Chapter Nine

Compost Nuts and Bolts

Composting is not waste disposal. It is organics recycling. Composting is a waste-free process. We do not compost waste; we discard waste — that's why it's called *waste*. Anyone who tells you he or she is composting waste doesn't know what waste is. We compost organic material; waste is what *isn't* composted; it's wasted. You don't look for waste to compost; you look for organic material to compost. Composting is a continuous natural cycle whereby organic material is recycled to make soil for plants, which in turn produce food, which is eaten by animals, which in turn produce manures, animal carcasses, and discarded food and agricultural residues. These organic by-products of life are then composted, and the cycle continues, without waste.

The composting industry sprang from the waste disposal industry. Waste management people had the trucks, the equipment, the machinery, the industrial sites, the permitting options, and whatever else was needed to jump into the composting arena. The unfortunate consequence of this is that they insist on referring to organic material as waste. Yes, it *was* waste when they dumped it in landfills. It's not waste when it's being composted.

The organic material utilized to make compost could be anything on Earth that had been alive, or from a living thing, such as manure, plants, leaves, sawdust, peat, straw, grass clippings, food scraps, and urine. A rule of thumb is that anything that will rot will compost, including such things as cotton clothing, wool rugs, rags, paper, animal carcasses, junk mail, and cardboard. Composting converts organic material, even humanure, into a stable material that does not attract insects or nuisance animals. Mature compost can be safely handled and stored indefinitely and is beneficial to the growth of plants.

Compost holds moisture and therefore increases the soil's capacity to absorb and hold water. It is said to hold nine times its weight in water (900 percent), as compared to sand which only holds 2 percent,

BENEFITS OF COMPOST

ENRICHES SOIL
- Adds organic material
- Improves fertility and productivity
- Suppresses plant diseases
- Discourages insects
- Increases water retention
- Inoculates soil with beneficial microorganisms
- Reduces or eliminates fertilizer needs
- Moderates soil temperature

PREVENTS POLLUTION
- Reduces methane production in landfills
- Reduces or eliminates organic garbage
- Reduces or eliminates sewage

FIGHTS EXISTING POLLUTION
- Degrades toxic chemicals
- Binds heavy metals
- Cleans contaminated air
- Cleans stormwater runoff

RESTORES LAND
- Aids in reforestation
- Helps restore wildlife habitats
- Helps reclaim mined lands
- Helps restore damaged wetlands
- Helps prevent erosion on flood plains

DESTROYS PATHOGENS
- Can destroy human disease organisms
- Can destroy plant pathogens
- Can destroy livestock pathogens

SAVES MONEY
- Can be used to produce food
- Can eliminate waste disposal costs
- Reduces the need for water, fertilizers, and pesticides
- Can be sold at a profit
- Extends landfill life by diverting materials
- Is a less costly bioremediation technique

Source: U.S. EPA (October 1997). *Compost-New Applications for an Age-Old Technology.* EPA530-F-97-047. And author's experience.

and clay 20 percent.[1] Compost also adds slow-release nutrients essential for plant growth, creates air spaces in soil, helps balance the soil pH, darkens the soil (thereby helping it to absorb heat), and supports microbial populations that add life to the soil. Nutrients such as nitrogen in compost are slowly released throughout the growing season, making them less susceptible to loss by leaching than more soluble chemical fertilizers.[2] Organic matter from compost enables the soil to immobilize and degrade pesticides, nitrates, phosphorus, and other chemicals that can become pollutants. Compost also binds pollutants in soil systems, reducing their leachability and absorption by plants.[3]

The building of topsoil by Mother Nature is a centuries long process. Adding compost to soil will help to quickly restore fertility that might otherwise take nature hundreds of years to replace. Humans deplete soils in relatively short periods of time. By composting our discarded organic material and returning it to the land, we can restore that fertility in relatively short periods of time. Fertile soil yields better food, thereby promoting good health.

The Hunzas of northern India have been studied to a great extent. Sir Albert Howard reported, *When the health and physique of the various northern Indian races were studied in detail, the best were those of the Hunzas, a hardy, agile, and vigorous people living in one of the high mountain valleys of the Gilgit Agency. . . . There is little or no difference between the kinds of food eaten by these hillmen and by the rest of northern India. There is, however, a great difference in the way these foods are grown. . . . The very greatest care is taken to return to the soil all human, animal, and vegetable [refuse] after being first composted together. Land is limited: upon the way it is looked after, life depends.*[4]

Compost is made above ground in piles, bins, vessels, and windrows. There are several reasons for piling composting material above ground. A contained pile (versus an open pile or windrow) keeps the material from drying out or cooling down prematurely. A high level of moisture (50-60 percent) is necessary for the microorganisms to be happy.[5] A contained pile helps to prevent leaching and waterlogging, and it holds heat. A neat, contained pile looks like you know what you're doing when you're making compost in your backyard or in your community, instead of looking like a dump. Compost bins, as opposed to open piles, also keep out nuisance animals such as dogs. A bin doesn't have to cost money; it can be made from recycled wood, cement blocks, hay bales, repurposed pallets, or whatever else is at hand.

A pile makes it easier to cover the compost. When a fresh deposit is added to a compost pile, especially a smelly deposit, it's essential to cover it with clean organic material to eliminate odors and to prevent flies from being attracted to the compost. Granted, large-scale municipal composting is often done in windrows, which are long open piles of organic material that are usually uncovered. These open piles have to be frequently turned and stirred because the exposed surfaces attract flies and can't heat up like the interior does. You will find that these large-scale windrow operations will often not accept animal manures, certainly not humanure, and often not even food scraps, due to the odor and fly issues these feedstocks will create when the uncovered piles are sitting and rotting in the sun or are being stirred up and releasing gases and a host of other things into the air. The good news is that smelly feedstocks such as humanure, dead animals, and food materials can be composted in contained, covered piles that do not need to be stirred up at all, thereby eliminating the odor and fly issues completely. A contained composting technique also eliminates the cost and labor involved in turning the compost piles. We will dwell more on this issue in subsequent chapters.

Moisture

Compost must be kept moist. A dry pile will not work; it will just sit there looking bored. It's amazing how much moisture an active compost pile can absorb. When people who don't have any experience with composting try to picture a humanure compost pile in someone's backyard, they imagine a giant, fly-infested, smelly heap of turds, draining noxious, stinky liquids out the bottom of the pile. However, a compost pile is not a pile of garbage or waste. Thanks to the miracle of composting, the pile of organic material becomes a living, breathing, biological mass, a sponge that absorbs quite a bit of moisture. The pile is not likely to create a leaching problem unless mismanaged or subjected to sustained heavy rains — then it can simply be covered with a roof, a tarp, or even just hay or straw.

Why do compost piles require moisture? For one thing, compost loses a lot of moisture into the air during the composting process, especially when the piles are turned or stirred up. It is not uncommon for compost piles to shrink 40 to 80 percent.[6] Even when wet materials are composted, a pile can undergo considerable drying.[7] An initial moisture content of 65 percent can dwindle down to 20 to 30 percent in only a week, according to some researchers, probably a result of turning or stirring up the hot piles.[8] Due to compost's need for liquid, it is more likely that one will have to *add* moisture to one's compost than have to deal with excess moisture leaching from it.

Also, microorganisms don't walk — they swim. They don't have legs like land animals do, and they need moisture for motility. Microbes live in biofilms coating the particles and surfaces in a compost pile. When the compost dries out, biological activity slows down and eventually grinds to a halt.

The amount of moisture a compost pile receives or needs depends on the materials put into the pile as well as the location of the pile. For example, in northwestern Pennsylvania, there are about forty-two inches (roughly one meter) of precipitation each year, on average. Outdoor, exposed compost piles rarely need watering under these conditions. According to Sir Albert Howard, it is also unnecessary to water a compost pile in a location in England where the annual rainfall is twenty-four inches. Nevertheless, the water required for compost-making may be around two hundred to three hundred gallons for each cubic yard of finished compost.[9] This moisture requirement can be met when human urine is used in the compost and the pile is receiving adequate rainfall. Additional water can come from moist organic materials such as food scraps. If adequate rainfall is not available and the contents of the pile are not moist, such as in a desert situation, watering will likely be necessary to produce a moisture content equivalent to a squeezed-out sponge. Graywater from household drains or collected rainwater might suffice for this purpose. Lately, I've been collecting discarded beer from a local brewery in five-gallon buckets and pouring it over my compost piles. The piles love it. Spent wine from brandy making is also a favorite. If the pile is above ground, it will remain aerobic. Aerobic bacteria will suffer from a lack of oxygen if drowned in liquid, which would occur, for example, at the bottom of a pit in standing water.

Anaerobic decomposition is a slower, cooler process that usually stinks. Anaerobic odors can smell like rotten eggs (caused by hydrogen sulfide), sour milk (caused by butyric acids), vinegar (acetic acids), vomit (valeic acids), and putrification (alcohols and phenolic compounds).[10] Obviously, we want to avoid such odors by maintaining an aerobic system, not an anaerobic one.

Keep it Covered

Compost need not offend one's sense of smell. However, for this to be true, two simple rules must be followed: (1) Never put any organic materials on top of a compost pile (the exception being cover materials). Always add new organic material (food scraps, toilet material, dead animals, etc.) *into* the pile by first digging a hole in the top center, dumping your material there, raking the existing compost over it, then covering it with the cover material, which brings us to: (2) Always keep the contents of a compost pile covered with a clean cover material (like straw, hay, grasses, weeds, bagasse, leaves) when using contained composting systems such as backyard or community bins.

If you're using a compost toilet, then you must also cover the deposits *inside your toilet* after each use. Good cover materials inside toilets include sawdust, peat moss, leaves, rice hulls, coco coir, sugar cane bagasse, and lots of other things provided they're a finer consistency with some level of moisture content, but we'll get back to this topic later.

Good cover materials for an *outdoor compost pile* include weeds, straw, hay, leaves, grass, and other materials that can be bulky, dry, or green, but not woody, such as tree branches. Adequately covering compost with a clean organic material is the simple secret to odor prevention. It also keeps flies and other vermin off the compost. The US Army once sprayed their compost piles with a mixture of toxic chemicals to keep off flies, much to the consternation of the microbes within, no doubt. A simple layer of straw, grasses, leaves, or other cover material thrown over the compost piles would have worked much better.

Adequate cover material insulates the pile, absorbs rainfall, and prevents dehydration. Dehydration will cause the compost microorganisms to stop working. So will freezing. Compost piles will not work if frozen. However, the microorganisms can simply wait until the temperature rises enough for them to thaw out, then they'll go back to work. You can continue to add material to a frozen compost pile. After a thaw, the pile should work up a steam as if nothing happened.

A good blend of materials (a good c*arbon/nitrogen balance* in compost lingo) is required for a nice, hot compost pile. Since most of the materials commonly added to a backyard compost pile are high in carbon — leaves, for example — a source of nitrogen must be incorporated into the blend of ingredients. This isn't as difficult as it may seem. You can carry bundles of weeds to your compost pile and add hay, straw, leaves and food scraps, but you may still be short on nitrogen. Of course, the solution is simple: add manure. Where can you get manure? From an animal. Where can you find an animal? Look in a mirror.

Rodale states in *The Complete Book of Composting* that the average gardener may have difficulty in obtaining manure for the compost heap, but with *a little ingenuity and a thorough search,* it can be found. A gardener in the book testifies that when he gets *all steamed up to build myself a good compost pile, there has always been one big question that sits and thumbs its nose at me: Where am I going to find the manure? I am willing to bet, too, that the lack of manure is one of the reasons why your compost pile is not the thriving humus factory that it might be.*

Hmmm. Where can a large animal such as a human being find animal manure? Gee, that's a tough one. Let's think hard about that. Perhaps with a little "ingenuity and a thorough search" we can come up with a source. Where is that mirror, anyway? Might be a clue there.

One way to understand the blend of ingredients in your compost pile is by using the C/N (carbon/nitrogen) ratio. Quite frankly, the chance of the average person measuring and monitoring the carbon and nitrogen quantities of her organic material is almost nil. If composting required this sort of drudgery, no one would do it.

However, by using all of the organic refuse a family produces, including humanure, urine, food scraps, weeds from the garden, and grass clippings, with some materials from the larger agricultural community such as a little straw or hay, and maybe some rotting sawdust or some collected leaves from the municipality, one can get a good mix of carbon and nitrogen for successful composting.

CARBON/NITROGEN RATIOS

Material	%N	C/N Ratio
Activated Sldg.	5-6	6
Amaranth	3.6	11
Apple Pomace	1.1	13
Blood	10-14	3
Bread	2.10	---
Cabbage	3.6	12
Cardboard	0.10	400-563
Coffee Grnds.	---	20
Cow Manure	2.4	19
Corn Cobs	0.6	56-123
Corn Stalks	0.6-0.8	60-73
Cottonseed Ml.	7.7	7
Cranberry Plant	0.9	61
Farm Manure	2.25	14
Fern	1.15	43
Fish Scrap	10.6	3.6
Fruit	1.4	40
Garbage (Raw)	2.15	15-25
Grass Clippings	2.4	12-19
Hardwood Bark	0.241	223
Hardwoods (Avg)	0.09	560
Hay (General)	2.10	---
Hay (legume)	2.5	16
Hen Manure	8	6-15
Horse Manure	1.6	25-30
Humanure	5-7	5-10
Leaves	0.9	54
Lettuce	3.7	---
Meat Scraps	5.1	---
Mussel Resid.	3.6	2.2
Mustard	1.5	26
Newsprint	.06-.14	398-852
Oat Straw	1.05	48
Olive Husks	1.2-1.5	30-35
Onion	2.65	15
Paper	---	100-800
Pepper	2.6	15
Pig Manure	3.1	14
Potato Tops	1.5	25
Poultry Carcasses	2.4	5
Purslane	4.5	8
Raw Sawdust	0.11	511
Red Clover	1.8	27
Rice Hulls	0.3	121
Rotted Sawdust	0.25	200-500
Seaweed	1.9	19
Sewage Sludge	2-6.9	5-16
Sheep Manure	2.7	16
Shrimp Residues	9.5	3.4
Slaughter Waste	7-10	2-4
Softwood Bark	0.14	496
Softwoods (Avg.)	0.09	641
Soybean Meal	7.2-7.6	4-6
Straw (General)	0.7	80
Straw (Oat)	0.9	60
Straw (Wheat)	0.4	80-127
Telephone Books	0.7	772
Timothy Hay	0.85	58
Tomato	3.3	12
Turkey Litter	2.6	16
Turnip Tops	2.3	19
Urine	15-18	0.8
Vegetable Prod.	2.7	19
Water Hyacinth	---	20-30
Wheat Straw	0.3	128-150
Whole Carrot	1.6	27
Whole Turnip	1.0	44

NITROGEN LOSS AND CARBON/NITROGEN RATIO

Initial C/N Ratio	Nitrogen Loss (%)
20.0	38.8
20.5	48.1
22.0	14.8
30.0	0.5
35.0	0.5
76.0	-8.0

Source: Gotaas, Composting, 1956, p. 92

Sources: Gotaas, Harold B. (1956). Composting - Sanitary Disposal and Reclamation of Organic Wastes (p.44). World Health Organization, Monograph Series Number 31. Geneva. *and* Rynk, Robert, ed. (1992). On-Farm Composting Handbook. Northeast Regional Agricultural Engineering Service. Ph: (607) 255-7654. pp. 106-113. Some data from Biocycle, Journal of Composting and Recycling, July 1998, p.18, 61, 62; and January 1998, p.20

COMPARISONS OF DIFFERENT MANURES

Manure	% Moisture	% N	% Phos	% K
Human	66-80	.5-7	3-5.4	1.0-2.5
Cattle	80	1.67	1.11	0.56
Horse	75	2.29	1.25	1.38
Sheep	68	3.75	1.87	1.25
Pig	82	3.75	1.87	1.25
Hen	56	6.27	5.92	3.27
Pigeon	52	5.68	5.74	3.23
Sewage	---	.5-10	2.5-4.5	3.0-4.5

Source: Gotaas, Harold B. (1956). Composting - Sanitary Disposal and Reclamation of Organic Wastes . pp. 35, 37, 40. World Health Organization, Monograph Series Number 31. Geneva.

COMPOSITION OF HUMANURE

Fecal Material

0.3-0.6 pounds/person/day
(135-270 grams), wet weight

Organic Matter (dry wt.)	88-97%
Moisture Content	66-80%
Nitrogen	5-7%
Phosphorous	3-5.4%
Potassium	1-2.5%
Carbon	40-55%
Calcium.	4-5%
C/N Ratio	5-10

Urine

1.75-2.25 pints per person per day
(1.0-1.3 liters)

Moisture	93-96%
Nitrogen	15-19%
Phosphorous	2.5-5%
Potassium	3-4.5%
Carbon	11-17%
Calcium	4.5-6%

Source: Gotaas, Composting, (1956), p. 35.

DECOMPOSITION RATES OF SELECTED SAWDUST

SAWDUST	RELATIVE DECOMPOSITION RATE
Red Cedar	3.9
Douglas Fir	8.4
White Pine	9.5
Western White Pine	22.2
Average of all softwoods	12.0
Chestnut	33.5
Yellow Poplar	44.3
Black Walnut	44.7
White Oak	49.1
Average of all hardwoods	45.1
Wheat straw	54.6

The lower the number, the slower the decomposition rate. Hardwood sawdust decomposes faster than softwood sawdust.

Source: Haug, Roger T. (1993). The Practical Handbook of Compost Engineering. CRC Press, Inc., 2000 Corporate Blvd. N.W., Boca Raton, FL 33431 U.S.A. as reported in BioCycle - Journal of Composting and Recycling. December, 1998. p. 19.

A good C/N ratio for a compost pile is between 20/1 and 35/1.[11] That's 20 parts of carbon to 1 part of nitrogen, up to 35 parts of carbon to 1 part of nitrogen. Or for simplicity you can figure on shooting for an optimum 30/1 ratio. You can think of carbon as something that originates from plants and that will burn if dry. Ashes don't burn; they're what's left after burning, so there's no carbon there. Rocks don't burn, so lime is not a carbon source. Most agricultural or natural plant residues, if dried out, will burn. Those are your carbon sources.

For microorganisms, carbon is the basic building block of life and is a source of energy, but nitrogen is also necessary for such things as proteins, genetic material, and cell structure. For a balanced diet, microorganisms that digest compost need about 30 parts of carbon for every part of nitrogen they consume. If there's too much nitrogen, the microorganisms can't use it all and the excess is lost in the form of smelly ammonia gas. Nitrogen loss due to excess nitrogen in a compost pile (a low C/N ratio) can be over 60 percent. At a C/N ratio of 30 or 35 to 1, only 0.5 percent of the nitrogen may be lost. You don't want too much nitrogen in your compost — the nitrogen will escape into the air as ammonia gas, and nitrogen is too valuable for plants to allow it to disappear into the atmosphere.[12] If you have a high-nitrogen feedstock such as humanure, chicken manure, urine, and so on, just add more carbon. How much? Enough that you can't smell anything — it really is that simple. Use your nose; it's a great tool!

Humanure and urine alone will not compost. They're too wet and they contain too much nitrogen and not enough carbon, and microorganisms, like humans, gag at the thought of eating it. Since there's nothing worse than the thought of several billion gagging microorganisms, a carbon material must be added to the humanure to make it into an appealing dinner. Plant by-products such as hay, straw, weeds or even paper products if ground to the proper consistency, will provide the needed carbon. Food scraps in general are already C/N balanced, so they can be readily added to your compost pile.

Sawmill sawdust has a moisture content of 40 to 65 percent, which is good for compost.[13] Lumber yard sawdust, on the other hand, is kiln-dried and is biologically inert due to dehydration. Therefore, it is not as desirable in compost unless rehydrated with water (or urine from your compost toilet) before being added to the compost pile. If you have a supply of kiln-dried sawdust being used as a cover material in a compost toilet, leave the sawdust outside in an open-topped, drained container and let it get rained on, rehydrated, and biologically activated. It makes a much better biofilter for odor control when it has a higher amount of moisture in it, and it's better for your compost pile. For simplicity, just dump the sawdust in an open pile outside and let it get wet that way, assuming it rains there.

Lumber yard sawdust nowadays can sometimes be contaminated with wood preservatives such as chromated copper arsenate (CCA) from "pressure treated lumber." Both chromium and arsenic are human carcinogens, so avoid such lumber and sawdust. The EPA began a voluntary phaseout of CCA lumber for residential use as of December 2004, but there is still lots of it around.[14]

Some backyard composters refer to organic materials as "browns" and "greens." The browns (such as dried leaves) supply carbon, and the greens (such as fresh grass clippings) supply nitrogen. It's recommended that two to three volumes of browns be mixed with one volume of greens to produce a mix with the correct C/N ratio for composting.[15] However, since most backyard composters are not humanure composters, many have a pile of material sitting in their compost bin showing little activity. What is usually missing are nitrogen and moisture, two critical ingredients to any compost pile. Both are provided by humanure when collected with urine and a carbon cover material. The humanure mix can be quite brown but is also quite high in nitrogen. So, the "brown/green" approach isn't necessary when composting humanure along with other household organic material. Let's face it, humanure composters are in a class by themselves.

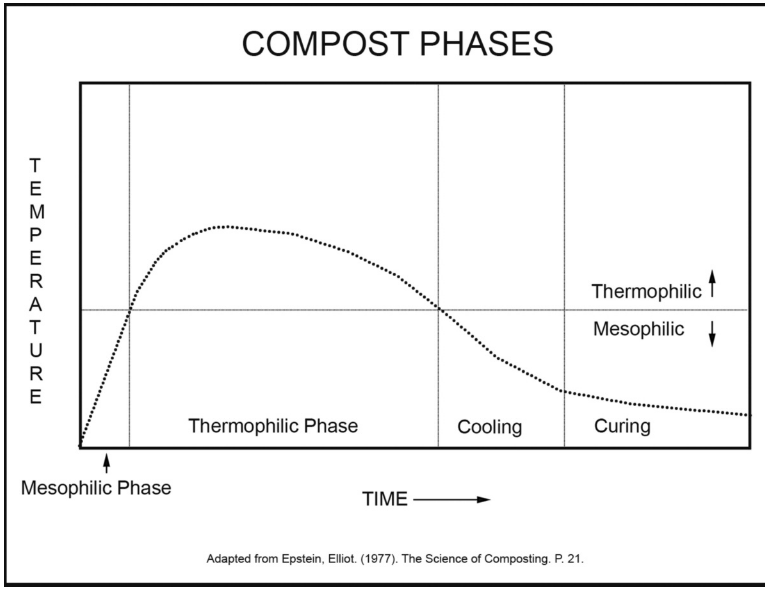
What about sanitary napkins and disposable diapers? Sure, they'll compost, but they'll leave strips of plastic throughout your finished compost, which are quite unsightly. Of course, that's OK if you don't mind picking the strips of plastic out of your compost, something I did for years when I was composting commercially available menstrual pads. Otherwise, use cloth diapers and washable cloth menstrual pads.

I personally have never composted disposable diapers because I never used them. My kids all used cloth diapers when they were babies. Fecal material was scraped off the diapers with toilet paper into the compost toilet. The diapers were then soaked in a "diaper bucket" in water, eventually wrung out, laundered, and reused. The soiled water from the diaper bucket was dumped into the compost pile.

Toilet paper composts, too. So do the cardboard tubes in the center of the rolls. Unbleached, recycled toilet paper is ideal. Or you can use the old-fashioned toilet paper, otherwise known as corncobs. Popcorn cobs work best, they're softer. Corncobs don't compost very readily though, so you have a good excuse not to use them. There are other things that don't compost very well: eggshells, bones, and hair to name a few. But these things won't hurt your compost pile. Throw them in.

Compost professionals have seized on the idea that "wood chips" are good for making compost. Nowadays, when novice composters want to begin making compost, the first thing they want to know is where can they get wood chips. But wood chips don't compost well at all, unless ground into fine particles, as in sawdust. Even commercial composters admit they must screen out the wood chips after the compost is finished because they didn't decompose. They insist on using them anyway, because they break up the compost consistency and maintain air spaces in their large masses of organic material. A home composter should avoid wood chips and use other bulking materials that degrade more quickly, such as hay, straw, sawdust, and weeds.

Never put woody-stemmed plants, such as tree saplings, in your compost pile. I hired a young lad to clear some brush for me one summer and he innocently put the small saplings on my compost pile. Later, I found them networked through the pile like iron rods. I'll bet the lad's ears were itching that day — I sure had some nasty things to say about him. Fortunately, only the compost pile heard me.



PHASES OF COMPOST

There is a huge difference between a backyard composter and a municipal composter. Municipal composters handle large batches of organic materials all at once, while backyard composters continuously produce small amounts of organic material every day. Municipal composters, therefore, could be termed "batch" composters, while backyard composters would be "continuous" composters. When organic material is composted in a batch, four distinct stages of the composting process are apparent. Although the same phases occur during continuous composting, they are not as apparent as they are in a batch, and in fact they may be occurring concurrently rather than sequentially.

The four phases include: (1) the preliminary mesophilic phase; (2) the hot thermophilic phase; (3) the cooling phase; and (4) the curing phase.

Compost bacteria combine carbon with oxygen to produce carbon dioxide and energy. Some of the energy is used by the microorganisms for reproduction and growth; the rest is given off as heat. When a pile of organic material begins to compost, mesophilic bacteria reproduce and multiply, raising the temperature of the composting mass up to about 111°F (44°C). This is the first stage of the composting process. These mesophilic bacteria can include *E. coli* and other bacteria from the human intestinal tract, but these soon become increasingly inhibited by the temperature, as the thermophilic bacteria take over in the transition range of 111°F to 125.6°F (44°C-52°C).

This begins the second stage of the process, when thermophilic microorganisms become very active and produce a lot of heat. This stage can then continue to about 158°F (70°C) in larger compost piles,[16] although such high temperatures are not common in smaller backyard compost bins. This heating stage takes place rather quickly and can last a few days, weeks, or many months depending on the amount and nature of the material being composted. The hot area tends to be localized in the central portion of a backyard compost bin, which is where you should be adding your fresh material. In batch compost, the entire composting mass may become thermophilic at once.

The thermophilic phase wipes out pathogens rather quickly, after which most of the organic material will appear to have been digested, but the coarser organic material will not. This is when the third stage of composting, the cooling phase, takes place. During this phase, the microorganisms that were chased away by the thermophiles migrate back into the compost and get to work digesting the more resistant organic materials. Fungi and macroorganisms such as earthworms and sow bugs also break the coarser elements down into compost.

After the thermophilic stage has been completed, only the readily available nutrients in the organic material have been digested. There's still a lot of food in the pile, and a lot of work to be done by the creatures in the compost. It takes many months to break down some of the more resistant organic materials such as "lignin," which comes from wood materials. Like humans, trees have evolved with a skin that is resistant to bacterial attack, and in a compost pile these lignins resist breakdown by thermophiles. However, other organisms, such as fungi, can break down lignin, given enough time.

The final stage of the composting process is called the curing, aging, or maturing stage, and it is an important one. Commercial composting professionals often want to make their compost as quickly as possible, sometimes sacrificing the compost's curing time. One municipal compost operator remarked that if he could shorten his compost time to four months, he could make three batches of compost a year instead of the two he was then making, increasing his output by 50 percent. Municipal composters see truckloads of organic material coming into their facilities daily, and they want to make sure they don't get inundated. Therefore, they feel a need to move their material through the composting process as quickly as possible to make room for the new stuff. Household composters don't have that problem, although there seem to be plenty of backyard composters who are obsessed with making compost as fast as possible. Yet, curing is a critically important stage of the compost-making process and should not be hastened.

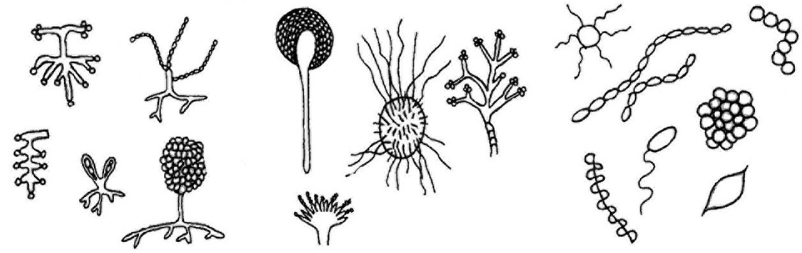
A long curing period adds a safety net for pathogen elimination. Many human pathogens have only a limited period of viability in the soil, and the longer they are subjected to the microbiological competition of the compost pile, the more likely they will die a swift death.

Immature or uncured compost produces substances called phytotoxins that are toxic to plants. It can also rob the soil of oxygen and nitrogen and can contain high levels of organic acids. So relax, sit back, put your feet up, and let your compost reach full maturity before you even think about using it. It doesn't cost anything to wait.

Let the microbes tell *you* when they're done. Keep a compost thermometer in your pile, and leave it there once you've finished building it. Shove it right into the center of the pile so the dial is against the surface of the cover material. Don't move it. As the pile shrinks, the dial will appear to move up from the surface, although the surface is really moving down, and the dial isn't moving at all. This shows you the amount of shrinkage that is occurring. Also, the dial will show you the temperature of the pile. Once that temperature has reached ambient (outdoor air temperature), then your pile is likely finished. If in doubt, take a sample from the pile, put it in a pot or cup, and germinate a seed in it, maybe a cucumber, squash, or pumpkin seed. If the compost is

COMPOST MICRORGANISMS

Magnified 1,000 Times



Actinomycetes
100 thousand - 100 million
per gram of compost

Fungi
10 thousand - 1 million
per gram of compost

Bacteria
100 million - 1 billion
per gram of compost

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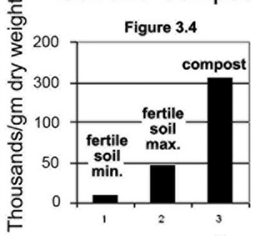
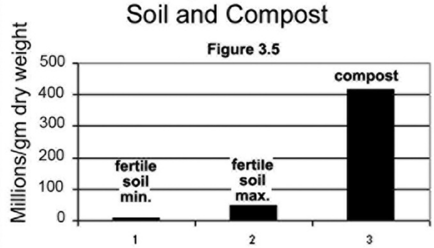
Fungi Populations in Fertile Soil and Compost



Bacteria Populations in Fertile Soil and Compost



Source: U.S. EPA (1998). EPA53 0-B-98-001, March, 1998

MICROORGANISMS IN COMPOST

Actinomycetes

Actinobifida chromogena
Microbispora bispora
Micropolyspora faeni
Nocardia sp.
Pseudocardia thermophilia
Streptomyces rectus
S. thermofuscus
S. thermoviolaceus
S. thermovulgaris
S. violaceus-ruber
Thermoactinomyces sacchari
T. vulgaris
Thermomonospora curvata
T. viridis

Fungi

Aspergillus fumigatus
Humicola grisea
H. insolens
H. lanuginosa
Malbranchea pulchella
Myriococcum thermophilum
Paecilomyces variotti
Papulaspora thermophila
Scytalidium thermophilum
Sporotrichum thermophile

Source: Palmisano, Anna C. and Barlaz, Morton A. (Eds.) (1996). Microbiology of Solid Waste. Pp. 125-127. CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, FL 33431 USA.

Bacteria

Alcaligenes faecalis
Bacillus brevis
B. circulans complex
B. coagulans type A
B. coagulans type B
B. licheniformis
B. megaterium
B. pumilus
B. sphaericus
B. stearothermophilus
B. subtilis
Clostridium thermocellum
Escherichia coli
Flavobacterium sp.
Pseudomonas sp.
Serratia sp.
Thermus sp.

immature, the seedling will look unhealthy.

The easiest way to determine when to use the finished compost is to simply follow an annual system. Once a pile is fully built, wait approximately a year before using it. That means having bins sized correctly so they are filled in a year, then left alone while another bin, or bins, are filled the following year. Once the second bin or set of bins is filled, then the first can be emptied and the compost utilized.

If you keep stirring up your compost, you risk cooling it down prematurely. You may think it's finished after three months, but it would still be composting if you had just left it alone. I have seen undisturbed compost in cubic meter piles stay above 131°F (55°C) for six months or longer, and larger undisturbed piles for over a year. Let the microbes tell you when they're done. Use a compost thermometer and they'll signal you that way. If the compost temperature is above the outside air temperature, the microbes are still busy. You don't need to stir or "turn" contained compost piles. There are plenty of reasons not to. Since this is a contentious and important topic, the turning of compost piles will be addressed in another chapter.

Compost is normally populated by three general categories of microorganisms: bacteria, actinomycetes, and fungi. Actinomycetes are intermediates between bacteria and fungi because they look like fungi and have similar nutritional preferences and growth habits. They tend to be more commonly found in the later stages of compost and are generally thought to follow the thermophilic bacteria in succession. They, in turn, are followed predominantly by fungi during the last stages of the composting process.

There are at least 100,000 known species of fungi; most of them are microscopic.[17] Most fungi cannot grow at 122°F (50°C) because it's too hot, although *thermophilic* fungi are heat tolerant. Fungi tend to be absent in compost above 140°F (60°C) and actinomycetes tend to be absent above 158°F (70°C). Above 180°F (82°C) biological activity effectively stops.[18]

To get an idea of the microbial diversity normally found in nature, consider this: A teaspoon of native grassland soil contains six hundred to eight hundred million bacteria comprising ten thousand species, plus perhaps five thousand species of fungi, the mycelia of which could be stretched out for several miles. In the same teaspoon, there may be ten thousand individual protozoa of perhaps a thousand species, plus twenty to thirty different nematodes from as many as one hundred species. Sounds crowded to me. Good compost will reinoculate depleted, sanitized, chemicalized soils with a wide variety of beneficial microorganisms.[19]

Pathogen Elimination

This section would be appropriate in the next chapter, *Compost Miracles*, as it certainly seems miraculous that Mother Nature provides us with a simple, free, non-chemical, non-pharmacological, non-technical, biological tool for the elimination of disease organisms — a tool accessible to almost anyone, anywhere, if they only knew it existed. But it does exist, and it is perhaps this characteristic of compost that most gives it its unique value and sets it apart from other forms of organics recycling. This is also why professionals in the compost industry don't want non-composted degraded organic material incorrectly characterized as "compost."

Compost kills human disease organisms (pathogens). This is well-established science, and very important. This is what makes composting such a valuable endeavor, especially the composting of humanure and other organic materials that are potential carriers of pathogens.

A common question often asked is, *How do you know that all potential pathogens have been killed in all parts of a compost pile?* The answer should be obvious: You don't. You never will. Unless, of course, you examine every cubic centimeter of your compost for pathogens in a laboratory. How do you know that all pathogenic bacteria on your hands were removed when you washed them? You don't, but that doesn't mean you stop washing your hands. Nor do you refrain from composting because you can't guarantee 100 percent removal of potential pathogens. Composting is a sanitation procedure, like hand-washing, or teeth-brushing. It works, so that's why we do it. There are practical procedures that will improve sanitation in compost piles, which we will discuss in the *Tao of Compost* chapter.

A combination of factors causes pathogen elimination in compost, including:

- Competition for food from compost microorganisms;
- Inhibition and antagonism by compost microorganisms;
- Consumption by compost organisms;
- Biological heat generated by compost microorganisms; and
- Antibiotics produced by compost microorganisms.

For example, when pathogens were grown in an incubator without compost at 122°F (50°C) and separately in compost at 122°F, they died in the compost after only seven days, but lived in the incubator for seventeen days. This indicated that it is more than just temperature that determines the fate of pathogenic bacteria. The other factors listed above undoubtedly affect the viability of non-indigenous microorganisms, such as human pathogens, in a compost pile. Those factors benefit from a diverse microbial population, which is best achieved by temperatures below 140°F (60°C). One researcher states that *significant reductions in pathogen numbers have been observed in compost piles which have not exceeded [104°F] 40°C.*[20]

There is no doubt that the heat produced by thermophilic bacteria kills pathogenic microorganisms, viruses, bacteria, protozoa, worms, and eggs that may inhabit compost feedstocks. A temperature of 122°F (50°C), if maintained for twenty-four hours, is said to be sufficient to kill all of the pathogens, according to some sources (this issue is covered more fully in the *Worms and Disease* chapter). A lower temperature will take longer to eliminate pathogens. A temperature of 115°F (46°C) may take nearly a week to reduce pathogens to non-detectable levels; a higher temperature may take only minutes. What we have yet to determine is how low those temperatures can be and still achieve satisfactory pathogen elimination over time. Some researchers insist that all pathogens will die at ambient temperatures (normal air temperature) eventually.

When Westerberg and Wiley composted sewage sludge which had been inoculated with polio virus, *Salmonella*, roundworm eggs, and *Candida albicans*, they found that after forty-three hours of composting, "no viable indicator organisms could be detected," with the polio virus being inactivated in the first hour. They concluded that a compost temperature of 140°F to 158°F (60°C to 70°C) maintained for three days would kill all of the pathogens.[21] This phenomenon has been confirmed by many other researchers, including Gotaas, who indicates that pathogenic bacteria are unable to survive compost temperatures of 131-140°F (55-60°C) for more than thirty minutes to one hour.[22] The first goal in making compost from humanure, therefore, should be to create a compost pile that will heat sufficiently to eliminate potential human pathogens that may be found in the manure.

Nevertheless, the heat of the compost pile is a highly lauded characteristic of compost that can be overblown. People may believe that it's only the heat of the compost pile that destroys pathogens, so they want their compost to become as hot as possible. This is a mistake. In fact, compost can become too hot, and when it does, it destroys the biodiversity of the microbial community. As one scientist states, *Research has indicated that temperature is not the only mechanism involved in pathogen suppression, and that the employment of higher than necessary temperatures may actually constitute a barrier to effective sanitization under certain circumstances.*[23] Perhaps only one species (e.g., *Bacillus stearothermophilus* otherwise known as *Geobacillus*) may dominate the compost pile during periods of excessive heat, thereby driving out or outright killing the other inhabitants of the compost, which include fungi and actinomycetes as well as the bigger organisms that you can actually see.

A compost pile that is too hot can destroy its own biological community and leave a mass of organic material that must be re-populated to continue the necessary conversion of organic matter to compost. Such sterilized compost is more likely to be colonized by unwanted microorganisms, such as *salmonella*, as researchers have shown that the biodiversity of compost acts as a barrier to colonization by such unwanted bacteria. In the absence of a biodiverse “indigenous flora,” such as caused by excess heat, *salmonella* were able to regrow.[24]

The microbial biodiversity of compost is also important because it aids in the breakdown of the organic material. For example, in high-temperature compost 176°F (80°C), only about 10 percent of sewage sludge solids could be decomposed in three weeks, whereas at 122° to 140°F (50°-60°C), 40 percent of the sludge solids were decomposed in only seven days. The lower temperatures apparently allowed for a richer diversity of living microbes which in turn had a greater effect on the degradation of the organic material.

One researcher indicated that optimal decomposition rates occur in the 131° to 138°F (55°-59°C) temperature range, and optimal thermophilic activity occurs at 131°F, which are both adequate temperatures for pathogen destruction.[25] A study conducted at Michigan State University, however, suggested that optimal decomposition occurs at an even lower temperature of 113°F (45°C).[26] Another researcher asserts that maximum biodegradation occurs at 113° to 131°F (45°-55°C), while maximum microbial diversity requires a temperature range of 95° to 113°F (35°-45°C).[27] Apparently, there is still some degree of flexibility in these estimates, as compost science is not an utterly precise one at this time. Control of excessive heat, however, is unlikely to be a concern for the backyard composter, as smaller masses of organic material do not develop temperatures as high as larger masses.

Some thermophilic actinomycetes, as well as mesophilic bacteria, produce antibiotics that display considerable potency toward other bacteria. Up to one half of thermophilic strains can produce antimicrobial compounds, some of which have been shown to be effective against *E. coli* and *Salmonella*. One thermophilic strain with an optimum growth temperature of 122°F (50°C) produces a substance that *significantly aided the healing of infected surface wounds in clinical tests on human subjects. The product(s) also stimulated growth of a variety of cell types, including various animal and plant tissue cultures and unicellular algae.*[28] The production of antibiotics by compost microorganisms theoretically assists in the destruction of human pathogens that may have existed in the organic material before composting.

Even if every speck of the composting material is not subjected to the high internal temperatures of the compost pile, the composting process nevertheless contributes immensely toward the creation of a sanitary organic material. Or, in the words of one group of composting professionals, *The high temperatures achieved during composting, assisted by the competition and antagonism among the microorganisms [i.e., biodiversity], considerably reduce the number of plant and animal pathogens. While some resistant pathogenic organisms may survive, and others may persist in cooler sections of the pile, the disease risk is, nevertheless, greatly reduced.* [29]

If a backyard or community composter has any doubt or concern about the existence of pathogenic organisms in his or her finished compost, s/he can use the compost for horticultural purposes rather than for food purposes. Compost can grow an amazing batch of berry bushes, flowers, shrubs, or trees. Furthermore, lingering pathogens continue to die after the compost has been applied to the soil, which is not surprising since human pathogens prefer the warm and moist environment of the human body. As World Bank researchers put it, "Even pathogens remaining in compost seem to disappear rapidly in the soil."[30] Compost can also be tested for pathogens by compost testing labs.

Some say that a few pathogens in soil or compost are OK. "Another point most folks don't realize is that no compost and no soil are completely pathogen free. You really don't want it to be completely pathogen free, because you always want [the human body's] defense mechanism to have something to practice on. So, a small number of disease-causing organisms is desirable. But that's it."[31] Pathogens are said to have "minimum infective doses," which vary widely from one type of pathogen to another, meaning that a number of pathogens is necessary to initiate an infection. The idea, therefore, that compost must be sterile is incorrect. It must be sanitary, which means it must have a greatly weakened, reduced, or destroyed pathogen population.

The average backyard composter usually knows whether his or her family is healthy. Healthy families have little to be concerned about and can feel confident that their compost can be safely returned to the soil, provided the simple instructions in this book are followed regarding compost temperatures, retention times, and compost management, as discussed in the *Tao of Compost* chapter.

Earthworms and Vermiculture

Worms don't make compost; humans do. So "worm composting" is both incorrect and misleading. This sort of misunderstanding permeates American culture. For example, according to the US Department of Agriculture, *"Called vermicomposting, composting with worms is easy and is an environmentally sound way to get rid of most kitchen wastes."*[32] But it's not *composting* by worms; it's worm *digestion*. The end product is worm *castings*, not compost. I should add that it's not disposal of waste, either; it's recycling of food scraps. I'm fighting an uphill battle trying to clean up and evolve the language, and I know it's a tough job, but somebody has to do it!

Vermiculture involves the use of redworms such as *Eisenia fetida* or *Lumbricus rubellus* to consume organic material, either in specially designed worm boxes, or in large-scale outdoor piles. Redworms prefer a dark, cool, well-aerated space, and thrive on moist bedding such as shredded newspaper. Kitchen food scraps placed in worm boxes are consumed by the worms and converted into worm castings, which can then be used like finished compost to grow plants. Vermiculture is popular among children who like to watch the worms, and among adults who prefer the convenience of being able to make worm castings under their kitchen counter or in a household closet.

Although vermiculture involves microorganisms as well as earthworms, it is not the same as composting. The hot stages of composting will drive away all earthworms from the hot area of the compost pile. However, they can migrate back in after the compost cools down. Earthworms are reported to actually eat root-feeding nematodes, pathogenic bacteria, and fungi, as well as small weed seeds.[33]

When compost is piled on bare earth, a large surface area is available underneath the pile for natural earthworms to migrate in and out of the compost. Properly prepared compost situated on bare earth should require no inoculation of earthworms since they will naturally migrate into the compost when it best suits them. My compost is so full of natural earthworms at certain stages in its development that, when dug into, it can look like spaghetti. Earthworms can play an important role in making compost, and their castings can contribute to a compost pile, but their castings alone are not compost.

Practice makes Compost

A compost neophyte may become overwhelmed with all that is involved in composting: bacteria, actinomycetes, fungi, thermophiles, mesophiles, C/N ratios, oxygen, moisture, temperatures, bins, pathogens, curing, and biodiversity. How do you translate this into your own personal situation? How does one become an accomplished composter, a master composter? That's easy — just do it. Then keep doing it. Set the books aside (not this one, of course) and get some good, old-fashioned experience. There's no better way to learn. Book learning will only get you so far, but not far enough. A book such as this one is for inspiring you, for sparking your interest, and for reference. But you have to get out there and do it if you really want to learn.

Work with the compost, get the feel of the process, look at your compost, smell the finished product, buy or borrow a compost thermometer and get an idea of how well your compost is heating up, then use your compost for food production. Rely on your compost. Make it a part of your life. Need it and value it. In no time, without the need for charts or graphs, Ph.D.s, or worry, your compost will be as good as the best of them. Perhaps someday we'll be like the Chinese who give prizes for the best compost in a county, then have inter-county competitions. Now that's getting your shit together. Literally.