). While Brady is referring to purchased fertilizers, the same would undoubtedly be the case for adding human manure to the soil. The layer of soil covering the manure will also help conceal it from animals.

> *"Thou shalt have a place also without the camp...and it shall be when thou wilt ease thyself, thou shalt dig therewith, and shalt turn back and cover that which cometh from thee."*
>
> - *Moses, King James version of Deuteronomy*, The Holy Bible

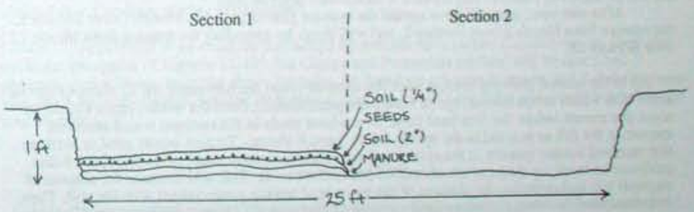
Sowing Seed

5) After you have spread and covered the manure in the excavated *sections*, sow seeds at the rate recommended in *How to Grow More Vegetables* (John Jeavons, Ten Speed Press, 1991) into each *section* that received manure. Any seeds that grow into plants that are tall (say three feet high or more, whose edible portion is not likely to contact the pathogen-rich soil), contain lots of carbon, and grow easily in this growing season are good candidates to try. Grain crops (corn, amaranth or millet, for example) are especially suitable: they have these characteristics and also produce food that is well above the surface of the soil and not likely to be contaminated by pathogens in manure-enriched soil. Although better yields are usually obtained when plants are transplanted, you should broadcast (scatter) the seeds over the area to minimize the amount of contact you have with the manure-enriched soil. Soaking the seeds overnight can greatly increase their ability to sprout, and they will need fairly regular watering thereafter. Alternatively, you can broadcast the unsoaked seeds and allow them to wait for the rains.

6) Cover the seeds with a light (about 1/4-inch) layer of soil, again using the soil you removed when you dug the beds. If the seeds have been soaked overnight, this layer of soil must be thoroughly watered after it is added in order for it not to dry out the pre-sprouted seeds.

Figure 9

Length-wise Cross Section of 100-Square-Foot Bed (25 feet by 4 feet)



7) Water the planted sections evenly and gently (probably as often as you water the rest of your garden) to keep the soil slightly moist for optimal germination and plant growth. Continue storing your manure each month in a separate container.

Harvesting the Crops

8) The crops should be harvested as they mature.

In order to generate the maximum amount of carbonaceous compost material, it is probably best to leave any carbonaceous crops, such as grains, to mature before they are harvested, unless they are growing in *sections* that will immediately receive an addition of human manure. The closer the carbonaceous crops can get to being fully mature before they must be harvested (so that the next crops will have sufficient time to mature), the more carbon and the more humus you will have to feed the soil and sustain, or even improve, its fertility.

When harvesting grain, cut the stalks just above ground level, leaving the roots in the soil to improve the soil's structure, aeration and fertility. Roots left in the ground will eventually decompose and transform into high-quality humus that will enrich the soil. (See Ecology Action's information sheet, "Roots In The Soil".) Compost the harvested plants. (Where *Ascaris* is prevalent, 2.3 to 5.3, 3-foot-by-3-foot-by-3-foot compost piles should contain no soil in order to produce enough soilless cured compost to apply to the beds of perennials as described on pages 91-92. Where *Ascaris* is not prevalent, 1.1 to 2.7, 3-foot-by-3-foot-by-3-foot soilless compost piles are needed.) Try to prevent the harvested plants from touching the manure-enriched soil, and try not to touch the soil yourself. After you are done, wash your hands and any other area that may have contacted the soil. By generating compost and humus and adding them back to the soil that grows your food and is not currently receiving human manure, you will replenish the minerals and humus the soil lost when it grew the food you consumed. That soil will then remain healthy and productive for as many years and generations as it is managed sustainably.

If you decide to eat the grain, be sure *not to eat any grain you know touched soil which received human manure*. Root and leaf crops grown in human manure-enriched soil should not be eaten until the soil has aged for 3.5 or 7 years (depending on the presence of *Ascaris* in the community) due to the intimate contact these crops will have had with the pathogen-rich soil. (Boiling the grain, roots or leaves for at least an hour will probably kill the pathogens, but this is not certain at this time.)

The Second Growing Season

9) If you have two growing seasons, at the beginning of the second growing season (optimally in the fall, for reasons that will be described on page 92), at least one month before the first hard frost, spread the manure you have stored the longest over the next *section* in sequential order that has not yet received manure, and cover it with a 2-inch layer of soil.

After one year, you will have spread the manure you collected in Month 1 over *Section* 1, the manure from Month 2 over *Section* 2, and will finish by spreading the manure from Month 12 over *Section* 12.

10) In the second growing season, after the summer crops are harvested, *all 12 sections* can be sown with winter crops (wheat, rye or barley are possibilities). Seed for winter crops should be sown one month before the first hard frost. Sow winter seeds in the sections which received manure in the fall as you did in the spring (steps 5 and 6 above). To sow winter seed in sections that received human manure in the spring and then grew a summer crop, first use a 1- or 4-tine cultivator to break up the network of residue and surface roots. This will increase the amount of exposed soil and optimize the chances of the sown seed having good contact with the soil. Then, broadcast seed for winter crops in these *sections* so that now *all 12 sections are sown*. Cover the seeds sown in all 12 *sections* with a light (1/4-inch) layer of soil, and water them as needed.

Figure 10

An Example Calendar for the First 18 Months of Using Grains and Perennials Assuming You Have Two Growing Seasons -- One 5-Month Season during the Summer and One 7-Month Season during the Winter

September - Begin storing your manure using a separate container each month.
October - Continue storing your manure in a separate container.
November - Continue storing your manure.
December - Continue storing your manure.
January - Continue storing your manure.
February - Continue storing your manure.
March - Continue storing your manure.

BEGINNING OF YEAR ONE

April - Dig out *Sections* 1-7. Spread the manure you collected in September over *Section* 1, October's manure over *Section* 2, November's manure over *Section* 3, etc., finishing by spreading March's manure over *Section* 7. Cover with soil all sections that received manure. Sow seeds for summer crops, cover the seeds and water as necessary. Continue storing your manure during this month.
May - Continue storing your manure.
June - Continue storing your manure.
July - Continue storing your manure. Harvest and compost mature crops.
August - Continue storing your manure. Harvest and compost mature crops.
September - Harvest and compost all remaining summer crops. Dig out *Sections* 8-12. Spread the manure you collected in April over *Section* 8, May's manure over *Section* 9, etc., finishing by spreading the manure you stored in August over *Section* 12. Cover the manure in *Sections* 8-12 with soil. Loosen the stubble and soil in Sections 1-7 with a 1- or 4-tine cultivator. Sow all 12 *sections* with seeds for winter crops, cover the seeds and water as necessary. Continue storing your manure during this month.
October - Continue storing your manure.
November - Continue storing your manure.
December - Continue storing your manure.

NOTE: This calendar is an example that would be specific for a certain climatic region. Hereafter (with the exception of Figures 11-14), the Grains and Perennials method will be described generally and will not, as in the above calendar, be based on a 5-month season and 7-month season year. With the non-climatic specific description, you can create a calendar and schedule specific for your climate.

The Second Year

11) In the second year, continue to store your manure using a separate container each month. Record the date on each storage container after each month, seal it, and begin collecting your manure in another container just as you did during the first year. *By storing your manure until the next growing season, the plants sown in the first year will have more time to mature (and will contain more carbon for the compost pile) before they need to be harvested and the manure added*

on top of their stubble. For this reason, you may want to store your manure for a period of time even if you can grow crops year-round. Harvest the crops sown the first year as they mature.

At the beginning of the next growing season, harvest the crops as needed to provide an area to receive manure and to optimize the carbon you will produce. Add the oldest manure to *Section* 1 on top of the stubble from the crops grown on the first layer of manure, the second oldest to *Section* 2, and repeat the same pattern you established the first year until you run out of stored manure. Cover the sections that received a second layer of manure with soil. Sow with summer crops. Cover the seeds with a light layer of soil and water the sections as described in steps 5 through 7 above.

In the sections that do not receive manure in the beginning of the first growing season (*Sections* 7-12), break up the stubble and loosen the soil with a cultivator to provide good seed-soil contact. Sow *these sections so that all 12 sections are sown with seed for summer crops.* Cover the seeds with soil, and water the sections as described in steps 5 through 7 above.

Repeat this pattern, outlined in "Summary of the Pattern" below, for as many growing seasons as you have. At the end of the second year of using this method, all 12 *sections* will have received a second layer of manure, soil, seeds and more soil.

A Summary of the Pattern

In every growing season after the first year, each section will fall under one of two categories, requiring different operations:

Category #1: The section *receives* human manure at the beginning of this season.
Operation for Category #1
1) Harvest any remaining crops planted the previous season.
2) Spread the manure.
3) Cover the manure with soil.
4) Sow seed appropriate for the season.
5) Cover the seed lightly with soil.
6) Water as needed.

Category #2: The section *does not receive* human manure at the beginning of this season.
Operation for Category #2
1) Harvest any remaining crops sown the previous season.
2) Break up the stubble layer and shallowly loosen the soil with a 1- or 4-tine cultivator to provide good soil contact for the seeds you will sow.
3) Sow seed appropriate for the season.
4) Cover the seed lightly with soil.
5) Water as needed.

The Third Year

12) In the third year, add a third layer of manure on top of the stubble from the crops grown on the second layer of manure in the same pattern you established in the first and second years, and continue growing and harvesting all 6 beds.

During the first three years, none of the 6 beds receiving human manure receives cured compost. By adding this manure to the soil at the rate of 0.5 pound of nitrogen per year, you will be returning to the soil the nutrients contained in the food eaten, *with the exception of carbon which is breathed out into the air.* In other words, simply returning your manure will not add enough humus to replenish the humus lost from the soil annually. However, if cured compost (which contains nitrogen) were added to the soil as well as 0.5 pound of nitrogen in the form of human manure, it is possible that too much nitrogen would be added to the soil. Therefore, the

cured compost generated from the harvested plants should probably be added to other beds or stored until the beds are ready to receive it.

When we grow crops, humus and nutrients are taken from the soil, but the plants themselves also add "cured compost" in the form of roots. Roots left in the soil are decomposed and transformed into the highest quality of humus and organic matter available to the soil. Depending on the plant, the amount of roots and rootlets left in the ground can be very high. For example, it is estimated that one cereal rye plant in good soil grows 3 miles of roots a day, 387 miles of roots in a season, and 6,603 miles of root hairs in a season.[196] So it is possible that the humus level of the soil will not be severely depleted if, during the three years it receives human manure before it grows perennials, it grows root-rich plants such as cereal rye.[197] More research is needed to determine the exact contribution the roots of different plants make in terms of soil humus.

If it is found that the organic matter level of most soils will suffer under this regime, it may be that, of the 0.5 pound of nitrogen added annually, some could come from human manure and some from humus-rich cured compost. This would increase the number of beds needed to recycle one person's annual production of manure. For example, if half of the nitrogen came from human manure and half from cured compost, 34 beds would be needed to recycle one person's manure in communities where *Ascaris* is present, and 22 beds where *Ascaris* is absent.[198]

Growing Perennials

After each set of 6 beds has received 3 layers of manure, soil, seeds and more soil, it will be used to grow perennials until the manure has aged sufficiently for the beds to be safely worked and used to grow crops whose edible portion may contact the soil.

In the late spring or early summer, harvest the plants grown on the third layer, and fill the beds with the soil you removed from them (it will probably be a layer 3 to 4 inches thick). Then, add 1.65 to 4 cubic feet of cured *soilless* compost (equivalent to 3.3 to 8 cubic feet of cured compost that is 50% soil by volume) to each bed.

Cured compost *which contains no soil* is best to add to beds growing perennials. This is because the beds that received human manure and then will grow perennials will not be double-dug for several years, until the perennials are removed and the human manure has sufficiently aged. In the process of double-digging to prepare a bed, some soil from the first trench that is excavated is used to build compost piles.[199] When the compost is cured and added to the bed, the soil that was removed from the bed, and that is now in the cured compost, is returned to the bed. However, beds growing perennials are not double-dug each year, so no soil is removed. When cured compost *without* soil is added to beds growing perennials, the amount of soil in the beds remains constant. If cured compost *with* soil were added to the beds of perennials, over time the beds growing annuals would sink for lack of soil, and the beds growing perennials would bulge with the excess soil they received from the cured compost.

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[196] Helen Philbrick and Richard B. Gregg, *Companion Plants and How to Use Them* (Old Greenwich, CT: Devin-Adair Company, 1966), pp. 75-76.

[197] A Rothamsted experiment that has been on-going for more than 100 years suggests this estimate is accurate. D. S. Jenkinson and J. H. Rayner, "The Turnover of Soil Organic Matter in Some of the Rothamsted Classical Experiments," *Soil Science*, Vol. 123, No. 1, 1977, pp. 298-305.

[198] 2.8 lbs. nitrogen total / (0.25 lb. nitrogen / bed / year) = 11.2 beds / year x 3 sets of beds (where *Ascaris* is present) = 34 beds. 11.2 beds / year x 2 sets of beds (where *Ascaris* is not present) = 22 beds.

[199] John Jeavons and Carol Cox, *Lazy-Bed Gardening: The Quick and Dirty Guide* (Berkeley, CA: Ten Speed Press, 1993), p. 29.

Spread the cured soilless compost evenly over the bed, and sift it into the top 2 to 3 inches of soil. Then, broadcast the seed of deep-rooted perennials such as alfalfa, medium red clover or others[200] into each filled bed, which can be harvested during the following years to provide compost material. Chop in the seeds lightly with a rake. Alfalfa and medium red clover can both be sown in the early spring, but if you wait until the late spring or early summer, the grains sown in the fall of the previous year will have additional time to mature before they need to be harvested and the perennials sown. Sown in the late spring or early summer, the perennials will still have time to become established before the winter in most climates.

Transplanting and Broadcasting Compared

From Ecology Action's experience, almost any bed that has been transplanted produces higher yields than one that is sown directly (broadcast). However, all beds that have received human manure that has not yet been purified of its pathogens should always be sown by broadcasting the seed rather than transplanting seedlings to minimize your contact with the pathogen-rich soil. The tool used to cover the seed after it is planted (e.g. a rake or, in the case of corn or other large seed, a planting stick) should be used *only in manure-enriched soil and never in soil that is pathogen-free.*

Start Collecting Manure in the Fall

Optimally, you will want to sow all 6 beds in perennials in the late spring. *This is the reason why it is best to start collecting your manure in the fall.* By starting to store your manure at the beginning of the fall growing season, you will be able to spread it over a maximum number of beds that can be sown in the spring. Even more importantly, at the beginning of the following fall growing season, all 12 *sections* of your first 6 beds will have received manure, and all can be sown in the fall with carbonaceous grain crops, for example, that can survive the winter. *This will put you on track so that all of the 6 beds will have received their third and last addition of manure in the fall of the third year. The grains, planted in the fall, will be harvested in the late spring or early summer of the fourth year, and the perennials can then be sown.*

The following year and for as many years as the bed is used to grow perennials, cured soilless compost should be added once each year. The best time of the year to add cured soilless compost to a bed growing perennials is at the beginning of the main growing season; it may not need to be added at the beginning of a cooler second growing season. Adding compost is best and most easily done after the first harvest of the perennial beds each year in most temperate zones. Harvest most perennials by cutting 1 to 1.5 inches above the crown of the plant. Once the bed is

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[200] Medium red clover is a less valuable crop for producing compost material than alfalfa, generally producing only about half the carbon that alfalfa produces during the growing season each year. Other varieties of clover produce one half or less of the carbon that medium red clover produces.

Unless soil nitrogen is so scarce that only nitrogen-fixing plants can thrive, it is more important for the sustainability of the soil and farm to grow perennials that are rich in carbon rather than rich in nitrogen. Once composted, the carbonaceous residues from the perennials will generate more cured compost and more humus than those from more nitrogenous perennials (such as clover, comfrey and others). Generally, carbon is the missing element in most compost piles, and it is essential for the production of sufficient humus to sustain or improve the fertility of the soil. To sustain our soils, in essence we must *grow carbon!*

A good example of a perennial that can produce a large amount of carbonaceous residue is Jerusalem artichoke. However, if it is grown in human manure, the tubers should not be eaten. To plant the tubers in human manure-enriched soil, lay the tubers on top of the stubble from the crops grown on the third layer of manure. Then, fill in the bed with 3 to 4 inches of soil, add the appropriate amount of cured soilless compost and sift it into the top 2 to 3 inches of soil.

harvested, loosen the soil between the plants and spread the cured compost as evenly as possible between the plants. Then, incorporate the cured compost between the plants into the top 2 to 3 inches of soil with a border fork. Afterwards, water the soil thoroughly to carry the nutrients and humus in the cured compost deeper into the soil.

Depending on your climate and the health of the perennials, additional harvests may be possible throughout the main growing season, or in some situations throughout the year. Since you will only add cured compost once each year, after any subsequent harvests, simply loosen the soil around the plants to the depth of 2 to 3 inches to aerate the soil, and water well, if necessary. The harvested alfalfa will re-establish itself more quickly if it is covered with shade-netting (or any available material that can lightly shade the plants) for a period of two weeks after harvest.

After 3 Years of Using the Method

The 6 beds you have dug are designed to process 3 years' worth of manure. If *Ascaris* infections are not common in your community, each *section* of all 6 beds can be safely worked after all of the manure it contains has matured for at least 3.5 years. As shown in Figure 11 on page 94, 4 years (more than the required 3.5 years) will have passed since the first *section* of the first bed (*Section* 1) was *filled and planted with perennials*, and this *section* should now be safe to dig and use to grow all types of crops.

Ascaris eggs, if they are present in the manure you have added to the soil, can survive in the soil for as long as 7 years, the longest of any known pathogen. If *Ascaris* is present in the community, a bed that has received human manure should not be worked until 7 years have passed since its last addition of human manure. In order to continue recycling your manure, after the first 3 years, you must begin to dig a second set of 6 beds, exactly as you did the first set, filling them in (*Sections* 13-24 as shown in Figure 11 page 94) in the same orderly pattern. After the second set of 6 beds is filled, a third set must be started. As shown in Figure 13 on page 101, after this third set is filled using the same pattern, 7 years will have passed since the first *section* was filled and planted with perennials, and this *section* could be safely used to grow all types of crops.

Instead of working and planting each *section* after it has aged for 3.5 or 7 years, you could wait until the last *section* of the first *bed* was filled in and all of the manure added to the bed has aged at least 3.5 or 7 years (which would be in about one more month depending on when the *sections* were filled). Then, you could safely dig the entire bed at once. In either case, after the last layer of manure in each *section* or *bed* has aged sufficiently, wait as long as possible before putting manure into the same *section*. By rotating the beds that receive manure rather than having 12 or 18 beds that are permanent receivers of manure, you will minimize the risk of any *sections* in your garden losing or accumulating minerals and becoming minerally imbalanced and less healthy.

The following four figures, Figures 11, 12, 13 and 14, outline the procedures and cycles involved in recycling human manure using grains and perennials where *Ascaris* is not and is prevalent in the community.

Figure 11

The First 10 Years and Beyond Using the Grains and Perennials Method in a Climate with Two Growing Seasons Where *Ascaris* Is Not Present in the Community

All pathogens in human manure, except for the eggs of *Ascaris*, will die after being exposed to healthy soil for 3.5 years or less. Therefore, if *Ascaris* infections are rare in your community, only 12 beds, or 2 sets of 6 beds, will be needed to recycle one person's manure.

- Optimally, begin storing your manure in the fall.

Year 1

Spring Growing Season

- Dig out all 6 beds or enough to receive the manure you have stored since fall.
- Spread the manure collected during Month 1 over *Section* 1, the manure you collected in Month 2 over *Section* 2, and so on until you run out of stored manure.
- Cover the manure with soil. Sow seeds of plants that like warm days. Cover the seeds with soil, and water as needed.
- Harvest the plants as they mature.

Fall Growing Season (at least one month before the first hard frost)

- Dig out any remaining beds.
- Put the manure you collected since the beginning of the first growing season over each of the next *sections* that has not yet received manure, in sequential order.
- Cover the manure with soil. Sow winter seed in all sections that received human manure. Cover seeds with soil. Water as needed.
- Harvest any crops that remain on sections that received manure in the spring. Loosen stubble and soil of these sections. Sow winter seed. Cover with soil. Water as needed. All 12 *sections* will now have received their first layer of manure.

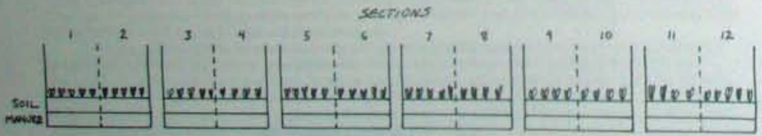


Figure 11 (cont.)

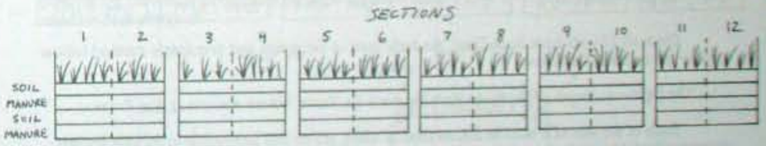
Year 2

Spring Growing Season

- Harvest the plants sown in the second growing season of Year 1 as they mature or as needed to provide enough area to apply the stored manure. Add the oldest month's worth of manure on top of the stubble in *Section* 1, the next oldest to *Section* 2, and continue in this pattern until you run out of manure.
- Cover the manure with soil. Sow summer seed, cover the seed with soil, and water the sections as needed.
- Allow plants sown in the fall on sections that do not receive human manure in the spring to mature as fully as possible. Harvest them when summer seed must be sown. Loosen the stubble and soil. Sow seed, cover the seed with soil, and water.
- Harvest summer crops as they mature.

Fall Growing Season (at least one month before the first hard frost)

- Dig out any remaining beds.
- Spread the manure you collected since the beginning of the first growing season of Year 2 over each of the next *sections* that has not yet received manure, in sequential order.
- Cover the manure with soil. Sow winter seed in all sections that received human manure. Cover the seed with soil. Water the sections as needed.
- Harvest any crops that remain on sections that received manure in the spring and not in the fall. Loosen stubble and soil of these sections. Sow winter seed. Cover the seed with soil. Water the sections as needed. All 12 *sections* will now have received their second layer of manure.



Year 3

Repeat the pattern you established in Year 2 of harvesting, adding stored manure (the third layer), covering the manure with soil, and sowing seed.

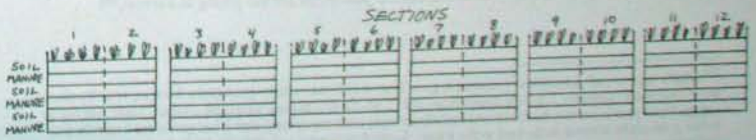


Figure 11 (cont.)

Years 4, 5 and 6

At the beginning of Year 4, harvest the grains or other crops growing in Beds 1-6 when they are mature (or in the late spring/early summer, whichever comes first), and sow perennial seeds.

During Year 4, dig out the second set of 6 beds (Beds 7-12), and, during Years 4, 5 and 6, fill them as you filled the first set in Years 1, 2 and 3.

Below is a length-wise cross section of all 12 beds. The numbers in each *section* represent the month and year (month / year, e.g. 9 / 95) that the manure was produced. Notice that *Section* 1 is filled with manure in 9 / 97, and all 12 beds are completely filled when manure from 8 / 01 is added. Therefore, at the end of 9 / 01, 4 years (more than 3.5 years) will have passed since the manure added last to *Section* 1 was produced, and *Section* 1 can now safely be either redug to receive more human manure, or preferably used to grow edible crops (including root and leaf crops). If *Section* 1 is not redug and does not receive manure, which may be more beneficial to the soil as mentioned earlier, a new bed *that has not received human manure for at least 4 years* would need to be dug to begin the new cycle.

SECTIONS

	1	2	3	4	5	6	7	8	9	10	11	12	LAYER
BEDS 1-6	9/97	10/97	11/97	12/97	1/98	2/98	3/98	4/98	5/98	6/98	7/98	8/98	3
	9/96	10/96	11/96	12/96	1/97	2/97	3/97	4/97	5/97	6/97	7/97	8/97	2
	9/95	10/95	11/95	12/95	1/96	2/96	3/96	4/96	5/96	6/96	7/96	8/96	1

	13	14	15	16	17	18	19	20	21	22	23	24	
BEDS 7-12	9/00	10/00	11/00	12/00	1/01	2/01	3/01	4/01	5/01	6/01	7/01	8/01	3
	9/99	10/99	11/99	12/99	1/00	2/00	3/00	4/00	5/00	6/00	7/00	8/00	2
	9/98	10/98	11/98	12/98	1/99	2/99	3/99	4/99	5/99	6/99	7/99	8/99	1

Once all 12 beds have been filled, the beds used in the grains and perennials method follow a cycle that is described below.

The Different Stages of the Beds After the First Six Years Where Ascaris *Is Not Present*

Each of the sets of 6 beds in this method of using grains and perennials to recycle human manure where *Ascaris* is not present will pass through 3 stages:

- *Stage I* lasts for 3 years when the set of 6 beds is receiving fresh human manure.
- *Stage II* occurs during the fourth year when the 6 beds have been filled with manure and are planted with perennials, but the perennials are too young to harvest.[201]

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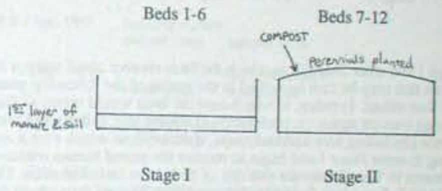
[201] Alfalfa (a perennial) takes about 7 months to grow from seed to harvestable plant (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 82-83). In most temperate climates, there will not be enough warm days to harvest the broadcasted alfalfa (or most other perennials) after it has grown for 7 months and before it should be allowed to die back in the winter. So the first harvest will probably be in the spring of the following year.

Figure 11 (cont.)

- *Stage III* begins in the fifth year, when the 6 beds of perennials are harvested and receive an annual application of cured soilless compost. After 2 years, the perennials in the set of 6 beds are removed.
- At the beginning of the seventh year of the cycle, the 6 beds can either be redug and return to *Stage I* of the cycle, or preferably removed from the cycle, in which case a new set of 6 beds would need to be dug to receive the manure that is being produced, and would enter the first stage of the cycle. This cycle, as it occurs from Year 7 to Year 10, is shown below.

Year 7

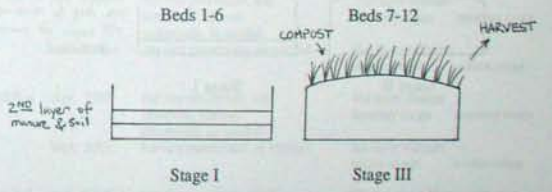
The perennials in *Beds 1-6* are removed, and *Beds 1-6* (either another set of 6 beds or the original first set of 6 beds) will be dug and receive their first layer of human manure, soil, seeds, and more soil, growing annuals throughout the year. *Beds 7-12*, the second set of 6 beds, will receive cured soilless compost and will be planted in perennials in the spring of this year. They will probably be first harvested in the spring of the following year.


Beds 1-6 Beds 7-12

Stage I Stage II

Year 8

Beds 1-6 will receive a second layer of manure, soil, seeds and soil and grow annuals throughout the year. *Beds 7-12* move from *Stage II* to *Stage III* as the perennials they have been growing are harvested throughout the growing season. *Beds 7-12* receive an annual application of cured soilless compost.

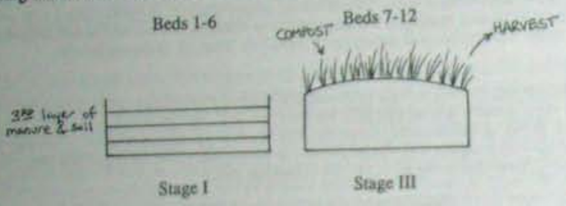

Beds 1-6 Beds 7-12

Stage I Stage III

Figure 11 (cont.)

Year 9

Beds 1-6 will receive their third and final layer of manure, soil, seeds and soil, and grow annuals throughout the year. *Beds 7-12* continue to grow perennials that are harvested throughout the growing season and receive an annual application of cured soilless compost.



Year 10

Beds 1-6 leave *Stage I* and enter *Stage II*, in which the beds receive cured soilless compost and begin to grow perennials that may be first harvested in the spring of the following year. *Beds 7-12* will be harvested and then either: 1) redug, in which case the beds would return to *Stage I* and begin to receive stored human manure again; or, preferably, 2) double-dug and planted with food, income and/or compost crops (including root and leaf crops, if desired), in which case a new set of 6 beds would need to be dug to enter *Stage I* and begin to receive the stored human manure. This is identical to the situation present in Year 7 only the two sets of beds have switched roles. The cycle will proceed similarly to Years 7, 8 and 9 as the method continues to be used throughout the years.

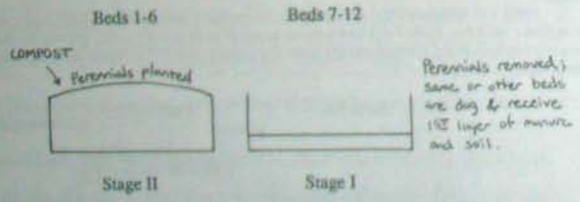


Figure 12

Timeline for Grains and Perennials Method Where *Ascaris* Is Not Present Assuming You Have Two Growing Seasons -- One 5-Month Season during the Summer and One 7-Month Season during the Winter

- Sept. 1995 - Start collecting your manure

	Beds 1-6		Beds 7-12	
	Sections 1-7	Sections 8-12	Sections 13-19	Sections 20-24
YEAR 1 - Apr. 1996	1st layer manure summer crops			
- Sept. 1996	winter crops	1st layer manure winter crops		
YEAR 2 - Apr. 1997	2nd layer manure summer crops	summer crops		
- Sept. 1997	winter crops	2nd layer manure winter crops		
YEAR 3 - Apr. 1998	3rd layer manure summer crops	summer crops		
- Sept. 1998	winter crops	3rd layer manure winter crops		
YEAR 4 - Apr. 1999	fill in beds, add compost, sow perennials		1st layer manure summer crops	
- Sept. 1999			winter crops	1st layer manure winter crops
YEAR 5 - Apr. 2000	harvest perennials, add compost, harvest perennials, as needed		2nd layer manure summer crops	summer crops
- Sept. 2000	harvest perennials, as needed		2nd layer manure winter crops	winter crops
YEAR 6 - Apr. 2001	harvest perennials, add compost, harvest perennials, as needed		3rd layer manure summer crops	summer crops
- Sept. 2001	harvest perennials, as needed		3rd layer manure winter crops	winter crops
YEAR 7 - Apr. 2002	remove perennials and grow food crops or redig to		fill in beds, add compost, sow perennials	
- Sept. 2002	receive manure (repeat YEAR 1)			
YEAR 8 - Apr. 2003	Repeat YEAR 2		harvest perennials, add compost, harvest perennials, as needed	
- Sept. 2003	harvest perennials, as needed		harvest perennials, as needed	

Figure 12 (cont.)

	Beds 1-6		Beds 7-12	
	Sections 1-7	Sections 8-12	Sections 13-19	Sections 20-24
YEAR 9 - Apr. 2004	Repeat YEAR 3		harvest perennials, add compost,	
			harvest perennials, as needed	
- Sept. 2004			harvest perennials, as needed	
YEAR 10 - Apr. 2005 - Sept. 2005	Repeat YEAR 4		remove perennials and grow food crops or redig to receive manure (repeat YEAR 4)	

Figure 13

The First 13 Years and Beyond Using the Grains and Perennials Method in a Climate with Two Growing Seasons Where *Ascaris* Is Present in the Community

The procedure for filling these beds is identical to that shown in Figure 11, except that 18 beds, instead of 12 beds, are dug out and receive manure, soil, seeds and more soil as shown in the length-wise cross section of the beds below. After the second set of beds is dug and filled with 3 layers of manure, soil, seeds and more soil, a third set of 6 beds (*Sections* 25-36) must be dug, filled and planted with perennials before the first set can be safely redug or, preferably, planted in a crop whose edible portion contacts the soil. Therefore, at the beginning of Year 7, harvest the second set of 6 beds of grain and sow perennials in those beds. Then, during Year 7, dig out the third and last set of 6 beds. During Years 7, 8 and 9, fill them exactly as you filled the first set in Years 1, 2 and 3. Then, in Year 10, the first set of beds can be redug, or a new set can be dug, and the cycle continued.

SECTIONS

	1	2	3	4	5	6	7	8	9	10	11	12
BEDS 1-6	9/97	10/97	11/97	12/97	1/98	2/98	3/98	4/98	5/98	6/98	7/98	8/98
	9/96	10/96	11/96	12/96	1/97	2/97	3/97	4/97	5/97	6/97	7/97	8/97
	9/95	10/95	11/95	12/95	1/96	2/96	3/96	4/96	5/96	6/96	7/96	8/96

	13	14	15	16	17	18	19	20	21	22	23	24
BEDS 7-12	9/00	10/00	11/00	12/00	1/01	2/01	3/01	4/01	5/01	6/01	7/01	8/01
	9/99	10/99	11/99	12/99	1/00	2/00	3/00	4/00	5/00	6/00	7/00	8/00
	9/98	10/98	11/98	12/98	1/99	2/99	3/99	4/99	5/99	6/99	7/99	8/99

	25	26	27	28	29	30	31	32	33	34	35	36
BEDS 13-18	9/03	10/03	11/03	12/03	1/04	2/04	3/04	4/04	5/04	6/04	7/04	8/04
	9/02	10/02	11/02	12/02	1/03	2/03	3/03	4/03	5/03	6/03	7/03	8/03
	9/01	10/01	11/01	12/01	1/02	2/02	3/02	4/02	5/02	6/02	7/02	8/02

Seven years will have passed between the time the last manure added to *Section* 1 was produced (which happened in 9 / 97, the first month of the third year) and when all 18 beds are filled (upon the addition of manure from 8 / 04) and sections must be dug to receive stored manure. In 9 / 04 or later, *Section* 1 can be safely redug to receive the manure collected, or used to grow edible crops (including root and leaf crops), in which case a new bed would need to be dug to receive the manure you have stored.

Once all 18 beds have been filled, the beds used in the grains and perennials method follow a cycle that is described below.

Figure 13 (cont.)

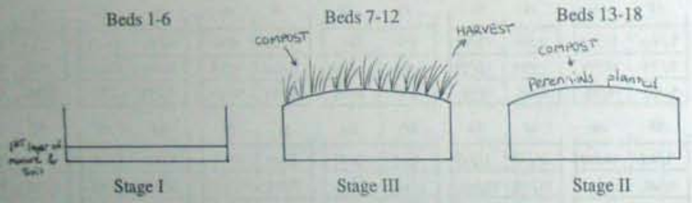
The Different Stages of the Beds After Ten Years Where Ascaris *Is Present*

Each of the sets of 6 beds in this method of using grains and perennials to recycle human manure where *Ascaris* is present will pass through 3 stages:

- *Stage I* lasts for 3 years when the set of 6 beds is receiving fresh human manure.
- *Stage II* occurs during the fourth year when the 6 beds have been filled with manure and are planted with perennials, but the perennials are too young to harvest.
- *Stage III* begins in the fifth year, when the 6 beds of perennials are harvested and receive an annual application of cured soilless compost. After 5 years (instead of 2 years, as is the case when *Ascaris* is not present), the perennials in the set of 6 beds are removed.
- At the beginning of the tenth year of the cycle, the 6 beds can either be redug and return to *Stage I* of the cycle, or preferably removed from the cycle, in which case a new set of 6 beds would need to be dug to receive the manure that is being produced, and would enter *Stage I* of the cycle. This cycle, as it occurs from Year 10 to Year 13, is shown below.

Year 10

The perennials in *Beds 1-6* are removed, and *Beds 1-6* (either another set of 6 beds or the original first set of 6 beds) are dug and receive their first layer of human manure, soil, seeds, and more soil. They will grow annuals throughout the year. *Beds 7-12* have been growing perennials that are harvested throughout the growing season, and they receive an annual application of cured soilless compost. *Beds 13-18* will receive cured soilless compost and will be planted in perennials in the spring of this year. The perennials in *Beds 13-18* will probably be first harvested in the spring of the following year.



Year 11

Beds 1-6 will receive a second layer of manure, soil, seeds and soil and grow annuals throughout the year. *Beds 7-12* and *Beds 13-18*, the older and newer beds of perennials respectively, will be harvested and receive cured soilless compost.

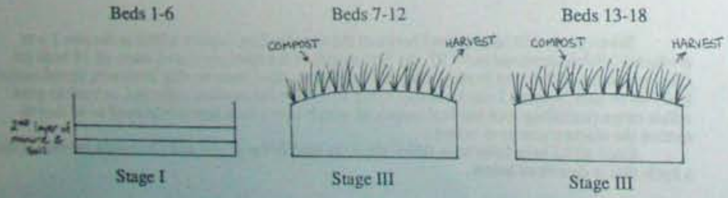
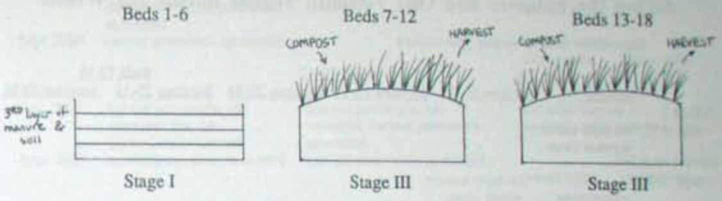


Figure 13 (cont.)

Year 12

Beds 1-6 will receive their third and final layer of manure, soil, seeds and more soil, and will grow annuals throughout the year. Again, *Beds 7-12* and *Beds 13-18* will be harvested and receive cured soilless compost.



Year 13

Beds 1-6 leave *Stage I* and enter *Stage II*, in which the beds receive cured soilless compost and begin to grow perennials that may be first harvested in the spring of the following year. *Beds 7-12*, the 6 older beds of perennials, will be harvested and then either: 1) redug, in which case the beds would return to *Stage I* and begin to receive stored human manure again; or, preferably, 2) double-dug and planted with food, income and/or compost crops (including root and leaf crops, if desired), in which case a new set of 6 beds would need to be dug to enter *Stage I* and begin to receive the stored human manure. *Beds 13-18* continue to be harvested and receive cured soilless compost once a year. Notice that this is identical to the situation present in Year 10, only the three sets of beds have switched roles. The cycle will proceed similarly to Years 10, 11 and 12 as the method continues to be used throughout the years.

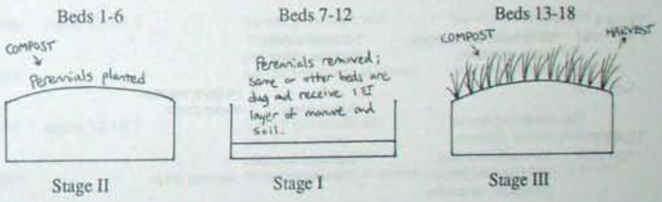


Figure 14

Timeline for Grains and Perennials Method Where *Ascaris* Is Present Assuming You Have Two Growing Seasons -- One 5-Month Season during the Summer and One 7-Month Season during the Winter

Sept. 1995 - Start collecting your manure

	Beds 1-6		Beds 7-12		Beds 13-18	
	Sections 1-7	Sections 8-12	Sections 13-19	Sections 20-24	Sections 25-31	Sections 32-36
YEAR 1 - Apr. 1996	1st layer manure summer crops					
- Sept. 1996	winter crops	1st layer manure winter crops				
YEAR 2 - Apr. 1997	2nd layer manure summer crops	summer crops				
- Sept. 1997	winter crops	2nd layer manure winter crops				
YEAR 3 - Apr. 1998	3rd layer manure summer crops	summer crops				
- Sept. 1998	winter crops	3rd layer manure winter crops				
YEAR 4 - Apr. 1999	fill in beds, add compost, sow perennials		1st layer manure summer crops			
- Sept. 1999			winter crops	1st layer manure winter crops		
YEAR 5 - Apr. 2000	harvest perennials, add compost, harvest perennials, as needed		2nd layer manure summer crops	summer crops		
- Sept. 2000	harvest perennials, as needed		winter crops	2nd layer manure winter crops		
YEAR 6 - Apr. 2001	harvest perennials, add compost, harvest perennials, as needed		3rd layer manure summer crops	summer crops		
- Sept. 2001	harvest perennials, as needed		winter crops	3rd layer manure winter crops		

Figure 14 (cont.)

	Beds 1-6		Beds 7-12		Beds 13-18	
	Sections 1-7	Sections 8-12	Sections 13-19	Sections 20-24	Sections 25-31	Sections 32-36
YEAR 7 - Apr. 2002	harvest perennials, add compost, harvest perennials as needed		fill in beds, add compost, sow perennials		1st layer manure summer crops	
- Sept. 2002	harvest perennials, as needed				1st layer manure winter crops	winter crops
YEAR 8 - Apr. 2003	harvest perennials, add compost, harvest perennials, as needed		harvest perennials, add compost, harvest perennials as needed		2nd layer manure summer crops	summer crops
- Sept. 2003	harvest perennials, as needed		harvest perennials, as needed		winter crops	2nd layer manure winter crops
YEAR 9 - Apr. 2004	harvest perennials, add compost, harvest perennials, as needed		harvest perennials, add compost, harvest perennials, as needed		3rd layer manure summer crops	summer crops
- Sept. 2004	harvest perennials, as needed		harvest perennials, as needed		winter crops	3rd layer manure winter crops
YEAR 10 - Apr. 2005	remove perennials and grow food crops or repeat YEAR 1		harvest perennials, add compost, harvest perennials as needed		fill in beds, add compost, sow perennials	
- Sept. 2005			harvest perennials, as needed			
YEAR 11 - Apr. 2006	repeat YEAR 2		harvest perennials, add compost, harvest perennials, as needed		harvest perennials, add compost, harvest perennials, as needed	
- Sept. 2006			harvest perennials, as needed		harvest perennials, as needed	
YEAR 12 - Apr. 2007	repeat YEAR 3		harvest perennials, add compost, harvest perennials, as needed		harvest perennials, add compost, harvest perennials, as needed	
- Sept. 2007			harvest perennials, as needed		harvest perennials, as needed	
YEAR 13 - Apr. 2008	repeat YEAR 4		remove perennials and grow food crops or repeat YEAR 4		harvest perennials, add compost, harvest perennials, as needed	
- Sept. 2008					harvest perennials, as neeeded	

Is Goal #1 Achieved?

Goal #1, purification of the manure, is achieved as it is in the method that uses trees to recycle human manure: the pathogens are killed over time when they are no longer able to withstand the rigors of living outside a human body. Since the method is usable by an individual and the manure need not enter a sewage system, the manure will be free of harmful levels of heavy metals and chemical toxins.

Is Goal #2 Achieved?

The beds growing perennials are given an annual application of cured soilless compost. The beds that are receiving manure will receive some humus produced from the decomposition of the manure and the roots of the crops they grew. If practiced for many years or decades, adding no more humus than the amount generated from the manure and roots probably will not be enough humus to maintain the soil's supply. However, this amount of humus is estimated to be sufficient during the three years that the beds are receiving human manure as long as enough cured compost to achieve *Goal #2, sufficient humus production*, is added to the soil in subsequent years. This is another reason for rotating the beds that receive human manure.

To estimate the amount of cured *soilless* compost this method will generate for itself, we will choose alfalfa to grow as our perennial crop and corn (during the summer) and wheat (during the winter) to grow in the 6 beds receiving human manure. If *Ascaris* is not a threat in our community, the 6 beds receiving manure and the 6 beds growing perennials will produce enough cured *soilless* compost so that each of the 6 beds of alfalfa receives 4 cubic feet, and there would still be 13.1 cubic feet remaining (see Appendix B: Detailed Calculation #17). If *Ascaris* is a threat, the 6 beds receiving manure and the 12 beds growing perennials will produce enough cured *soilless* compost to apply 4 cubic feet (equivalent to 8 cubic feet of cured compost that is 50% soil by volume) to all 12 beds of alfalfa, with a surplus of 11.9 cubic feet of cured *soilless* compost that could be applied to other perennials in your garden or farm (see Appendix B: Detailed Calculation #18).

It is possible to produce ample cured compost with this method to achieve Goal #2, at mid-range Biointensive yields. In addition, if the 6 beds receiving human manure are growing corn (flour corn) in the summer and wheat in the winter, each year they may also provide more than 25% of the calories needed by one person for all year[202] so long as no edible portion touches the ground during harvesting.

Is Goal #3 Achieved?

Since the minerals in the manure probably came from more beds than the 6 that are currently receiving human manure, it is probably best to distribute the cured compost produced from decomposing the plants grown in the manure-enriched beds to all of the beds growing food crops. This can be easily accomplished by creating separate compost piles with the residues from the manure-enriched beds and equally distributing the cured compost produced to all food-producing beds. (Because the compost will be added to soil that is producing annuals, soil should be added when constructing the compost piles to return some of the soil removed in the double-digging process.) Like the method that uses trees, this is a form of secondary recycling whereby the nutrients in the manure can be returned, in the form of cured compost, to the soil from which they came. You will then minimize the possibility of concentrating the nutrients in the manure in a few beds, and minimize the risk of a toxic build-up of minerals the manure may contain in excess.

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[202] Calculated from field produced data presented by John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 78-81, based on a 5-month warm growing season for corn.

The Advantages and Disadvantages of Growing Perennials

The advantage of growing perennials is that, since they do not need to be replanted each year, they minimize the risk of contacting pathogens in soil which has received human manure, while still providing material for your compost pile. Suitable perennials are ones that will live for at least 7 years in your climate under any water restrictions you may have. Preferably, they should produce a lot of carbonaceous material for your compost pile. One possibility is alfalfa, since it is a long-lived perennial and there are varieties that are fairly tolerant of drought and cold and produce a large amount of somewhat carbonaceous plant material. Birdsfoot trefoil and medium red clover, like alfalfa, are also legumes and may be good choices, though they are often shorter-lived and do not produce as much biomass and carbon as alfalfa. The advantage to planting legumes is that they have nodules attached to their roots which store nitrogen that has been taken from the air by bacteria and converted into a form that plants can use. When their roots grow old and die, the nodules slough off and add nitrogen, as well as humus, to the soil. "Fixing" or converting atmospheric nitrogen into a form that plants can use brings nitrogen into the soil in a way that is sustainable. Nitrogen from the soil can escape into the air and can only be returned from the air into the soil, where it is so essential, by the action of nitrogen-fixing bacteria (see pages 22-23). Still, non-leguminous perennials like Kentucky Bluegrass, bromegrass and others can be important since they are drought-tolerant and cold-hardy and produce a substantial amount of compost material, including root matter. To help you select which perennials to use, ask your local agricultural agent and/or local farmers which perennials thrive in your area.

The disadvantage of growing perennials is that they are generally not "area efficient"[203] -- they often do not provide you with many calories of human food per square foot of planted area.

An Alternative to Perennials

If you prefer to continue growing crops that produce both food and compost materials, such as annual grains instead of perennials, once the beds are filled, all of the non-edible plant residues that remain after harvest should be composted.[204] Since grain crop residues (straw) are rich in carbon, to create a compost pile with an initial carbon-to-nitrogen ratio of approximately 30 to 1, fresh green plant material should be added to the dry material in the ratio of 1 part dry to 1.25 parts green *by volume*.[205] (This green plant material could be generated by interplanting the grain-producing beds with fava beans appropriate to the season and/or vetch, or from an additional bed producing chard, radishes or other prolific green crop.) If amaranth is grown in the summer and oats (interplanted with fava beans and vetch) in the winter (instead of perennials) in all beds used to recycle human manure, enough cured soilless compost can be generated in the 12-bed system so that each bed will receive about 3.5 cubic feet of cured soilless compost (equivalent in terms of nitrogen and humus to 7.0 cubic feet of cured compost that is 50% soil by volume).[206] Amaranth and interplanted oats, favas and vetch in the 18-bed system will produce 3.6 cubic feet of cured soilless compost (equivalent in terms of nitrogen and humus to 7.1 cubic feet of cured compost that is 50% soil by volume) for each bed.[207] Therefore, *Goal #2, the production of sufficient humus,*

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[203] David Duhon, *One Circle* (Willits, CA: Ecology Action, 1985), pp. 21-22.

[204] Trees could also be grown, though they have the disadvantage that the area cannot receive human manure until the tree is removed or dies. This means that you would constantly need to search for new areas to receive your manure, unless you used a system such as the one described on pages 74-82.

[205] Based on preliminary investigations by the author and Ecology Action.

[206] See Appendix B: Detailed Calculation #19 for the derivation of the amount of cured compost produced.

[207] See Appendix B: Detailed Calculation #20 for the derivation of the amount of cured compost produced.

is still achieved. In addition, the 12 or 18 beds of oats and amaranth can provide 35% or 53% respectively of the calories one person needs on the average annually.[208]

Be sure not to grow only one type of grain on these beds year after year, but to grow a *rotation* of different crops. Grains such as amaranth, corn, millet, barley, oats and rye should be emphasized since they produce a lot of carbon for the compost pile, but other crops whose edible portion is well above the soil and can be propagated by broadcasting seed, such as pole beans and peas and flowers, could be grown in smaller amounts as well. If only one type of grain is grown year after year, over time the minerals that that crop needs most will be extracted from the soil, which may imbalance the soil and impair its health. By rotating a *diverse variety* of crops throughout the years, you can prevent the extraction of certain minerals in the soil that one crop may especially need, as well as provide a more diverse diet for the soil organisms and create a more stable farm and garden ecosystem. Stability and security always and only come from diversity.

The Enjoyment of Discovery

Any crop which provides plenty of carbonaceous compost material and whose edible portion is well above the soil is suitable and worth trying in this system of recycling human manure. You will then discover which crops grow best in manure-rich soil and which best enrich the soil with their roots and the compost created from their stalks. You can also choose to use some of the straw to build a house, with the latest straw-bale construction technology that is growing in popularity. Also, you can discover which crops provide the most calories from a given area. There are many opportunities to learn from which will expand your understanding of how best to recycle human manure.

Possible Modifications

In the method as described above, humus is produced from the composted residues of the crops grown in human manure-enriched soil. Similar to the modifications described in "Trees," two possible modifications to this method of recycling human manure are:

1) *The excavated beds are treated as sunken compost sites.* In this case, enough carbonaceous material would be added to the manure when it is dumped into each section so that the total carbon-to-nitrogen ratio is 30 to 1. A layer of soil would then be added to help the manure and carbonaceous material to decompose, and to exclude animals. Since less available nitrogen is present in the surrounding soil as the manure and carbonaceous material decompose, as described in the section on using trees to recycle human manure (see pages 74-82), it is possible that plants will not grow on the manure and carbonaceous material until both are adequately decomposed.[209] The disadvantage is that the soil will be bare and subject to wind erosion, compaction due to rainfall, and drying due to the sun. One advantage may be that more carbonaceous material would be present to feed more microorganisms which would in turn consume and hold more of the nitrogen in the manure in their bodies, and more humus may be generated.

However, if too much undecomposed carbonaceous material is added to soil, denitrification could take place and cause a loss of nitrogen from the manure and soil (see page 37). A second advantage is that the excavated beds which contain human manure and carbonaceous material may

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[208] Of the approximately 876,000 calories a person needs each year, the amaranth and wheat produced at mid-range Biointensive yields on 12 or 18, 100-square-foot beds can provide an average of 307,163 or 466,661 calories respectively each year. See Appendix B: Detailed Calculations #19 and #20. From data in John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], pp. 78-81.

[209] See page 75. It is possible that legumes such as alfalfa, peas, beans, clover and vetch could grow where soil nitrogen is less available since they have access to nitrogen fixed from the air by bacteria associated with their roots, as described in the following paragraph in the text.

be able to be worked and planted in crops whose edible portions may contact the soil sooner than the 3.5 years where *Ascaris* is not common or 7 years where *Ascaris* is common as stated above if the decomposing manure and straw heat up enough to kill the pathogens contained in the manure. The temperature and the duration that temperature could be sustained would not likely meet the temperature and duration requirements described in "Composting Human Manure". The extent to which *Goal #1, purification of the manure*, is met before 3.5 or 7 years has passed could only be determined by sending a sample of the manure-enriched soil to a laboratory that is able to test for the presence of human pathogens. However, through precise experimentation in various locations, we can gain enough experience to establish the requirements that must be met for purification of manure when it is processed as described above.

2) *The excavated beds are treated as part compost site, part growing bed.* This modification may generate the most humus, since carbonaceous plant material is both added to the soil with the human manure *and* produced above ground. The carbonaceous material added to the manure can generate humus as in the first modification to this method, and the carbonaceous material grown in the manure-enriched soil can be composted and converted into humus (as is the result when the method is used without modification). However, the only way of growing plants on soil that contains raw carbonaceous material as well as human manure is to add only enough carbonaceous material to the manure so that the overall carbon-to-nitrogen ratio of the carbonaceous material and manure is less than 30 to 1, and conservatively, it is probably best if the ratio is closer to 10 to 1, the carbon-to-nitrogen ratio of most soils (see page 75).[210] Soil without raw carbonaceous material does not generally inhibit crop growth. By creating an overall carbon-to-nitrogen ratio equal to the carbon-to-nitrogen ratio of soils which does not inhibit plant growth, there may be enough nitrogen that is not being used to decompose the carbonaceous material that could be used for plant growth. The additional, though minimal, carbonaceous material buried with the manure will help trap the manure's nitrogen and generate more humus for the soil. Also, creating a low carbon-to-nitrogen ratio in the soil will minimize the risk of denitrification that is substantial when the first modification to this method is used. Good candidates for growing in this undecomposed carbon-rich environment are plants in the Legume family, which associate with bacteria that can transform nitrogen in the air into a form that is usable by the plants. This allow legumes to be less dependent on the availability of soil nitrogen for their growth and health. The disadvantage to legumes is that they generally contain little carbon (with the possible exception of alfalfa). A workable compromise may be to grow a legume the first season, and carbonaceous crops the following seasons. Again, we discover another opportunity to learn more about recycling human waste and sustaining the fertility of the soil most efficiently.

While the original method and the two modifications can all achieve Goal #1, currently, it is difficult to determine which will best conserve the nitrogen, carbon and other nutrients in the manure and produce the most humus. Again, further research and experimentation are necessary in order to better understand the benefits and deficiencies of each method.

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[210] Helmut Kohnke, *Soil Science Simplified*, 3rd ed. (Prospect Heights, IL: Waveland Press, 1966), p. 20.

"When one is willing and eager, the gods join in."
- Aeschylus

Chapter 5

Two Examples of Systems to Grow All Our Food and Recycle All Our Waste

Example #1

Urine and manure are composted (separately).

In this example, 24 beds are needed. These beds are used to grow all of the calories one person needs for all year. During the winter, all 24 beds grow wheat, but 3 are harvested before grain is produced and are planted with potatoes. In the late spring and summer, the wheat and potatoes are harvested; 10 beds are planted with corn, 5 with millet and 8 with quinoa. In addition, there will be 1 bed of miscellaneous vegetables for extra vitamins, minerals and variety in the diet.[211] The total amount of straw produced by the millet, quinoa and wheat is more than enough to compost all of the urine and manure produced by one person each year, as seen in Table 4 on page 111.

Assumptions

1) Crops can be grown annually during one 4-month growing season in the summer and one 8-month growing season in the winter.
2) Mid-range Biointensive yields are obtained.[212]
3) Straw production of millet is approximately equal to that of wheat. Straw production of quinoa is approximately 3/4 that of wheat.
4) The composition of quinoa straw, in terms of carbon and nitrogen, is equivalent to wheat. (The composition of most straw from grain crops is similar.)
5) The compost generated from the manure and urine is added to all 24 garden beds after it has aged sufficiently.

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[211] "100 square feet can yield over 300 pounds of vegetables and soft fruit in a 4- to 6-month growing season. The average person in the United States consumes about 322 pounds of vegetables and soft fruits annually." (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], p. 7.)
[212] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 70-82, Column E, second figure.

System Requirements

1) All urine and manure produced during the year are processed to achieve the four goals of recycling human waste.
2) About 943 pounds of straw must be produced in order to compost one person's annual urine and manure by the methods outlined in this book. (The exact amount of straw needed to create a human urine- or manure-enriched compost pile will depend on the crop and the percentages of carbon and nitrogen in its straw.)
3) At least 876,000 calories must be produced to feed one person for all year.

Table 4

Food Produced for the Soil and One Person in Example #1

Season	Crop	No. of Beds	Lbs. of Straw Produced (Harvest Weight)	Lbs. of Carbon Produced[213]	Lbs. of Nitrogen Produced[214]	Calories Produced	Calories Produced/ Sq. Ft.[215]
Winter	Wheat, Hard Red Spring	21	630	296.6	3.61	314,370	150
	Potatoes, Irish	3	0	0	0	167,400	558
	Total:	24					
Summer	Corn, Flour	10	535	253.7	4.56	268,430	268
	Millet, Proso	5	150	70.9	0.82	44,490	89
	Quinoa	8	180	84.7	1.03	102,400	128
	Misc. Vegetables	1	0	0	0	10,000	100
	TOTAL:	24	1,495			907,090	

Analysis

Straw and Calorie Production

Twenty-four beds used as described above could provide all of the straw (960 pounds not including the corn stalks) needed to recycle one person's urine and manure and all of the calories that person needs for all year.

The corn stalks are not optimal carbonaceous material with which to compost human waste: they are too thick to readily absorb urine and they take a long time to break down. By being somewhat resistant to decomposition, their carbon may not be readily available enough for the microorganisms to use and trap the nitrogen. Corn stalks are ideal at the bottom of a compost pile that does not contain human waste because they increase the pile's aeration and drainage. They can

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[213] Pounds of carbon = Pounds of crop (100% dry weight) x % Carbon / 100. See Table 9 for the data for individual crops.
[214] Pounds of nitrogen = Pounds of crop (100% dry weight) x % Nitrogen / 100. See Table 9 for the data for individual crops.
[215] The higher the number, the greater the area efficiency -- more calories can be grown in a given area. See David Duhon, *One Circle* (Willits, CA: Ecology Action, 1985), pp. 21-22.

also be composted separately as will be done in this example, but smashing them with a sledge hammer or other heavy object encourages them to decompose more efficiently.

Percentage of Area in Compost, Food and Income Crops

94.4% compost crops, 5.6% food crops, 0% income crops. (See Appendix B: Detailed Calculation #22 for the derivation of these figures.) This differs from the guideline for sustainability of 70% compost crops, 20% food crops and 10% income crops because the goal in creating the example was to minimize the number of beds needed. More beds could be added in order to include some income beds (10% or less).

Cured Compost Production

Enough cured compost that is 50% soil by volume is produced by this system to achieve *Goal #2* for **15.9 to 44.7 beds, or all of the beds in the system** depending on the application rate of cured compost (see Appendix B: Detailed Calculation #21).

Achievement of Goals #1, #3 and #4 of Recycling Human Waste

If the temperature and duration requirements are met, or the cured compost is sufficiently mature, *Goal #1, purification of the manure*, will be achieved. By applying the cured compost generated to all of the food-raising beds, *Goal #3, return of the nutrients*, is achieved. Since the application rate of cured compost is less than 8 cubic feet per 100 square feet, *Goal #4, proper application of nitrogen*, is also achieved.

Example #2

Urine is composted. Manure is recycled through the use of grains and perennials.

In this example, 35 beds are needed. 18 of these beds are used to recycle the manure generated by one person each year, as described in the section "Grains and Perennials", of which 12 are used to grow alfalfa (the selected perennial for this example) after the beds are filled with manure, and 6 are used to grow wheat in the winter and quinoa in the summer to provide both straw for compost and food for people. The urine is composted. The 17 beds not receiving human manure are used to grow crops for food and compost material. Therefore, 23 beds in total are used to grow crops for food and compost material, and 12 beds are used to grow alfalfa for compost material only, for a total of 35 beds.

As shown in Table 5 on page 114, in the winter, all 23 food-growing beds grow wheat, 6 of which are the excavated beds that have received stored human manure and are shown in bold in Table 5. 3.2 of the 17 beds that have not received human manure are harvested before grain is produced and planted with potatoes. In the spring and summer, the wheat and potatoes are harvested; 10 beds are planted with corn, 5 with millet, 6 with quinoa (in the manure-enriched sections, shown in bold in Table 5), 1 with dry beans, and 1 with miscellaneous vegetables. The total amount of straw produced by the millet, quinoa and wheat is more than enough straw to compost all of the urine produced by one person each year, as seen in Table 5.

Assumptions

1) Crops can be grown during one 4-month growing season and one 8-month growing season.
2) Mid-range Biointensive yields are obtained.[216]
3) Straw production of millet is approximately equal to that of wheat. Straw production of quinoa is approximately 3/4 that of wheat.
4) The composition of quinoa straw, in terms of carbon and nitrogen, is equivalent to wheat. (The composition of most straw from grain crops is similar.)
5) *Ascaris* worms are common in the community. Therefore, 18 beds will be needed to recycle the manure one person generates each year.

System Requirements

1) All urine and manure produced during the year are processed to achieve the four goals of recycling human waste.
2) Enough straw (about 733 pounds if it is wheat straw; this will vary slightly if it is straw from another crop) must be produced in order to compost one person's annual urine and increase the initial carbon-to-nitrogen ratio to approximately 30 to 1. No straw is required to process the manure by the method using grains and perennials on pages 83-108. (This would not be the case if the manure were composted or processed using one of the two modifications to the method of using grains and perennials as described on pages 108-109.)
3) At least 876,000 calories must be produced to feed one person for all year.

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[216] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), pp. 70-82, Column E, second figure.

Table 5

Food Produced for the Soil and One Person in Example #2

Season	Crop	No. of beds	Lbs. of Straw Produced (Harvest Weight)	Lbs. of Carbon Produced[217]	Lbs. of Nitrogen Produced[218]	Calories Produced	Calories Produced/ Sq. Ft.[219]
Winter	Wheat, Hard Red Spring	**6**	180	84.7	1.03	**89,820**	150
	Wheat, Hard Red Spring	13.8	414	194.9	2.37	206,586	150
	Potatoes, Irish	3.2	0	0	0	178,560	558
	Subtotal:	23					
Summer	Corn, Flour	10	535	253.7	4.56	268,430	268
	Millet, Proso	5	150	70.9	0.82	44,490	89
	Quinoa	6[220]	116	54.6	0.67	66,136	128
	Beans	1	0	0	0	15,830	158
	Misc. Vegetables	1	0	0	0	10,000	100
	Subtotal:	23					
All Year:	Alfalfa	12		392.9	20.55		
	TOTAL:	35	1,395	1,051.7	30.0	879,852	

Note: Crops in bold are grown on the 6 beds currently receiving human manure, as described in "Grains and Perennials" in Chapter 4. If the crops are harvested so that the edible portion does not contact the soil which contains human manure, the grains can be consumed. If you prefer not to consume the grains from these 6 beds, but to compost them instead, you will need to grow additional crops to have enough calories for yourself all year. Perhaps you will need 41 rather than 35 total beds. 40, 100-square-foot beds growing grains can be worked by one skilled person in much less than an *average* of 40 hours a week.[221]

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[217] Pounds of carbon = Pounds of crop (100% dry weight) x % Carbon / 100. See Table 9 for the data for individual crops.

[218] Pounds of nitrogen = Pounds of crop (100% dry weight) x % Nitrogen / 100. See Table 9 for the data for individual crops.

[219] The higher the number, the greater the area efficiency -- more calories can be grown in a given area. See David Duhon, *One Circle* (Willits, CA: Ecology Action, 1985), pp. 21-22.

[220] As described in the "Grains and Perennials" section, not all of the 6 beds receiving manure are planted in the spring of the first year. In the second and third years, all 6 beds are planted. Therefore, the data above (with the exception of "calories produced per sq. ft.") reflect the annual average yield of quinoa planted in the 6 human manure-enriched beds over this three-year period.

[221] Based on the research and experience of Ecology Action and other Biointensive mini-farmers.

Analysis

Straw and Calorie Production

Thirty-five beds used as described above could recycle one person's manure and provide all of the straw (860 pounds, not including the corn stalks for the reasons described in Example #1) needed to recycle that person's urine. All of the calories that person needs for all year can be produced in this example.

Percentage of Compost, Food and Income Crops

95% compost crops, 5% food crops, 0% income crops. This differs from the guideline for sustainability of 70% compost crops, 20% food crops and 10% income crops because Example #2, like Example #1, was created with the goal of minimizing the number of beds needed. See Appendix B: Detailed Calculation #24 for the derivation of these figures. More beds could be added in order to include some income beds (10% or less).

Cured Compost Production

Enough cured compost is produced by this system to achieve *Goal #2* for **24.8 to 64.2 beds**, or all 29 beds in the system that will receive cured compost annually (6 beds will receive only human waste, as described in the section, "Grains and Perennials"). See Appendix B: Detailed Calculation #23.

Achievement of Goals #1, #3 and #4 of Recycling Human Waste

As long as the urine and manure are processed and added to the beds as described in the "Composting Human Urine" and "Grains and Perennials" sections respectively, *Goal #1, purification of the waste*, is achieved. *Goal #3, return of the nutrients*, is achieved when the cured compost is applied to food-raising beds. Finally, *Goal #4, proper application of nitrogen*, is achieved when only the manure generated by one person in one month is added to each section, and no additional nitrogen, in the form of cured compost, is added.

Comparison of Examples #1 and #2

Example #1 requires fewer beds compared to Example #2.

Example #1 may require less labor than Example #2, since 18 beds need to be excavated to the depth of 1 foot over a period of three years when Example #2 is used, and no beds are excavated when Example #1 is used. Furthermore, since there are fewer beds needed in Example #1 compared to Example #2, there are fewer beds to prepare (double-dig), plant, water, weed and harvest . Still, the building, turning and storing of compost that needs to be done each year in Example #1 can provide good exercise, too.

Example #2 has a greater chance of achieving Goal #1 than does Example #1. Killing the pathogens in human manure with the grains and perennials method requires much less skill, attention and experience than it does when composting is utilized.

Both examples generate enough cured compost and humus to replenish the supply lost from each bed and achieve Goal #2. Note: Changing the crops grown in either example will change the amount of cured compost and calories produced.

Both examples achieve Goals #3 and #4 when the cured compost is added to the soil at an annual rate not greater than 8 cubic feet of cured compost that is 50% soil by volume (or the equivalent of soilless cured compost for the perennial beds in terms of humus and nitrogen).

Chapter 6

Our Challenge and Opportunity

The methods of recycling human urine and manure that have been described not only are probably *illegal* at this time in your area but also may be inappropriate for your living situation. The challenge is then yours: to develop an appropriate method to return your nutrient-rich waste to the soil that achieves the four goals of recycling human waste.

Before you begin to experiment with a method of recycling your urine or manure, discuss the method you plan to use with your local health authority. Prepare yourself thoroughly beforehand so that you are familiar with the current health codes and can describe how your method meets the code requirements and overcomes the dangers and difficulties of recycling human waste. In discussing your proposed method with your local health representative, you can receive good suggestions and support. Through these discussions, you may also become aware of weaknesses in your approach that you can correct. Because recycling human waste is normally illegal and can be dangerous, you will generally need to receive permission from the health department in order to begin testing your method. Due to the risks to public health involved, obtaining permission may be difficult. If you find this to be the case, you may want to discuss your idea, why you feel it is important, and the details of the method you propose to use, with your neighbors and friends in the community. They may have additional ideas for improving your method. After finding no fault in your proposal, some may even be willing to support your endeavor, which may help you obtain approval from your health department. Community support was essential for the establishment of Arcata's wetlands system. You will discover, as you go, what you need to do to turn your vision into reality.

Through the efforts of all of us, an appropriate way can be found so that each of us on the planet can return the nutrients in our urine and manure to the soil. We can all be a part of this learning process simply by choosing to do so, to begin understanding the dangers, working on creating ways to overcome them and *transforming our waste into wealth.* As we begin to improve and maintain the fertility of the soil with human waste, our knowledge and understanding of the process will grow. Ecology Action is interested in learning about your key ideas and experiences, so that together we can discover and share with others the safest and most efficient means to recycle the nutrients in human waste. We can then pass on to our children not only healthier soil but the knowledge we have gained on how to maintain the soil's health, as well as our own health and the health of the planet, in a way that is sustainable, and have fun in the process.

> *"'Pooh,' said Piglet, feeling quite happy again now, 'I will.' And then he said, 'How shall we do it?' and Pooh said, 'That's just it. How?' And then they sat down together to think it out.*
>
> *"Pooh's first idea was that they should dig a Very Deep Pit..."*
>
> - *A. A. Milne*, Winnie-the-Pooh

Select Bibliography

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2. R. G. Feachem, et al. *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review.*Washington, D.C.: World Bank, 1981.

3. Dr. Robert Parnes. *Fertile Soil.* Davis, CA: AgAccess, 1990. Excellent for understanding soils and the value that different methods of processing animal manures have on improving soil fertility.

4. Paul D. Sachs. *Edaphos.* Newbury, VT: The Edaphic Press, 1993. Excellent for understanding the soil ecosystem.

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Appendix A

Table 6

English and Metric Conversions and Formulas

Length
1 foot = 12 inches
1 inch = 2.54 centimeters

Area
1 acre = 43,560 square feet
1 acre = 0.4 hectare

Volume
1 gallon = 4 quarts
1 quart = 2 pints
1 quart = 0.95 liters
5 gallons = approx. 0.67 cubic foot
1 cubic yard = 27 cubic feet
8 cubic feet of cured compost spread over 100 square feet = a layer 1-inch deep
1 inch of rainfall = 0.62 gallons of water per square foot
1, 3-wire bale of straw = 1.5 feet by 2 feet by 4 feet[222] = 12 cubic feet
3.6 lbs. of carbonaceous material = approximately 1 cubic foot in a built compost pile[223]
8.5 lbs. of nitrogenous material = approximately 1 cubic foot in a built compost pile[223]
Dry vegetation in a *built* compost pile shrinks by a factor of approximately 6.57 after it has fully cured.[224]
Freshly harvested green vegetation or kitchen scraps in a *built* compost pile shrinks by a factor of approximately 8.5 after it has fully cured.[224]

Weight
1 gallon of water = approximately 8 pounds
1 ton = 2000 pounds
1 pound = 0.454 kilogram

Density
1, 3-wire bale of straw = 70 to 95 pounds[225] (average = 83 pounds)
1 cubic foot of baled straw = 6 to 10 pounds[226]
1 cubic foot of loose straw = 3.5 to 4.5 pounds[227]
1 quart of urine = 2.2 pounds[228]

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[222] Richard Freudenberger, "A Straw-Bale Revolution," *BackHome*, Fall 1993, p. 30.
[223] Based on experimental data from compost piles built at Ecology Action's Common Ground Mini-Farm in Willits, CA.
[224] John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7.
[225] Richard Freudenberger, "A Straw-Bale Revolution," *BackHome*, Fall 1993, p. 30.
[226] University of Wisconsin, Special Bulletin #4.
[227] University of Wisconsin, Special Bulletin #4.
[228] L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973), p. 14.

1 gallon of fresh human manure = 11 pounds[229]

Temperature
5/9 x (°F - 32) = °C

Miscellaneous
1 milligram / liter (mg / l) = 64 x milliequivalent / liter (meq / l)[230]
1 mg / l = 1 part per million (ppm)
1 mg / l = 640 x electrical conductivity (EC) in millimhos / centimeter (mmhos / cm)[231]
% Carbon (C) = (100 - % mineral matter) / 1.8
Carbon contained in material harvested *dry* =
(Harvest weight) x (% Dry matter [Dry] / 100) x (% C / 100)
Carbon contained in material harvested *green* =
(Harvest weight) x (% Dry matter [Green] / 100) x (% C / 100)
Nitrogen contained in material harvested *dry* =
(Harvest weight) x (% Dry matter [Dry] / 100) x (% N / 100)
Nitrogen contained in material harvested *green* = (Harvest Weight) x (% N / 100)
% moisture of human manure[232] = 70 - 85%
% moisture of human urine[233] = 93 - 96%

Formula to Convert Dry Weight of Compost Material to an Approximate Volume of Cured Compost Produced

1) *Initial* volume (in cubic feet) of *carbonaceous* compost material = Dry weight of carbonaceous material (lbs.) / (3.6 lbs./ ft^3)
2) *Initial* volume (in cubic feet) of *nitrogenous* compost material = Dry weight of nitrogenous material (lbs.) / (8.5 lbs. / ft^3)
3) *Total* volume (in cubic feet) of ***built soilless*** compost = Volume of *built soilless* carbonaceous material (1) + Volume of *built soilless* nitrogenous material (2)
4) Volume (in cubic feet) of *cured soilless carbonaceous* material = Initial volume of carbonaceous material (1) / 6.57
5) Volume (in cubic feet) of *cured soilless nitrogenous* material = Initial volume of nitrogenous material (2) / 8.5
6) *Total* volume (in cubic feet) of ***cured soilless*** compost = Volume of *cured soilless* carbonaceous material (4) + Volume of *cured soilless* nitrogenous material (5)
7) *Total* volume (in cubic feet) of *cured* compost *that is 50% soil by volume* = Total volume of *cured soilless* compost (6) / (1 - 0.50)

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[229] Sim Van der Ryn, *The Toilet Papers* (Santa Barbara, CA: Capra Press, 1978), p. 68.
[230] A good explanation of meq as a unit of measurement can be found in Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), pp. 154-155.
[231] Mho (equal to 1000 millimhos) is the practical unit of conductance equal to the reciprocal of the ohm (mho is ohm spelled backward) (*Webster's New Collegiate Dictionary* [Springfield, MA: G. & C. Merriam Company, 1974]). Mmhos / cm is simply a measure of the electrical conductivity of a solution.
[232] R. G. Feachem, et al., *Appropriate Technology for Water Supply and Sanitation Vol. 3: Health Aspects of Excreta and Sullage Management -- A State of the Art Review*, (Washington, D.C.: World Bank, 1981), p. 10. Feachem's figure is an adaptation of Gotaas's figure of 66-80% and is based on more recent and extensive testing of manure from people all over the world living in a variety of situations.
[233] Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956), p. 35.

Formula to Estimate Weight of Cured Carbon and Nitrogen in the Cured Compost Generated from a Weight of Dry Material Whose Carbon Content Is Known

Weight of cured carbon in cured compost = weight of initial carbon x 0.50[234]

Weight of cured nitrogen in cured compost = weight of cured carbon / 15[235]

Table 7

Minimum Time Required to Purify Human Manure in Various Environments and under Various Conditions

Environment	Conditions	Time
Under water	Hookworm present	1.5 years
	Hookworm not present	1 year
Compost pile	Center of the pile's temperature is 140° to 158° F (60° to 70°C) for 3 consecutive days before and after the pile is turned	1 year
	Above condition not met, *Ascaris* present	7 years
	Above condition not met, *Ascaris* not present	2 years
Compost toilet	*Ascaris* present	7 years
	Ascaris not present	2 years
Solar oven		1 sunny day
Buried in soil	*Ascaris* present	7 years
	Ascaris not present	3.5 years

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[234] See John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7.

[235] The carbon-to-nitrogen ratio of the organic fraction of cured compost is reported to be between 10 and 20 to 1.
10 to 1: Helmut Kohnke, *Soil Science Simplified*, 3rd ed. (Prospect Heights, IL: Waveland Press, Inc., 1966), p. 39.
15 to 20 to 1: Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), p. 113.
17 to 20 to 1: Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 53.

After compost with an initial carbon-to-nitrogen ratio of 30 to 1 has matured, it has lost approximately half of the carbon (by weight) that it initially contained (John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* [Willits, CA: Ecology Action, 1981], p. 7). *If none of its nitrogen is lost*, then the mature compost will have a carbon-to-nitrogen ratio of 15 to 1. Therefore, cured compost is estimated to have a carbon-to-nitrogen ratio of 15 to 1 throughout this publication. Earlier Ecology Action publications have estimated the carbon-to-nitrogen ratio of cured compost to be 10 to 1, based on earlier data.

Table 8

Nitrogen (N) Content and Carbon-to-Nitrogen (C/N) Ratios of Some Compostable Materials on Dry Weight Basis[236]

	%N	C/N
Human manure	5-7	5-10
Human urine	15-19	0.6-1.1
Cow manure	1.7	18
Rotted sawdust	0.25	208
Raw sawdust	0.11	511

Table 9

Approximate Nitrogen (N), Carbon (C) and Dry Matter Content of Compostable Materials[237]

Crops Harvested *Dry*	%C (Dry)	%C (Green)	%N (Dry)	%N (Green)	% Dry Matter (Dry)	% Dry Matter (Green)
Wheat straw	50.9	-----	0.62	-----	92.5	-----
Rye straw	53.6	-----	0.56	-----	92.8	-----
Corn stalks	52.3	54.8	0.94	0.21	90.6	22.7
Barley straw	52.2	-----	0.59	-----	90.0	22.2
Sunflower	52.1	54.6	0.93	0.22	90.6	-----
Millet Straw	52.5	-----	0.61	-----	90.0	-----
Crops Harvested *Green*						
Fava Beans	50.8	54.6	1.38	0.56	87.9	17.4
Vetch, Common	52.1	54.4	2.13	0.61	89.0	20.4
Alfalfa	50.9	54.3	2.45	0.70	90.5	26.3
Red Clover	52.1	54.4	2.00	0.66	90.5	27.5
Comfrey	45.6	54.3	3.53	0.54	90.5	11.0

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[236] All of the data in this table was taken from Harold B. Gotaas, *Composting: Sanitary Disposal & Reclamation of Organic Wastes, World Health Organization Monograph Series No. 31* (Geneva, Switzerland: World Health Organization, 1956), p. 44.

[237] Table based on data from Frank B. Morrison, *Feeds & Feeding*, 21st ed. (Ithaca, NY: Morrison Publishing Co., 1949), pp. 1086-1109, with the exception of data on comfrey, from Robert G. Robinson, *Comfrey -- A Controversial Crop* (1983 Minnesota Report, Item No. AD-MR-2210, Agricultural Experiment Station, University of Minnesota).

Appendix B

Detailed Calculations

Detailed Calculation #1

Volume of Cured Compost That Contains 0.5 Pound of Nitrogen

From pages 17, 26 and 38

Human Urine-Enriched Cured Compost

Approximation: When urine is added to a bucket of straw and soil, the volume of the contents remains the same.

Material	Harvest Weight (Lbs.)	Initial Carbon (Lbs.)	Cured Carbon (Lbs.)	Initial Volume (Ft^3)	Cured Volume (Ft^3)
Wheat straw	733	345	172.5	203.6	31
Urine	----	6	3	-----	0.8[238]
TOTAL			175.5		31.8

Total Cured Nitrogen = Total Cured Carbon / 15
= 175.5 / 15
= 11.7 lbs.

Volume of cured compost (that is 50% soil by volume) that contains 0.5 lb of cured nitrogen = [(0.5 / 11.7) x 31.8] / (1 - 0.50) = **2.7 ft^3**

Human Manure-Enriched Cured Compost

Material	Harvest Weight (Lbs.)	Initial Carbon (Lbs.)	Cured Carbon (Lbs.)	Initial Volume (Ft^3)	Cured Volume (Ft^3)
Wheat straw	210	98.9	49.45	58.3	8.9
Manure	200 (wet)	21	10.50	2.7	0.8[239]
TOTAL			59.95		9.7

Total Cured Nitrogen = Total Cured Carbon / 15
= 59.95 / 15
= 4.0 lbs.

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[238] Estimated based on the assumption that the moisture level of human urine is the same by weight and by volume. The original moisture level of 94.5% was converted to 20% (typical of cured compost that is stored or ready to be applied): 12.2 ft^3 (equivalent to 91 gallons) x (1 - 0.94.5) / (1 - 0.20) = 0.8 ft^3.

[239] Estimated based on the assumption that the moisture level of human manure is the same by weight and by volume. The original moisture level of 77% was converted to 20% (typical of cured compost that is stored or ready to be applied): 2.7 ft^{3}x (1 - 0.77) / (1 - 0.20) = 0.8 ft^3.

Volume of cured compost (that is 50% soil by volume) that contains 0.5 lb of cured nitrogen = [(0.5 / 4.0) x 9.7] / (1 - 0.50) = **2.4 ft^3**

Cured Compost Not Containing Human Waste

Similar analyses of several compost piles that do not contain human waste show that the amount of cured compost (that is 50% soil by volume, with an initial carbon-to-nitrogen of 30 to 1) that contains 0.5 lb of cured nitrogen = **3.3 ft^3.**

Throughout this book, it is assumed that all of the nitrogen originally in the urine and manure is retained in the final human waste-enriched cured compost. In fact, the loss of nitrogen can be anywhere from approximately 0% to 100%.[240] Table 10 below shows the volume of cured compost needed to be applied to a garden bed to add 0.5 lb. of cured nitrogen, depending on the original ingredients of the compost and the percentage of original nitrogen that is retained in the cured compost.

Table 10

Theoretical Volume (ft^3) of Cured Compost (that is 50% soil by volume) That Contains 0.5 lb Cured Nitrogen When 100%, 85%, 41% and 15% of the Original Nitrogen is Retained

	100%	**85%**	**41%**[241]	**15%**
Human urine-enriched cured compost	2.7	3.2	6.6	18
Human manure-enriched cured compost	2.4	2.8	5.9	16
Non-human waste cured compost	3.3	3.9	8.0	22

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[240] See footnotes #76 and #152.

[241] A loss of 41% of the original nitrogen creates cured compost that contains 0.5 lb of cured nitrogen (generally the maximum amount that should be applied per 100 square feet of soil) in 8 cubic feet of cured compost (the historically successful application rate per 100 square feet of soil).

Detailed Calculation #2

Percentages of a Farm Used to Grow Crops for Compost, Food and Income

From page 15

For a farm to be sustainable, 70% of the *"Bed-Crop-Months"* needs to be devoted to growing crops for compost. Bed-crop-months (BCM) is a concept used to guide the planning of a sustainable mini-farm. The number of bed-crop-months is determined by multiplying the number of 100-square-foot beds a crop occupies by the number of months the crop is in the ground. A perennial crop in a single bed accounts for 12 BCM since it occupies that bed for the entire year. Most food and income crops are grown only part of the year, during the main growing season, and some crops can be planted 2 or more times during that season. Below are sample calculations of BCM for various crops:

Alfalfa:	1 crop in 1 bed for 12 months	= 12 bed-crop-months (BCM)
Corn:	1 crop in 1 bed for 4 months	= 4 BCM
	1 crop in 2 beds for 4 months	= 8 BCM
	1 crop in 1/2 bed for 4 months	= 2 BCM
Lettuce:	1 crop in 1 bed for 3 months followed by a second crop in the same bed for 3 months	= 6 BCM

To calculate the percentages of the farm devoted to the production of compost, food and income, first classify each crop you are planning on growing, or already are growing, as either a producer of carbonaceous compost material, a producer of food for the farmers, or a producer of income. Although some crops are producers of compost material and food, and perhaps income as well, it is important to include each crop in only *one* of the above groups. If the crop produces carbonaceous material for the compost pile, and the carbonaceous material is not sold, it is a "*compost crop*"; it may also produce food, in the form of grain, but for our purposes here, it should be considered a compost crop. If the crop does not produce much carbonaceous compost material and is eaten by those on the farm, the crop is a "*food crop*". If the crop does not produce much carbonaceous compost material and is sold, it is an "*income crop*".

Next, calculate the BCM for all of the crops in each group and add up each group's BCM. Then, divide the total BCM of each group by the total BCM of the farm and multiply each result by 100. The final figures represent the percentages of BCM devoted to the production of compost material, food and income on the farm, which, for a farm to be sustainable, should be about 70%, 20% and 10% (*or less*) for compost, food and income respectively. Remember: *the fewer crops that are marketed, the easier it is to maintain and improve the fertility of your mini-farm's soil.*

Because it can sometimes be difficult and confusing to determine whether some crops are compost, food or income crops when, in fact, they fall under two or all of these categories, a simple rule of thumb to ensure sufficient compost material and food are produced by the farm itself is: 2/3 of all of the compost crops grown on the farm should also produce high-calorie food (such as grains) and 2/3 of all of the food crops grown on the farm should produce high-carbon compost material.

Detailed Calculation #3

Straw Needed to Create a Compost Pile of Human Urine, Soil and Straw with an Initial Carbon-to-Nitrogen Ratio of 30 to 1

From page 27

Dry[242] human urine is 17% nitrogen and has a carbon-to-nitrogen ratio of 0.8 (see Table 8 in Appendix A).

The amount of dry urine produced / person / year = (1 quart / day) x (2.2 lbs. / quart) x 5.5% [amount of solids by weight in wet urine] x 365 days / year
= 44 lbs.

The amount of **nitrogen** in 44 lbs. dry urine = 44 lbs. x 0.17 = **7.5 lbs.**

The amount of **carbon** in 44 lbs. dry urine = 7.5 lbs. x 0.8 = **6 lbs.**

We will let "S" represent the total pounds of harvested wheat straw needed to combine with the urine to create a carbon-to-nitrogen ratio of 30 to 1, which is what we are trying to determine. (Wheat straw is 50.9% carbon and 0.62% nitrogen by dry weight. See Table 9 in Appendix A.)

The amount of **nitrogen** in "S" lbs. of wheat straw =
% moisture of harvested straw x % nitrogen of wheat straw x S =
0.925 x 0.0062 x S =
0.00574 x S

The amount of **carbon** in "S" lbs. of wheat straw = **% moisture of harvested straw x**
% carbon of wheat straw x S =
0.925 x 0.509 x S =
0.4708 x S

Total C in Straw and Urine / Total N in Straw and Urine = 30
[(0.4708 x S) + 6] / [(.00574 x S) + 7.5] = 30
(0.4708 x S) + 6 = 0.172 x S + 225
0.2988 x S = 219
S = 733

Therefore, 733 lbs. (harvest weight, 92.5% dry matter) of wheat straw added to the urine one person produces annually will create a compost pile (which also includes soil) with a carbon-to-nitrogen ratio of about 30 to 1.

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[242] The nitrogen content of any compost material (including human urine and manure) that is "harvested" and added fresh to a compost pile changes when that material is dried. Nitrogen is lost to the air. Therefore, the most accurate estimate of the nitrogen content of such material is determined by analyzing a sample of the material while it is still "wet." This data is available and has been used in this publication to determine the nitrogen content of compost material that is harvested green. Unfortunately, data is not currently available on "wet" human urine and manure, only on urine and manure that has been dried. Depending on the percentage of nitrogen that was lost in the drying process, there may be more nitrogen in the wet human waste than is indicated in this publication.

Detailed Calculation #4

*Amount of **Built** Compost Generated from the Method Used to Compost Human Urine*

From page 27

Volume of the straw
3.6 pounds of straw, or any thoroughly dry material, occupies approximately 1 ft^3 in a newly built compost pile.[243]
733 lbs. of wheat straw x (1 ft^3 / 3.6 lbs.) = **203.6 ft^3**

Volume of the soil
1/4, 5-gallon bucket / day x 365 x (0.67 ft^3 / 5-gallon bucket) = 61.1 ft^3 of soil + 10, 5-gallon buckets of soil to cap all 10 (see below) urine-enriched compost piles (6.7 ft^3) = **67.8 ft^3**

Volume of the straw and soil = 203.6 ft^3 + 67.8 ft^3 = 271.4 ft^3 of built compost or approximately **10, 3-foot-by-3-foot-by-3-foot compost piles.**

*Percentage of soil in **built** piles* = 67.8 ft^3 / 271.4 ft^3 = 25%[244]

Detailed Calculation #5

*Amount of **Cured** Compost Generated from Urine-Enriched Built Compost*

From page 28

Volume of straw once it is cured =
203.6 ft^3 of dry straw initially (see Detailed Calculation #4) / 6.57[245] = **31 ft^3**
Volume of soil remains the same throughout the composting process[246] = **67.8 ft^3**
Total volume of cured compost generated = 31 ft^3 + 67.8 ft^3 = **98.8 ft^3**
Percentage of soil in cured piles = 67.8 ft^3 / 98.8 ft^3 = **68.6%**

Cured compost that is 68.6% soil by volume contains approximately only (1 - 0.686) / (1 - 0.50) or 62.8% of the nitrogen and humus compared to an equal volume of cured compost that is 50% soil by volume. Therefore, in order to apply the equivalent, in terms of organic matter, humus and minerals, of 2.7 ft^3 (see Detailed Calculation #1) to 8 ft^3 of cured compost (that is 50% soil by volume) per 100 sq. ft., (2.7 / 0.628 to 8 / 0.628) 4.3 to 12.7 ft^3 of cured compost (that is 68.6% soil by volume) must be added per 100 sq. ft. Added

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[243] See Table 6 in Appendix A.

[244] This is approximately 2 times more than the amount of soil in mature compost generated from a compost pile built according to the recipe: 4 parts dry, carbonaceous material; 5 parts green, nitrogenous material; and 1 part soil by volume. (The recipe is an average based on many theoretical built compost piles calculated to have an initial carbon-to-nitrogen ratio of 30 to 1 using data shown in Table 9 and the conversion factors shown in Table 6.) Therefore, this recipe allows one to build a compost pile that does not contain human waste which has an initial carbon-to-nitrogen ratio of approximately 30 to 1.

[245] See Appendix A for this conversion factor.

[246] John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7.

at this rate, 98.8 ft^3 of cured compost that is 68.6% soil by volume is enough for (98.8 / 12.7 to 98.8 / 4.3) **7.8 to 23.0 beds.**[247]

Detailed Calculation #6

Estimated Danger of Increasing Soil Salinity, Decreasing Soil Permeability and Increasing Sodium and Chloride Ions in the Soil to Toxic Levels Due to the Application of Composted Urine to the Soil[248]

From pages 33-34

Assumptions

1) All of the urine produced by one person in one year will be composted.

2) 24 beds are needed to grow all the food and calories for one person for all year. This number is based on Example #1 (on pages 110-112 of this book) which assumes mid-range Biointensive yields. The urine-enriched cured compost that is generated is then applied equally to all 24 beds.

3) All of the nutrients that the urine originally contained exist in the cured urine-enriched compost. This will probably not occur fully for all of the minerals in the urine, but determining this is difficult since a major and minor mineral analysis of composted urine will vary with different carbonaceous materials used to compost the urine. However, assuming that all of the nutrients are retained allows the calculation to represent the worst possible effect that urine will have on the soil since all of its original salts are assumed to be contained in the cured compost that is applied. (It is likely that some of the salts originally in the urine will leach out of the compost pile during the decomposition process.)

4) After the cured compost is applied, each bed will receive about 10 gallons of water per day for every day of the year. In total, 24 x 10 x 365 = 87,600 gallons of water is added to the 24 beds during the year. This is approximately the amount that a bed needs after it is revitalized Biointensively. This amount will be more before the soil's organic matter level is increased and its structure improved. However, using the potential minimum amount of water needed per bed will allow us to overestimate, rather than underestimate, the risk of increasing soil salinity to a toxic level through the use of urine-enriched cured compost.

5) The irrigation water we have available is "ideal" in that it will not cause any problems in terms of soil salinity or permeability, or sodium or chloride ion toxicity over time. This does not mean that the irrigation water will not contain soluble salts, only that the quantity of salts it contains is optimal for long-term soil health.

6) When the beds containing urine-enriched cured compost are irrigated, the salts in the urine-containing cured compost contact and dissolve in the irrigation water. Therefore, the calculation of the adjusted Sodium Adsorption Ratio and the electrical conductivity of the soil solution (which will be used to predict the probability that using the urine-enriched cured compost will compromise the health of the soil over time) is based on the salt concentration of the blend of irrigation water and urine. Since one person produces about 91 gallons of urine each year, and each year the salts in the urine are combined with 87,600 gallons of water, the blend will be 91 gallons / 87,691 gallons = 0.1% urine (by volume) and 87,600 / 87,691 = 99.9% irrigation water (by volume).

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[247] This assumes that all of the nitrogen in the urine and straw is retained. 15% of the nitrogen may be lost from urine-containing compost piles built according to the method described on pages 27-33 and footnote #76, in which case only 6.6 to 21 beds may be fertilized in terms of the nitrogen and humus content of the cured compost.

More than the 15 beds that could be fertilized with human urine alone (applied at a rate equivalent to 0.5 lb of nitrogen per 100 square feet) can be fertilized when the urine is composted because the wheat straw that is composted with the urine adds the additional nitrogen necessary to fertilize the additional beds. Again these estimations assume that all of the nitrogen will be retained.

[248] Boron toxicity can also be a problem to the health of the soil. However, no data on the average amount of boron in urine was available at the time of writing.

Composition of "Ideal" Irrigation Water[249]

For the water not to increase the soil's salinity over time, it must have an electrical conductivity (EC) of less than 0.75 mmhos / cm.

For the water not to decrease the soil's permeability over time, it must have an electrical conductivity (EC) of greater than 0.5 and an adjusted Sodium Adsorption Ratio (adj. SAR) of less than 6.

For the water not to increase the amount of sodium in the soil to toxic levels over time, it must have an adj. SAR of less than 3.

For the water not to increase the amount of chloride ions in the soil to toxic levels over time, it must have a chloride concentration less than 4 milliequivalents / liter (meq / l).

Taking all of these guidelines into consideration, we will assume we have water with an electrical conductivity of 0.60 mmhos / cm, a chloride concentration of 3.00 meq / l and an adj. SAR of 1.85.

To achieve a calculated adj. SAR of 2.19 we will allow the water's concentration of sodium, calcium + magnesium and carbonate + bicarbonate to be as follows:

<u>Ideal Irrigation Water</u>
Sodium (Na) = 3.10 meq / l
Calcium + Magnesium (Ca + Mg) = 1.00 meq / l
Carbonate + Bicarbonate ($CO_3 + HCO_3$) = 0.40 meq / l

adj. SAR = [Na / $\sqrt{((Ca + Mg) / 2)}$][1+ (8.4 - pH_c)]
$pH_c = (pK_2' - pK_c') + p(Ca + Mg) + p(Alk)$
$(pK_2' - pK_c')$ is obtained from the table below, using the sum of Ca + Mg + Na in meq / l.
p(Ca + Mg) is obtained from the table below, using the sum of Ca + Mg in meq / l.
p(Alk) is obtained from the table below, using the sum of $CO_3 + HCO_3$ in meq / l.

Sum of Concentrations(meq / l)[250]	$(pK_2' - pK_c')$	p(Ca + Mg)	p(Alk)
0.40	2.0	3.7	**3.4**
1.00	2.1	**3.3**	3.0
4.00	**2.2**	2.7	2.4

$pH_c = (pK_2' - pK_c') + p(Ca + Mg) + p(Alk)$
$= (\mathbf{2.2} + \mathbf{3.3} + \mathbf{3.4})$
$= 8.9$

adj. SAR = [Na / $\sqrt{((Ca + Mg) / 2)}$][1+ (8.4 - pH_c)]
= [3.10 / $\sqrt{(1.00 / 2)}$][1+ (8.4 - 8.9)]
= **2.19**

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[249] Based on R. S. Ayers and D. W. Westcot, *Water Quality in Agriculture, Irrigation and Drainage Paper #29* (Rome: Food and Agriculture Organization of the United Nations, 1976), p. 7.

[250] For the complete data table, see R. S. Ayers and D. W. Westcot, *Water Quality in Agriculture, Irrigation and Drainage Paper #29* (Rome: Food and Agriculture Organization of the United Nations, 1976), p. 11.

Average Composition of Human Urine[251]

Element	mg / kg body weight / day	mg / quart from average (70 kg) person*	mg / liter**	meq / liter
Sodium (Na)	60	4,200	4,421	69.1
Calcium (Ca)	5.7	399	420	6.6
Magnesium (Mg)	1.35	94.5	99.5	1.6
Carbonate (CO_3)	2.7	189	199	3.1
Bicarbonate (HCO_3)	2.0	140	147	2.3
Chloride (Cl)	100	7,000	7,368	115

* mg / day = mg / quart since each person produces on average 1 quart of urine / day.
** mg / quart / 0.95 = mg / liter

Total Solids = 394 mg / kg body weight / day[252]
= 27,580 mg / quart from 70 kg person
= 29,032 mg / l
Electrical conductivity (EC) of urine = 29,032 / 640 = 45.4 mmhos / cm

Composition of Blend of Irrigation Water and Urine

Element(s)	*Urine*	*Water*	*Meq/l*
Na	(69.1 x 0.001) +	(3.10 x 0.999)	= 3.17 meq / l
Ca + Mg	(8.2 x 0.001) +	(1.00 x 0.999)	= 1.01 meq / l
$CO_3 + HCO_3$	(5.4 x 0.001) +	(0.40 x 0.999)	= 0.405 meq / l
Cl	(115 x 0.001) +	(3.00 x 0.999)	= 3.11 meq / l
EC =	(45.4 x 0.001) +	(0.60 x 0.999)	= 0.64 mmhos / cm

<u>Results</u>

1) *Salinity:* Since the EC of the blend is less than 0.75 mmhos / cm, the blend is not predicted to increase the soil's salinity over time.

2) *Permeability:* The adj. SAR of the blend is calculated below.
adj. SAR = [Na / $\sqrt{((Ca + Mg) / 2)}$][1+ (8.4 - pH_c)]
$pH_c = (pK_2' - pK_c') + p(Ca + Mg) + p(Alk)$
$(pK_2' - pK_c')$ is obtained from the table below, using the sum of Ca + Mg + Na in meq / l.
p(Ca + Mg) is obtained from the table below, using the sum of Ca + Mg in meq / l.
p(Alk) is obtained from the table below, using the sum of $CO_3 + HCO_3$ in meq / l.
Ca + Mg + Na = 3.17 + 1.01 = **4.18**
Ca + Mg = **1.01**
$CO_3 + HCO_3$ = **0.405**

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[251] Adapted from Philip L. Altman and Dorothy Dittmer, eds., *The Biology Data Book Vol. 3*, 2nd ed. (Bethesda, MD: American Societies for Experimental Biology, 1974), p. 1496.

[252] Philip L. Altman and Dorothy Dittmer, eds., *The Biology Data Book Vol. 3*, 2nd ed. (Bethesda, MD: American Societies for Experimental Biology, 1974), p. 1496.

Sum of Concentrations(meq / l)[253]	$(pK_2' - pK_c')$	$p(Ca + Mg)$	$p(Alk)$
0.40	2.0	3.7	**3.4**
1.00	2.1	**3.3**	3.0
4.00	**2.2**	2.7	2.4

$$\begin{aligned} pH_c &= (pK_2' - pK_c') + p(Ca + Mg) + p(Alk) \\ &= (2.2 + 3.3 + 3.4) \\ &= 8.9 \end{aligned}$$

$$\begin{aligned} \text{adj. SAR} &= [Na / \sqrt{((\underline{Ca + Mg}) / 2)}][1 + (8.4 - pH_c)] \\ &= [3.17 / \sqrt{(1.01 / 2)}][1 + (8.4 - 8.9)] \\ &= \mathbf{2.23} \end{aligned}$$

Since the EC of the blend is above 0.5 mmhos / cm and the adj. SAR of the blend in less than 6, the blend is not predicted to decrease the soil's permeability over time.

3) *Sodium toxicity:* Since the adj. SAR of the blend is below 3, the blend is not predicted to cause the soil to accumulate sodium ions to toxic levels over time.

4) *Chloride toxicity:* Since the concentration of chloride ions in the blend is less than 4 meq / l, the blend is not predicted to cause the soil to accumulate chloride ions to toxic levels over time.

Conclusion

On the basis of the above calculations, composted urine is not predicted to cause problems in terms of soil salinity, permeability and chloride toxicity when applied to 24 beds, each of which receives 10 gallons of "ideal" irrigation water each day (1,290 gallons per bed per 4-month growing season). *In fact, the quality of the irrigation water has a much greater impact on soil salinity, permeability and ion concentrations over time than does the annual application of all of the urine you produce and compost to 24 beds each year.* (In commercial chemical mechanized agriculture, approximately 80% of the salt build-up in the soil results from the irrigation water used.)

Therefore, if you gain the permission of your health authority and begin adding composted urine to your beds, use the above model to calculate the composted urine's impact on the number of beds to which it will be applied, depending on the amount of water with which each bed is irrigated. Problems with salinity, permeability and chloride toxicity could occur when the composted urine is applied to fewer beds (as well as problems caused by an excessive application of nitrogen) and/or when less water is applied to each bed. (At least 7.5 inches of water needs to be added to a growing area for each 4-month crop [487.5 gallons per 100 square feet of growing area] in order for salt accumulations to be sufficiently leached out.)

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[253] For the complete data table, see R. S. Ayers and D. W. Westcot, *Water Quality in Agriculture, Irrigation and Drainage Paper #29* (Rome: Food and Agriculture Organization of the United Nations, 1976), p. 11.

Detailed Calculation #7

Amount of Biogas Produced from Anaerobically Digesting the Urine and Manure Produced by One Person Each Day

From page 52

	Amount produced (wet) / day	% Dry Matter	Dry Matter produced / day
Human urine	1 quart (2.2 lbs.)	5.5	0.12 lb.
Human manure	0.55 lbs.	23.0	0.13 lb.
Both	2.75 lbs.	9.0[254]	0.25 lb.

Conventional sewage produces between 6 and 9 (average = 7.5) ft^3 of biogas per pound of dry matter.

Average amount of biogas from digesting one's daily output of waste = 7.5 x 0.25 = 1.88 ft^3

Maximum amount of biogas from digesting one's daily output of waste = 9 x 0.25 = 2.25 ft^3

The average American uses the equivalent in energy of 60 ft^3 of biogas every day.[255]

1.88 ft^3 is approximately 3.1% of that used by the average American.

2.25 ft^3 is approximately 3.8% of that used by the average American.

An average lighting fixture requires 2.5 ft^3 / mantle / hour; a 2- to 4-inch burner requires 8 to 16 ft^3 per hour.[256]

At best, 2.25 ft^3 would provide lighting for slightly less than 1 hour or heat from a 2- to 4-inch burner for 17 minutes each day, with no additional power for any other needs.

Detailed Calculation #8

Does the Algal Regenerative System Achieve Goal #2?

From pages 54-55

Feed	Lbs. of Food a 2-Year-Old Jersey Dairy Cow Requires / Day[257]	% Dry Matter[258]	% Mineral Matter[259]
corn silage	20	26.0	1.6
alfalfa hay	8	90.5	8.2

Area Needed to Biointensively Grow All of the Food the Cow Needs Annually

Corn silage (74% moisture) needed / year[260] = 20 lbs. / day x 365 days / year = 7,300 lbs. / year

Alfalfa hay (9.5% moisture) needed / year = 8 lbs. / day x 365 days / year = 2,920 lbs. / year

Corn silage (0% moisture) needed / year = 7,300 lbs. / year x 0.260 (% dry matter)
= 1,898 lbs. / year

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[254] This is a weighted average since the human waste produced per day is 80% urine and 20% manure by weight.

[255] L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973), p. 23.

[256] L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973), p. 23.

[257] Clarence H. Eckles, *Dairy Cattle & Milk Production*, 3rd ed. (New York: The Macmillan Co., 1939), p. 281.

[258] Frank B. Morrison, *Feeds & Feeding*, 21st ed. (New York: The Morrison Publishing Co., 1949), pp. 1086, 1110.

[259] Frank B. Morrison, *Feeds & Feeding*, 21st ed. (New York: The Morrison Publishing Co., 1949), pp. 1086, 1110.

[260] To produce silage for a cow, the harvested and wilted corn can be allowed to ferment in underground earth pits – a silo is unnecessary and impractical for producing silage for only one cow.

Area needed annually to grow corn silage at mid-range Biointensive yields =
1,898 lbs. / (51.8 lbs. / bed)[261] = **36.6 beds**
Area needed annually to grow alfalfa at mid-range Biointensive yields =
2,920 lbs. / (80 lbs. / bed)[262] = **36.5 beds**
Total area required to grow feed for one cow annually = 36.6 beds + 36.5 beds
= 73.1 beds
= **7,310 sq. ft.**[263]

Weight of Carbon in Feed

The total weight of carbon in the crops grown to feed the cow is determined by multiplying the *dry* weight of the crops by the percentage of carbon in the crops. The percentage of carbon in the crops can be derived from the percentage of mineral matter in the crops with the following formula:

% Carbon = (100 - % Mineral Matter) / 1.8

% mineral matter of corn silage = 1.6 %
% mineral matter of alfalfa hay = 8.2 %
% carbon in corn silage = [(100 - 1.6) / 1.8] = 54.67 %
% carbon in alfalfa hay = [(100 - 8.2) / 1.8] = 51 %
Carbon contained in 7,300 lbs. of corn silage = 7,300 x 0.26 x 0.5467 = **1,038 lbs.**
Carbon contained in 2,920 lbs. alfalfa hay = 2,920 lbs. x 0.905 x 0.51 = **1,348 lbs.**
Total carbon contained in corn silage and alfalfa hay = 1,038 lbs. + 1,348 lbs. = **2,386 lbs.**

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[261] "The proper time to cut corn [for silage] is when it shows the first signs of ripening. In a year of normal rainfall, this is when the husks first begin to turn yellow at the end of the ear, while the leaves are still green. The kernels should be dented and glazed." Corn harvested for silage yields approximately 8,929 pounds (dry weight) per acre, according to Clarence H. Eckles, *Dairy Cattle & Milk Production*, 3rd ed. (New York: The Macmillan Co., 1939), pp. 451-452. 8,929 pounds per acre is equivalent to 25.88 pounds per 100 square feet. (There are approximately 345, 100-square-foot beds, including paths, in 1 acre). In general, mid-range Biointensive yields are two times average conventional yields, so corn grown Biointensively for silage at mid-range Biointensive yields will produce about 51.8 pounds of dry corn matter per 100 square feet. This correlates with the mid-range Biointensive yield data of 48.5 pounds of dry corn plants with the ears removed (J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #15: One Basic Mexican Diet*, "Supplement" [Willits, CA: Ecology Action, 1988]) and 17 pounds of dry corn kernels (John Jeavons, *How To Grow More Vegetables* [Berkeley, CA: Ten Speed Press, 1991], p. 86.) for a total of 65.5 pounds of dry corn biomass produced per 100 square feet. This is higher than the estimate of 51.8 pounds per 100 square feet because corn plants harvested for corn silage are harvested early, and therefore will have less total biomass than fully mature corn plants.

It is assumed that this dry corn matter figure, when rehydrated to the moisture content of corn silage, represents the amount of corn silage that is generated, and that the corn does not lose a significant amount of carbon while fermenting to produce silage. This assumption may cause an overestimation of the amount of carbon available and cured compost generated from the sludge produced during the production of biogas from animal manure. If, in fact, there is a loss of corn biomass during the fermentation process involved in silage production, more beds of corn will be needed to produce sufficient silage, and there will be even *less* cured compost available for each corn-producing bed.

[262] Mid-range Biointensive yield for alfalfa (air-dry weight, presumed to be 90.5% dry matter) from John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82.

[263] Cross-checking this figure, 1/6 to 1/3 of an acre (7,260 to 14,520 square feet) is the approximate area needed to feed one dairy cow using data presented by John Jeavons, et al., *Backyard Homestead Mini-Farm & Garden Log Book* (Berkeley, CA: Ten Speed Press, 1983), p. 6; and John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 86.

Weight of Biogas Produced / Year

	Lbs. Dry Manure / Year	%N (Dry)	Carbon-to-Nitrogen Ratio	Lbs. of Carbon
Cow[264]	3,650	1.7	18	1,117

Dry cow manure produced / day = (3,650 lbs. / year) / (365 days / year) = 10 lbs.
(Approximate weight of wet cow manure produced / day = 50 lbs.)
Biogas produced / lb. of dry cow manure produced = 3.9 ft^3
Total biogas produced / day = 3.9 x 10 = 39 ft^3.
Total biogas produced / year = 39 x 365 = 14,235 ft^3.
Biogas weighs 0.04 lb. / ft^3.
Weight of biogas produced / year = 14,235 ft^3 x 0.04 lb. / ft^3 = 569 lbs.

Weight of Carbon in Biogas

Biogas is 60% methane (CH_4), 30% carbon dioxide (CO_2) and 0.1% carbon monoxide (CO) by weight. The total amount of carbon in the biogas is the amount of carbon in the methane plus the amount of carbon in the carbon dioxide plus the amount of carbon in the carbon monoxide.
Based on the atomic weights of the elements that make up the following molecules:
Methane is 75% carbon by weight.
Carbon dioxide is 27% carbon by weight.
Carbon monoxide is 43% carbon by weight.
The amount of carbon in the methane produced / year = 569 lbs. x .60 x .75 = 256 lbs.
The amount of carbon in the carbon dioxide produced / year= 569 lbs. x .30 x .27 = 46 lbs.
The amount of carbon in the carbon monoxide produced / year = 569 lbs. x 0.001 x .43 = 0.2 lb.
The total amount of carbon in the biogas produced / year, or the amount of carbon lost when the biogas is burned = 256 lbs. + 46 lbs. + 0.2 lbs. = approx. 302 lbs.

Weight of Carbon Remaining in Sludge from Anaerobically Decomposing the Cow's Manure

Since there was initially 1,117 lbs. of carbon in the manure, the amount of carbon remaining in the digester as sludge that could be composted = 1,117 lbs. - 302 lbs. = 815 lbs.
After aerobic decomposition, the cured sludge compost contains only 50% of the carbon originally contained in the material (see footnote #142).

The amount of carbon in the cured sludge compost = 815 lbs. x 50% = **408 lbs.**
The amount of carbon if the alfalfa and corn used for corn silage were composted rather than fed to a cow and turned into biogas = 2,386 lbs. x 50% = **1,193 lbs.**
This is almost 3 times more than the amount of carbon that remains in the composted sludge!

Cured Compost Equivalent of Remaining Carbon

There is approximately 2.5 lbs. of cured carbon in 1 ft^3 of cured compost that is 50% soil by volume.[265]
Therefore, 408 lbs. of cured compost is the equivalent of (408 lbs. x 1 ft^3 / 2.5 lbs.) **163 ft^3** of cured compost that is 50% soil by volume.

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[264] Data for composition of cow manure from L. John Fry, *Methane Digesters for Fuel, Gas and Fertilizers* (Santa Barbara, CA: L. John Fry, 1973). Only non-lignin carbon (carbon that is digestible in the biogas generator) was accounted for in determining the carbon-to-nitrogen ratio of cow manure.

[265] See Detailed Calculation #9.

Applied at a rate of 3.3[266] to 8 ft^3 per bed (100 square feet), 163 ft^3 of cured sludge compost can maintain the humus level of = (163 ft^3/ [8 ft^3/bed]) to (163 ft^3/ 3.3 ft^3/bed]) **= 20.4 to 49.4 beds.**

Since 73.1 beds need cured compost, [(73.1 beds - 49.4 beds) to (73.1 beds - 20.4 beds)] 23.7 to 52.7 beds will not receive any cured compost. Over time, these soils will lose both their humus and many of the essential minerals for healthy plant growth, and eventually become incapable of growing most crops. One way to remedy this shortage of cured compost is to grow wheat in the beds that produced the corn for the cow to generate more carbonaceous compost material.

Cured Compost Generated from Wheat Straw Grown in the Beds Which Grew Corn

Pounds of wheat straw at mid-range Biointensive yields generated by growing wheat in the beds which grew corn[267] = (30 lbs. / bed x 36.6 beds) = 1,098 lbs.

Volume of **built** compost generated from 1,098 lbs. of wheat straw = 1,098 lbs. / (3.6 lbs. / ft^3) = 305 ft^3

Volume of **cured** *soilless* compost generated from straw = 305 ft^3 / 6.57 = 46.4 ft^3

Volume of **cured** compost that is 50% soil by volume generated from straw = 46.4 ft^3 / (1 - 0.50) **= 92.8 ft^3**

Applied at a rate of 3.3 to 8 ft^3 per bed (100 square feet), 92.8 ft^3 of *cured* wheat straw compost can maintain the humus level of = (92.8 ft^3 / [8 ft^3/ bed]) to (92.8 ft^3 /[3.3 ft^3/ bed]) **= 11.6 to 28.1 beds.**

Total area of which *cured* compost from alfalfa and corn and additional wheat straw can maintain the humus level = (20.4 beds+ 11.6 beds) to (49.4 beds + 28.1 beds) **= 32 to 77.5 beds**

Since 73.1 beds are needed, if wheat is grown in the beds growing corn after the corn is harvested, ***enough cured compost can be generated*** *to maintain the humus level of all beds and achieve Goal #2. However, only about [(163 ft^3+ 92.8 ft^3) / 73.1 beds = 3.5] 3.5 ft^3* (compared to the minimum of 3.3 ft^3 necessary to achieve Goal #2 when using *cured* compost that is not enriched by *cured* human waste) *of* ***cured*** *compost that is 50% soil by volume can be added to each bed. This may be enough* ***cured*** *compost to maintain the soil's supply of humus unless the climate is especially hot and humid and the soil is well-aerated, in which case humus may be lost from the soil faster[268] than this rate can replenish. If so, the soil will become less healthy and less able to grow healthy crops until it loses its fertility altogether.*

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[266] While the sludge came from a digester to which human waste was added, most of the nitrogen in the waste will be lost since there is little or no humus or soil in the digester to capture it. Therefore, we will assume that the cured sludge contains the same concentration of nitrogen and humus as cured compost from compost that did not originally contain human waste. See Detailed Calculation #1.

[267] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82.

[268] In general, organic matter is produced and used up five times faster in the tropics than in most temperate climates. See John Jeavons and J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #11: Examining the Tropics: A Small Scale Approach to Sustainable Agriculture* (Willits, CA: Ecology Action, 1982).

Detailed Calculation #9

*Comparison of the Amount of **Cured** Compost Generated from the Production of Biogas from Manure from a Cow Fed Alfalfa and Corn with the Amount Generated from the Same Amount of Alfalfa and Corn Aerobic Compost*

From page 55

Cured Compost from Aerobically Decomposing Alfalfa and Corn

36.5 beds of alfalfa produce 2,920 lbs. of alfalfa (air-dry weight: 90.5% dry matter).

2,920 lbs. alfalfa (air dry) at 90.5% dry matter = 2,920 x 0.905 / 0.263 **= 10,048 lbs.** of alfalfa (wet harvest weight: 26.3% dry matter)

36.6 beds of corn produce **7,300 lbs.** of corn (wet harvest weight: 26.0% dry matter).

Total weight of harvested organic matter = 10,048 lbs. + 7,300 lbs. = 17,348 lbs.

Volume of *built* compost from fresh organic matter (wet weight) = 17,348 lbs. / (8.5 lbs./ft^3) = 2,041 f

Volume of *cured soilless* compost = Volume of *built* compost / 8.5[269] = 2,041 ft^3 / 8.5 = 240 ft^3

Volume of *cured* compost *that is 50% soil by volume* = 240 ft^3 / (1 - 0.50) = **480 ft^3**

Approximate amount of *cured* carbon in 480 ft^3 of *cured* compost that is 50% soil by volume = 2,386 lbs. x 0.50[270] = 1,193 lbs.

Cured carbon per ft^3 of *cured* compost that is 50% soil by volume = 1,193 lbs. / 480 ft^3 **= 2.5 lbs. / ft^3** (this figure is used in Detailed Calculation #8 above)

Applied at a rate of 3.3[271] to 8 ft^3 per bed (100 square feet), **the *cured* compost** (that is 50% soil by volume) **generated from the alfalfa and corn** can maintain the humus level of [(480 ft^3/ [8ft^3/bed]) to (480 ft^3 / [3.3 ft^3/bed])] **60 to 145 beds.**

Applied at a rate of 3.3 to 8 ft^3 per bed (100 square feet), **the *cured* compost** (that is 50% soil by volume) **from the sludge remaining after the production of biogas from the manure produced from a cow fed the same quantity of alfalfa and corn** can maintain the humus level of **20.4 to 49.4 beds** (see Detailed Calculation #8). This is only about **one-third** of the *cured* compost that can be generated if the plants are not fed to animals and transformed into biogas.

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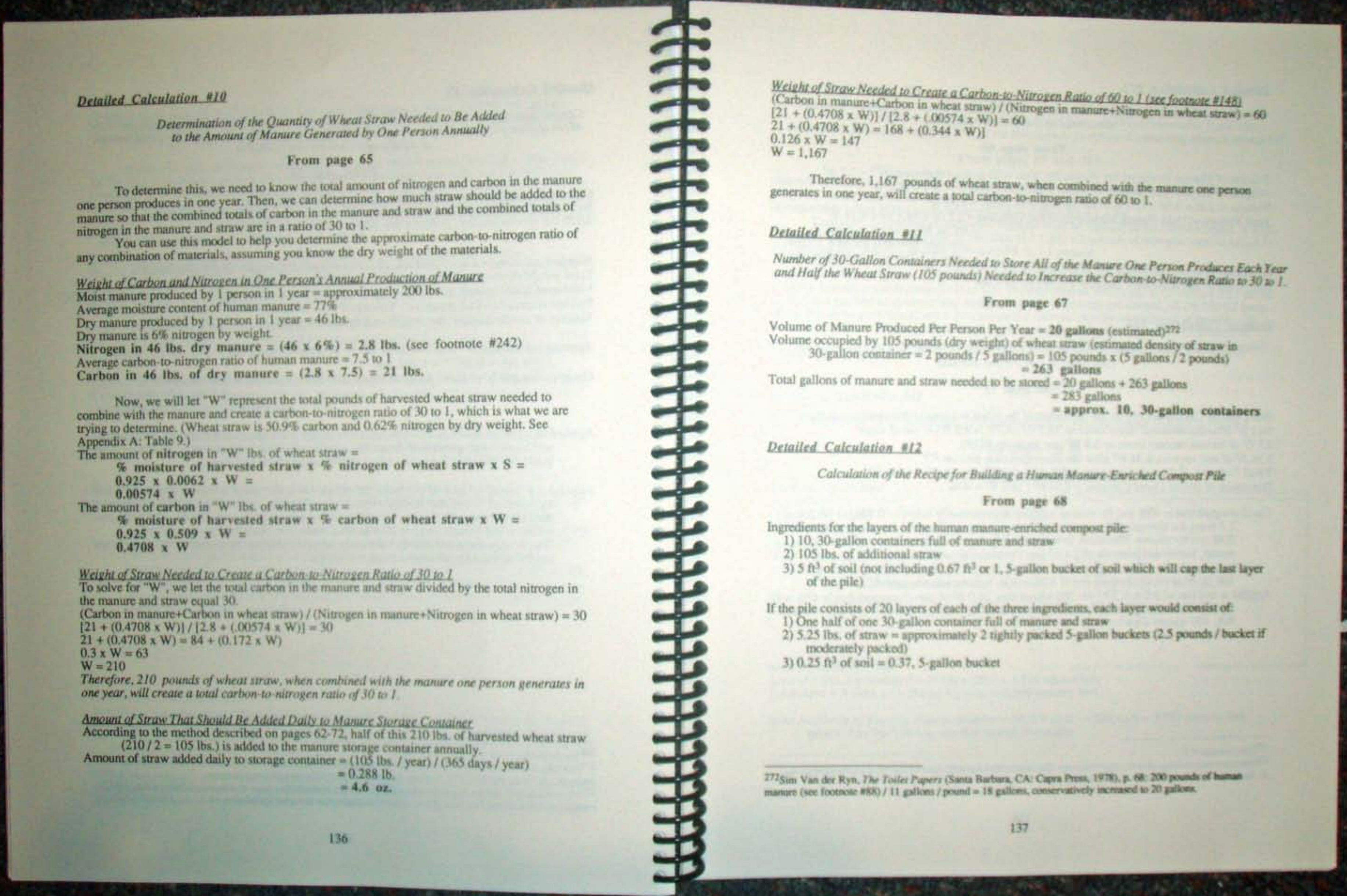
[269] See Appendix A for this conversion factor.

[270] See John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7 for this conversion factor.

[271] If a compost pile did not originally contain fresh human waste (either urine or manure), 3.3 ft^3 of the cured compost that is generated contains 0.5 lb of cured nitrogen. See Detailed Calculation #1.



Detailed Calculation #10

Determination of the Quantity of Wheat Straw Needed to Be Added to the Amount of Manure Generated by One Person Annually

From page 65

To determine this, we need to know the total amount of nitrogen and carbon in the manure one person produces in one year. Then, we can determine how much straw should be added to the manure so that the combined totals of carbon in the manure and straw and the combined totals of nitrogen in the manure and straw are in a ratio of 30 to 1.

You can use this model to help you determine the approximate carbon-to-nitrogen ratio of any combination of materials, assuming you know the dry weight of the materials.

Weight of Carbon and Nitrogen in One Person's Annual Production of Manure
Moist manure produced by 1 person in 1 year = approximately 200 lbs.
Average moisture content of human manure = 77%
Dry manure produced by 1 person in 1 year = 46 lbs.
Dry manure is 6% nitrogen by weight.
Nitrogen in 46 lbs. dry manure = (46 x 6%) = 2.8 lbs. (see footnote #242)
Average carbon-to-nitrogen ratio of human manure = 7.5 to 1
Carbon in 46 lbs. of dry manure = (2.8 x 7.5) = 21 lbs.

Now, we will let "W" represent the total pounds of harvested wheat straw needed to combine with the manure and create a carbon-to-nitrogen ratio of 30 to 1, which is what we are trying to determine. (Wheat straw is 50.9% carbon and 0.62% nitrogen by dry weight. See Appendix A: Table 9.)
The amount of **nitrogen** in "W" lbs. of wheat straw =
% moisture of harvested straw x % nitrogen of wheat straw x S =
0.925 x 0.0062 x W =
0.00574 x W
The amount of **carbon** in "W" lbs. of wheat straw =
% moisture of harvested straw x % carbon of wheat straw x W =
0.925 x 0.509 x W =
0.4708 x W

Weight of Straw Needed to Create a Carbon-to-Nitrogen Ratio of 30 to 1
To solve for "W", we let the total carbon in the manure and straw divided by the total nitrogen in the manure and straw equal 30.
(Carbon in manure+Carbon in wheat straw) / (Nitrogen in manure+Nitrogen in wheat straw) = 30
[21 + (0.4708 x W)] / [2.8 + (.00574 x W)] = 30
21 + (0.4708 x W) = 84 + (0.172 x W)
0.3 x W = 63
W = 210
Therefore, 210 pounds of wheat straw, when combined with the manure one person generates in one year, will create a total carbon-to-nitrogen ratio of 30 to 1.

Amount of Straw That Should Be Added Daily to Manure Storage Container
According to the method described on pages 62-72, half of this 210 lbs. of harvested wheat straw (210 / 2 = 105 lbs.) is added to the manure storage container annually.
Amount of straw added daily to storage container = (105 lbs. / year) / (365 days / year)
= 0.288 lb.
= 4.6 oz.

Weight of Straw Needed to Create a Carbon-to-Nitrogen Ratio of 60 to 1 (see footnote #148)
(Carbon in manure+Carbon in wheat straw) / (Nitrogen in manure+Nitrogen in wheat straw) = 60
[21 + (0.4708 x W)] / [2.8 + (.00574 x W)] = 60
21 + (0.4708 x W) = 168 + (0.344 x W)]
0.126 x W = 147
W = 1,167

Therefore, 1,167 pounds of wheat straw, when combined with the manure one person generates in one year, will create a total carbon-to-nitrogen ratio of 60 to 1.

Detailed Calculation #11

Number of 30-Gallon Containers Needed to Store All of the Manure One Person Produces Each Year and Half the Wheat Straw (105 pounds) Needed to Increase the Carbon-to-Nitrogen Ratio to 30 to 1.

From page 67

Volume of Manure Produced Per Person Per Year = **20 gallons** (estimated)[272]
Volume occupied by 105 pounds (dry weight) of wheat straw (estimated density of straw in 30-gallon container = 2 pounds / 5 gallons) = 105 pounds x (5 gallons / 2 pounds)
= 263 gallons
Total gallons of manure and straw needed to be stored = 20 gallons + 263 gallons
= 283 gallons
= approx. 10, 30-gallon containers

Detailed Calculation #12

Calculation of the Recipe for Building a Human Manure-Enriched Compost Pile

From page 68

Ingredients for the layers of the human manure-enriched compost pile:
1) 10, 30-gallon containers full of manure and straw
2) 105 lbs. of additional straw
3) 5 ft^3 of soil (not including 0.67 ft^3 or 1, 5-gallon bucket of soil which will cap the last layer of the pile)

If the pile consists of 20 layers of each of the three ingredients, each layer would consist of:
1) One half of one 30-gallon container full of manure and straw
2) 5.25 lbs. of straw = approximately 2 tightly packed 5-gallon buckets (2.5 pounds / bucket if moderately packed)
3) 0.25 ft^3 of soil = 0.37, 5-gallon bucket

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[272] Sim Van der Ryn, *The Toilet Papers* (Santa Barbara, CA: Capra Press, 1978), p. 68: 200 pounds of human manure (see footnote #88) / 11 gallons / pound = 18 gallons, conservatively increased to 20 gallons.

Detailed Calculation #13

*Volume of **Built** Compost Produced from 210 Pounds of Straw, Soil and the Manure Generated by One Person Annually*

From page 69

Volume of Manure Produced Per Person Per Year = 20 gallons (estimated)[273] = **2.7 ft^3**
Volume of 210 lbs. (dry weight) of straw = 210 lbs. / (3.6 lbs / ft^3) = **58.3 ft^3**
Volume of soil = 5 ft^3 + (2 x 0.67 ft$^{3)}$ (to cap both piles) = **6.34 ft^3**
Total Volume of Built Human Manure-Enriched Compost = 2.7 ft^3 + 58.3 ft^3 + 6.34 ft^3
= **67.34 ft^3**, enough to build 2 compost piles that are each 3.3 feet long, 3.3 feet wide and 3 feet high.

Percentage of human manure in the built compost = 2.7 / 67.34 = 4%
Percentage of soil in the built compost = 6.34 / 67.34 = 9%

Detailed Calculation #14

*Volume of **Cured** Compost Produced from 210 Pounds of Straw, Soil and the Manure Generated by One Person Annually*

From page 71

(See Detailed Calculation #13 for the derivation of the initial volumes of the various materials)
58.3 ft^3 of undecomposed straw cures to 58.3 ft^3 / 6.57 = **8.9 ft^3** of cured straw
2.7 ft^3 of human manure cures to **0.8 ft^3** (see footnote #239).
6.34 ft^3 of soil remains **6.34 ft^3** after the decomposition process.[274]
Total Volume of *Cured* Compost = 8.9 ft^3 + 0.8 ft^3 + 6.34 ft^3 = **16.0 ft^3**
Percentage of Soil in *Cured* Compost = 6.34 ft^3 / 16.0 ft^3 = 40%

Cured compost that is 40% soil by volume contains approximately only (1 - 0.40) / (1 - 0.50) or 1.2 times the nitrogen and humus compared to an equal volume of *cured* compost that is 50% soil by volume. Therefore, in order to apply the equivalent in terms of organic matter, humus and minerals of 2.4 ft^3 (see Detailed Calculation #1) to 8 ft^3 of cured compost that is 50% soil by volume / 100 sq. ft., (2.4 / 1.2 to 8 / 1.2), or 2.0 to 6.7 ft^3 / 100 sq. ft. of cured compost that is 40% soil by volume must be added.

Applied at this rate of 2.0 to 6.7 ft^3 per 100 square feet, 16.0 ft^3 of *cured* compost that is 40% soil by volume is enough to maintain the humus level of = (16.0 / 6.7 to 16.0 / 2.0) = **2.4 to 8.0**, 100-square-foot beds.

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[273] See footnote #272.

[274] John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #10: Grow Your Own Compost Materials At Home* (Willits, CA: Ecology Action, 1981), p. 7.

Detailed Calculation #15

Amount of Beds Interplanted with Wheat, Fava Beans and Vetch Needed to Replenish the Soil's Supply of Nitrogen If 35% of the Nitrogen Is Lost from Composting Human Manure[275]

From pages 63 and 72

Amount of nitrogen contained in the one person's annual production of manure and 210 pooounds of wheat straw = 2.8 pounds + 1.2 pounds = 4.0 pounds.
Nitrogen that is lost in the composting process = 4.0 x 0.35 = 1.4 lbs.

Therefore, 1.4 pounds of additional nitrogen must be retained in the *cured* compost. If 35% of the nitrogen in the compost pile is lost, then (1.4 / .65) 2.2 pounds of nitrogen must be added to the compost pile initially, in order to retain 65% or 1.4 pounds.

Fava beans and vetch, interplanted with wheat as described in John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #14: The Complete 21-Bed Biointensive Mini-Farm: Fertility, Nutrition and Income* (Willits, CA: Ecology Action, 1987), pp. 4-15, contain 0.53 pound of nitrogen per bed in aboveground biomass. Since 2.2 pounds are needed, (2.2/0.53) **4.2 beds of the 7** used to grow wheat straw to compost the manure must be interplanted as described in Booklet #14. When the 2.2 pounds of nitrogen are composted and 35% is lost, 1.4 pounds of nitrogen will remain, enough to replace the nitrogen lost when the human manure and 210 pounds of straw are composted.

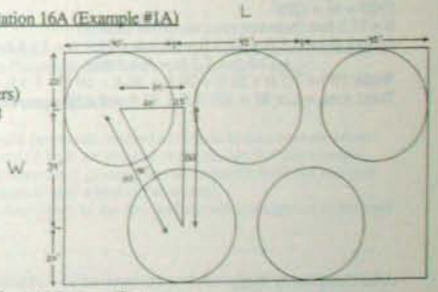
Detailed Calculation #16

Total Area of the Orchards and the Area Available to Receive Human Manure in Figure 8

From pages 78-81

Calculation 16A (Example #1A)

Total Area of Orchard
$a^2 + b^2 = c^2$
$(22.5)^2 + b^2 = (45)^2$
b = 39.0 feet (between rows on offset centers)
Length (L) = 40 ft + 45 ft + 45 ft = 130 feet
Width (W) = 20 ft + 39 ft + 20 ft = 79 feet
Total Area = L x W = 79 ft x 130 ft
= **10,270 square feet**



Area Occupied by Trees
Area of 1 tree = π (radius)^2 = (3.14) x (20)^2 = 1,256 square feet
Total Area = 5 trees x (1,256 sq ft / tree) = **6,280 square feet**

Area Available to Receive Human Manure = 10,270 sq ft - 6,280 sq ft = **3,990 square feet**, greater than the 3,864 square feet needed minimally.

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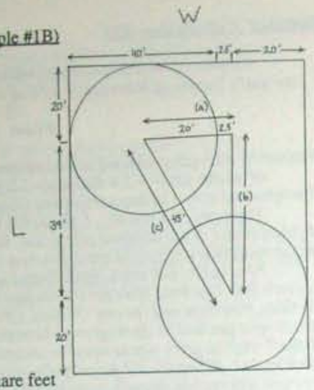
[275] The estimate of 35% loss of nitrogen through composting will vary depending on the initial carbon-to-nitrogen ratio of the pile and is given as an average loss of nitrogen during composting by Dr. Robert Parnes, *Fertile Soil* [Davis, CA: AgAccess, 1990], p. 56. See footnote #152.

Calculation 16B (Example #1B)

Total Area of Orchard
$a^2 + b^2 = c^2$
$(22.5)^2 + b^2 = (45)^2$
b = 39.0 feet (between rows on offset centers)
Length (L) = 20 ft + 39 ft + 20 ft = 79 feet
Width (W) = 40 ft + 2.5 ft + 20 ft = 62.5 feet
Total Area = L x W = 79 ft x 62.5 ft
= **4,938 square feet**

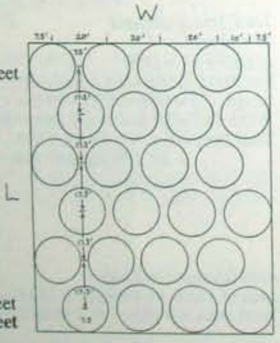


Area Occupied by Trees
Area of 1 tree = π (radius)^2 = (3.14) x $(20)^2$ = 1,256 square feet
Total Area = 2 trees x (1,256 sq ft / tree) = **2,512 square feet**

Area Available to Receive Human Manure = 4,938 sq ft - 2,512 sq ft = **2,426 square feet**, greater than the 1,932 square feet needed minimally.

Calculation 16C (Example #2A)

Total Area of Orchard
$a^2 + b^2 = c^2$
$(10)^2 + b^2 = (20)^2$
b = 17.3 feet (between rows on offset centers)
Length (L) = 7.5 ft + 17.3 ft + 17.3 ft + 17.3 ft
+ 17.3 ft + 7.5 ft = 101.5 feet
Width (W) = 7.5 ft + 20 ft + 20 ft + 20 ft + 10 ft + 7.5 ft = 85 feet
Total Area = L x W = 101.5 ft x 85 ft = **8,628 square feet**

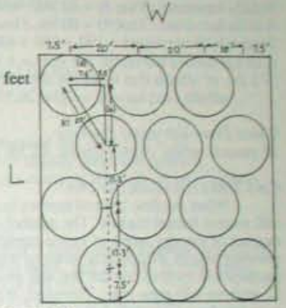


Area Occupied by Trees
Area of 1 tree = π (radius)^2 = (3.14) x $(7.5)^2$ = 176.6 square feet
Total Area = 24 trees x (176.6 sq ft / tree) = **4,238 square feet**

Area Available to Receive Human Manure = 8,628 sq ft - 4,238 sq ft = **4,390 square feet**, greater than the 3,864 square feet needed minimally.

Calculation 16D (Example #2B)

Total Area of Orchard
$a^2 + b^2 = c^2$
$(10)^2 + b^2 = (20)^2$
b = 17.3 feet
Length (L) = 7.5 ft + 17.3 ft + 17.3 ft + 17.3 + 7.5 ft
= 66.9 feet
Width (W) = 7.5 ft + 20 ft + 20 ft + 10 ft + 7.5 ft = 65 feet
Total Area = L x W = 66.9 ft x 65 ft
= **4,349 square feet**



Area Occupied by Trees
Area of 1 tree = π (radius)^2 = (3.14) x $(7.5)^2$ = 176.6 square feet
Total Area = 12 trees x (176.6 sq ft / tree) = **2,119 square feet**

Area Available to Receive Human Manure = 4,349 sq ft - 2,119 sq ft = **2,230 square feet**, greater than the 1,932 square feet needed minimally.

Detailed Calculation #17

*Amount of **Cured Soilless Compost** Generated by the 12 Beds Using Grains and Perennials to Recycle Human Manure in Communities Where Ascaris Is Not Present*

From page 106

After 6 years of using the grains and perennials method to recycle human manure where *Ascaris* is not present, all 12 beds are in use: 6 beds are planted in perennials (for this example, alfalfa) and 6 beds are receiving human manure and growing annual crops for food and compost materials (for this example, corn in the summer and wheat in the winter).

Assumption: Mid-range Biointensive yields of the first and second crops grown in the layer of manure are produced.

Alfalfa Harvested Per Year

In Year 7, 6 beds of perennials (alfalfa) will be removed, and these beds or a new set of 6 beds will be excavated to receive stored human manure. During that year, the 6 other beds are planted with alfalfa. During the following two years, those 6 beds of alfalfa are harvested 3 times during an annual 5-month growing season. During the fourth year, those 6 beds of alfalfa are removed and redug (or a new set of 6 beds is dug) to receive manure, and the first set of 6 beds, now filled with human manure, is planted with perennials. As shown in Figure 12 on pages 99-100, this cycle repeats itself every 3 years, with the 2 sets og 6 beds alternating.

In a 5-month growing season, mature alfalfa can be harvested 3 times annually on the average. At mid-range Biointensive yields, 1 bed of alfalfa produces 80 lbs. of alfalfa (air-dry

weight: approximately 90.5% dry matter) per year.[276] In the spring, when a bed of alfalfa is removed, the yield is estimated to be equal to one harvest or 1/3 of 80 lbs.
Alfalfa harvested (Year 7) = 1/3 x (80 lbs / bed x 6) = 160 lbs.
Alfalfa harvested (Year 8) = 80 lbs. / bed x 6 = 480 lbs.
Alfalfa harvested (Year 9) = 80 lbs. / bed x 6 = 480 lbs.
Total alfalfa harvested = 160 + 480 + 480 = 1,120 lbs.
Average alfalfa harvested per year = 1,120 / 3 = **373 lbs.**[277]
373 lbs. of alfalfa that is 90.5% dry matter is produced from (373 x 0.905 / 0.263) **1,284 lbs.** of alfalfa (wet harvest weight: 26.3% dry matter).

Wheat Straw Harvested Per Year
30 pounds wheat straw (approx. 92.5% dry matter)[278] / bed x 6 beds = **180 lbs.**

Corn Stalks Harvested Per Year

When the first layer of manure is added in the spring, not all of the sections of the 6 beds will receive human manure. The number of sections that receive human manure will depend on the number of months' worth of stored manure available, and therefore on the length of the winter growing season. Below, it is assumed that there is a 7-month winter season, so 7 of the 12 sections will receive manure and will grow corn the first summer. In the following two years, all 12 sections will grow corn. Therefore, the corn stalk yield below is an average of the annual yields over this three-year period.

YEAR 1
7 / 12 x 48.5 lbs. corn stalks (post ear harvest, 100% dry matter)[279] / bed x 6 beds = **170 lbs.**
170 lbs. of corn stalks that is 100% dry matter is produced from (170 x 1.00 / 0.906) **188 lbs.** of corn stalks that are harvested when they are mature but not entirely dry (90.6% dry matter).

YEARS 2 and 3
48.5 lbs. corn stalks (post ear harvest, 100% dry matter)[280] / bed x 6 beds = **291 lbs.**
291 lbs. of corn stalks that is 100% dry matter is produced from (291 lbs. x 1.00 / 0.906) **321 lbs.** of corn stalks that are harvested when they are mature but not entirely dry (90.6% dry matter).

Average annual corn stalk yield (harvest weight: 90.6% dry matter) =
(188 lbs. + 321 lbs. + 321 lbs.) / 3 = **277 lbs.**

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[276] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82; and Frank B. Morrison, *Feeds & Feeding*, 21st ed. (Ithaca, NY: Morrison Publishing Co., 1949), p. 1086.

[277] In order to have alfalfa to add to a compost pile in the year when no alfalfa is harvested, during the two years that alfalfa is harvested, two-thirds of each harvest can be used to build compost and one-third of each harvest should be air-dried (to prevent it from molding) and stored. With one-third of each harvest stored for two years, the equivalent of two-thirds of a year's harvest (equal to the amount of alfalfa used to build compost in the previous two years) will be available to build compost during the third year.

[278] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82; and Frank B. Morrison, *Feeds & Feeding*, 21st ed. (Ithaca, NY: Morrison Publishing Co., 1949), p. 1096.

[279] Estimated from J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #15: One Basic Mexican Diet*, "Supplement" (Willits, CA: Ecology Action, 1988). Since *Booklet #15* assumes high-range Biointensive yields, the corn biomass yield of 97 pounds dry weight per 100 square feet was divided by 2 to approximate mid-range Biointensive yields.

[280] Estimated from J. Mogador Griffin, *Ecology Action's Self-Teaching Mini-Series Booklet #15: One Basic Mexican Diet*, "Supplement" (Willits, CA: Ecology Action, 1988). Since *Booklet #15* assumes high-range Biointensive yields, the corn biomass yield of 97 pounds dry weight per 100 square feet was divided by 2 to approximate mid-range Biointensive yields.

Carbon-to-Nitrogen Ratio of Built Compost from All of the Alfalfa, Wheat Straw and Corn Stalks Generated

Carbon in Alfalfa = 1,284 x 0.263 x 0.509 (see Appendix A: Table 9) = 171.9 lbs.
Carbon in Wheat Straw = 180 x 0.925 x 0.509 = 84.7 lbs.
Carbon in Corn Stalks = 277 x 0.523 = 145 lbs.
Total Carbon = 171.9 + 84.7 + 145 = **401.6 lbs.**
Nitrogen in Alfalfa = 1,284 x 0.0070 = 8.99 lbs.
Nitrogen in Wheat Straw = 180 x 0.925 x 0.0062 = 1.03 lbs.
Nitrogen in Corn Stalks = 277 x 0.0094 = 2.60 lbs.
Total Nitrogen = 8.99 + 1.03 + 2.60 = **12.62 lbs.**

Carbon-to-Nitrogen Ratio = Total Carbon / Total Nitrogen = 401.6 / 12.62 = **32**

A pile with an initial carbon-to-nitrogen ratio of 30 or slightly more will produce proportionally more cured compost and humus compared to a compost pile with an intial carbon-to-nitrogen ratio of less than 30.

Built Compost from Alfalfa, Wheat Straw and Corn Stalks

The estimated volume of *built* compost from organic material is based on the **harvest** weights of the materials: 1,284 lbs. of alfalfa, 180 lbs. of wheat straw, and 277 lbs. of corn stalks.
Total carbonaceous material (wheat and corn) = 180 + 277 = 457 lbs.
Volume of carbonaceous material in a compost pile = 457 / (3.6 lbs. / ft^3) = 127 ft^3
Total nitrogenous material (alfalfa) = 1,284 lbs.
Volume of nitrogenous material in a compost pile = 1,284 / (8.5 lbs. / ft^3) = 151 ft^3
Total volume of *built* compost pile = 127 ft^3 + 151 ft^3 = 278 ft^3

Cured Compost from Alfalfa, Wheat Straw and Corn Stalks

Initial volume of carbonaceous material = 127 ft^3
Cured volume of carbonaceous material = 127 ft^3 / 6.57 = **19.3 ft^3**
Initial volume of nitrogenous material = 151 ft^3
Cured volume of nitrogenous material = 151 ft^3 / 8.50 = **17.8 ft^3**

Total volume of *cured soilless* compost = 19.3 + 17.8 = **37.1 ft^3**

This is enough *cured soilless* compost to apply 4 ft^3 (equivalent to 8 ft^3 of *cured* compst that is 50% soil by volume) to all 6 beds of alfalfa, and there would still be (37.1 ft^3 - 24 ft^3) 13.1 ft^3 of *cured soilless compost* in surplus.

Detailed Calculation #18

Amount of Cured Soilless Compost Generated by the 18 Beds Using Grains and Perennials to Recycle Human Manure in Communities Where Ascaris Is Present

From page 106

After 9 years of using the grains and perennials method to recycle human manure, all 18 beds are in use: 12 beds are planted in perennials (for this example, alfalfa) and 6 beds are receiving human manure and growing annual crops for food and compost materials (for this example, corn in the summer and wheat in the winter).

Assumption: Mid-range Biointensive yields of the first and second crops grown in the layer of manure are produced.

Alfalfa Harvested Per Year

In Year 10, 6 beds of perennials (alfalfa) will be removed, and these beds or a new set of 6 beds will be excavated to receive stored human manure (see Figure 13, page 102). Thereafter, a cycle as described in Figure 13 repeats itself every 3 years: during the first year, 6 beds of alfalfa are removed (Beds 1-6 in Year 10 in Figure 13), and 6 beds of alfalfa are harvested 3 times during a 5-month growing season. During the second and third years, 3 cuttings can be had from 12 beds of alfalfa each year.

In a 5-month growing season, mature alfalfa can be harvested 3 times. At mid-range Biointensive yields, 1 bed of alfalfa produces 80 lbs. of alfalfa (air-dry weight: approximately 90.5% dry matter) per year.[281] In the spring, when a bed of alfalfa is removed, the yield is estimated to be equal to one harvest or 1/3 of 80 lbs.

Alfalfa harvested (Year 10) = 1/3 x (80 lbs / bed x 6) + (80 lbs./ bed x 6) = 640 lbs.
Alfalfa harvested (Year 11) = 80 lbs. / bed x 12 = 960 lbs.
Alfalfa harvested (Year 12) = 80 lbs. / bed x 12 = 960 lbs.
Total alfalfa harvested = 640 + 960 + 960 = 2,560 lbs.
Average alfalfa harvested per year = 2,560 / 3 = **853 lbs.**[282]
853 lbs. of alfalfa that is 90.5% dry matter is produced from (853 x 0.905 / 0.263) **2,935 lbs. of** alfalfa (wet harvest weight: 26.3% dry matter).

Wheat Straw and Corn Stalks Harvested Per Year

Same as when 12 beds are used (see Detailed Calculation #17): 180 lbs. (harvest weight) of wheat straw, and 277 lbs. (harvest weight) of corn stalks.

Carbon-to-Nitrogen Ratio of Built Compost from All of the Alfalfa, Wheat Straw and Corn Stalks Generated

Carbon in Alfalfa = 2,935 x 0.263 x 0.509 = 392.9 lbs.
Carbon in Wheat Straw = 180 x 0.925 x 0.509 = 84.7 lbs.
Carbon in Corn Stalks = 277 x 0.523 = 145 lbs.
Total Carbon = 392.9 lbs.+ 84.7 lbs. + 145 lbs. = **622.6 lbs.**
Nitrogen in Alfalfa = 2,935 x 0.0070 = 20.55 lbs.
Nitrogen in Wheat Straw = 180 x 0.925 x 0.0062 = 1.03 lbs.
Nitrogen in Corn Stalks = 277 x 0.0094 = 2.60 lbs.
Total Nitrogen = 20.55 lbs. + 1.03 lbs. + 2.60 lbs. = **24.16 lbs.**

Carbon-to-Nitrogen Ratio = Total Carbon / Total Nitrogen = 626.6 / 24.16 = **25.9**

A compost pile with an intitial carbon-to-nitrogen ratio of 25.9 (less than 30) will produce slightly less cured compost and humus than will a compost pile of equal initial volume with an intitial carbon-to-nitrogen ratio of 30. More carbon could be added by growing more carbonaceous crops either on beds other than the 18 used in this system, by spacing the corn, for example, more tightly so that more biomass (though perhaps fewer ears) is produced, and/or growing more carbonaceous crops in place of some of the alfalfa.

Built Compost from Alfalfa, Wheat Straw and Corn Stalks

The estimated volume of *built* compost from organic material is based on the **harvest** weights of the materials: 2,935 lbs. of alfalfa, 180 lbs. of wheat straw, and 277 lbs. of corn stalks.

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[281] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 82; and Frank B. Morrison, *Feeds & Feeding*, 21st ed. (Ithaca, NY: Morrison Publishing Co., 1949), p. 1086.

[282] In order to have alfalfa to add to a compost pile in the times of the year when no alfalfa is harvested, during the two years that alfalfa is harvested, two-thirds of each harvest can be used to build compost during those two years and one-third of each harvest should be air-dried (to prevent it from molding) and stored. With one-third of each harvest stored for two years, you will have the equivalent of two-thirds of a year's harvest, equal to the amount of alfalfa that you used to build compost in the previous two years, with which to build compost during the third year.

Total carbonaceous material (wheat and corn) = 180 + 277 = 457 lbs.
Volume of carbonaceous material in a compost pile = 457 / (3.6 lbs. / ft^3) = 127 ft^3
Total nitrogenous material (alfalfa) = 2,935 lbs.
Volume of nitrogenous material in a compost pile = 2,935 / (8.5 lbs. / ft^3) = 345 ft^3
Total volume of *built* compost pile = 127 + 345 = 472 ft^3

Cured Compost from Alfalfa, Wheat Straw and Corn Stalks

Initial volume of carbonaceous material = 127 ft^3
Cured volume of carbonaceous material = 127 ft^3 / 6.57 = **19.3 ft^3**
Initial volume of nitrogenous material = 345 ft^3
Cured volume of nitrogenous material = 345 ft^3 / 8.50 = **40.6 ft^3**

Total volume of *cured soilless* compost = 19.3 ft^3 + 40.6 ft^3 = **59.9 ft^3**

This is enough *cured soilless* compost to apply 4 ft^3 (equivalent to 8 ft^3 of cured compst that is 50% soil by volume) to all 12 beds of alfalfa, and there would still be (59.9 ft^3 - 48 ft^3) 11.9 ft^3 of *cured soilless* compost in surplus.

Detailed Calculation #19

*Amount of **Cured** Compost and Calories Generated by the 12 Beds Using Grains Only to Recycle Hun Manure (assuming a 5-month warm growing season and a 7-month cold weather growing season)*

From page 107

Assumptions:
1) Inedible biomass yield from amaranth is (by weight and volume) 1.5 times that of wheat.
2) Mid-range Biointensive yields of the first and second crops grown in the layer of manure are produced.

12 beds grow interplanted oats, fava beans and vetch in the winter[283] and amaranth in the summer.

YEAR 1

Summer Growing Season - 7 of the 12 sections (3.5 beds) in Beds 1-6 (since only 7 sections will receive manure in the spring; see Figure 12 on page 99) and 12 of the 12 sections in Beds 7-12 grow amaranth.
Straw produced = (3.5 beds + 6 beds) x (45 lbs. / bed) = 427.5 lbs. straw
Calories produced = (3.5 beds + 6 beds) x (8 lbs. seed / bed) x (1,775 calories / lb.)
= 134,900

Winter Growing Season - All sections of all 12 beds grow interplanted oats, favas and vetch
Straw produced = 12 beds x (30 lbs. / bed) = 360 lbs.
Fava Bean Biomass = 12 beds x (180 lbs. / bed x 0.125 bed) = 270 lbs.
Vetch Biomass = 12 beds x (50 lbs. / bed x 0.25 bed) = 150 lbs.
Calories produced = 12 beds x (7 lbs. seed / bed) x (1,769 calories / lb.)
= 148,596

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[283] Oats are planted at a regular sowing rate and the fava beans and vetch are planted at 12.5% and 25% the regular sowing rates. This is virtually the same interplanting recipe as shown in John Jeavons, Ecology Action's Self-Teaching Mini-Series, *Booklet #14: The Complete 21-Bed Biointensive Mini-Farm* (Willits, CA: Ecology Action, 1987), pp. 14-15 and used successfully for many years in the field.

YEARS 2 and 3
Summer Growing Season - All sections of all 12 beds grow amaranth.
Straw produced = 12 beds x (45 lbs. / bed) = 540 lbs.
Calories produced = 12 beds x (8 lbs. seed / bed) x (1,775 calories / lb.)
= 170,400

Winter Growing Season - All sections of all 12 beds grow interplanted oats, favas and vetch
Straw produced = 12 beds x (30 lbs. / bed) = 360 lbs.
Fava Bean Biomass = 12 beds x (180 lbs. / bed x 0.125 bed) = 270 lbs.
Vetch Biomass = 12 beds x (50 lbs. / bed x 0.25 bed) = 150 lbs.
Calories produced = 12 beds x (7 lbs. seed / bed) x (1,769 calories / lb.)
= 148,596

Average annual *summer* straw production over three years = (427.5 + 540 + 540) / 3 = 502.5 lbs.
Volume of *built* compost generated from average annual *summer* straw production =
502.5 lbs / (3.6 lbs. / ft^3) = 139.6 ft^3
Volume of *cured* compost generated from average annual *summer* straw production =
139.6 ft^3 / 6.57 = **21.2 ft^3**

Volume of *built* compost generated from annual *winter* straw production =
360 lbs. / (3.6 lbs. / ft^3) = 100 ft^3
Volume of *cured* compost generated from annual *winter* straw production =
100 ft^3 / 6.57 = **15.2 ft^3**
Volume of *built* compost generated from annual *winter* fava bean and vetch production =
(270 lbs. + 150 lbs.) / (8.5 lbs. / ft^3) = 49.4 ft^3

Volume of *cured* compost generated from annual *winter* fava bean and vetch production =
49.4 ft^3 / 8.5 = **5.8 ft^3**
Total volume of *cured* compost generated from interplanted oats, favas and vetch =
15.2 + 5.8 = **21.0 ft^3**

Volume of *cured* compost generated from average annual *summer* and *winter* crops =
21.2 ft^3 + 21.0 ft^3 = **42.2 ft^3**

Added equally to the 12 beds in the system, 42.2 ft^3 of *cured soilless* compost is enough for each bed to receive (42.2 ft^3 / 12 beds) **3.5 ft^3 annually** (equivalent to 7.0 ft^3 of cured compost that is 50% soil by volume). Therefore, *Goal #2, the production of sufficient humus*, is achieved.

Average *summer* caloric production over three years = (134,900 + 170,400 + 170,400) / 3
= 158,567
Average total (summer + winter) caloric production per year = 158,567 + 148,596 = 307,163, or approximately **35%** of the 876,000 calories needed by the average person each year.

Detailed Calculation #20

Amount of **Cured** *Compost and Calories Generated by the 18 Beds*
Using Grains Only to Recycle Human Manure
(assuming a 5-month warm growing season and a 7-month cold weather growing season)

From page 107

Assumption: Inedible biomass yield from amaranth is (by weight and volume) 1.5 times that of wheat.
18 beds grow interplanted oats, fava beans and vetch in the winter[284] and amaranth in the summer.

YEAR 1
Summer Growing Season - 7 of the 12 sections (3.5 beds) in Beds 1-6 (since only 7 sections will receive manure in the spring; see Figure 14 on page 104) and all of the sections in Beds 7-18 grow amaranth.
Straw produced = (3.5 beds + 12 beds) x (45 lbs. / bed) = 697.5 lbs. straw
Calories produced = (3.5 beds + 12 beds) x (8 lbs. seed / bed) x (1,775 calories / lb.)
= 220,100

Winter Growing Season - All sections of all 18 beds grow interplanted oats, favas and vetch
Straw produced = 18 beds x (30 lbs. / bed) = 540 lbs.
Fava Bean Biomass = 18 beds x (180 lbs. / bed x 0.125 bed) = 405 lbs.
Vetch Biomass = 18 beds x (50 lbs. / bed x 0.25 bed) = 225 lbs.
Calories produced = 18 beds x (7 lbs. seed / bed) x (1,769 calories / lb.)
= 222,894

YEARS 2 and 3
Summer Growing Season - All sections of all 18 beds grow amaranth.
Straw produced = 18 beds x (45 lbs. / bed) = 810 lbs.

Calories produced = 18 beds x (8 lbs. seed / bed) x (1,775 calories / lb.)
= 255,600
Winter Growing Season - All sections of all 18 beds grow interplanted oats, favas and vetch
Straw produced = 18 beds x (30 lbs. / bed) = 540 lbs.
Fava Bean Biomass = 18 beds x (180 lbs. / bed x 0.125 bed) = 405 lbs.
Vetch Biomass = 18 beds x (50 lbs. / bed x 0.25 bed) = 225 lbs.
Calories produced = 18 beds x (7 lbs. seed / bed) x (1,769 calories / lb.)
= 222,894

Average annual *summer* straw production over three years = (697.5 + 810 + 810) / 3 = 772.5 lbs.
Volume of *built* compost generated from average annual *summer* straw production =
772.5 lbs / (3.6 lbs. / ft^3) = 214.6 ft^3
Volume of *cured* compost generated from average annual *summer* straw production =
212.5 ft^3 / 6.57 = **32.6 ft^3**

Volume of *built* compost generated from annual *winter* straw production =
540 lbs. / (3.6 lbs. / ft^3) = 150 ft^3

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[284] Oats are planted at a regular sowing rate and the fava beans and vetch are planted at 12.5% and 25% the regular sowing rates. This is virtually the same interplanting recipe as shown in John Jeavons, Ecology Action's Self-Teaching Mini-Series, *Booklet #14: The Complete 21-Bed Biointensive Mini-Farm* (Willits, CA: Ecology Action, 1987), pp. 14-15 and used successfully for many years in the field.

Volume of *cured* compost generated from annual *winter* straw production =
150 ft^3 / 6.57 = **22.8 ft^3**
Volume of *built* compost generated from annual *winter* fava bean and vetch production =
(405 lbs. + 225 lbs.) / (8.5 lbs. / ft^3) = 74.1 ft^3
Volume of *cured* compost generated from annual *winter* fava bean and vetch production =
74.1 ft^3 / 8.5 = **8.7 ft^3**
Total volume of *cured* compost generated from interplanted oats, favas and vetch =
22.8 + 8.7 = **31.5 ft^3**

Volume of *cured* compost generated from average annual *summer* and *winter* crops =
32.6 ft^3 + 31.5 ft^3 = **64.1 ft^3**

Added equally to the 18 beds in the system, 64.1 ft^3 of *cured soilless* compost is enough for each bed to receive (64.1 ft^3 / 18 beds) **3.6 ft^3** annually (equivalent to 7.1 ft^3 of *cured* compost that is 50% soil by volume). Therefore, *Goal #2, the production of sufficient humus,* is achieved.

Average *summer* caloric production over three years = (220,100 + 255,600 + 255,600) / 3
= 243,767
Average total (summer + winter) caloric production per year = 243,767 + 222,894 = 466,661, or approximately **53%** of the 876,000 calories needed by the average person each year.

Detailed Calculation #21

Amount of ***Built*** *and* ***Cured*** *Compost Generated by Example #1*

From page 112

Note: All compost production figures will be converted to the equivalent amount of **cured** *compost that is 50% soil by volume in order to easily compare the amount of* **cured** *compost that Example #1 and Example #2 generate which is available for each of the beds.*

Compost material	Average lbs. (harvest weight) produced / year
Straw (wheat, millet, quinoa)	960
Corn stalks	535

From Table 4 (page 111) and Detailed Calculations #3 and #10:

The **carbon** in 960 lbs. of straw and one person's annual production of urine and manure =
(296.6 lbs. + 70.9 lbs. + 84.7 lbs.) + 6 lbs. + 21 lbs. = **479.2 lbs.**
The **nitrogen** in 960 lbs. of straw and one person's annual production of urine and manure =
(3.61 lbs. + 0.82 lbs. + 1.03 lbs.) + 7.5 lbs. + 2.8 lbs. = **15.76 lbs.**
Total Carbon / Total Nitrogen = 479.2 lbs. / 15.76 lbs. = **30.4**

Therefore, if all of the straw is used to compost the urine and manure separately, we can create piles with initial carbon-to-nitrogen ratios of 30.

Now, we need to determine how much of the 960 pounds of assorted straw should be used to compost the urine and how much should be used to compost the manure. If only wheat straw is used, (733 lbs. + 210 lbs.) 943 lbs. of wheat straw is needed, and (733 lbs. / 943 lbs.) 78% is used to compost urine and (210 lbs. / 943 lbs.) 22% is used to compost the manure. So, (960 lbs.x 0.78) **748.8 lbs.** is needed to compost the urine and (960 lbs. x 0.22) **211.2 lbs.** is needed to compost the manure.[285]

Carbon-to-Nitrogen Ratio of Human Urine-Enriched Compost

The **carbon** in 748.8 lbs. of straw and one person's annual production of urine =
[(296.6 lbs. x .78) + (70.9 lbs. x 0.78) + (84.7 lbs. x 0.78)] + 6 lbs. = **358.7 lbs.**
The **nitrogen** in 748.8 lbs. of straw and one person's annual production of urine =
[(3.61 lbs. x 0.78) + (0.82 lbs. x 0.78) + (1.03 lbs. x 0.78)] + 7.5 lbs. = **11.8 lbs.**
Carbon-to-Nitrogen ratio of urine-enriched compost = 358.7 lbs. / 11.8 lbs. = **30.4**

Carbon-to-Nitrogen Ratio of Human Manure-Enriched Compost

The **carbon** in 211.2 lbs. of straw and one person's annual production of manure =
[(296.6 lbs. x .22) + (70.9 lbs. x 0.22) + (84.7 lbs. x 0.22)] + 21 lbs. = **120.5 lbs.**
The **nitrogen** in 748.8 lbs. of straw and one person's annual production of manure =
[(3.61 lbs. x 0.22) + (0.82 lbs. x 0.22) + (1.03 lbs. x 0.22)] + 2.8 lbs. = **4.0 lbs.**
Carbon-to-Nitrogen ratio of manure-enriched compost = 120.5 lbs. / 4.0 lbs. = **30.1**

Built and Cured Compost Produced from Composting Urine and Manure Separately with Straw

The *built* and *cured* compost generated are estimated to be the same as estimated in Detailed Calculations #4, #5, #13 and #14, since the amounts of carbon and nitrogen initially in the piles are approximately the same:
Volume of *cured* compost generated from composting *urine* with straw is enough to maintain the humus level of **7.8 to 23.0 beds.**
Volume of *cured* compost generated from composting *manure* with straw is enough to maintain the humus level of **2.4 to 8.0 beds.**
Note: Composted urine generates more cured compost than composted manure because more straw must be added to a person's annual production of urine to increase the carbon-to-nitrogen ratio to 30 to 1.

Built Compost Produced from the Corn Stalks

Volume of 535 lbs. of harvested mature corn stalks = 535 lbs. / (3.6 lbs. / ft^3) = 148.6 ft^3

Note: A compost pile made only of corn stalks will not decompose very efficiently. It is best to add green materials and soil, so that the ratio of dry corn stalks to green material to soil is approximately 4 to 5 to 1 by volume. The green material could be generated in additional beds, and/or by interplanting the corn with beans, squash or other crop for compost. For this calculation, however, we will estimate the amount of *built* compost generated from the corn stalks alone.

Cured Compost Produced from the Corn Stalks

Volume of *cured soilless* compost generated from corn stalks = 148.6 ft^3 / 6.57 (see Appendix A)
= 22.6 ft^3

Volume of *cured* compost that is 50% soil by volume = 22.6 ft^3 / (1 - 0.50) = **45.2 ft^3**
Applied at a rate of 3.3 to 8 ft^3 / bed, this is enough *cured* compost to fertilize [(45.2 / 8) to (45.2 / 3.3)] **5.7 to 13.7 beds.**

Total Cured Compost Produced in Example #1

Total cured compost produced is enough to maintain the fertility of [(7.8 + 2.4 + 5.7) to (23.0 beds + 8.0 beds + 13.7 beds)] **15.9 to 44.7 beds.**
Therefore, enough humus is produced to maintain the fertility of the 24 beds used in Example #1.

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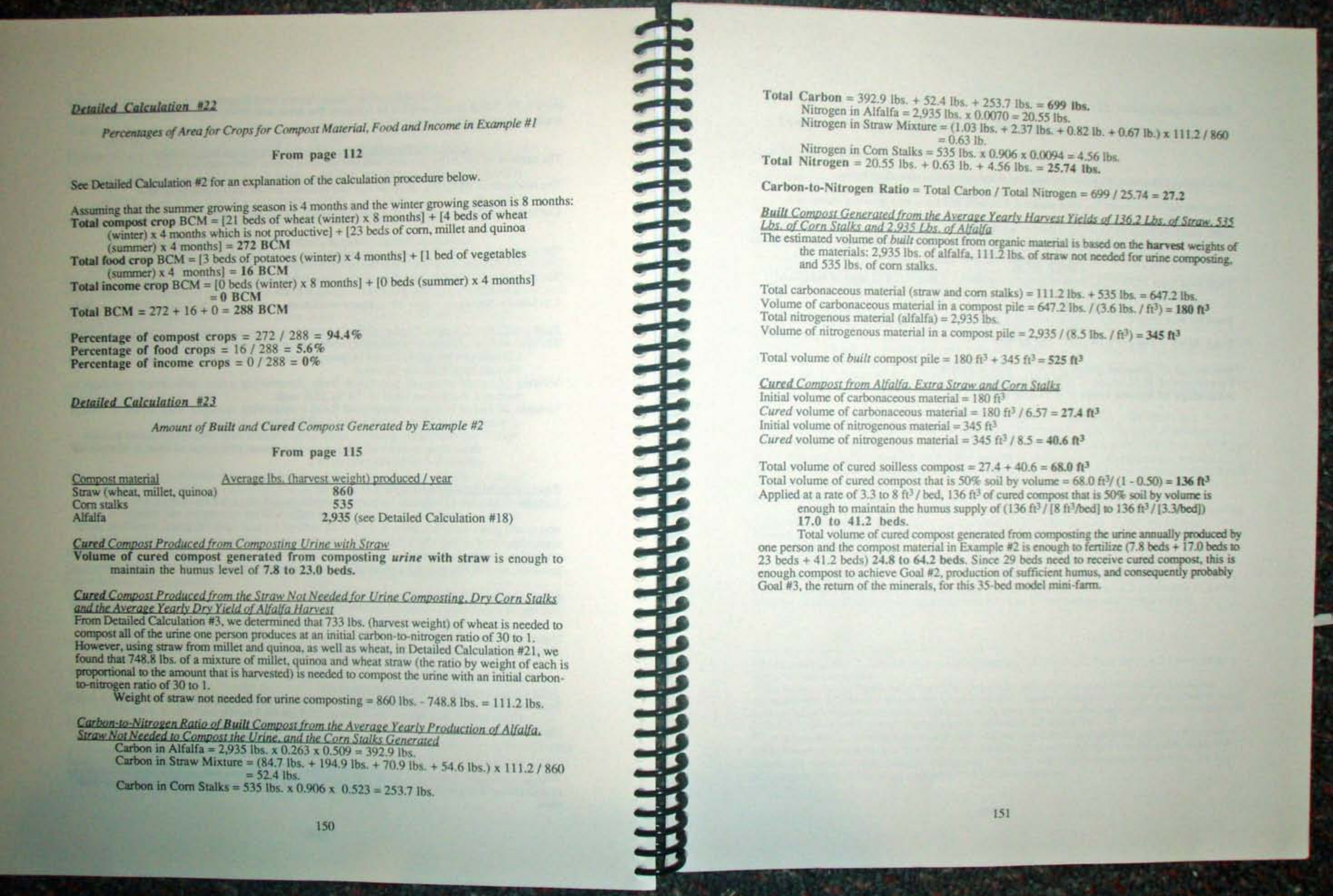
[285] These figures differ from the 733 lbs. and 210 lbs. of wheat straw calculated to be needed in Detailed Calculations #3 and #10 respectively because the percentages of dry matter and carbon in millet straw differ from those of wheat straw.



Detailed Calculation #22

Percentages of Area for Crops for Compost Material, Food and Income in Example #1

From page 112

See Detailed Calculation #2 for an explanation of the calculation procedure below.

Assuming that the summer growing season is 4 months and the winter growing season is 8 months:
Total compost crop BCM = [21 beds of wheat (winter) x 8 months] + [4 beds of wheat (winter) x 4 months which is not productive] + [23 beds of corn, millet and quinoa (summer) x 4 months] = **272 BCM**
Total food crop BCM = [3 beds of potatoes (winter) x 4 months] + [1 bed of vegetables (summer) x 4 months] = **16 BCM**
Total income crop BCM = [0 beds (winter) x 8 months] + [0 beds (summer) x 4 months] = **0 BCM**
Total BCM = 272 + 16 + 0 = **288 BCM**

Percentage of compost crops = 272 / 288 = **94.4%**
Percentage of food crops = 16 / 288 = **5.6%**
Percentage of income crops = 0 / 288 = **0%**

Detailed Calculation #23

*Amount of **Built** and **Cured** Compost Generated by Example #2*

From page 115

Compost material	Average lbs. (harvest weight) produced / year
Straw (wheat, millet, quinoa)	**860**
Corn stalks	**535**
Alfalfa	**2,935** (see Detailed Calculation #18)

***Cured** Compost Produced from Composting Urine with Straw*
Volume of cured compost generated from composting *urine* with straw is enough to maintain the humus level of **7.8 to 23.0 beds.**

***Cured** Compost Produced from the Straw Not Needed for Urine Composting, Dry Corn Stalks and the Average Yearly Dry Yield of Alfalfa Harvest*
From Detailed Calculation #3, we determined that 733 lbs. (harvest weight) of wheat is needed to compost all of the urine one person produces at an initial carbon-to-nitrogen ratio of 30 to 1. However, using straw from millet and quinoa, as well as wheat, in Detailed Calculation #21, we found that 748.8 lbs. of a mixture of millet, quinoa and wheat straw (the ratio by weight of each is proportional to the amount that is harvested) is needed to compost the urine with an initial carbon-to-nitrogen ratio of 30 to 1.

Weight of straw not needed for urine composting = 860 lbs. - 748.8 lbs. = 111.2 lbs.

*Carbon-to-Nitrogen Ratio of **Built** Compost from the Average Yearly Production of Alfalfa, Straw Not Needed to Compost the Urine, and the Corn Stalks Generated*
Carbon in Alfalfa = 2,935 lbs. x 0.263 x 0.509 = 392.9 lbs.
Carbon in Straw Mixture = (84.7 lbs. + 194.9 lbs. + 70.9 lbs. + 54.6 lbs.) x 111.2 / 860 = 52.4 lbs.
Carbon in Corn Stalks = 535 lbs. x 0.906 x 0.523 = 253.7 lbs.

Total Carbon = 392.9 lbs. + 52.4 lbs. + 253.7 lbs. = **699 lbs.**
Nitrogen in Alfalfa = 2,935 lbs. x 0.0070 = 20.55 lbs.
Nitrogen in Straw Mixture = (1.03 lbs. + 2.37 lbs. + 0.82 lb. + 0.67 lb.) x 111.2 / 860 = 0.63 lb.
Nitrogen in Corn Stalks = 535 lbs. x 0.906 x 0.0094 = 4.56 lbs.
Total Nitrogen = 20.55 lbs. + 0.63 lb. + 4.56 lbs. = **25.74 lbs.**

Carbon-to-Nitrogen Ratio = Total Carbon / Total Nitrogen = 699 / 25.74 = **27.2**

***Built** Compost Generated from the Average Yearly Harvest Yields of 136.2 Lbs. of Straw, 535 Lbs. of Corn Stalks and 2,935 Lbs. of Alfalfa*
The estimated volume of *built* compost from organic material is based on the **harvest** weights of the materials: 2,935 lbs. of alfalfa, 111.2 lbs. of straw not needed for urine composting, and 535 lbs. of corn stalks.

Total carbonaceous material (straw and corn stalks) = 111.2 lbs. + 535 lbs. = 647.2 lbs.
Volume of carbonaceous material in a compost pile = 647.2 lbs. / (3.6 lbs. / ft^3) = **180 ft^3**
Total nitrogenous material (alfalfa) = 2,935 lbs.
Volume of nitrogenous material in a compost pile = 2,935 / (8.5 lbs. / ft^3) = **345 ft^3**

Total volume of *built* compost pile = 180 ft^3 + 345 ft^3 = **525 ft^3**

Cured Compost from Alfalfa, Extra Straw and Corn Stalks
Initial volume of carbonaceous material = 180 ft^3
Cured volume of carbonaceous material = 180 ft^3 / 6.57 = **27.4 ft^3**
Initial volume of nitrogenous material = 345 ft^3
Cured volume of nitrogenous material = 345 ft^3 / 8.5 = **40.6 ft^3**

Total volume of cured soilless compost = 27.4 + 40.6 = **68.0 ft^3**
Total volume of cured compost that is 50% soil by volume = 68.0 ft^3/ (1 - 0.50) = **136 ft^3**
Applied at a rate of 3.3 to 8 ft^3 / bed, 136 ft^3 of cured compost that is 50% soil by volume is enough to maintain the humus supply of (136 ft^3 / [8 ft^3/bed] to 136 ft^3 / [3.3/bed]) **17.0 to 41.2 beds.**

Total volume of cured compost generated from composting the urine annually produced by one person and the compost material in Example #2 is enough to fertilize (7.8 beds + 17.0 beds to 23 beds + 41.2 beds) **24.8 to 64.2 beds.** Since 29 beds need to receive cured compost, this is enough compost to achieve Goal #2, production of sufficient humus, and consequently probably Goal #3, the return of the minerals, for this 35-bed model mini-farm.

Detailed Calculation #24

Percentages of Area for Crops for Compost Material, Food and Income in Example #2

From page 115

See Detailed Calculation #2 for an explanation of the calculation procedure below.

Assuming that the summer growing season is 4 months and the winter growing season is 8 months:
Total compost crop BCM = [19.8 beds of wheat (winter) x 8 months] + [3.2 beds of wheat (winter) x 4 months that is not productive] + [21 beds of corn, millet and quinoa (summer) x 4 months] + [12 beds of alfalfa x 12 months]
= **399.2 BCM**
Total food crop BCM = [3.2 beds of potatoes (winter) x 4 months] + [2 beds of beans and vegetables (summer) x 4 months]
= **20.8 BCM**
Total income crop BCM = [0 beds (winter) x 8 months] + [0 beds (summer) x 4 months]
= **0 BCM**
Total BCM = 399.2 + 20.8 + 0 = **420 BCM**

Percentage of compost crops = 399.2 / 420 = **95.0%**
Percentage of food crops = 20.8 / 420 = **5.0%**
Percentage of income crops = 0 / 420 = **0%**

Appendix C

Further Discussions

Further Discussion #1

*How much **cured** compost should be added so that the soil receives the proper amounts of **cured** carbon and nitrogen to improve and maintain its fertility?*

An annual application of nitrogen in some form is generally necessary to maintain the fertility of the soil. Nitrogen in the air can be added to the soil through the action of bacteria that can transform it into a form that is usable to plants. Nitrogen can also be added to the soil when lightning converts atmospheric nitrogen to water-soluble nitrogen that accompanying rain can carry into the soil. Since the soil continuously loses nitrogen through various pathways (ammonification, denitrification, leaching and marketing are some examples), it is essential that adequate nitrogen is returned to the soil for the soil to remain fertile and productive. One of our goals at Ecology Action is to learn to balance the nutrients in the soil and improve its structure so that eventually no purchased fertilizers are needed to maintain the fertility of the soil. Organic matter and humus that leave the soil are returned to the soil by growing carbonaceous compost crops. Nitrogen is returned to the soil by growing a healthy soil with a good population of free-living and symbiotic nitrogen-fixing bacteria and legumes. Finally, both nitrogen and the other elements that the soil loses when it grows plants for human and animal consumption can be returned by processing and returning all of the resulting human, animal and plant wastes. This would be truly sustainable farming and living.

In order to maintain the nitrogen and humus supply sustainably, 100 square feet of soil surface should receive no more than the equivalent of approximately 0.5 pound of nitrogen per year. This guideline is based on: 1) the maximum amount of nitrogen a soil should receive[286]; and 2) the nitrogen requirement for the healthy growth of most crops.[287] The minimum amount of nitrogen that must be added depends on the crops grown, the soil structure and the climate. At mid-range Biointensive yields, one bed of 100 square feet can grow enough compost material to generate a quantity of *cured* compost that contains 0.5 pound of nitrogen or more.[288]

Cured compost also contains other essential ingredients for soil health, namely potassium, phosphorus, sulfur and other nutrients, and most importantly organic matter and humus. According to data from compost piles built without human waste at Ecology Action's Common Ground Mini-Farm in Willits, CA, and estimates on human waste-enriched compost piles (see Appendix B: Detailed Calculation #1), approximately **2.7 cubic feet** of human urine-enriched *cured* compost (produced as described on pages 27-33), **2.4 cubic feet** of human manure-enriched *cured* compost (produced as described on pages 62-72), and **3.3 cubic feet** of *cured* compost generated without any human waste (with an initial carbon-to-nitrogen ratio of

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[286] John Jeavons, *How To Grow More Vegetables* (Berkeley, CA: Ten Speed Press, 1991), p. 23. From 1978 La Motte soil test instructions.

[287] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 131 lists the nitrogen needs of various vegetable crops; 0.5 pound of nitrogen per 100 square feet is adequate for all except possibly white potatoes. From Ecology Action's experience in Willits, California, white potatoes produce good yields (commonly yielding 2 times the U.S. average) with 0.5 pound of nitrogen or less applied per 100 square feet.

[288] From Appendix B: Detailed Calculation #1, 3.3 cubic feet of cured compost generated only from plant material and no human waste and that is 50% soil by volume contains 0.5 pound of nitrogen. One bed growing corn in the summer and oats in the winter produces approximately 53.5 + 30 = 83.5 lbs of carbonaceous material, 23.2 ft^3 of built compost which shrinks to approximately 3.5 ft^3 of cured compost.

approximately 30 to 1), that is 50% soil by volume and has a carbon-to-nitrogen ratio of 15 to 1[289], each contain **0.5 pound of cured nitrogen.**

However, when we add cured compost to soil, we also add organic matter, which is essential for the health of the soil. Therefore, another goal for the quantity of cured compost to add to a bed is the amount needed to improve and maintain the soil's organic matter level at 4 to 6% for temperate climates and about 3% for tropical climates. Most agricultural soils have an organic matter level of 0.5 to 2%, and the organic matter content of Midwest soils has fallen by 50% over the past 100 years.[290] Generally, if the soil organic matter falls below 4%, there is not enough organic matter to hold important soil minerals, and these minerals may leach from the soil, impairing the soil's health and preventing its fertility from being sustained. Further research needs to be done before we can predict the consequences of various application rates of cured compost on different types of soils in various climates.

When we rely solely on cured compost for the soil's source of nitrogen and organic matter, we may not be able to apply the proper amount of each of these simultaneously. That is, when we add the cured compost, we may be adding not enough (or even too much) organic matter or other nutrients to the soil. It may also be that we may need to add too much nitrogen to the soil in order to add enough organic matter or vice versa.

Historically, applying 8 cubic feet of cured compost that is 50% soil by volume to 100 square feet once every year in various temperate climates has given excellent results in terms of crop yields and improved soil fertility. It is because of this experience that this quantity of 8 cubic feet of cured compost that is 50% soil by volume is given as the high end of the three application ranges of 2.4, 2.7 or 3.3 (depending on the original materials used to produce the cured compost; see Appendix B: Detailed Calculation #1) to 8 cubic feet that is given throughout this publication. In a temperate climate, 8 cubic feet of cured compost that is 50% soil by volume can be generated from the plants grown in 100 square feet of soil *(at high-range Biointensive yields with crops that produce significant biomass and carbon).* Soil that produces at *mid-range Biointensive yields* can grow enough compost crops to generate about 4.0 cubic feet of cured compost that is 50% soil by volume or more, depending on the compost crops that are grown.[291]

At this rate of application, it is possible that more than three times the maximum recommended amount of nitrogen may be added to the soil. However, the guideline of 0.5 pound of nitrogen is based on the assumption that nitrogen is being applied in the form of a chemical nitrogen fertilizer. The nitrogen in cured compost is much less readily available: only 15% to 50% of the nitrogen in cured compost is released and available to the crops annually.[292] The amount of nitrogen that is released may depend on the carbon-to-nitrogen ratio of the cured compost and the carbon-to-nitrogen ratio of the initial compost materials, among possibly other factors. Cured compost with an initially high carbon-to-nitrogen ratio, or made from highly carbonaceous compost materials such as wood chips or sawdust, releases its nitrogen more slowly. Therefore, the precise amount of cured compost that will add the correct amount of nitrogen to the soil will vary from compost to compost. Furthermore, adding 0.5 pound of nitrogen in the form of cured compost that is 50% soil by volume will probably add less total available nitrogen than adding 0.5 pound of nitrogen in the form of fresh human manure, as in the Trees and Grains and Perennials methods. For a discussion on whether an excessive application of nitrogen can lead to an increase in soil humus degradation, see Appendix C: Further Discussion #3.

Despite historically good results, 8 cubic feet of cured compost does not always produce the best crop yields compared to those produced with less applied cured compost. **Dr. Ed Glenn** of the **Environmental Research Laboratory at the University of Arizona** found that an application rate of 1.4 cubic feet of cured *soiless* compost (which contains approximately equivalent amounts of nitrogen and humus as 2.8 cubic feet of cured compost that is 50% soil by volume) per 100 square feet per year produced the best crop yields compared to application rates of 4, 8 and 18.6 cubic feet of cured *soiless* compost (the equivalent of 8, 16 and 37.2 cubic feet of cured compost that is 50% soil by volume) per 100 square feet per year. According to Glenn, crops grown in soils that received cured compost at the three highest rates "suffered from salt damage and probably an excess of nitrogen". Glenn reported that even 0.8 cubic feet of cured soiless compost (the equivalent of 1.6cubic feet of cured compost that is 50% soil by volume) per 100 square feet per year supported high yields.[293] *Interestingly, 1.4 cubic feet of cured soiless compost generated only from plant matter and no human waste is equivalent to 2.8 cubic feet of cured compost that is 50% soil by volume, correlating closely with the amount of 3.3 cubic feet of cured compost that contains 0.5 pound of nitrogen.*

Similar to Dr. Glenn's findings, **Hillel I. Shuval** recommends 1.4 to 2.8 cubic feet of cured soiless compost (the equivalent of 2.8 to 5.6 cubic feet of cured compost that is 50% soil by volume) to be applied per 100 square feet per year depending on the groundwater level, the soil quality and crop requirements.[294] Dr. Glenn's and H.I. Shuval's findings correlate closely with the quantity of cured compost that we estimate to contain 0.5 pound of nitrogen.

Whether 2.4 to 3.3 cubic feet, or as low as 1.6 cubic feet as Glenn suggests, of cured compost that is 50% soil by volume contains enough organic matter and humus to establish and maintain a 4 to 6% organic matter level of the 100 square feet of soil (in temperate regions; 3% in tropical regions) is the other currently unanswerable question at this time. Ongoing research at Ecology Action's Common Ground Mini-Farm in Willits, CA suggests that this may be the case, but continued research over a 50 to 100-year period in various soils around the world by as many people as are interested and willing will be essential for us to answer these key questions and live sustainably.

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[289] See footnote #234.

[290] Dr. David Pimental, et al., "Land Degradation: Effects on Food and Energy Resources," *Science*, October 8, 1976, p. 150; and Barry Commoner, "Nature Under Attack," *Columbia Forum*, Spring 1978, Vol. 11, No. 1. There are exceptions -- some soils, called "muck soils", have organic matter levels as high as 15% -- but these soils are generally not providing us with the majority of our calories.

[291] Approximately 4.0 cubic feet of cured compost that is 50% soil by volume is generated from the materials produced by one bed growing corn during the warm season and a mixture of wheat, rye, fava beans and vetch, as described by John Jeavons, *Ecology Action's Self-Teaching Mini-Series Booklet #14: The Complete 21-Bed Biointensive Mini-Farm* (Willits, CA: Ecology Action, 1987), pp. 14-15. A detailed calculation of the derivation of this figure is not given, but could be found using biomass data from John Jeavons, *How to Grow More Vegetables*, and Appendix A: Formula to Convert Dry Weight.

[292] H. I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* (Washington, D.C.: World Bank, 1981), p. 78; and Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 58.

[293] - Ed Glenn, personal communication, December 12, 1989.

[294] - H.I. Shuval, et al., *Appropriate Technology for Water Supply and Sanitation, Vol. 10: Night-Soil Composting* (Washington, D.C.: World Bank, 1981), pp. 79-80.

Further Discussion #2

Can human urine be used to kill eggs of the worms in the genus Ascaris *that may be present in human manure?*

When urine is stored with manure and not separated or diluted, the ammonia produced as the urea in the urine decomposes is reported to be able to kill parasitic worm eggs, including those from worms in the genus *Ascaris*, in the manure.[295] The difficulty with this solution is that when urine and manure are stored together, much of the nitrogen in the urine will escape into the air as ammonia, and the manure will likely decompose anaerobically and not get hot enough to destroy the pathogens it contains. The final product, rather than being easy to spread and incorporate into the soil, will be a wet, noxious stew that will be difficult and unpleasant to add to soil and likely to spread other diseases.

However, E. I. Hamdy reported that *Ascaris* eggs die in undiluted human urine after only 16 hours.[296] Although some of the urea in the urine will be converted into ammonia and result in a loss of nitrogen, significant anaerobic decomposition of the manure during that time period is unlikely. There may be a creative and simple way to expose the manure to urine for only 16 hours and then separate the two for further processing. Since the urine would likely have acquired other pathogens from the human manure, both the urine and manure would need to be processed to meet the requirements that human manure must meet before it can be considered safe to handle and apply to soil that is growing food (especially root and leaf crops) for human consumption.

Further Discussion #3

Can an excessive application of nitrogen increase the rate at which humus is lost from the soil?

According to **Lea Harrison**, a **permaculture** (permanent agriculture) **teacher** for the past 13 years, the answer is yes. Where aerobic soil microorganisms are most actively growing and consuming humus and oxygen in the soil, pockets with very little air form. These pockets become populated by anaerobic bacteria (which do not need air to grow) that begin producing ethylene which inhibits aerobic bacteria activity. However, nitrate prevents the anaerobic bacteria from producing ethylene. Therefore, excessive nitrate from an over-application of nitrogen fertilizer can allow the aerobic bacteria to continue to break down humus[297] (until they run out of air).

For different reasons, **Dr. William Albrecht**, once **Chairman of the Department of Soils at the University of Missouri**, would agree that too much nitrogen applied to the soil will cause the soil to lose more humus. Sixty-five years of experimentation and analysis of the Sanborn Field at the Missouri Experiment Station led Dr. Albrecht to issue this warning about chemical nitrogen fertilizers increasing the loss of humus from the soil: "It is evident that the three cases of applied chemicals, particularly the nitrogen alone, were rapidly destroying the soil organic matter when the microbial action of balancing the salts called for carbon as energy to effect that, and consequently, bring about its oxidation rapidly. This is a soil process much as is that for the urine in livestock, mixed with the straw-bedding and piled, which heats rapidly in destruction of the straw with its wide carbon-nitrogen ratio suddenly given extra nitrogen and other salts for microbial balance of the less active carbonaceous organic matter, preserving itself against decay in absence of nitrogen."[298] However, on plots that received comparable amounts of nitrogen in the form of animal manure, the amount of soil organic matter increased. Therefore, it may be the lack of carbon in the chemical nitrogen fertilizer that caused, in part at least, this effect, since the humus lost from the soil was not being replenished.

Dr. Robert Parnes, operator of a commercial soil testing service for the last 10 years and holder of a Ph.D. in physics from Ohio State University, is sceptical that nitrogen can increase the loss of soil humus. Decomposing microorganisms consume approximately 30 parts carbon for every 1 part nitrogen, hence the guideline that a compost pile should initially contain 30 parts carbon to 1 part nitrogen for optimal decomposition and production of humus. When the cured compost is ready to be used, it has a carbon-to-nitrogen ratio of about 15 parts carbon to 1 part nitrogen (see footnote #234). The author estimates that this is approximately the carbon-to-nitrogen ratio of the organic fraction of soil. If this estimation is correct, then the organic matter and humus in the soil has an "excess" of nitrogen since the microbes responsible for decomposition only consume 1 part nitrogen for every 30 parts of carbon. Therefore, there is plenty of nitrogen for the microbes to continue to consume the carbon and humus in the soil organic matter. Adding more nitrogen to the soil should not have the effect of stimulating the microorganisms and increasing the rate of humus loss since nitrogen is not the limiting factor.[299]

While there may be 1 part nitrogen to 15 parts carbon, according to **Paul D. Sachs**, who has researched soil system dynamics for 10 years, most of the nitrogen in the organic fraction of soil in the form of humus is very resistant to biological use[300] and therefore largely unavailable. Therefore, different from Parnes's understanding, available nitrogen in the soil *is* a limiting factor to further microbial activity and decomposition. According to Sachs, the soil and the compost pile are two very different environments, and the availability of the nitrogen in either environment cannot be determined by the carbon-to-nitrogen ratio of the environment. The carbon-to-nitrogen ratio of a compost pile can be three times that of soil, but the nitrogen in a recently built compost pile is generally much more readily available to the decomposing microorganisms.

However, even when excess inorganic (readily available) nitrogen is added to the soil, stable soil humus is relatively resistant to rapid decay. It is the newly produced soil humus on its way to becoming stable humus that may be consumed and degraded by soil organisms when excessive amounts of readily available nitrogen are added to the soil. If some of the newly synthesized humus is consumed, less will be eventually stabilized and the total amount of humus in the soil will slowly decline.[301]

From Paul D. Sachs's book, *Edaphos*, it appears that nitrogen in the soil can exist in four different forms: 1) as an inorganic chemical compound such as ammonia and nitrate, the common form of nitrogen in chemical fertilizers. In this form, it is readily consumed by soil microorganisms; 2) as organic nitrogen in the proteins and other molecules that are in plants and animal and human waste. In this form, it must first be broken down into ammonia or nitrate, after which it can be assimilated into the bodies of the microbes or escape from the soil as gas or through leaching. If the nitrogen leaves the soil, its potential to combine with carbon in the bodies of microorganisms and create humus leaves as well; 3) as nitrogen-containing humus (such as that in cured compost) that has been newly created and is unstable. In this form, since the humus can still be oxidized and degraded, the nitrogen can be converted into ammonia and nitrate and, as in form #2, can be reconsumed by microorganisms or escape from the soil; and 4) as nitrogen-containing humus that cannot be degraded and which contains nitrogen that is stable for 10, 100 and even 1,000 years. Furthermore, carbon exists in the soil in different forms as well which vary

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[295] H. T. Ch'on, et al., "Achievements in the fight against parasitic diseases in New China," *Chinese Medical Journal* 79, December 1959, pp. 493-520.
[296] E. I. Hamdy, "Urine as an *Ascaris lumbricoides* Ovicide," *Journal of the Egyptian Medical Association* Vol. 53, nos. 3-4, 1970, pp. 261-264.
[297] Lea Harrison, "Soil Fertility," *The Permaculture Activist*, May 1992, pp. 8-11.
[298] Dr. William A. Albrecht, *The Albrecht Papers*, Charles Walters, Jr., ed. (Raytown, Missouri: Acres U.S.A., 1975), p. 193.
[299] Dr. Robert Parnes, personal communication, September 11, 1993.
[300] This nitrogen (which accumulates in soil organic matter) often is attached to phenolic compounds and is much more difficult to mineralize than that emanating from living organisms (E. A. Paul and F. E. Clark, *Soil Microbiology and Biochemistry* [New York: Academic Press, Inc., 1989], p. 134).
[301] Paul D. Sachs, personal communication, December 7, 1993.

in their availability to be consumed be soil microbes. The carbon in fresh green vegetables is very readily available; the carbon in straw is less readily available; the carbon in sawdust is even less readily available; and the *carbon in stable humus is the least readily available.*[302]

So the question "Can excess nitrogen in the soil cause humus to be lost more rapidly?" may not be answerable unless the amounts of available nitrogen and carbon in the soil are known. If there is carbon that can be consumed by the soil microbes (that is in the form of unstable humus, which would be present in a soil that has recently received cured compost, for example) and there is an insufficient amount of available nitrogen, then the answer is yes: an excessive application of available nitrogen will tend to increase the rate at which the unstable humus is degraded. However, if carbon is relatively unavailable (as in the case of stable humus), then an excessive application of nitrogen will not affect its rate of degradation. *Still, for the soil humus level to be maintained, some of the unstable humus must be allowed to age and become stabilized to replenish the stable humus that eventually does degrade. If excessive applications of nitrogen prevent this stabilization process from happening, eventually the overall humus level of the soil will decline and endanger the productivity and health of the soil.*

Another way an excessive application of nitrogen fertilizer could cause humus in the soil to break down more quickly is if the nitrogen fertilizer has an acidifying effect on the soil. Organic matter in the soil is less stable in acidic soils and breaks down more quickly.[303] Nitrogen fertilizers reported to have an acidifying effect on the soil are: ammonia nitrate, anhydrous ammonia, aqua ammonia, ammonia chloride,[304] ammonia sulfate[305], monoammonium phosphate, diammonium phosphate and urea[306] (both of the latter are synthetic chemical nitrogen fertilizers). Other acidifying fertilizers are: potassium chloride, sulfur, acid rain, superphosphate and triple phosphate.[307]

In conclusion, processed human urine and manure should probably not be added to the soil at a rate greater than the equivalent of 0.5 pound of nitrogen per 100 square feet per year. While a greater application rate could reduce the number of beds needed to recycle one person's annual production of urine and manure, it may also deplete the soil of its organic matter and humus and its ability to grow food.

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[302] Based on personal experience and Paul D. Sachs, *Edaphos* (Newbury, VT: The Edaphic Press, 1993), p. 45.

[303] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 76.

[304] Nyle C. Brady, *The Nature and Properties of Soils*, 9th ed. (New York: Macmillan Publishing Company, 1984), p. 311.

[305] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), p. 165.

[306] Garce Gershuny and Joseph Smillie, *The Soul of Soil*, 2nd Ed. (St. Johnsbury, VT: Gaia Services, 1986), p. 84.

[307] Dr. Robert Parnes, *Fertile Soil* (Davis, CA: AgAccess, 1990), pp. 165-167.

Food-Growing Areas Assuming Different Agricultural Techniques

Appendix D

The Circle Chart

Approximate area used to feed one person annually with

U.S. Mechanized Chemical and Organic Agriculture:

43-85	22-42	10*
High Meat Diet[1]	Average Diet[1]	Vegetarian Diet[1] (Vegan)

* (10) may increase to (30-40) in a post-fossil-fuel era (due to input reduction) for U.S. mechanized chemical agriculture.

Arable area per capita available in

Developing Nations✣

for producing food with techniques in use:

30	22	16**	9***
Actual Average[2] 1977	Actual Average[3] 1988	Best Case Projection[4] 2000	Updated Projection[5] 2014 - 2021

✣ 80% of the world's people will live in developing countries by the year 2000.

*** In many countries, only (4) worth of water is available per person annually.

Approximate area used to feed one person annually with

Biointensive Agriculture:

4◊	2	1
Intermediate Yields -Sustainable[5] (Vegan)	High Yields -Sustainable[5] (Vegan)	High Yields -Not Sustainable[5] (Vegan)

◊ Low area requirement means that over 50% of the world's arable land might be left in wild to preserve plant and animal genetic diversity.

(1) circle = 1000 square feet = 93 m²
1 acre ≅ (43) circles = 0.4 hectare

updated 2/2/96

Notes & Sources of Data for The Circle Chart (pg. 159)

1. Dr. Kenneth E.F. Watt, *The Titanic Effect*, 1974, Sinauer Associates, Inc., Stamford, Conneticut. p. 41. (43 circles, 22 circles, and 10 circles). The figures for the upper end of the ranges have been developed from other data.

2. Source to be identified.

3. UN/FAO Yearbook statistics from 1988.

4. United Nations State of the World Environment Report, 1977. Also see *Backyard Homestead*, p. 19.

5. Ecology Action *conservative projection for developing nations* based on:
    a) P. Buringh, "Availability of Agricultural Land for Crop and Livestock Production", 1989, in D. Pimentel and C.W. Hall (Eds.), *Food and Natuaral Resources*, pp. 69-83, San Diego; Academic Press, as noted in "Natural Resources and an Optimum Human Population", David Pimentel, et al, *Population and Environment: A Journal of Interdisciplinary Studies*, Vol. 15, No. 5, May, 1994;

    b) UN/FAO data, Worldwatch Institute data and other information.

The *Complete Loss of World Agriculture Production* might occur:

a) In the year 2044: *accelerated projection* (production loss if soil deterioration occurs at an increasing, rather than linear rate: 30%, on the average, in the first 25 years, doubled rate, on the average, in following 25 years);
b) In the year 2060: *Pimentel/Buringh's worst case projection* (loss if production at the rate of 30% every 25 years). Many think this projection has a good chance of occuring.
c) Or in the year 2118: *Pimentel/Buringh's best case projection* (loss of production at the rate of 15% every 25 years.

6. Developed from Ecology Action research and publications.

Appendix E

Sustainable Application of Composted Vegetable Matter, Composted Cow Manure and Organic Fertilizers

Sustainable Application of Composted Vegetable Matter

Ecology Action and others have found that 8 cubic feet of *cured* compost (that is 50% soil by volume) is the maximum and perhaps optimal amount of cured compost to add to 100 square feet of soil per year. Only under very unusual circumstances (such as when one is improving a soil that has no topsoil or subsoil, but just has C- and R-horizon material) is more than 8 cubic feet of cured compost (that is 50% soil by volume) needed. Under such circumstances, no more than 16 cubic feet of cured compost (that is 50% soil by volume) should be added, and it should be added *on a one-time basis only*. The reason for this is based on long-term sustainability and productivity goals for the soil and farm.

The goal of Sustainable Biointensive Mini-Farming is for the farm *to produce essentially all of the soil's fertility sustainably and to eventually need no outside inputs*. This is possible once the soil nutrients are balanced through competent soil analysis followed by the application of the appropriate quantities of organic fertilizers. Sustainability can be achieved by accomplishing two goals: a) growing compost crops to generate sufficient cured compost; and b) returning all of the soil nutrients contained in the crops to the soil through the compost and the proper recycling of human waste. If these two goals are accomplished, both humus and nutrient levels of the soil can be replenished in a way that is sustainable. That is, the soil's fertility can be maintained virtually indefinitely, since these practices do not rely on nonrenewable resources directly (as in the use of chemical fertilizers which are produced from petroleum) or indirectly. Examples of practices that use nonrenewable resources indirectly are: a) the use of organic fertilizers which are generally produced from crops grown with chemical fertilizers or from animals whose feed is grown chemically, and b) the bringing in of organic matter from other areas that are not maintained sustainably. When nutrients and/or organic matter are brought to the farm from another area, that area's nutrients and humus levels will decline until the area will no longer be able to produce the organic fertilizer and/or amendments.

Sustainable Biointensive Mini-Farming has excellent potential for nutrition intervention and complete nutrition provision, and at the same time it *can* be sustainable. However, using more than the sustainable amount of compost necessarily requires another soil to be depleted. How much soil will be depleted depends on the amount of cured compost that is applied. For example, instead of the optimal maximum application rate of 8 cubic feet of *cured* compost that is 50% soil by volume per 100 square feet of soil, 27 cubic feet of *cured* compost that is 50% soil by volume per 100 square feet of soil is applied. Approximately 193 square feet *(assuming high yields)* is needed to produce 27 cubic feet of *cured* compost (that is 50% soil by volume). If all 27 cubic feet is added to only 100 square feet, 93 square feet cannot receive *cured* compost and will lose its organic matter, minerals and fertility over time. Eventually, the 93 square feet will become so depleted that it will be unable to produce enough organic matter to maintain even the other 100 square feet of soil.

High (Maximum) Biointensive Yields

Area needed to produce 27 cubic feet of ***cured*** *compost = 193 square feet*
Area that will receive 27 cubic feet of ***cured*** *compost = 100 square feet*
Area that will not receive any compost and will eventually lose its fertility = 93 square feet

*At **mid-range** Biointensive yields*, the *maximum* amount of cured compost that 100 square feet can generate is approximately 7 cubic feet (that is 50% soil by volume). Therefore, approximately 386 square feet is required to generate 27 cubic feet of cured compost for 100 square feet, depleting the other 286 square feet of soil in the process.

Mid-range Biointensive Yields
*Area needed to produce 27 cubic feet of **cured** compost = 386 square feet*
*Area that will receive 27 cubic feet of **cured** compost = 100 square feet*
Area that will not receive any compost and will eventually lose its fertility = 286 square feet

It is most important that beginning Biointensive Mini-Farmers begin growing their own compost, apply what they have, and strive to eventually produce enough *cured* compost to be able to apply up to 8 cubic feet (that is 50% soil by volume) per 100 square feet per four-month growing season. The soil's fertility then may be sustainable on an approximate "closed system" basis that does not deplete other soils in the process.

After doing a number of experiments on the sustainability of Biointensive Mini-Farming at the Environmental Research Laboratory, Dr. Glenn states, "Although funding was not available to continue these experiments for the number of years necessary to draw final conclusions, the results supported the hypothesis that sustainable food production with few or no outside inputs will not only continue to produce high yields but will improve rather than deplete the organic constituents in the soil."

Sustainable Application of Cow Manure

Often, a half-inch layer of animal manure *compostedwithout soil* (equivalent to approximately 4 cubic feet per 100 square feet) is recommended to be applied to a growing area, in addition to a one-inch layer (8 cubic feet per 100 square feet) or more of *cured* plant compost (that is 50% soil by volume). However, this is an overapplication of nitrogen which could lead to nitrate toxicity in the crops, nitrate in the groundwater, crop lodging, acidification of the soil, and possibly a loss of soil humus, as described on pages 20-23.

Even more important, adding this amount of *soilless composted* manure is insustainable. Annual fodder production for the cow, using Biointensive Mini-Farming with zero-grazing techniques, requires *(at **mid-range** Biointensive yields)* approximately 7,500 square feet of soil (75, 100-square-foot beds). The cow produces approximately 220 cubic feet of manure (dry) annually or approximately 110 cubic feet once the manure is decomposed. 110 cubic feet is enough *cured* manure (without soil) to apply to about 2,750 square feet (or 27.5, 100-square-foot beds) of soil once per year at the rate described above. Therefore, 4,750 square feet (or 47.5, 100-square-foot beds) will not receive compost, and their minerals, as well as humus, will not be replenished. This practice will eventually cause the 47.5 beds to lose organic matter, minerals, fertility and productivity.

Mid-range Biointensive Yields[308]
Area required to feed one cow = 7,500 square feet
Area that will be fertilized with one cow's manure = 2,750 square feet
Area that will lose its fertility = 4,750 square feet

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[308] The data for chickens and horses are being researched.

Appropriate Use of Organic Fertilizers

Unless the soil is analyzed by a competent laboratory, or the farmer is able to tell by the presence and growth characteristics of certain plants which minerals are missing in the soil, organic fertilizers should not be applied, and only *cured* compost generated from residues produced by the farm should be used. Indiscriminately added organic fertilizers usually do more harm than good. Optimally, the minerals which the soil lacks will be identified through plant or chemical analysis and added in the form of organic fertilizers until the minerals are sufficient and balanced. Thereafter, because the nutrients are being recycled, no additions of organic fertilizers are needed.

Compost Application Procedure

Unless it is necessary to drastically amend a soil that has no topsoil and/or subsoil, or a soil with extremely low organic matter, the 8 cubic feet (or less, if only that amount is needed, or if that is all that is available) of *cured* compost (that is 50% soil by volume) should be applied only **after** the bed has been double-dug, not before the double-dig. Compost that is added before the double-dig tends to be buried too deep in the soil to be immediately accessible to and most effectively used by the seedlings when they most need it. The lower placement of compost also tends to prevent the upward movement of water to the roots.

We have the ability to respond to the gift of life the soil gives to us each day by giving back to the soil at least as much as we take from it. When we use our response ability, we find we are richer for it. We can learn to take care of ourselves, our families and the generous soil. With the life we give to the soil, the soil responds as well, by growing stronger and producing crops that give even more life and strength to us and to the other creatures on the planet.

To take our response ability and use it fully is our choice, as it is our choice to use our minds to think, our voices to sing and our hands to join.

About the Author

After earning a Bachelor's degree in Microbiology from the University of California at Santa Barbara, **John Beeby** began his research on recycling human waste in 1991. From 1992 to 1995, John was an apprentice at Ecology Action's Common Ground Mini-Farm in Willits, California, learning the basics of GROW BIOINTENSIVE® Sustainable Mini-Farming and continuing his human waste recycling research. He continued his work at the Common Ground Mini-Farm through 1996 as a staff person, mini-farming, teaching, researching and writing. He is also the author of *Test Your Soil With Plants!*, published by Ecology Action, which explains how to use wild, native and cultivated plants to determine the texture and the mineral and organic matter content of soils naturally.

John Beeby currently resides in rural Ithaca, New York with his wife Meghan and various special needs companion animals on their 'Kindred Spirits Farm'. He works at Cornell University as the Supervisor of the Molecular Diagnostic Lab, which is part of the NY State Animal Health Diagnostic Laboratory. He can be reached at kindredspiritsfarm@ecoisp.com

About the Organization

For 30 years, **Ecology Action** has been researching, testing, documenting and teaching how to grow one person's complete diet on as small an area as possible while maintaining and even improving the fertility of the soil. Ecology Action began with a method of food production called the Biodynamic/French intensive method, which was brought to the United States by master horticulturalist, Alan Chadwick. The result of Ecology Action's three decades of work is the GROW BIOINTENSIVE® Sustainable Mini-Farming method, which produces 2 to 6 times the yield per unit of area while using 67% to 88% less water, 50% to 100% less purchased fertilizer in organic form, and 99% less energy compared with conventional farming techniques. However, in order for any method of food production to be *sustainable*, all of the nutrients that come from the soil must be returned to the soil, including the nutrients that we eat and that remain in our waste. Ecology Action's goal for *Future Fertility* is to promote the understanding of the processes involved in doing this safely and effectively and to encourage people to explore and expand upon the possibilities discussed.

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