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For more information, see our online book Composting in the Classroom or view the video It's Gotten Rotten.

Table of Contents

Why Composting?

Composting is a topic of growing interest in schools throughout the country. Why composting? There are a number of reasons.
Composting provides a partial solution to an issue of great concern in many communities. All around the country, landfills are filling up, garbage incineration is becoming increasingly unpopular, and other waste disposal options are becoming ever harder to find.

Composting provides a way not only of reducing the amount of waste that needs to be disposed of but also of converting it into a product that is useful for gardening, landscaping, or house plants.
By addressing the solid waste issue, composting provides a way of instilling in children a sense of environmental stewardship. Many educational programs focus on reducing, reusing, and recycling our solid wastes. Composting fits in with this idea but takes it a step beyond.

With composting, children can do more than just sending cans or newspapers off for recycling -- they can see the entire cycle, from "yucky" food scraps or other organic wastes...

... to something that is pleasant to handle and is good for the soil. Contrary to the "out of sight, out of mind" philosophy, children who compost become aware of organic wastes as potential resources rather than just as something "gross" to be thrown away and forgotten. They learn through direct experience that they personally can make a difference and have a positive effect on the environment.

Another reason for composting in schools is that it provides a rich topic for scientific investigation and discovery. Although composting is simple (you just put organic matter in a pile and wait for it to decompose), it also involves some fascinating and as yet incompletely understood interactions between biological, chemical, and physical processes.

Composting is appealing to a wide range of ages. Worm bins are a popular form of composting with young children, who are fascinated with the worms' feeding and reproductive habits. School children feed their lunch scraps to classroom worms and use the worms for projects ranging from measurement to story writing.

Teens can use composting as a focus for scientific exploration or research projects on a wide range of topics in biology, chemistry, and physics. In outdoor compost systems, there is a complex food web at work. Some of the more familiar soil invertebrates, such as millipedes, sow bugs, snails, and slugs help to shred the organic matter into smaller sized pieces, creating greater surface area for action by microorganisms, which are in turn eaten by invertebrates such as mites and springtails. Children can observe compost organisms at work and study their life cycles or carry out food preference experiments.

The vast bulk of the decomposition work in compost is carried out by microorganisms including fungi, bacteria, and actinomycetes (organisms that resemble fungi but actually are filamentous bacteria). Microbes can be plated for study of individual species, or their populations can be charted through something as simple as daily temperature measurements.

Under optimal conditions, a compost pile will heat up to temperatures in the range of 50-65°C (120-150°F), caused by the metabolic heat of the microbes. You can see evidence of this when a steamy mist rises from your compost pile as you turn it or dig into it. Students conducting composting experiments can use daily temperature readings to compare how quickly the system heats up, how hot it gets, and how long it retains its heat. Some classes have made this into a competition, for example to see whose compost reaches the hottest temperature or stays hot the longest.

If you want your compost to heat up, then some knowledge of the process is important. The heat is produced by the metabolism of microorganisms as they decompose organic matter. Chemistry plays a role in composting because for rapid microbial growth you need to provide the right mix of nutrients, primarily carbon and nitrogen. Not all of the carbon or nitrogen present may be in a form that is readily available to microbes, and it is not well understood how the various chemical forms are used or how availability is affected by other variables such as particle size, pH, or moisture content. This is an area in which many questions remain, and research by students could provide a real contribution to the field.

Physics is also important in composting. Physical characteristics of the compost ingredients, including moisture content and particle size, affect the rate at which composting occurs. Other physical considerations include the size and shape of the system, which affect the rate of aeration and the tendency of the compost to retain or dissipate the heat that is generated.

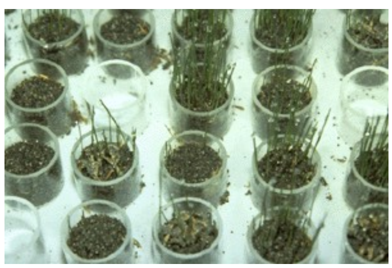
Many topics exist for scientific discovery, such as how mixing a pile affects the shape of its temperature curve. If you turn the pile, the temperature temporarily drops, then rises again. How often should a pile be turned in order to maximize the rate of decomposition? This is a topic that students could investigate.

A common assumption is that composting makes sense only out in the country or in suburban areas where people have large yards. Some of the most avid composters, however, live in the heart of inner cities, where the compost they make helps to restore or replace worn-out or contaminated soils for school or community gardens. These gardens and accompanying compost systems appear in former vacant lots, and even on roof tops and balconies of schools and community buildings.

Composting can successfully be carried out at a wide range of scales, from multi-acre commercial or municipal windrows to simple backyard heaps. It can also be carried out indoors in garbage can bioreactors or worm bins.

For research purposes, composting can even be carried out in soda bottle bioreactors, which are small and inexpensive enough to enable students to build their own individualized systems.

Once made, compost can be used for gardening projects or for plant growth experiments ranging from nutrient analysis of compost-enriched soils to use of composts to suppress plant diseases.



To sum it all up, composting is a topic that addresses a real-world issue and helps to instill a sense of environmental stewardship in youth. It can be carried out at a wide range of scales, indoors or out, in any geographic location. Because it is a process that relies on biology, chemistry, and physics, it can be used for a wide range of scientific projects or experiments and can help students to see the interconnections between various scientific fields.

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Teachers Page - Rationale for School Composting

Composting as a Waste Management Technique

- A major issue facing modern society is waste management. More simply put, what should we do with the waste we produce? A growing emphasis has been placed on the three R's: Reduce, Reuse, and Recycle. Composting provides a means of accomplishing all three of the R's. Through composting the amount of garbage sent to the landfill is reduced, the organic matter is reused rather than dumped, and it is recycled into a useful soil amendment.
- Natural ecosystems have a proven method of breaking down organic materials into a useful end-product: the decomposers found within the food chain break down nature's organic waste and turn it into humus, the organic component of soil.
- Composting is a way of harnessing the natural process of decomposition to speed up the decay of waste. The history of composting dates back to the history of early agriculture. Many find that composting is as much of an art as a science. Recent concern about managing wastes and producing food in an environmentally sound manner has led to a renewed interest in small-scale, backyard composting as well as an interest in developing large-scale, commercial and municipal composting systems.
- Designing successful composting systems requires an understanding of certain biological, chemical, and physical processes such as the movement of air, uptake of carbon and nitrogen, and heat production and transfer. Students can be a part of the process of obtaining scientific information about composting, whether their results are applied in their own home, school, or by industry. At the same time, students engage in hands-on, minds-on composting activities with an opportunity to improve their understanding of many scientific processes and disciplines.
- The study of waste production and management lends itself to interdisciplinary study, and school composting provides an opportunity for real-world problem solving with cooperative learning groups. It therefore can motivate students who feel alienated by traditional "science" experiences. Furthermore, students gain an awareness of individuals' roles in the world today as they learn how waste is produced and how it can be reduced. Finally, through construction of compost systems, students are empowered to make a positive change in their world. For it is, after all, our youth to whom this planet belongs.

Composting as a Topic for Independent Study

- Contemporary high school science teachers are being challenged to change the way science is taught. These challenges come both from educational policy-makers and from the students. Policy-makers see a need to create a scientifically-literate populace. They envision a future generation able to analyze confusing arguments presented by the media or politicians about the efficacy of new policies designed to solve societal problems. Policy-makers also see the need for training the next generation of scientists to work in industry and academia. Students, on the other hand, want science that is relevant to their lives. They want to see the connection between what goes on in the classroom and the realities they face outside of school.

- Students who have the opportunity to conduct meaningful, applied scientific research develop many of the analytical thinking skills called for in today's complex society. They also get a chance to see whether they may be suited for a career as a research scientist. At the same time, if the research in which they are engaged is relevant to issues they face in their daily lives, their motivation for conducting research will be high.
- Many of the activities on this WWW site were written by a group of high school teachers who spent several years conducting research at Cornell University, and then engaged their classroom and after-school science club students in similar research. The research focused on an important societal issue -- finding ways to handle the 20-40% of our waste stream comprising food and yard wastes. Properly managed through composting, these wastes can be converted into valuable soil amendments.
- The composting research we conducted at Cornell University lends itself well to classroom research for a number of logistical and educational reasons. First, it does not involve any expensive equipment; all the materials are readily available. In addition, although long-term composting research projects are possible, there are many experiments that can be conducted within one-two weeks or less. Composting is not limited to rural areas. In cities it is carried out in community gardens, and even in containers on rooftops and balconies. There is an endless number of experiments that students can design focusing on composting, and because much remains unknown about the science of composting, the students' results will be original and meaningful. For example, students can conduct experiments on determining mixtures of wastes and types of composting systems that promote rapid decomposition. Once they have set up a composting system, students can use the compost for experiments including assessing microbial activity in decomposing organic wastes, observing the behavior of soil invertebrates, and determining how the microorganisms and invertebrates relate to each other in the composting food web. They can also determine the effect of the composts they have produced on plant germination and growth. The possibilities for designing experiments with different independent variables are endless.
- In addition to experiencing the scientific process, students engaged in composting research gain some important other skills. By discussing how their results relate to the larger issue of waste management, students develop an appreciation for the role of science in policy-making. Students can also examine their contribution to solving solid waste problems, through applying what they learn to their personal consumption and waste reduction habits. Additionally, they can acquire social skills that will aid them in the workplace and their personal lives, through working together in cooperative learning groups while conducting their research. They can develop presentations of their research results, and incorporate them into portfolios to be used for assessment purposes.
- Students can also improve their understanding of some of the basic sciences through their composting research. Designing successful composting systems requires an understanding of biological, chemical, and physical processes, such as uptake of carbon and nitrogen by microorganisms, the movement of air, and heat production and transfer. We have incorporated composting into a number of subjects, including biology, environmental studies, earth sciences, horticulture, microbiology, and science research. Students participating in a summer engineering research program designed compost systems using computer assisted design (CAD) programs. Composting, and the overriding issue of waste management, can also be approached from the social sciences, including economics, social studies, and history.

Setting the Scene

- Trash Goes to School: K-12 Solid Waste Lesson Plans

Lab Activities

Observing Compost Invertebrates
by Elaina Olynciw

Background
In outdoor compost piles, a wide range of invertebrates take part in the decompostion of organic matter. Try monitoring invertebrate life in the pile over the course of the compost process. How long is it before you locate the first invertebrates? What happens to them when the pile heats up? Do you find different organisms later on, after the pile cools down?
In indoor container composting you may find fewer (or no) invertebrates, and decomposition is accomplished by microbes alone.

Materials

- light-colored trays or pans
- tweezers, spoons, or tongue depressors

Procedure
One method of collecting invertebrates is to take grab samples of compost from various locations in the heap. Some organisms such as centipedes and sowbugs will be more likely to be found near the surface. Others will be found deeper in the heap. Spread each compost sample in a large tray or pan, preferably light in color for maximum contrast. Students should use wooden tongue depressors, plastic spoons, or other instruments that will not hurt the organisms, to sort through the compost. Flashlights and magnifying lenses can be used to enhance the observation. The larger organisms, such as worms, centipedes, millipedes, sowbugs, earwigs, spiders, ants, beetles, snails, slugs, some mites, etc., can be observed with the naked eye. To get a closer look, place samples of the compost in petri dishes or watch glasses and observe them under a dissecting microscope.

An alternative method of separating small arthropods in compost is by using a "Berlese funnel". This method will provide a higher concentration of arthropods to view. Place a funnel with a 10-30 cm upper diameter in a ring stand. Attach a circle of 10mm wire mesh (hardware cloth) or window screen 8 cm below the funnel. Just below the funnel, place a vial to collect the specimens. Position a light source (25 watt) 2.0 - 2.5 cm above the funnel, or place the collecting apparatus in a sunny location. The light and heat drive the negatively phototaxic compost organisms downward through the funnel and into the collecting jar. If you use too strong a light source, the organisms will dry up and die before making it through the funnel.

Place compost in the funnel and then partially fill the vial with water if you want to observe live organisms. Observe the organisms about 2 to 4 days later. They will remain alive and float on top of the water. You can place them in a petri dish or watch glass and observe them under a dissecting microscope or with a magnifying glass. You should find small arthropods, including many different kinds of mites, a few different insect larvae, springtails, small millipedes, ants, etc.

The organisms can be lifted out with a paint brush and maintained in small chambers of plaster of paris (mixed with powdered charcoal to aid observation). This substrate must be kept continually moist to keep the arthropods alive. Adding brewer's yeast to the substrate provides a food supply for many species.

A mixture of 90% percent ethanol and 10% glycerol can be used to collect the arthropods if preserved organisms are needed for quantitative study. A grid of 1.0cm squares can be set up on a petri dish for counting. Removal of organisms can be accomplished with an angled sewing needle that has been filed flat. The pointed end can be imbedded in a cork or wooden dowel or matchstick. Thin, drawn out pipettes can also be used and rinsed out with alcohol if organisms get stuck.

Observing Compost Microorganisms

This protocol was written by Elaina Olynciw, biology teacher at A. Philip Randolph High School, New York City, while working in the laboratory of Dr. Eric Nelson at Cornell University as part of the Teacher Institute of Environmental Sciences.

Introduction

Observe the microbial communities in your compost over the course of several weeks or months as the compost heats up and then later returns to ambient temperature. Can you identify differences in microbial communities at various stages of the composting process?

Materials

- compound microscope
- .85% NaCl (physiological saline)
- methylene blue stain (Prepare stain by adding 1.6 g methylene blue chloride to 100 ml of 95% ethanol, then mixing 30 ml of this solution with 100 ml of 0.01% aqueous solution of KOH)

Procedure

1. Make a wet mount by putting a drop of water or physiological saline on a microscope slide and transfering a small amount of compost to the drop. Make sure not to add too much compost or you will not have enough light to observe the organisms.
2. Stir the compost into the water or saline (the preparation should be watery) and apply a cover slip.
3. Observe under low and high power. You should be able to find many nematodes (they should be very wiggly), flatworms, rotifers (notice the rotary motion of cilia at the anterior end of the rotifer and the contracting motion of the body), mites, springtails and fast-moving protozoans. Pieces of fungi mycelia can be seen, but might be difficult to recognize. Bacteria can be seen as very tiny, roundish particles, which seem to be vibrating in the background.
4. If you want to observe the bacteria directly, you can prepare a stained slide and observe the slide using a 100X oil immersion lens. To prepare a stained slide, mix a small amount of compost with a drop of physiological saline on a slide. Spread with a toothpick. Let the mixture air dry until you see a white dried film on the slide. Next fix the bacteria to the slide by passing the slide through a hot flame a few times. Stain the slide using methylene blue stain. Flood the slide with the methylene blue stain for one minute and then rinse with distilled water and gently blot dry using blotting or filter paper.

5. Fungi and actinomycetes may be difficult to recognize with the above technique because the entire organism (including the mycelium, reproductive bodies and cells) will probably not remain together. Fungi and actinomycetes will be observed best if you can find fungal growth on the surface of the compost heap. The growth looks fuzzy, powdery, or like a spiderweb. Lift some compost with the sample on top, and and prepare a slide with cover slip to view under the microscope. You should be able to see the fungi well under 100X and 400X. The actinomycetes can be heat-fixed and gram-stained to view under oil immersion at 1000X.
6. To separate nematodes, rotifers, and protozoans, a continuous column of water leading from the compost to the collection vial is necessary, and the following adaptation of the above method should be used: The compost is put into a beaker with the screen stretched across the top and taped in place. The beaker is then turned over into the funnel. Plastic tubing is placed at the end of the funnel stem and a screw clamp is placed a few inches below the end of the funnel stem on the pastic tubing.The plastic tubing should lead into a collection vial or small beaker. The clamp is closed and water is poured into the funnel until the beaker is about 1/2 filled. After a few days the clamp is slightly and slowly opened and organisms which have concentrated at the end of the tubing should fall into the vial.

Techniques for Detailed Study of Compost Microorganisms

These protocols were written by Elaina Olynciw, biology teacher at A. Philip Randolph High School, New York City, while working in the laboratory of Dr. Eric Nelson at Cornell University as part of the Teacher Institute of Environmental Sciences.

Collecting Samples

Microorganisms are not distributed uniformly throughout compost; they commonly occur in clumps or colonies ranging from few to thousands of individual cells. The populations vary greatly depending upon the amount of undecomposed organic matter and the micro-environment in a specific location. How wet the sample is, and whether it contains anaerobic or aerobic regions, also will affect the types of microbial life that are found. Multiple samples therefore should be taken to determine microorganism numbers or activity in compost.

Calculating Dry Weight

Water content of different composts may vary greatly. When comparing how much microbial activity there is in a gram of compost, you must allow for the difference in water content so that you can accurately compare what is happening in equal amounts of two different composts while discounting the weight of the water.

To determine the ratio of wet to dry weight of a compost, a sample of wet compost is weighed and then dried for 24 hours in a 105-110C oven. It is then reweighed, and the ratio between wet and dry weight is calculated.

When using the actual (wet) compost in a study, the moisture ratio is used to calculate how much compost to use. For example:

Amount of vegetable waste compost needed = 5 g

Predetermined wet weight of a sample = 4.3 g

Measured dry weight of the same sample = 2.8 g

Ratio of wet/dry = 1.54
Actual amount of compost needed for the experiment would be:
5 g x 1.54 or 7.7 g (wet weight)

Culturing Microorganisms

These protocols were written by Elaina Olynciw, biology teacher at A. Philip Randolph High School, New York City, while working in the laboratory of Dr. Eric Nelson at Cornell University as part of the Teacher Institute of Environmental Sciences.

The procedures to use in culturing micooganisms depend on which types of organisms you wish to study.

Culturing Bacteria
To culture bacteria, the following media should be used to prepare agar plates:
Growth Media: 1/10-strength Trypticase Soy Agar (TSA) Media:

Ingredients:
2 g Trypticase Soy Agar
7.5 g Bacto Agar
500 ml distilled water

Mix the ingredients, autoclave for 20 minutes, and pour into sterile petri dishes.

Plate out the bacteria using a 10^{-7} dilution starting with 5 g dry weight of the compost in 45 ml of an autoclaved .06M $NaHPO_4/NaH_2PO_4$ buffer of 7.6 pH. (approximately 4:1 dibasic:monobasic). Put this first dilution in a blender for 40 sec. at high speed.

Perform serial dilutions to 10^{-7} and add 0.1 ml of the dilution per plate. Incubate at 28C for 4 days. Count the colonies as colonies per unit after 4 days. Prepare slides of specific colonies the same day.

Culturing Actinomycetes
Growth Media: 1/50-strength TSAPoly B

Ingredients:
0.4 g Typticase Soy Agar
10.0 g Bacto Agar
500 ml distilled water
10 mg Polymixin B in 10 ml 70% Ethanol

Mix the first 3 ingredients, autoclave for 20 minutes, and cool to room temperature. Add the antibiotic and pour into sterile petri dishes.

Plate out the actinomycetes using a 10^{-7} dilution starting with 5 g dry weight of compost in 45 ml of the autoclaved buffer. Put this first dilution in a blender at high speed for 40 sec.

Perform serial dilutions to 10^{-7} and add 0.1 ml of the final dilution to each plate.

Incubate the plates at 28C for 14 days.

Take counts and samples of actinomycetes colonies after 14 days. Many of the colonies will look powdery white. However, some may take on a rough appearance and produce a variety of pigments.

Note: If you are comparing mesophilic compost to thermophilic compost, you should prepare double the usual number of plates so that you can incubate plates at both 28C and 50C.

Culturing Fungi
Growth Media: 1/3-strength PDARP

Ingredients:
6.5 g Potato Dextrose Agar
5.0 g Bacto Agar
500 ml distilled water
15 mg Rifampicin in 10 ml Methanol
15 mg Penicillin G in 10 ml 70% Ethanol

Mix the first 3 ingredients, autoclave for 20 min. and cool to room temperature. Add the antibiotics and pour into sterile petri dishes.

Plate out the fungi using a 10^{-4} dilution starting with 5 g dry weight of compost in 45 ml of the autoclaved phosphate buffer. Put this first dilution in a blender at high speed for 40 sec.

Perform serials dilutions to 10^{-4} and add 0.l ml of the final dilution to each plate.

Incubate the plates at 28C for 3 days.

Take counts and samples of fungal colonies at 3 days.

Preparing Slides of Microorganisms

These protocols were written by Elaina Olynciw, biology teacher at A. Philip Randolph High School, New York City, while working in the laboratory of Dr. Eric Nelson at Cornell University as part of the Teacher Institute of Environmental Sciences.

Bacteria
Use sterile techniques to prepare your slide! Use an inoculating needle to add a drop of saline to a clean slide. Take a sample of a single bacterial colony and mix it into the saline. Let air dry until a white film appears. Heat fix by passing the slide through a flame a few times.

Actinomycetes
Follow the above procedure but try to get a portion of the colony on the slide intact. You can try lifting it with a sterile scalpel. It will be too crowded to observe on most of the slide, but at the edges of the colony you will be able to see the pattern that the filaments form.

Fungi
Lift a portion of the colony intact onto a clean slide (it will still be attached to the agar), add a cover slip and observe without staining. Look at the edges of the colony where the sample will be thinner and there will be enough light to observe.

Staining Slides
Gram staining can be used to make slides of bacteria and actinomycetes:

Preparation of Gram Stains

Crystal Violet:

Dissolve 2 g of crystal violet in 20 ml of 95% ethanol. Add this solution to 80 ml of a 1% Ammonium Oxalate solution. Let stand for 24 hours and filter.

Gram Iodine:

Add 1 g Iodine and 3 g Potassium Iodide to 300 ml distilled water. Store in an amber bottle.

Decolorizer: 95% Ethyl Alcohol

Safranin:

Add 2.5 g safranin to 10 ml 95% ethanol. Add this solution to 100 ml distilled water

Procedure for Gram Staining

1. Flood slide with crystal violet - 20 sec.
2. Wash with distilled water - 2 sec.
3. Flood slide with Gram iodine - 1 min.
4. Decolorize by tilting slide and drop by drop rinsing with 95% ethanol until ethanol runs clear - about 10 to 20 sec.
5. Wash with distilled water - 2 sec.
6. Flood with safranin - 20 sec.
7. Wash with distilled water - 2 sec.
8. Blot dry.

Monitoring the Composting Process

As composting proceeds, a number of changes occur in its physical, chemical, and biological characteristics. Monitoring some of these variables will help you to assess the status of your compost and to compare the progress of systems with different initial conditions or ingredients.

Monitoring Compost Moisture

Composting proceeds best at a moisture content of 40-60% by weight. At lower moisture levels, microbial activity is limited. At higher levels, the process is likely to become anaerobic and foul-smelling.

When you are choosing and mixing your compost ingredients, you may wish to measure the moisture content. After the composting is underway, you probably don't need to repeat this measurement because you can observe whether appropriate moisture levels are being maintained.

If your compost starts to smell bad, chances are it's too wet. Excess water fills the pore spaces, impeding diffusion of oxygen through the compost materials and leading to anaerobic conditions. Mixing in additional bulking agent such as dry wood chips, cardboard pieces, or newspaper strips is likely to alleviate the problem. If you are composting in a bioreactor with drainage holes, you may notice leachate draining out. This liquid is often rich in nutrients and can be diluted for use on plants. You may find it useful to record the amount of leachate produced by each system, for comparison with initial moisture content, temperature curves, or other variables.

If you are blowing air through your compost system, you will need to be careful not to dry it out. If the temperature drops sooner than expected and the compost looks dry, moisture may have become the limiting factor. In this case try mixing in some water and see if the temperature rises again.

Monitoring Compost Temperature

Temperature is one of the key indicators in composting. Is the system heating up? How hot does it get? How long does it remain hot? How does mixing affect the temperature profile?

Heat is generated as a byproduct of microbial breakdown of organic material, and you can use the temperature of your compost to gauge how well the system is working and how far along the decomposition has progressed. For example, if your compost heats up to 40 or 50C, you can deduce that the ingredients contained adequate nitrogen and moisture for rapid microbial growth.

To take your temperature readings, make sure to use a probe that reaches deep into the compost. Leave the probe in place long enough for the reading to stabilize, then move it to a new location. Take readings in several locations, including at various depths from the top and sides. Compost may have hotter and colder pockets depending on the moisture content and chemical composition of ingredients. Can you find temperature gradients with depth? Where do you find your hottest readings? For systems in which air enters from the bottom, the hottest locations tend to be two-thirds or more of the way up. Is this true for your system?

By graphing compost temperature over time, you can tell how far along the decomposition has progressed. A well constructed compost system will heat up to 40 or 50C within two to three days. As readily decomposable organic matter becomes depleted, the temperature begins to drop and the process slows considerably.

The temperature at any point depends primarily on how much heat is being produced by microorganisms and how much is lost through aeration and surface cooling. How long the system remains hot therefore depends on the chemical composition of the ingredients as well as the size and shape of the system. Moisture content also affects temperature change; since water has a higher specific heat than most other materials, drier compost mixtures tend to heat up and cool off more quickly than wetter mixtures, providing adequate moisture levels for microbial growth are maintained.

Monitoring Compost pH

Why is compost pH worth measuring? Primarily because you can use it to follow the process of decomposition. Compost microorganisms operate best under neutral to acidic conditions, with pH's in the range of 5.5 to 8. During the initial stages of decomposition, organic acids are formed. The acidic conditions are favorable for growth of fungi and breakdown of lignin and cellulose. As composting proceeds, the organic acids become neutralized, and mature compost generally has a pH between 6 and 8.

If anaerobic conditions develop during composting, organic acids may accumulate rather than break down. Aerating or mixing the system should reduce this acidity. Adding lime (calcium carbonate) generally is not recommended because it causes ammonium nitrogen to be lost to the atmosphere as ammonia gas. Not only does this cause odors, it also depletes nitrogen that is better kept in the compost for future use by plants.

At any point during composting, you can measure the pH of the mixture. In doing this, keep in mind that your compost is unlikely to be homogeneous. You may have found that the temperature varied from location to location within your compost, and the pH is likely to vary as well. You therefore should plan to take samples from a variety of spots. You can mix these together and do a combined pH test, or test each of the samples individually. In either case, make sure to make several replicate tests and to report all of your answers. (Since pH is measured on a logarithmic scale, it doesn't make sense mathematically to take a simple average of your replicates.)

pH can be measured using any of the following methods. Whichever method you choose, make sure to measure the pH as soon as possible after sampling so that continuing chemical changes will not affect your results:

Soil Test Kit

Test kits for analysis of soil pH can be used without modification for compost samples. Simply follow the manufacturer's instructions.

pH Paper

If your compost is moist but not muddy, you can insert a pH indicator strip into the compost, let it sit for a few minutes to soak up water, then read the pH using color comparison.

Compost Extractions

Using a calibrated meter or pH paper, you can measure pH in a compost extract made by mixing compost with distilled water. It is important to be consistent in the ratio of compost to water and to account for the initial moisture content of the compost, but there is no universally accepted protocol specifying these procedures.

One approach is to read the pH in oven-dried samples that have been reconstituted with distilled water.

1. Spread compost in a thin layer in a pan, and dry for 24 hours in a 105-110°C oven.
2. Weigh or measure 5 g samples of oved-dried compost into small containers.
3. Add 25 ml distilled water to each sample.
4. Mix thoroughly for 5 seconds then let stand for 10 minutes.
5. Read the pH with a calibrated meter or with pH paper and record as compost pH in water, or pHw.

An alternative is to measure pH in samples that have not been dried. In this case, the amount of water that you add will need to vary to compensate for the varying moisture content of the compost. You will still need to dry some of the compost in order to measure moisture content, but you can take the pH readings on samples that haven't been altered by drying.

1. Calculate the % moisture of your compost:
   a) Weigh a small container.
   b) Weigh 10 g of compost into the container.
   c) Dry the sample for 24 hours in a 105-110°C oven, or for 5 minutes in a microwave oven. If you use a microwave oven, place a beaker containing 100 ml of water in the oven during the drying to protect the oven's magnetron.
   d) Reweigh the sample, subtract the weight of the container, and determine the moisture content using the following equation:$M = ((W_w - W_d)/W_w) \times 100$
   in which:
   M = moisture content (%) of compost sample
   W_W = wet weight of the sample, and
   W_d = weight of the sample after drying.

2. Use the % moisture to figure out how much water to add.
   For example, if your compost sample is 40% moisture, you will compensate by adding only 60% of the water you would need if the sample were air dried (0.60 x 5 ml = 3 ml water needed).
3. Weigh or measure 5 g samples of compost into small containers.
4. Add the calculated amount of distilled water to each sample.
5. Mix thoroughly for 5 seconds.
6. Let stand for 10 minutes.
7. Read the pH with pH paper or a calibrated meter and record as compost pH in water, or pHw.

Monitoring Compost Odors

A well-constructed compost system should not produce offensive odors, although it will not be odor-free. You can use your nose to detect potential problems as your composting progresses. For example, if you notice an ammonia odor, your mix probably is too rich in nitrogen (the C/N ratio is too low), and you should mix in a carbon source such as leaves or wood shavings. If you smell a musty odor, it may be because the mix is too moist, which you can correct by adding more of your bulking agent. Left uncorrected, compost that is too wet may go anaerobic, producing a foul sulfurous odor that is hard to ignore. If this occurs in indoor bioreactors, you may wish to take them outside or vent them to the outside, then aerate or mix thoroughly and add additional absorbent material such as wood chips or sawdust. In an outdoor compost pile, turning the pile may be sufficient to correct the anaerobic condition, although initially this may make the odor even more pronounced.

Observing Compost Invertebrates

by Elaina Olynciw

Background

In outdoor compost piles, a wide range of invertebrates take part in the decompostion of organic matter. Try monitoring invertebrate life in the pile over the course of the compost process. How long is it before you locate the first invertebrates? What happens to them when the pile heats up? Do you find different organisms later on, after the pile cools down?

In indoor container composting you may find fewer (or no) invertebrates, and decomposition is accomplished by microbes alone.

Materials

- light-colored trays or pans
- tweezers, spoons, or tongue depressors

Procedure

One method of collecting invertebrates is to take grab samples of compost from various locations in the heap. Some organisms such as centipedes and sowbugs will be more likely to be found near the surface. Others will be found deeper in the heap. Spread each compost sample in a large tray or pan, preferably light in color for maximum contrast. Students should use wooden tongue depressors, plastic spoons, or other instruments that will not hurt the organisms, to sort through the compost. Flashlights and magnifying lenses can be used to enhance the observation. The larger organisms, such as worms, centipedes, millipedes, sowbugs, earwigs, spiders, ants, beetles, snails, slugs, some mites, etc., can be observed with the naked eye. To get a closer look, place samples of the compost in petri dishes or watch glasses and observe them under a dissecting microscope.

An alternative method of separating small arthropods in compost is by using a "Berlese funnel". This method will provide a higher concentration of arthropods to view. Place a funnel with a 10-30 cm upper diameter in a ring stand. Attach a circle of 10mm wire mesh (hardware cloth) or window screen 8 cm below the funnel. Just below the funnel, place a vial to collect the specimens. Position a light source (25 watt) 2.0 - 2.5 cm above the funnel, or place the collecting apparatus in a sunny location. The light and heat drive the negatively phototaxic compost organisms downward through the funnel and into the collecting jar. If you use too strong a light source, the organisms will dry up and die before making it through the funnel.

Place compost in the funnel and then partially fill the vial with water if you want to observe live organisms. Observe the organisms about 2 to 4 days later. They will remain alive and float on top of the water. You can place them in a petri dish or watch glass and observe them under a dissecting microscope or with a magnifying glass. You should find small arthropods, including many different kinds of mites, a few different insect larvae, springtails, small millipedes, ants, etc.

The organisms can be lifted out with a paint brush and maintained in small chambers of plaster of paris (mixed with powdered charcoal to aid observation). This substrate must be kept continually moist to keep the arthropods alive. Adding brewer's yeast to the substrate provides a food supply for many species.

A mixture of 90% percent ethanol and 10% glycerol can be used to collect the arthropods if preserved organisms are needed for quantitative study. A grid of 1.0cm squares can be set up on a petri dish for counting. Removal of organisms can be accomplished with an angled sewing needle that has been filed flat. The pointed end can be imbedded in a cork or wooden dowel or matchstick. Thin, drawn out pipettes can also be used and rinsed out with alcohol if organisms get stuck.

Observing Compost Microorganisms

Introduction

Observe the microbial communities in your compost over the course of several weeks or months as the compost heats up and then later returns to ambient temperature. Can you identify differences in microbial communities at various stages of the composting process?

Materials

- compound microscope
- .85% NaCl (physiological saline)
- methylene blue stain (Prepare stain by adding 1.6 g methylene blue chloride to 100 ml of 95% ethanol, then mixing 30 ml of this solution with 100 ml of 0.01% aqueous solution of KOH)

Procedure

1. Make a wet mount by putting a drop of water or physiological saline on a microscope slide and transfering a small amount of compost to the drop. Make sure not to add too much compost or you will not have enough light to observe the organisms.
2. Stir the compost into the water or saline (the preparation should be watery) and apply a cover slip.
3. Observe under low and high power. You should be able to find many nematodes (they should be very wiggly), flatworms, rotifers (notice the rotary motion of cilia at the anterior end of the rotifer and the contracting motion of the body), mites, springtails and fast-moving protozoans. Pieces of fungi mycelia can be seen, but might be difficult to recognize. Bacteria can be seen as very tiny, roundish particles, which seem to be vibrating in the background.
4. If you want to observe the bacteria directly, you can prepare a stained slide and observe the slide using a 100X oil immersion lens. To prepare a stained slide, mix a small amount of

compost with a drop of physiological saline on a slide. Spread with a toothpick. Let the mixture air dry until you see a white dried film on the slide. Next fix the bacteria to the slide by passing the slide through a hot flame a few times. Stain the slide using methylene blue stain. Flood the slide with the methylene blue stain for one minute and then rinse with distilled water and gently blot dry using blotting or filter paper.

5. Fungi and actinomycetes may be difficult to recognize with the above technique because the entire organism (including the mycelium, reproductive bodies and cells) will probably not remain together. Fungi and actinomycetes will be observed best if you can find fungal growth on the surface of the compost heap. The growth looks fuzzy, powdery, or like a spiderweb. Lift some compost with the sample on top, and and prepare a slide with cover slip to view under the microscope. You should be able to see the fungi well under 100X and 400X. The actinomycetes can be heat-fixed and gram-stained to view under oil immersion at 1000X.
6. To separate nematodes, rotifers, and protozoans, a continuous column of water leading from the compost to the collection vial is necessary, and the following adaptation of the above method should be used: The compost is put into a beaker with the screen stretched across the top and taped in place. The beaker is then turned over into the funnel. Plastic tubing is placed at the end of the funnel stem and a screw clamp is placed a few inches below the end of the funnel stem on the pastic tubing.The plastic tubing should lead into a collection vial or small beaker. The clamp is closed and water is poured into the funnel until the beaker is about 1/2 filled. After a few days the clamp is slightly and slowly opened and organisms which have concentrated at the end of the tubing should fall into the vial.

Composting Health Considerations

by Tom Richard (modified)

Health concerns relating to compost are dependent both on the individual and on the material being composted. Dog and cat manures can contain harmful pathogens and should be avoided. While few human pathogenic organisms are found in vegetative wastes, normal sanitary measures (i.e., washing hands before touching food, eyes, etc.) are important. Although most people are unlikely to have any problems, there are a few concerns which place some individuals at risk.

Just as individuals vary in their resistance to disease, a few individuals may be particularly sensitive to some of the organisms in compost. The high populations of many different species of molds and fungi in an active compost process can cause allergic responses in some people, though most experience no adverse reaction. One of these fungal species, Aspergillus fumigatus, can infect the respiratory system of a sensitive person who is heavily exposed. Conditions that may predispose individuals to infection or an allergic response include: a weakened immune system, allergies, asthma, some medications such as antibiotics and adrenal cortical hormones, or a punctured eardrum. People with these conditions should avoid turning compost piles or take precautions to minimize exposure.

To minimize these potential risks, common OSHA approved dust masks can be worn under dry and dusty conditions, especially when the compost is being turned. If, following these precautions, individuals still develop an infection or have an allergic reaction to compost, they should consult a medical professional.

See also Cornell Waste Management Institute fact sheet, "Health and Safety Guidance for Small Scale Composting".

Ideas for Student Research Projects

Compost Ingredients

1. Garden supply stores and catalogs often sell compost "starters," which supposedly speed up the composting process. Develop a recipe for a compost starter and design a research project to test its effect on the compost temperature profile.
2. How well do human nutrition concepts apply to compost microorganisms? For example, will the microbes get a "sugar high," demonstrated by a quick, high temperature peak when fed sugary foods, compared with a longer but lower peak for more complex carbohydrates?
3. Measure the pH of a number of different compost mixes. How does the pH of initial ingredients affect the pH of finished compost?
4. Some instructions call for adding lime to increase the pH when compost ingredients are mixed. Other instructions caution to avoid this because it causes a loss of nitrogen. How does adding various amounts of lime to the initial ingredients affect the pH of finished compost?

Microorganisms

1. Composting recipes sometimes call for inoculating the pile by mixing in a few handfuls of finished compost. Is there any observable difference in appearance of microbes between systems that have and have not been inoculated?
2. Does the pH of the initial compost ingredients affect the populations of microorganisms during composting?

Compost Physics

1. What type of insulation works best for soda bottle bioreactors? Does it help to have a reflective layer? Do different insulative materials or different thicknesses affect the temperature profile?
2. When constructing compost bins or piles, some people incorporate perforated pipe, wire mesh, or other systems to increase passive air flow. What is the effect of different methods of aeration on the temperature profile of any one compost system?
3. How do various means and schedules for turning a pile affect the temperature profile and the time needed for production of finished compost?
4. What is the effect of forced aeration (with an aquarium pump or similar apparatus) on the temperature profile in a soda bottle or a two-can bioreactor?
5. Try mixing the same ingredients in a large outdoor pile, a two-can bioreactor, and a soda bottle bioreactor. Which system reaches the hottest temperatures? Which remains hot the longest? How does this affect the compost produced?
6. What is the effect of layering versus mixing organic ingredients on the compost pile temperature profile?

Worm Composting

1. Do organic wastes in compost break down more readily in the presence of worms than through composting that depends solely on microbial decomposition?
2. In some experiments, plants have not show increased growth when planted in fresh worm castings. Does aging or "curing" worm castings increase their ability to enhance plant growth? Are there chemical differences between fresh and older worm castings? Should worm compost be mixed with soil before being used to grow plants?
3. How do different food sources affect reproductive and growth rates of red worms (*Eisenia fetida*)?

4. Red worms grow best in wastes with pH between 5.0 and 8.0. How sensitive are their cocoons to pH? Will they hatch after being exposed to extreme pH? How sensitive are they to extreme drought or temperatures?
5. Effects of Compost on Plant Growth
6. Some leaves, such as those of black walnut or eucalyptus trees, contain chemicals that inhibit growth of other plants. Are these compounds broken down by composting?
7. Finished compost is near neutral pH. Can you design an experiment to answer one or more of the following questions: Is compost detrimental to use on acid-loving plants such as blueberries or azaleas? Does compost buffer the soil pH, making it harder to provide acidic conditions? How does it compare to peat moss in this regard?
8. Water in which compost has been soaked (often called compost tea) is said to be beneficial to plants. Can you design experiments to test whether different types, concentrations, and amounts of compost tea enhance plant growth?
9. In China, farmers dig parallel trenches and fill them with organic wastes mixed with cocoons of Eisenia fetida. Soybeans planted in rows between the trenches are highly productive. Can you design and test a planting system using vermicompost?

These are a few ideas about possibilities for student research projects on composting. For more ideas, plus detailed information about techniques for carrying out composting experiments, refer to our book, Composting in the Classroom: Scientific Inquiry for High School Students, by N.M. Trautmann and M.E. Krasny. ISBN 0-7872-4433-3. Available online from e-Commons (OUT OF PRINT)

Compost Quiz

This quiz consists of 13 true/false questions. The answers, with explanations, are on the next page.

1. Composting requires a lot of time and expensive equipment.
2. Yard wastes, such as leaves or grass clippings, make up a relatively small proportion of total refuse from a typical household and need not be considered for recycling.
3. Moisture is necessary for the composting process to occur.
4. Disposal of solid wastes is a problem that should be dealt with only through municipal government action.
5. If you are throwing away grass clippings, you are throwing away money.
6. To compost grass clippings, you should just put them in a pile in a back corner of your yard.
7. To be a composter, you need to live out in the country, or at least in an area with plenty of yard space.
8. All kitchen scraps and garbage should be included in home or school compost systems.
9. Diseased vegetable and flower plants should NOT be composted in typical home or school systems.
10. Weeds heavily laden with seeds should NOT be composted in typical home or school composting systems.
11. A tightly closed bin or enclosure is necessary for the production of good compost.
12. It is a good idea to use compost for starting flower and vegetable seedlings and transplants indoors.
13. For the composting process to occur most efficiently, special microorganisms, hormones, and activators need to be added to the compost pile.

Compost Quiz Answers

1. False: Composting can be as simple as making a pile of leaves and letting it sit until it decomposes. At the other end of the spectrum are the commercial or municipal composting facilities that use heavy duty equipment for shredding, mixing, aerating, and moving the organic matter as it composts.
2. False: Yard waste makes up 20-30% of a community's waste. On average, each rural or suburban household produces about 6000 pounds of yard waster per year, which could easily be composted to produce a useful soil amendment.
3. True: Composting occurs best at a moisture content of 50-60% (by weight). A simple way to check the moisture content of your compost mixture is to use the "squeeze test". When yo squeeze a sample of your organic matter, you should be able to squeeze out a few drops of water, similar to that from a damp sponge.
4. False: Each of us can play our individual part to reduce the volume of solid waste that we generate. Most kitchen and yard wastes can be recycled naturally through the process of composting. Composting at home or at a local community garden requires much less energy and is less expensive than bagging, hauling, and processing organic wastes at landfills.
5. True: You can save time and money by letting short grass clippings fall back to the lawn rather than bagging and discarding them. Clippings break down rapidly and provide nitrogen. If the clippings are ling and heavy, they should be composted rather than remaining as clumps on the lawn.
6. False: Because fresh grass clippings are quite moist and high in nitrogen, they should be mixed with a drier, browner material such as autumn leaves, wood chips, or sawdust for composting. Otherwise, the pile may become anaerobic and smell bad.
7. False: Many people compost at the heart of inner cities, in community gardens or even on the roofs or balconies of schools and apartment buildings. Worm bins fit in small indoor spaces and can be used successfully in apartments or classrooms with no outdoor land.
8. False: Although most food wastes can be composted, in small-scale compost systems you should avoid grease, fat, bones, fish, and meat scraps. These materials attract dogs and nuisance animals, and often develop odors while composting. Fats are slow to break down and greatly increase the length of time required before compost can be used.
9. True: Diseased plants from the garden should not be used for compost if the compost is to be returned to the garden. Most diseases are killed by heating during compost formation, but unless the compost is turned frequently and allowed to remain unused for several years, some of these disease organisms may be returned to the garden with the compost.
10. True: Although most plants and their seeds are killed during composting, some can be returned alive to the garden with the compost. Most weeds that have been pulled or cut before developing seeds can be composted without problem.
11. False: Building a compost pile is not an exact process. It can be as simple as making a pile of leaves and garden clippings, or it can involve building or buying a bin or enclosure. If a bin is used, it should be designed to allow adequate air circulation.
12. False: Young seedlings and transplants are very susceptible to the disease microorganisms that are found in most soils and composts. To reduce the possibility of infection, it is best to use a commercially prepared sterilized potting mix when starting seedlings and transplants. It is very difficult to efficiently sterilize compost.
13. False: The microorganisms that are needed to break wastes into compost are present in great numbers in all garden soil. In fact, there usually are sufficient microbes floating in the air to start the

decomposition process. A few handfuls of garden soil added to the compost pile will ensure inoculation of the pile with microorganisms, eliminating the need to purchase any sort of 'compost starter.'

Composting Indoors

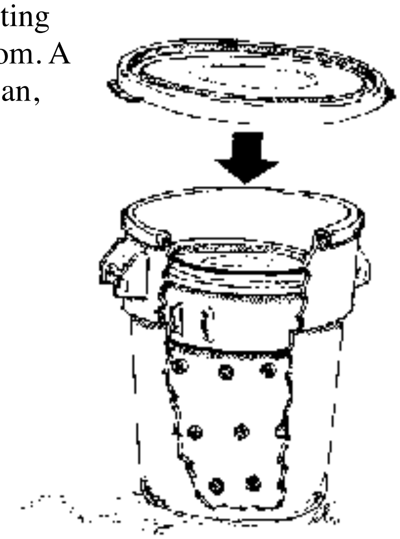
When you think of composting, chances are you envision one of a variety of bins or holding systems that are used for composting outdoors. For fastest composting, these bins need to provide adequate moisture, heat retention, and air flow to facilitate aerobic, heat-producing decomposition of organic matter. Composting can also be carried out right in the classroom, in containers ranging in size from soda bottles to garbage cans. Because these units are so much smaller than the outdoor bins, they need to be carefully designed to provide proper conditions for aerobic, heat-producing composting to occur.

Three types of composting vessels, or bioreactors, are described here:

Building a Two-Can Bioreactor

Purpose

Two-can bioreactors are designed to be used as small-scale indoor composting units for families, and for composting as an educational tool in the classroom. A two-can Bioreactor will process enough organic matter to fill a 20-gallon can, producing finished compost within two to three months.



Materials

- 32-gallon plastic garbage can
- 20-gallon plastic garbage can
- drill
- brick
- spigot (optional)
- duct tape (optional)
- insulation (optional)

Construction

1. Using a drill, make 15 to 20 holes (0.5" to 1" diameter) through the bottom of the 20-gallon can. Next drill three rows of holes through the sides of this can, six to eight inches apart with four to five inches between rows, ending about two inches below where the can expands at the top.
2. Place a brick or some other object in the bottom of the 32-gallon can. This is to separate the leachate from the compost and allow for its measurement and addition back into the compost pile. The leachate, often referred to as "compost tea," is rich in nutrients which may be in a form readily usable by plants. If not used right away on growing plants, pour the leachate back into the

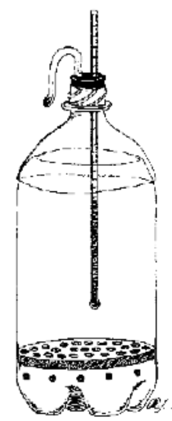
compost. Excessive leachate can be responsible for foul smells. If your system produces enough leachate to cause odor problems, your initial compost mixture was probably too wet.

3. Variations on the design:
    - Add insulation to the barrels (inner and outer) with duct tape.
    - Include a spigot to draw off the leachate.
    - Add a layer of old compost, wood chips, or soil inside the outer barrel. This will allow the leachate to be absorbed and may cause fewer leachate/odor issues.

Note: A system of 10-gallon plastic garbage cans that can fit inside 20-gallon cans can be substituted if space is a problem. The smaller system may operate at lower temperatures. This should not affect the final product; it will just take longer before the product can be used.

The composting process in the cans will take from three to five weeks. After this period, you can transfer the compost to other containers or an outdoor pile for several weeks of curing while starting up a new batch of compost in the 2-can system.

Building a Soda Bottle Bioreactor



Purpose

Soda bottle bioreactors are designed to be used as tools for composting research. They are small and inexpensive enough to enable students to design and carry out individualized research projects, comparing variables such as reactor design, moisture content, and nutrient ratios of mixtures to be composted.

The design described here is meant to be used as a starting point only -- please improvise and allow your students to use their own ideas in designing and building their bioreactors.

Materials (per student or group of students)

- two 2-liter or 3-liter soda bottles
- one smaller container, about 5-cm high, that fits inside the soda bottle
- one Styrofoam plate or tray
- drill or nail for making holes
- duct tape or clear packaging tape
- utility knife
- insulation materials such as sheets of fiberglass or foam rubber, or Styrofoam peanuts
- fine-meshed screen or fabric large enough to cover top of soda bottle and air holes in bottom half
- thermometer that will fit into the top of the soda bottle and be long enough to reach down into the center of the compost
- chopped vegetable scraps such as lettuce leaves, carrot or potato peelings, and apple cores, or garden wastes such as weeds or grass clippings

- bulking agent such as wood shavings or 1-2 cm pieces of paper egg cartons, cardboard, or wood
- optional: hollow tubing to provide ventilation

Construction

1. Using a utility knife or sharp-pointed scissors, cut the top off one soda bottle just below the shoulder and the other just above the shoulder. Using the larger pieces of the two bottles, you will now have a top from one that fits snugly over the bottom from the other.
2. Place a smaller container (roughly 4-5 cm high) upside down into the bottom of the soda bottle. This will form a stand to support the tray that will hold the compost. You can use any plastic container that will fit inside the bottle and provide adequate support for the styrofoam stand and overlying compost.
3. The next step is to make a styrofoam circle. Trace a circle the diameter of the soda bottle on a styrofoam plate or try and cut it out, forming a piece that fits snugly inside the soda bottle. Use a nail to punch holes through the styrofoam for aeration.
4. Assemble the bottom of your bioreactor by placing the stand into the soda bottle, then resting the styrofoam circle on top of the stand. Make a mark on your bottle to indicate where the styrofoam circle sits. Above this point is where the compost will be, and below it is where you want to make air holes.
5. Make air holes in the sides of the soda bottle in the area below the mark that you made. This can be done with a drill or by carefully heating a nail and using it to melt holes through the plastic. Avoid making holes in the very bottom of the bottle unless you plan to use a tray underneath to collect whatever leachate may be generated during composting. Reassemble the bioreactor pieces, making sure that you have provided sufficient air holes to allow air to enter the bottle and flow up through the stand and styrofoam circle.
6. Fill the bioreactor with the mixture you wish to compost. A variety of materials will work, but in general you want a bulking agent to provide air flow plus some vegetable scraps to provide food

Bulking Agents	Food for the Microbes
Wood shavings	Lettuce scraps
Small wood chips	Carrot peelings
Newspapaer strips	Apple cores
Pieces of paper egg cartons	Bread crusts
Chopped straw	Banana peels
	Weeds
	Grass clippings

for the microbes (see following table for some possibilities). In these mini-bioreactors, composting proceeds best if the bulking agent and food scraps are cut or chopped into roughly 1-2 cm pieces. Soak the bulking agent in water until thoroughly moist, then drain off excess water.

7. Mix roughly equal amounts of bulking agent and food scraps, then fill your reactor. Remember that you want air to be able to diffuse through the pores in the compost, so make sure to keep your mix light and fluffy and do not pack it down.
8. Put the top piece of the soda bottle back on and seal it in place with tape.
9. Cover the top hole with a piece of screen or nylon stocking, rubber banded into place. Alternatively, if you are worried about potential odors you can ventilate your bioreactor using rubber tubing out the top. Simply use the screw-on soda bottle cover with a hole drilled through it for a piece of rubber tubing, which leads out the window or into a ventilation hood.
10. If you want to eliminate the possibility of flies becoming a problem, you can cover all air holes with a piece of nylon stocking or other fine-meshed fabric.
11. Insulate the bioreactor, making sure not to block the ventilation holes. (Because these soda bottle bioreactors are much smaller than the typical compost pile, they will work best if insulated to retain the heat that is generated during decomposition.) You can experiment with various types and amounts of insulation.

Now you are ready to watch the compost process at work! You can chart the daily progress of your compost by taking temperature readings, inserting a thermometer down into the compost through the top of the soda bottle. Using temperature charts, you can compare variables such as the types of compostable materials, moisture levels, amounts of air flow, and insulation systems. Because the bottles are so small, you may not end up with a product that looks as finished as the compost from larger piles or bioreactors. You should find, though, that the volume shrinks by 1/2 to 2/3 and that the original materials are no longer recognizable. You can let the compost age in the soda bottles for several months, or transfer it to other containers for curing while starting up a new batch of compost in the soda bottles.

High-Tech Bioreactors

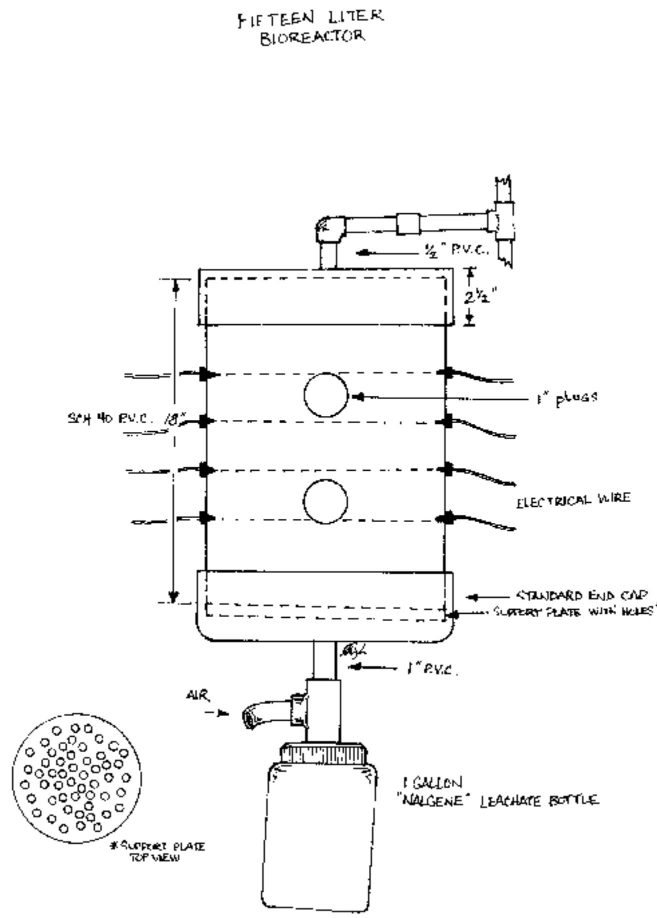
A bioreactor is a name given to an enclosed composting vessel. The difference between a bioreactor and a typical composting system is that more parameters of the composting process can be measured and controlled in bioreactors. Even though the degradation of organic wastes has been happening since the introduction of life on our planet, it still is not completely understood. Using a bioreactor enables students and teachers to study and manipulate composting parameters inside a classroom or lab setting.

This is a complicated construction project, and access to a machine shop is highly recommended. For simpler classroom composting systems, try Soda Bottle Bioreactors or Garbage Can Bioreactors (above).

Materials

- 18" length of 12" diameter PVC plastic sewer pipe
- 1 PVC end cap for 12 PVC pipe
- 1/4 to 3/8 inch thick plastic plate (2' x 2')
- PVC fittings:

- 3.5" x 3" nipple
    - 1.5” threaded elbow
    - threaded 0.5" coupler
    - 2.5" x 6” nipple
    - 1.5" threaded T
    - 1" x 3" nipple
    - 1” threaded T
    - 1" x 6" nipple
    - 1" to 0.25"reducer
    - 1.25" nozzle
    - two 1" plugs
- Epoxy for PVC pipe (small can)
- roll of Teflon tape
- tube of silicon caulk
- 1 gal. Nalgene bottle with cap
- thermocouple wire and male and female connectors (T type-constantine/copper)
- thermocouple reader
- clear plastic tubing:
    - 5 to 6 feet 3/4"
    - 4 feet 3/8"
- basic tools: crescent wrenches, permanent markers, power drill, drill bits, etc.



Procedure

Building the Bioreactor

1. On a band saw, cut 3" off the end cap. Save this ring as it will be used to make the top cap.
2. Drill a hole in the center of the end cap large enough for a 1" tap. With a 1" tap thread hole for 1" PVC nipple.
3. Using the same drill bit, drill two holes in the side of the 18" of PVC pipe. The first one should be 7 inches from the edge and the other should be 14 inches from the same edge directly above the first. Using the 1" tap, thread the hole. These are where the 1" plugs will be placed.
4. Using the ring formed from the cut on the end cap, draw the outline of the outer diameter on the plastic plate with the permanent marker. Cut this out with a band saw or jig saw. Glue this to the ring using the epoxy (&laqno;DO THIS OUTSIDE OR IN AN AREA WITH PLENTY OF VENTILATION!) Allow to dry overnight. Drill a hole in the center of this plate large enough for a 1/2" tap. With a 1/2" tap, thread this hole.
5. Place the 18" section of PVC pipe upright on the plastic plate. Using the marker, draw on the plate the inside diameter of the PVC pipe. Cut this plastic plate using the same equipment used in #4. With a drill press, drill 1/4" holes uniformly over the entire plate. {how many?, spacing?}
6. Using a band saw, cut 1" off the 18" section of PVC pipe. This will be used as your support for the plate you made in #5. Cut a section out of this ring so that it will fit snugly inside the remaining 17" of

PVC pipe. (It will be an inside ring.) Using the epoxy, glue this ring inside the remaining 17" of PVC pipe so that the bottom edge is flush with the bottom of the pipe.

7. Glue the bottom end cap with epoxy to the 17" section on the side with the plate ring. Use excess epoxy for a tight seal.
8. Using a hand drill with a 1/8" drill bit, drill four holes on each side of the reactor body directly across from one another. These should be arranged so that you can obtain temperature readings from above, the top 1/3, the center, and the bottom 1/3 of the composting material.

Constructing the Exhaust and Condensate Collection System

1. Put Teflon tape on all threaded fittings.
2. Thread a 1/2" x 3" nipple into 1/2" elbow, thread a 1/2" x 6" nipple into other end of elbow, put a coupler onto this 6" nipple, and to this coupler add a 1/2" x 6" nipple. To this nipple, thread on the 1/2" T at the middle junction and to each side of the T, add the other two 1/2" x 3" nipples.
3. Thread the nipple closest to the elbow into the top of the reactor. The 6" nipples should be in a position perpendicular to the floor. To the 6" nipple facing down, put a condensate collection bottle. (This doesn't have to be air tight). To the 6" nipple, pointing upward, place the 3/4" tubing over the top and the other end will be put outdoors.

Constructing the Leachate Collection and Air Input Systems

1. Drill a hole in the top of the nalgene bottle large enough for the 1" tap. (It's easier if cap is left on the bottle during drilling.) Using a 1" tap, thread the hole.
2. Thread the 1" x 3" nipple into the end of the 1" T, the reducer into the middle port of the T, the 1/2" nozzle into the reducer, the 1" x 6" nipple into the top of the T.
3. Connect the 6" nipple to the bottom of the end cap and the gal. Nalgene bottle to the 3" nipple. (These must be airtight; use silicon caulk.)

A reactor stand is recommended, but its design is up to the individual. The only criteria are that it be near an outside wall for the ventilation of the exhaust gases from the reactor and that it hold the reactor high enough for the leachate bottle to be installed.

You are now ready to begin composting and experimenting!

Worm Bins

Worm Bins are another form of indoor composting. Here the decomposition is accomplished by redworms as well as microorganisms, and the temperatures do not get as high as in the bioreactors above. Worm bins are popular in elementary school classrooms, where the students use them for activities ranging from scientific measurement to story writing.

Worm Composting Basics

by Jen Fong and Paula Hewitt

What is worm composting?

Worm composting is using worms to recycle food scraps and other organic material into a valuable soil amendment called vermicompost, or worm compost. Worms eat food scraps, which become compost as they pass through the worm's body. Compost exits the worm through its' tail end. This compost can then be used to grow plants. To understand why vermicompost is good for plants, remember that the worms are eating nutrient-rich fruit and vegetable scraps, and turning them into nutrient-rich compost.

Materials to use (and avoid) in a classroom worm bin

For millions of years, worms have been hard at work breaking down organic materials and returning nutrients to the soil. By bringing a worm bin into the classroom, you are simulating the worm's role in nature. Though worms could eat any organic material, certain foods are better for the classroom worm bin.

We recommend using only raw fruit and vegetable scraps. Stay away from meats, oils and dairy products, which are more complex materials than fruits and vegetables. Thus, they take longer to break down and can attract pests. Cooked foods are often oily or buttery, which can also attract pests.

Avoid orange rinds and other citrus fruits, which are too acidic, and can attract fruit flies. Try to use a variety of materials. We have found the more vegetable matter, the better the worm bin. Stay away from onions and broccoli which tend to have a strong odor.

Setting up a worm bin

Setting up a worm bin is easy. All you need is a box, moist newspaper strips, and worms. To figure out how to set up a worm bin, first consider what worms need to live. If your bin provides what worms need, then it will be successful. Worms need moisture, air, food, darkness, and warm (but not hot) temperatures. Bedding, made of newspaper strips or leaves, will hold moisture and contain air spaces essential to worms.

You should use red worms or red wigglers in the worm bin, which can be ordered from a worm farm and mailed to your school. The scientific name for the two commonly used red worms are Eisenia foetida and Lumbricus rubellus.

Containers

When choosing a container in which to compost with worms, you should keep in mind the amount of food scraps you wish to compost, and where the bin will be located. A good size bin for the classroom is a 5- to 10- gallon box or approximately 24" X 18" X 8". The box should be shallow rather than deep, as red wigglers are surface-dwellers and prefer to live in the top 6" of the soil..

Whether you choose a plastic, wooden or glass container to use as a worm bin is a matter of personal preference based primarily on what is available. Some teachers have extra aquariums available. Some have wooden boxes which they would like to reuse. Others may prefer to buy or reuse a plastic container, such as commercially manufactured storage bin (e.g. "Rubbermaid," "Tucker," "Sterilite").No matter what material you choose, make sure to rinse out the container before using. For wooden bins, line the bottom with plastic (e.g. from a plastic bag or old shower curtain). Cover the bin with a loose fitting lid. This lid should allow air into the bin.

Harvesting

If you take care of your worms and create a favorable environment for them, they will work tirelessly to eat your "garbage" and produce compost. As time progresses, you will notice less and less bedding and more and more compost in your bin. After 3-5 months, when your bin is filled with compost (and very little bedding), it is time to harvest the bin. Harvesting means removing the finished compost from the bin.

After several months, worms need to be separated from their castings which, at high concentrations, create an unhealthy environment for them.

To prepare for harvesting, do not add new food to the bin for two weeks. Then try one of two methods for harvesting:

Push all of the worm bin contents to one half of the bin, removing any large pieces of undecomposed food or newspaper. Put fresh bedding and food scraps in empty side of bin. Continue burying food scraps only in freshly bedded half.

Over the next 2-3 weeks, the worms will move over to the new side (where the food is), conveniently leaving their compost behind in one section. When this has happened, remove the compost and replace it with fresh bedding. To facilitate worm migration, cover only the new side of the bin, causing the old side to dry out and encouraging the worms to leave the old side.

Hands-On Method:

Dump the entire contents of the worm bin onto a sheet of plastic or paper. Make several individual cone-shaped piles. Each pile will contain worms, compost and undecomposed food and bedding. As the piles are exposed to light,, the worms will migrate towards the bottom of the pile. Remove the top layer of compost from the pile, separating out pieces of undecomposed food and newspaper. After removing the top layer, let pile sit under light for 2-3 minutes as the worms migrate down. Then remove the next layer of compost. Repeat this process until all of the worms are left at the bottom of the pile. Collect the worms, weigh them (for your record keeping) and put them back in their bin with fresh bedding.

Regardless of which method you choose, the compost you harvest will most likely contain a worm or two, along with old food scraps and bedding. If you are using the compost outdoors, there is no need to worry--the worms will find a happy home and the food scraps and bedding will eventually decompose. If you are using the compost indoors, you may want to remove old bedding and food scraps for aesthetic purposes and ensure that there are no worms in the compost. Though the worms will not harm your plants, the worms may not like living in a small pot.

For both methods, you may continue to compost your food scraps after harvesting. Just add fresh bedding and food scraps. If, for some reason, you do not want to continue composting, please offer the setup to another teacher or to someone who will take the worm bin home. Anyone with a garden will find the worm compost extremely valuable. As a last resort, if you cannot find anyone who wants good worm compost, you may add the worms to a garden bed.

Using worm compost

You can use your compost immediately, or you can store it and use it during the gardening season, or whenever. The compost can be directly mixed with your potting soil or garden soil as a soil amendment, which helps make nutrients available to plants. Or, the compost can be used as a top dressing for your indoor or outdoor plants.

You can also make "compost tea" with your compost. Simply add 1-2" of compost to your water can or rain barrel. Allow compost and water to "steep" for a day, mixing occasionally. Then water plants as you normally would. The resulting "tea" helps make nutrients already in the soil available to plants.

Biology of worms

Worms can live for about one year in the worm bin. If a worm dies in your bin, you probably will not notice it. Since the worm's body is about 90% water, it will shrivel up and become part of the compost rather quickly. New worms are born and others die all the time.

Worms are hermaphrodites, which means they are both male and female at the same time. In order to mate, they still require two worms. The worms line up in opposite directions near their band (or clitellum), which contains some of the sexual organs. The worms are attached for about 15 minutes while they exchange sperm cells. Several days later, eggs come in contact with the sperm cells and form a cocoon, or egg case. The cocoon separates from the worm, then fertilization takes place. Inside the cocoon, 2-5 baby worms may be found.

The baby worms live in the egg case for at least 3 weeks, sometimes longer depending on the surrounding conditions. For example, in the winter time, baby worms may stay in the cocoon for many weeks until the temperature warms up again. When the baby worms eventually crawl out, they are the thickness of a piece of thread and possibly 1 cm 1/4" long. Usually the worms appear white, as they have not yet developed pigmentation, or do not have enough pigmentation (or blood) to be seen.

Successful vermicompost projects

Many schools have been successfully composting with worms over the past few years. Some elementary school classes keep worm bins as part of an environmental unit, others for science. In most cases, teachers find a variety of multidisciplinary ways to use a worm bin. For example, one class called their room the "Worm World." Writing assignments, math lessons and art work focused on worms as a theme.

Six Easy Steps to Setting Up a Worm Bin

by Jen Fong and Paula Hewitt

Once you have worms and a bin, follow these six easy steps to set up a worm bin. Soon worms will be recycling food scraps into a healthy, nutrient-rich soil amendment called compost.

1. Acquire a bin. Reuse an old dresser drawer or fish tank, build a box out of wood or find/buy a plastic bin. The approximate size is 16" x 24" x 8" or 10 gallons. Make sure the bin is clean by rinsing it with tap water to remove any residues which may be harmful to the worms. For wooden bins, line the bottom and sides with plastic (an old shower curtain or plastic garbage bag works well).
2. Prepare the bedding. Instead of soil, composting red worms live in moist newspaper bedding. Like soil, newspaper strips provide air, water, and food for the worms.
   - Using about 50 pages, tear newspaper into 1/2" to 1" strips. Avoid using colored print, which may be toxic to the worms.

- Place newspaper strips into a large plastic garbage bag or container. Add water until bedding feels like a damp sponge, moist but not dripping. Add dry strips if it gets too wet.
- Add the strips to the bin, making sure bedding is fluffy (not packed down) to provide air for the worms. Bin should be 3/4 full of wet newspaper strips.
- Sprinkle 2-4 cups of soil in bin, which introduces beneficial microorganisms. Gritty soil particles also aids the worms' digestive process. Potting soil, or soil from outdoors is fine.

3. Add the worms. Before adding the worms, find out how many worms you are starting with. The easiest method is to weigh the worms. If you do not have access to a scale, determine the worms' volume. The amount of worms is important for knowing how much food to feed them and for record keeping.
4. Bury food scraps under bedding. Feed the worms fruit and vegetable scraps that would normally be thrown away, such as peels, rinds, cores, etc. Limit the amount of citrus fruits that you place in the bin. NO MEATS, BONES, OILS OR DAIRY PRODUCTS.
   - Cut or break food scraps into small pieces--the smaller, the better.
   - Measure the amount of food. Feed worms approximately 3 times their weight per week. Monitor the bin every week to see if the worms are or are not eating the food. Adjust feeding levels accordingly. (If you start with one pound of worms, add 3 pounds of food per week.)
   - Bury food scraps in the bin. Lift up bedding, add food scraps, then cover food with bedding.
5. Place a full sheet of dry newspaper on top of the bedding. This will help maintain the moisture balance, keep any possible odors in the bin, and help prevent fruit flies from making a home in the bin. Replace this sheet frequently if fruit flies are present, or if bin gets too wet.
6. Cover and choose a spot for the bin. Cover the bin with a lid made of plastic, plywood or cloth, but leave the lid ajar so the bin receives some air. If desired, you may drill holes into the bin. Place the bin away from windows and heaters.
7. FEED, WATER and FLUFF!!! To keep worms happy, feed them about once a week. If bedding dries up, spray with water. (If bedding gets too wet, add dry newspaper strips.) Fluff up bedding once a week so the worms get enough air.

More About Worms... And Related Classroom Activities

by Jen Fong and Paula Hewitt
(Adapted from Cornell Cooperative Extension)

1. Worms can eat their weight in soil each day. Over 1 million worms may be present in one acre of soil, and these worms can produce 700 pounds of castings each day. Two thousand red worms in a worm bin can produce 7 pounds of castings in one month.
   - ❖ *Ask children to estimate how much food waste they produce each day. What happens to it? What ways can food waste and other waste be recycled?*

2. Worms do not have teeth. Their food is softened by moisture or by microorganisms which break it down. Food is further broken down in the worms' gizzard, which contains hard particles and muscles which grind ingested food.
   - *Observe which food wastes decompose the fastest, and try to explain why. What are your worms' favorite foods? Do worms like dry or wet garbage best? Why?*
3. Worms are not the only living organisms in the worm bin. All sorts of microorganisms (in fact, billions of them) live in a worm bin. These microorganisms are introduced to the bin from the skin of the worm and from soil added to the bedding. Added garbage introduces more microorganisms, as do fungal and bacterial spores that land in the bin from the air.
   - *Are other creatures besides worms present in your classroom worm bin? Look for composting critters outside, in piles of decaying leaves. Where else can you find them?*
4. Worms do not have eyes, but they can sense light, especially at their front end. They move away from light, and will become paralyzed if exposed to light for too long (approximately one hour). If a worm's skin dries out, it will die.
   - *Observe worms' reactions to light. Why do worms stay inside your covered worm bin?*
5. While worms need moisture to survive, too much moisture will kill them. Have you ever noticed worms on the sidewalk after a rainstorm? This happens because the worms' homes in the soil got flooded, and the worms came to the surface in search of less soggy conditions. Once on the pavement, worms often get disoriented and cannot find their way back to the soil. They then dry up and die when the sun comes out.
   - *After a heavy rainstorm, go out on a worm hunt. What should you do when you see worms on the pavement? (Stepping on them is not the right answer!) Be a worm rescuer- put them back in the soil where they belong and can survive. Why do we want worms to survive?*
6. Worms are hermaphrodites; each worm has both male and female organs. Worms mate by joining their clitella (the swollen area near the head of a mature worm) and exchanging sperm. Then each worm forms an egg capsule in its clitellum; after 7-10 days, this is shed into the castings. Egg capsules are lemon-shaped and about the size of a match head. After 14-21 days baby worms hatch from the eggs. One to five worms emerge from each egg. In 60-90 days, the young worms are mature.
   - *Try to find mature worms, young worms and worm eggs in your worm bin.*
7. Worms can live as long as four years. When worms die in the bin, their bodies decompose and are recycled by other worms, along with the food scraps. Worm castings are toxic to live worms. After all the food scraps in a bin are recycled, the worms will eat their own castings which will poison them.
   - Why should a worm bin be harvested every few months? Harvest your worm bin when it is filled with compost.
8. Contrary to popular belief, worms cannot reproduce by being cut into small pieces. However, they do have amazing healing powers. If you cut a worm in half, both sides will continue wiggling. The portion with the head may grow a new tail if the cut is after the segments that contain vital organs. The tail portion will continue to wiggle until the nerve cells die. The tail end will not grow a new head.
   - *What other animals can regenerate parts of their bodies?*
9. Worm castings contain nitrogen and other nutrients necessary for plant growth. When added to soil, worm compost increases nutrient availability and improves soil structure and drainage.
   - *Transplant a few plants, seedlings or seeds in a potting mix with worm compost added, and transplant other plants or seeds into pure potting mix. Observe what plants grow the best, and try to explain why.*

10. In addition to making soil, worms are natural soil tillers. They mix layers of soil while producing tunnels in the soil to help air and water to reach plant roots. Tiny feeler-like bristles, called setae, on the bottom of worms help worms to move through the soil.
    - *Put worms into a glass container with soil, and watch them make tunnels in the soil. Put layers of different types of soil into the glass container, and watch the worms mix the soil.*
11. There are over 3000 species of earthworms in the world. Red worms (Eisenia foetida) are best for a worm bin because they are natural surface feeders that do not burrow as nightcrawlers do. Thus, living in a worm bin is not as confining to red worms as it would be to nightcrawlers. Red worms for worm composting can be purchased from worm farms. Composting worms are usually sold by the pound.
    - *Look for worms in garden soil, vacant lots, etc. How many kinds of worms did you find? Where did you find the most worms? Research worms from around the world. Where in the world kind you find worms several feet long?*
12. Many people mistakenly believe that garbage sent to landfills decomposes quickly, like it does in a worm bin or compost pile. However, this is not at all true because the key ingredients of air and moisture are missing in a landfill environment. Additionally, worms and other important decomposers can not live or function in such conditions.
    - *Put some worm food in an air tight bag. Compare what happens to this food to what happens to food in a worm bin.*

Potential Cross-Curricular Applications of a Worm Bin For the Elementary School Classroom

by Jen Fong and Paula Hewitt

Language Arts:

- read/write stories about worms
- vocabulary development
- worm bin journals
- worm puppet shows
- create newsletter/information sheet on worm composting
- library work to find out information/books about worms and recycling
- write to Department of Sanitation requesting information on recycling

Math:

- count worms
- measure and weigh worms, food scraps
- sort worms (by size, color, etc.)
- metric measurements/conversions
- graph worm information such as population increase, amount of food eaten
- measure bin, three dimensional measuring, calculate area and volume
- ratios (worms to garbage, big worms to small worms, etc.)
- averages (how much food per day, week, month)

Science:

- worm anatomy
- worm needs and adaptations

- worm life cycle and reproduction
- scientific method/ worm experiments
- organic vs. non organic
- decomposition, mold, fungi
- food chain, food webs, ecology
- scientific classification and different species of worms
- other worm bin organisms (e.g., sowbugs, ants, mites, millipedes, centipedes)

Geography and Social Studies:

- climate and worms (red worms are native to the South)
- farming techniques/ crops around the world
- garbage around the world (how much do other countries produce?)

Horticulture:

- soil composition
- compost, compost piles
- plant parts/needs
- planting lessons and experiments (do plants grow better in compost?)

Other Potential Topics:

- waste reduction: reduce, reuse, recycle
- landfills

Troubleshooting Worm Bins

by Jen Fong and Paula Hewitt

Fruit Flies

Though fruit flies do not pose any health hazards, these little creatures can be a nuisance in the classroom. To help prevent these potentially prolific pests, do the following:

1. Avoid putting rotting or rotten food in your worm bin. Fly larvae are more likely to be present on rotten food.
2. Cut food scraps into small pieces. Worms will be able to eat smaller pieces more quickly, thereby limiting the possibility of fruit flies thriving on decomposing food.
3. Don't overfeed worms. Ripe food that sits around in the bin attracts (and may contain) flies.
4. Bury food. Burying the food will help keep unwanted pests and pets from intruding on your bin.
5. Keep bedding material moist, but not too wet. Overly wet conditions encourage the proliferation of fruit flies. Wet conditions might also cause an odor problem, as anaerobic bacteria thrive when it is too wet.
6. Feed worms a varied diet. If citric foods dominate the bin, the bin may become too acidic, which may attract fruit flies.
7. Loosely place a piece of plastic or a sheet of newspaper inside the bin on top of the worm bin contents. This plastic or newspaper cover will create another barrier to help prevent flies from getting in (or out) of the bin.
8. Limit citrus fruits.

To help control an existing fruit fly problem, try the following:

1. Remove rotten food from the bin when fruit flies are present. Fruit flies often lay their eggs on decomposing food.

2. Tape or staple flypaper strips on the inside of the bin lid, and/or hang a strip near the bin. Flypaper strips can be purchased cheaply at most hardware stores.
3. Create a fly trap to put in the bin. A bowl of apple cider vinegar with a drop of dish detergent, placed near the bin, will attract and kill flies. Change liquid regularly to keep fly trap potent.
4. Place a whole sheet of newspaper on top of bin contents. Change this sheet regularly as flies tend to congregate on the newspaper.
5. Sprinkle lime in the bin to neutralize excessively acidic conditions.
6. For temporary relief, take bin outside and leave uncovered for up to four hours to air out the bin (out of direct sunlight).

If the problem cannot be controlled, have your class analyze the problem, and speculate about what is causing it. The best solution may be to harvest the worms and start a new bin from scratch, using what you have learned from your past experience to create a better bin.

Odor Problem
If your worm bin has an unpleasant odor, one of the following may be the culprit:
1. Bin is too wet. Solve the problem by not adding any water or foods with a high percentage of water (e.g., melons) and by adding more dry bedding.
2. Bin does not get enough air. Anaerobic bacteria (bacteria which thrive without air) is smelly. To aerate, add fresh bedding and mix bin contents daily.
3. The food in bin is naturally smelly. For instance, we have found that onions and broccoli do not smell very pleasant when they decompose in the worm bin. Simply remove any food source that smells bad from the bin.
4. Bin contains non-compostables. Meat, bones, dairy and oily products should not be fed to the worms because these items become rancid when decomposing.

Worm Death
If you notice the worm population dwindling, or worms crawling all over the bin trying to escape, check for the following:
1. Bin is too wet and worms are drowning.
2. Bin is too dry and worms dry out.
3. Bin does not get enough air and worms suffocate.
4. Worms do not get enough food. Once the worms devour all of their food and newspaper bedding, they will start to eat their own castings which are poisonous to them. TIME TO HARVEST
5. The bin is exposed to extreme temperatures. The worms thrive in temperatures from 55 to 77 degrees F.

NOTE: Dead worms decompose rather quickly. If you do not monitor the above conditions you can have a dead box of worms before you even realize it.

Frequently Asked Questions About Worms in Composting

by Jen Fong and Paula Hewitt

- **Do I need to add worms to my compost pile?**

You do not need to add worms to your compost pile. Outside, composting happens with and without the help of earthworms. Worms will usually find their own way to a compost pile.

- **What can I do with my coffee grounds?**
  Coffee grounds, as an organic material, can be added to your compost pile. Worms like coffee grounds, so you may want to put a layer of coffee on the bottom of your pile to attract worms.

- **How often do I have to turn the pile?**
  The more you turn the pile, the quicker you will produce compost. Many people would rather let their pile sit and let nature do her work over a several month period. If you turn your pile frequently, you may produce compost in one month. If you turn your pile once in a while, you may produce compost in 3-6 months.

- **Should I add compost activator to my bin?**
  Most commercially sold compost bioactivators contain microorganisms which will help your pile start composting. However, similar microorganisms are readily available in a handful of soil or finished compost.

- **Won't rats be attracted to my compost pile?**
  With proper management, rats and other pests should not be a problem. Rats are attracted to food odors. By avoiding odiferous foods such as meats, dairy and oil, and mixing in or covering with a good layer of brown material (dry leaves, wood shavings, crumpled or shredded paper) odors will be filtered out.

- **Are the worms used in a worm bin the same as earthworms?**
  When most people think of "earthworms", they usually mean "nightcrawlers," which can be 8-10" long and 1/2" in diameter. These nightcrawlers are different from red wigglers, although both may be called "earthworms" since they both are found in the earth. Nightcrawlers are soil-dwellers, thus they like to burrow several feet below the surface. By burrowing, the nightcrawlers mix different layers of the soil, while creating tunnels which aerate the soil. On the other hand, red wigglers are surface-dwellers and prefer to live within the top 6" of the soil (which is why red wigglers prefer shallow boxes as homes). Red wigglers are often found among the fallen leaves of the forest floor, as well as in manure piles.

- **Can worms bite?**
  Worms do not have teeth, therefore they cannot bite you. Do not be afraid to hold a worm. Most people find that the worms are soft and ticklish.

- **What is the yellow liquid which the worm releases?**
  The yellow liquid is not urine, which many people first guess. The yellow liquid, called coelomic fluid, is released when the worm is stressed, which often happens when students touch the worm. When a worm is placed on a student's dry hand, the worm's body will begin to dry out. The worm will start wiggling, trying to find its' way back to the soil or bin, then release a yellow liquid in order to make its' body moist again. Exposure to light also triggers the release of the coelomic fluid. This yellow liquid may smell like garlic, hence the scientific name Eisenia foetida. Foetida means smelly.

When conducting experiments with worms, you may want to gently spray the worms with water every few minutes.

- **What happens if you cut a worm in half?**
  Almost everyone wants to know the answer to this question. Some species of worms can regenerate, or re-grow, a new tail, if their tail is cut off. However, a worm cut too closely to its' head will have difficulty growing a new tail. Most worms will not regenerate a head.
  Generally, we tell students that if you cut a worm in half, you will most likely end up with two dead pieces of worms. However, if you are lucky, the piece with the head may grow a new tail, so you will have one alive worm and one piece of dead worm.
  Some worms have a natural reflex, in which they will eject their tail when the tail is pulled. For example, when a bird catches the tail end of a worm, the worm would eject or sever its' tail from the rest of its' body. Thus, the worm remains alive and safe, while the bird gets only part of the worm.

- **Why is worm compost so good for plants?**
  Worm compost makes nutrients available to plants. When compost is mixed with water, it has the ability to hold many positively-charged mineral ions (cations), or nutrients, which can then be taken up by plants. Also, as worms process (digest) the food scraps, the nutrients in the food are changed into forms which can then be used by plants.

Composting Outdoors

Best Ever Compost

This is an excerpt from Composting: Wastes to Resources, a 4-H Leader's/Teacher's Guide written by Jean Bonhotal and Marianne Krasny and published by Cornell Cooperative Extension.

Just Follow the Recipe!
Composting is like baking a cake. Simply add the ingredients, stir, "bake," and out comes -- compost!

Whether you compost kitchen wastes or yard and garden wastes, there are a few basic steps to follow. Here are the necessary ingredients and general directions for composting.

Ingredients:

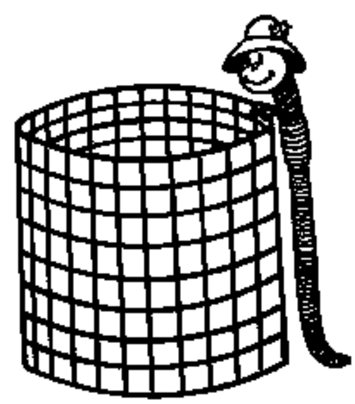
KITCHEN COMPOST
Add a mixture of some or all of the following ingredients:

- vegetable peels and seeds
- egg shells
- fruit peels and seeds
- nut shells
- coffee grounds
- any other vegetable or fruit scraps

Note: (Do not add meat scraps, bones, dairy products, oils, or fat. They may attract pesty animals.)

YARD OR GARDEN COMPOST
Add a mixture of some or all of the following ingredients:

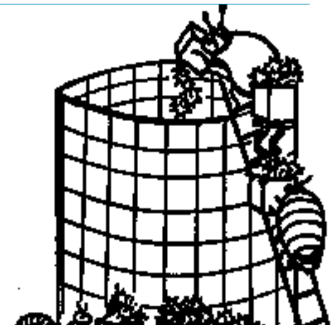
- hay or straw
- wood chips
- grass clippings
- weeds and other garden waste
- leaves
- manure
- ashes
- shredded paper
- sawdust



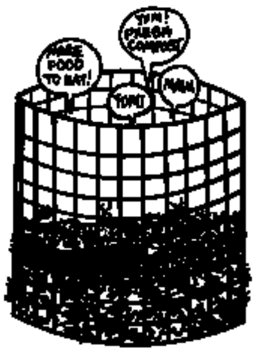
Directions

1. Choose a "pot" for baking your compost. Any type of composting bin will do.

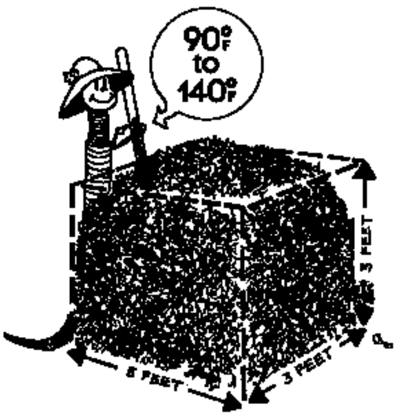
2. Place kitchen or yard wastes into the composting bin. Chop or shred the organic materials if you want them to compost quickly.



3. Spread soil or "already done" compost over the compost pile. This layer contains the microorganisms and soil animals that do the work of making the compost. It also helps keep the surface from drying out.

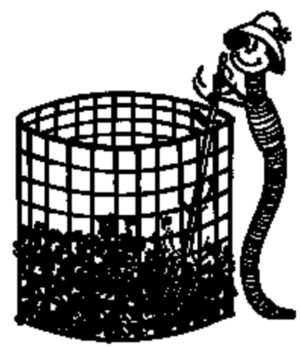


4. Adjust the moisture in your compost pile. Add dry straw or sawdust to soggy materials, or add water to a pile that is too dry. The materials should be damp to the touch, but not so wet that drops come out when you squeeze it.

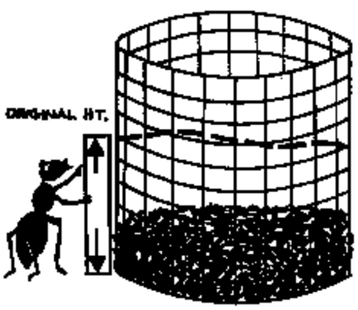


5. Allow the pile to "bake." It should heat up quickly and reach the desired temperature (90° to 140°F, or 32° to 60°C) in four to five days.

6. Stir your compost as it bakes if you want to speed up the baking time.



7. The pile will settle down from its original height. This is a good sign that the compost is baking properly.



8. If you mix or turn your compost pile every week, it should be "done," or ready to use, in one to two months. If you don't turn it, the compost should be ready in about six to twelve months.

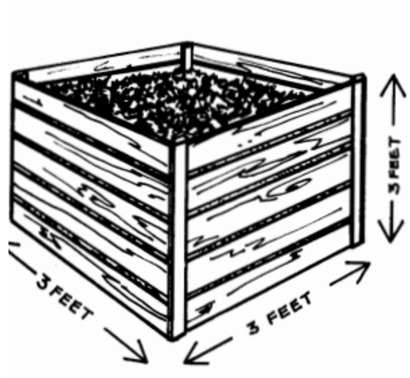
9. Your "best ever compost" should look like dark crumbly soil mixed with small pieces of organic material. It should have a sweet, earthy smell.

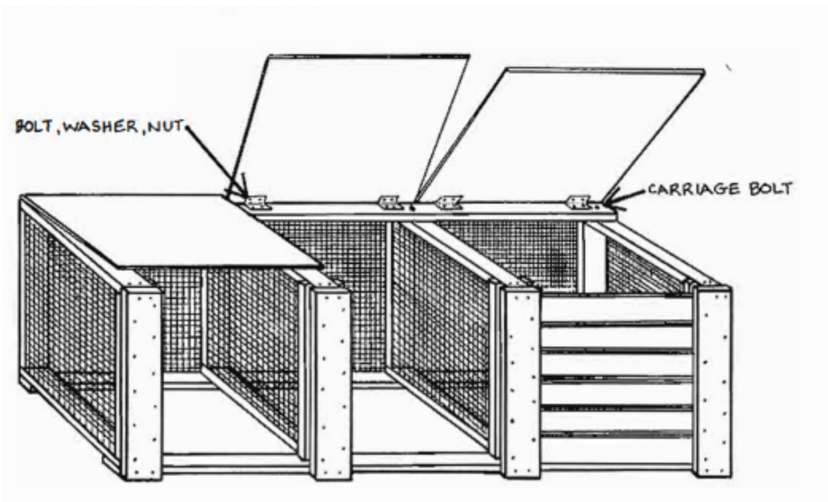
10. Feed compost to hungry plants by mixing it with the soil.

Bin Designs

Plans for other [OUTDOOR BIN DESIGNS]() from Compost: Waste to Resources include:

Wooden Box Bin
Wood and Wire Three-Bin Turning Unit
Cinder Block Bin
Cinder Block Turning Unit
Wire Mesh Bin
Snow Fence Bin
Garbage Can Composter
Worm Composting Bin
Compost Mound
Compost Pockets Mulch
Compost





And don't forget to keep a Project Record!

Outdoor Composting

Outdoor composting systems can be larger than indoor bioreactors, allowing students to compost greater quantities of food scraps and landscaping trimmings. Although slightly less convenient than a system right in the classroom, students can monitor the temperature, moisture content, and other aspects of an outdoor system, and they can bring samples of the compost inside for observation and experimentation. Many schools have developed outdoor composting systems into demonstration sites, with signs explaining the composting process.

Unlike indoor systems, outdoor systems are home to a diverse range of invertebrates such as millipedes, centipedes, earthworms, pseudoscorpions, beetles, snails, mites, and springtails. These organisms form an intricate food web, and they can be used for illustrating ecological principles as well as for investigating topics such as life cycles and feeding preferences.

In some outdoor systems, the organic materials are periodically mixed or "turned." This redistributes materials that were on the outside of the pile and exposes them to the higher levels of moisture, warmth, and microbial activity found in the center. It also fluffs up the compost materials, allowing better air flow through the pile. The net result generally is to speed up the composting process.

Bins should be located close to a water source in case they become too dry. Good drainage is also important in order to avoid standing water and the build-up of anaerobic conditions. Other considerations include avoiding exposure to high winds which may dry and cool the pile, and to direct sunlight which may also dry out the pile. The pile should not touch wooden structures or trees because it may cause them to decay. There should be space nearby for temporary storage of organic wastes.

There is an endless variety of outdoor composting systems, so feel free to design your own outdoor bins using readily available scrap materials. Three general types of systems are described below. Refer to *Composting: Wastes to Resources* (Bonhotal and Krasny, 1990) for more details on outdoor bin designs.

Holding Units

Holding units provide a low-maintenance form of composting. You simply build the unit, fill it with organic materials, and then wait for the materials to decompose. A holding unit can be any container that holds organic materials while they are breaking down. The unit should be about a cubic meter in size (1 m x 1 m x 1 m), and it can be built from wire mesh, snow fence, cinder blocks, wooden pallets, or other materials. You can fill holding units with high-carbon materials such as autumn leaves and yard trimmings, realizing that these materials by themselves will not heat up and will require a year or more to fully decompose. If your system is dominated by leaves, you may want to avoid adding any food scraps, which might attract rodents or raccoons during the slow decomposition process. Alternatively, if you start with a mix that has the right C:N ratio and moisture level to become thermophilic, food scraps should break down quickly before any pests become a problem.

Turning Units

A turning unit looks like three holding units placed side by side. Each unit should be a cubic meter (1 m x 1 m x 1 m) in size. Leave one side open or build a gate along one edge for easy access. Fill one bin at a time, using a mixture of high-nitrogen and high-carbon materials. For rapid composting, turn the contents into the empty adjoining bin every week or two, or each time the temperature begins to decline. A pile that is kept "hot" like this should produce compost within a couple of months, although an additional period of curing is necessary before the compost is used for growing plants. The final bin provides the space needed for curing while a new batch of compost is started in the first bin.

Enclosed Bins

For small-scale outdoor composting, enclosed bins are an option. They can be purchased from home and garden centers or inexpensively built from a large garbage can. Simply drill 2-cm aeration holes in rows at roughly 15-cm intervals around the can. Fill the cans with a mixture of high-carbon and high-nitrogen materials. Stir the contents occasionally to avoid anaerobic pockets and to speed up the composting process. Although no type of bin is rodent-proof, enclosed bins do help to deter rodents and are popular for food scrap composting.

Troubleshooting Compost Problems

Symptom	Problem	Solution
Pile is wet and smells like a mixture of rancid butter, vinegar, ad rotten eggs	Not enough air	Turn pile
	Or too much nitrogen	Mix in straw, sawdust or wood chips
	Or too wet	Turn pile and add straw, sawdust or wood chips: provide drainage
Pile does not heat up	Pile too small	Make pile larger or provide insulation
	Or pile is too dry	Add water while turning the pile
Pile is damp and sweet smelling but will not heat up	Not enough nitrogen	Mix in grass clippings, food scraps, or other sources of nitrogen
Pile is attracting animals	Meat and other animal products have been included	Keep meat and other animal products out of the pile: enclose pile in 1/4-inch hardware cloth
	Or food scraps are not well covered	Cover all food with brown materials such as leaves, wood chips, or finished compost

Weird and Unusual Composting

Birds That Make Compost
by Nancy Trautmann

In Australia, there is a bird called the Brush-turkey (*Alectura lathami*) that builds compost piles to incubate the eggs so that they won't have to sit on them! They build mounds of decomposing vegetation, and the heat produced by the microbial decay maintains the eggs at about 33°C (92°F), 15°C warmer than the ambient air temperature. Because each nest generates more than 20 times the heat production of a resting adult Brush-turkey, many more eggs can be incubated this way than if they relied on warmth from the parent birds. Initially the adult birds tend the composting nest, occasionally mixing and either adding or removing vegetation as needed to regulate the temperature, which they sense through their bills. After this initial adjustment, the nests require little attention, and larger ones can stay warm for several weeks without tending.

The largest nests are on Kangaroo Island in South Australia, where the average mound measures about 12.7 cubic meters and weighs about 6,800 kg. Scientists have constructed a computer model using data on mound size, ambient temperature, and the nest's rate of heat production, water content, dry density, and thermal conductivity. The model predicts that as little as 1 cm of litter added to the mound will raise the core temperature about 1.5°C. Experiments indicate that the composting nests require (1) a critical mass of fresh litter (ca. 3,000 kg), (2) sufficient water content (> 0.2 ml/g dry material), and (3) occasional mixing of the litter.

For more information on this clever bird, see this article:
Seymour, R.S. and D.F. Bradford. 1992. Temperature regulation in the incubation mounds of the Australian Brush-turkey. Condor 94(1): 134-150.

Composting Drowned Turkeys
by Nancy Trautmann

Remember the massive flooding along the Mississippi River in 1993? One of the casualties of a flash flood in central Missouri that summer was a group of 20,000 turkeys!

The Missouri Department of Natural Resources advised the turkey farm owner that composting would be the easiest and safest way to dispose of the carcasses. Over 150 neighbors helped to collect the dead birds, haul sawdust from local sawmills, and build the composter. Three large round hay bales were arranged in a U-shape to provide the walls for the 60-foot-long by 5-foot tall windrow. A foot of sawdust formed the bottom layer, which was covered with alternating layers of turkey bodies (which are high in nitrogen) and sawdust (which is high in carbon).

The turkeys composted for three months, during which no problems occurred with rodents or odors. The temperature rose above 55°C (130°F) for one week during this period. The finished compost was applied to farm land as a fertilizer.

Composting Zebra Mussels
by Erin McDonnell

What are zebra mussels?

Zebra mussels (Dreissena polymorpha) are small mollusks which have invaded the freshwaters of North America. While these creatures are no bigger than the end of your thumb, they have turned into a big problem. They probably hitched a ride on a ship from Eastern Europe through the St. Lawrence Seaway to Lake Erie, where they found plenty of nutrients in the North American waters and decided they liked the New World. Unfortunately, there were no predators or other means of naturally limiting their growth, and they spread through the tributaries of the Great Lakes and grew prolifically in places where they were not welcome. They clogged water intake pipes for power and water treatment plants. Divers were needed to scrape them off surfaces, and then the mussels were dumped on land to be hauled to landfills. But the wet creatures, which are mostly shell, were heavy and expensive to transport and dispose of, so some folks started looking for a more beneficial way to use them; enter composting.

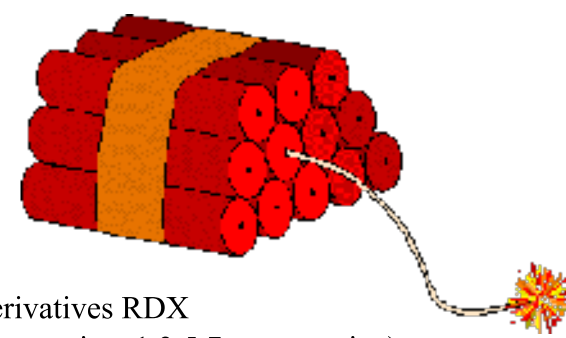
Why compost them?

Shells have been used to lime, or raise the pH, of soils for years, so it wasn't so far fetched to think that a useful compost could be made from Zebra Mussels. In fact, Ontario Hydro of Toronto and the Monroe Power Plant in Michigan collected zebra mussels for composting for several years. Ontario Hydro layered the zebra mussels to form windrows with debris also removed in cleaning out its pipes, periodically turned the windrows, and eventually used the compost to cover a landfill on the property. At Detroit Edison's Monroe Power Plant, the zebra mussels and debris were mixed together, piled into windrows, and eventually spread onto grounds where coal used to be piled to encourage grass growth and discourage an overwhelming population of nesting seagulls.

Cornell researchers wanted to see if they could make a recipe for folks who might want to compost anywhere from 100 to 1000 pounds of zebra mussels. Since a zebra mussel is mostly shell and hardly any organic matter, you probably need to mix mussels with some other organic material to provide the right nutrients for compost microorganisms. After a number of small tests, the researchers found that a co-composting mixture of 1:14:17:18 parts by weight of peat, sawdust, poultry litter and water could be made and then mixed 1:1 with zebra mussels for composting. An equal volume of wood chips for bulking was then added. Two compost piles were built, each containing one cubic yard of zebra mussels supplied by Rochester Gas and Electric on a bed of wood chips and perforated PVC drainage pipes. In monitoring the compost, it was observed that the shells probably help maintain good pore structure for air flow.

After three months of composting and maturing, the wood chips were screened out, the compost was mixed with various ratios of topsoil, and tomatoes and radishes were grown in the mixtures. All seedlings did as well or better than the topsoil alone.

What Better Way to Get Rid of Old Explosives?
by Nancy Trautmann



TNT is not the kind of substance that most people think of composting, but it can be done! At several U.S. Army depots, the water used in processing explosives was disposed of through evaporation from unlined lagoons. This has resulted in sediments and soils that are contaminated with TNT (2,4,6- trinitrotoluene) and its derivatives RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) and HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine).

One way of cleaning up these sediments is by incinerating them. A less expensive and more environmentally friendly method is "bioremediation," or use of natural biological and chemical processes to degrade the contaminants. That's where composting comes in. TNT, RDX, and HMX are complex organic compounds made up of carbon, nitrogen, oxygen, and hydrogen. When combined with more conventional compost ingredients such as manures, sawdust, straw, and fruit and vegetable processing wastes, the explosives become broken down into harmless chemical forms.

The Army is using composting to clean up munitions processing wastes at several of its ammunition plants, including ones in Louisiana, Wisconsin, and Oregon. At the Oregon site, composting is projected to save 2.6 million dollars compared with incinerating the contaminated soils. In addition to saving money, composting will also avoid the need for burning fossil fuels and will produce an end product usable for backfilling, landscaping, or erosion control.

For more information, take a look at these articles:

Williams, R.T. and C.A. Myler. 1990. Bioremediation using composting. Biocycle 31(11): 78-83.

Ziegenfuss, P.S. and R.T. Williams. 1991. Hazardous materials composting. Journal of Hazardous Materials 28: 91-99.

Biocycle staff. 1996. Clean Up at Munitions Sites. Biocycle 37(3): 49-50.

Compost Yourself!

These are the words to a song written by Lee Hays, a member of the Weavers, a folk group who sang in the 1940's and 50's and were blacklisted during the McCarthy era because of their "unAmerican" ideas.

If I should die before I wake,
All my bones and sinew take;
Put me in the compost pile,
And decompose me for a while.
Wind, water, rain will have their way,
Returning me to common clay!
All that I am will feed the trees,
and little fishes in the seas.
On radishes and corn you munch--
You might be having me for lunch!
And then excrete me with a grin--
Chortling, "There goes Lee again!!"

Frequently Asked Questions

by Nancy Trautmann and Tom Richard

1. **How long does it take?**
   - The answer to this question ranges widely, depending on the process used, the compost ingredients, and how the system is managed. Perhaps most importantly, it depends on the intended use of the compost: many ingredients can be used as a mulch immediately, while it may take many months to achieve the stability required for germination of sensitive seedlings. Here we assume the compost will be incorporated in soil for general garden use.
   - Under optimum conditions, thermophilic composting with frequent mixing or turning can produce useable compost within a month or two. A worm bin requires three to six months to turn food scraps to compost, and an unmanaged leaf pile may take more than a year to break down.
   - In general, it is best to let compost "cure" for several months even after it appears finished. During this additional time, degradation occurs at a slower rate, resulting in a more chemically stable end product.
2. **How can you tell when compost is finished?**
   - Finished compost will no longer heat up, even after mixing. The initial ingredients are no longer recognizable, and what is left is an earthysmelling substance similar to a rich organic soil.
3. **Is newspaper safe to compost? Are the inks toxic?**
   - Newspaper is safe to compost, but it breaks down quite slowly because of its high lignin content. (Lignin is a substance found in the woody cell walls of plants, and it is highly resistant to decomposition).
   - Most newspapers today use water or soy-based inks. Although these may contain small amounts of toxic compounds, the trace levels are not of significant toxicological concern. Some caution should still be used with glossy magazines, which sometimes use heavy metal based inks to produce vivid colors.
4. **Which kinds of pet wastes can safely be composted?**
   - Wastes from classroom critters such as guinea pigs, rabbits, hamsters, or gerbils can be safely composted, along with the wood or paper shavings used in their cages. Droppings from dogs or cats should be avoided, though, because they may contain parasites or disease organisms harmful to humans.
5. **Are inoculants, activators, or other additives a good idea?**
   - Commercial inoculants are made up of dormant microorganisms. Although composting depends on microorganisms, you do not need to purchase them. They are already present, on the leaves, food scraps, and other materials you are composting. If you wish to augment these populations, addition of soil or finished compost will work as well as commercial inoculants.
   - Activators are designed to speed up the compost process by providing sugar or nitrogen to trigger rapid microbial growth. Normally an activator is not needed. If your mixture of materials to be composted has a C:N ratio higher than about 30:1, however, then addition of nitrogen will speed up the composting process.
   - Lime is sometimes added to compost piles but is not necessary unless the initial pH is lower than about 5. If the compost process becomes anaerobic, the organic acids that are produced may lower the pH of the mixture. Aerating the system to return it to aerobic conditions will also cause the pH to return to a near-neutral range.

6. **Can compost harm plants?**
    - In general, compost is good for plants -- it helps build soil structure, retains moisture, increases soil organic matter, and provides a slow release of nutrients important for plant growth. If you use compost that has not adequately matured, however, it may cause chemical burns on plants or compete with them for use of soil nitrogen.
    - Fresh compost should not be used for starting sensitive seedlings such as tomatoes and peppers because they may succumb to damping-off disease. These seedlings should be started using a sterilized potting mixture.
7. **If you use compost, do you still need fertilizer?**
    - That depends on the nutrient requirements of your plants and the nutrient status of your soil. Compost does provide needed plant nutrients, but this occurs in small doses gradually over the course of the growing season. If your soil is particularly barren, or you are growing a crop that needs aburst of nitrogen soon after planting, then you may want to supplement with other types of fertilizer. Your best bet is to have the soil tested, then make your decision based on the test results and your intended plantings.
8. **How do you keep rats away?**
    - The best way to keep rodents and other animal pests from becoming a problem is to avoid creating conditions that will attract them. If you add meat or dairy products, or leave cooked foods such as pizza crusts lying around, you will be inviting rodents to a feast. On the other hand, if you stick to composting vegetation such as leaves and grass clippings, you will minimize your chance of hosting rodents. Adding fruit and vegetable scraps is safe as long as they are buried in the other compost ingredients and the system heats up so that the food wastes are quickly broken down.
9. **What about flies?**
    - Fruit flies or house flies can become a problem for indoor composters unless preventative steps are taken. If food scraps are composted, they should not be left exposed to the air. Instead, they should be covered by a layer of brown material such as soil, old compost, leaves, or wood shavings. In worm bins, food scraps should be buried in the bedding rather than placed on the surface.
    - If fruit flies do become a problem, you can make a simple but highly effective trap. Just take a soda bottle and remove the lid. Cut the bottle in half, and pour cider vinegar into the bottom half to a depth of about 2 centimeters. Then invert the top half of the bottle into the bottom half, forming a funnel leading into the bottle. Fruit flies will be attracted to the vinegar and will get trapped or drowned in bottle.
10. **Will there be leachate?**
    - Composting in containers does produce leachate, a rich organic soup called "compost tea" that is prized by gardeners. It is best to design your bioreactors to catch the leachate so that it will not make a mess or cause odor or fly problems. In the 2-can bioreactor, leachate is trapped by absorbant material in the outer can. The soda bottle bioreactors hold the leachate in the bottom of the bottle unless you make holes down low enough so that it drains into a dish or tray underneath.
11. **Will it smell bad?**
    - As long as your compost has enough airflow so that it remains aerobic, there may be some odor but it shouldn't be objectionable. If you do get foul-smelling odors, you should add more wood chips or other bulking agent, and mix the system to reaerate it. Ammonia odors may develop if you compost materials that are high in nitrogen, such as fresh grass clippings. To prevent this, you can calculate the appropriate mixture of materials to achieve the right carbon-to-nitrogen ratio.

- If you are using soda bottle bioreactors in a classroom, you can vent them through a window using flexible tubing to prevent any possibility of odor problems.

12. Will composting break down pesticide residues?

- Yes -- the microbial decomposition that occurs during composting breaks down the types of pesticides currently on the market, and composting is sometimes used to degrade pesticide residues commercially. (Non-biodegradable pesticides such as DDT and chlordane are no longer allowed to be sold in the U.S.).

Glossary of Composting Terms

AERATED STATIC PILE - composting system that uses a series of perforated pipes as an air distribution system running under the compost pile and connected to a blower. The pile is not turned.

AERATION - bringing about the contact of the compost with air through turning, or ventilating to allow microbial aerobic metabolism.

AEROBIC - occurring in the presence of oxygen. For successful composting, sufficient oxygen should be provided to keep the system aerobic. This ensures that the composting proceeds rapidly and with minimal odor.

AMBIENT TEMPERATURE - temperature outside the compost pile.

ANAEROBIC - occurring in the absence of oxygen. Anaerobic composting proceeds slowly and is odiferous.

BIODEGRADABILITY - the potential of an organic substance to be broken down into simpler compounds or molecules through the action of microorganisms.

BULKING AGENT - material, such as wood chips, added to compost primarily to help create good pore structure for air flow. Often provides part of carbon source as well.

BULK DENSITY - the mass of a unit volume of soil, generally expressed in gm/cm3. The volume includes both solids and pores. Thus soils that are light and porous will have low bulk densities, while heavy or compact soils will have high bulk densities.

CATION EXCHANGE CAPACITY - a measure of the negative charge on soils (primarily on clays and organic matter). It is expressed as the quantity of cations (positive ions) that can be adsorbed by the soil and is expressed in centimoles of charge/kg of soil (6x1023 charged particles are contained in one mole of charge).

CELLULOSE - a polysaccharide composing cell walls.

CONTAMINANT - unwanted material. Physical contaminants of compost include glass, plastic, and stones, and chemical contaminants include trace heavy metals and toxic compounds.

CURING - the last stage of composting that occurs after much of the readily metabolized material has been decomposed. Provides for additional stabilization and reduction of pathogens and allows further decomposition of cellulose and lignin.

DECOMPOSITION - the breakdown of organic matter through microbial action.

HEAVY METALS, TRACE METALS - trace elements whose concentrations are regulated because of the potential for toxicity to humans, animals, or plants. Examples include chromium, copper, nickel, cadmium, lead, mercury, and zinc.

HUMUS - a complex aggregate made during the decomposition of plant and animal residues; mainly derivatives of lignin, proteins, and cellulose combined with inorganic soil parts.

INORGANIC - substances in which carbon-to-carbon bonds are absent. Mineral matter.

LEACHATE - liquid that drains from the mix of fresh organic matter.

LIGNIN - a hard substance embedded in the cellulose of plant cell walls that provides support.

MATURE COMPOST - the stabilized and sanitized product of composting; it has undergone decomposition and is in the process of stabilization. it is characterized as containing readily available forms of plant nutrients; it is low in phytotoxic acids.

METABOLISM - exchange of matter and energy between an organism and its environment and the transformation of this matter and energy within the organism.

MOISTURE CONTENT - weight of water in material divided by weight of solids in material.

ORGANIC - all compounds whose molecules contain carbon with a few exceptions such as carbon dioxide.

PATHOGEN - an organism including viruses, bacteria, fungi and protozoa capable of producing an infection or disease in a susceptible host.

PERMEABILITY - A measure of the rate at which water can percolate through soil.

PHENOL - a caustic, poisonous acidic compound present in coal tar and wood tar; a hydroxyl derivative of aromatic hydrocarbons.

PHYTOTOXIN - an element or compound that injures plants.

SOURCE SEPARATION - the practice of separating waste generated within each household or commercial operation into separate fractions such as newspapers, glass etc., and placing them in separate containers for recycling, composting, and disposal.

STABILITY - the degree to which the composted material can be stored or used without giving rise to nuisances, or can be applied to the soil without causing problems due to incomplete degradation of readily biodegradable materials.

THERMOPHILIC - relating to organisms growing at high temperatures (40¡C-60¡C). A stage in composting.

TOXINS - substances that cause a reduction of viability or functionality in living things.

WINDROW SYSTEM - composting mixture is placed in elongated piles called windrows. These windrows are aerated naturally through the chimney effect, or by mechanically turning the piles with a machine or by forced aeration.

YARD TRIMMINGS - grass clippings, leaves, and weeds and shrub and tree prunings six inches or less in diameter from a residence or business.