Vermicomposting in Waste Management

Best Management Practices
Introduction

Vermicomposting in Waste Management: Best Management Practices

Definitions

- **Waste Management**
  
  *Waste* is anything rejected as useless or worthless; refuse, garbage, trash. In *solid waste management*, an *integrated* approach uses alternatives such as recycling, composting, energy recovery (through incineration), and landfilling. A significant portion of that which is discarded as waste may be recovered and utilized through *resource recovery*. For example, approximately 60% of the *waste stream* is organic and therefore degradable and compostable. Waste management seeks to *reduce the volume* of waste and *stabilize* organic wastes that may attract vectors and produce odors, combustible gases (methane) and leachates.

- **Composting**

  Composting is the managed process of controlled, biological decomposition of organic material into a humus-like substance called compost. Unlike most manufacturing operations, compost facilities may enjoy a *dual* source of revenue, including *tipping fees* for incoming raw materials as well as revenues from product sales.
• Soil Ecology

Soil is composed of a variable combination of minerals (in the form of sand, silt and clay) organic matter, water, air and living soil organisms. It provides mechanical support and sustenance for plants. Ecology is the branch of biology dealing with the relations and interactions between organisms and their environment. The processes and results of both composting and vermicomposting are best understood within the larger context of soil ecology since the activity of soil organisms is fundamental to both.

• Vermicomposting

Vermicomposting is the process by which earthworms convert organic matter into earthworm castings. Vermicomposting shares many similarities with composting and offers unique benefits that differentiate it from composting. As a viable organic waste management option, vermicomposting stands solidly upon scientific validation that has been in existence for decades, yet lags considerably behind composting in actual usage.

• Soil Fertility

Compost and vermicompost, when added to soils, increases soil fertility. Soil fertility is of interest to farmers, nursemen, greenhouse growers, landscapers, gardeners, athletic turf applications, silviculture, and in every application where soil is used for plant production.

Best Management Practices A best management practices (BMP) approach to vermicomposting provides recommendations to be used as guidelines for processing organic wastes into marketable products without adversely affecting the environment. Each set of “BMPs” is designed to improve the success of vermicomposting operations in every aspect of business operation, from initial planning to end-product marketing. While the scope of this manual is not exhaustive, the Best Management Practices contained herein provide information, techniques, and resources that should prove to be useful to those considering a project or business in vermicomposting.

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Waste Management

Waste Stream Constituents

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Newspaper</td>
<td>Every Sunday, more than 500,000 trees are used to produce the 88% of newspapers that are <em>never recycled</em>.</td>
</tr>
<tr>
<td>* Office paper</td>
<td>We throw away enough office and writing paper annually to build a wall <em>twelve feet high</em> stretching from Los Angeles to New York City.</td>
</tr>
<tr>
<td>* Plastic</td>
<td>Americans go through 2.5 million plastic bottles <em>every hour</em>, only a small percentage of which are now recycled.</td>
</tr>
<tr>
<td>* Yard Debris</td>
<td>Every year we dispose of <em>24 million tons</em> of leaves and grass clippings, which could be composted to conserve landfill space.</td>
</tr>
<tr>
<td>* Ferrous Metals</td>
<td>We throw away enough iron and steel to <em>continuously supply</em> all the nation’s automakers.</td>
</tr>
<tr>
<td>* Aluminum</td>
<td>American consumers and industry throw away enough aluminum to rebuild our entire commercial air fleet <em>every three months</em>.</td>
</tr>
<tr>
<td>* Glass</td>
<td>We throw away enough glass bottles and jars to fill the 1,350-foot twin towers of New York’s World Trade Center <em>every two weeks</em>.</td>
</tr>
</tbody>
</table>

The History of Garbage

* Pre-Civilization | Waste materials from plant foods were burned as fuel, used to fertilize crops, or fed to livestock. If garbage became a problem, people simply moved on.

* Early Towns, Cities | Organic waste in cities was too far from farms where it could have been utilized. Instead, garbage heaps grew. For centuries garbage became a prime source of disease through contaminated water or as a breeding ground for rats and flies.
* Athens, ca. 500 B.C.  
Issues the first known law against throwing garbage in the streets. Waste must be dumped outside the city walls.

* Jerusalem 500 B.C.  
Valley of the Son of Hinnom, a place of perpetual burning of trash. The Hebrew ge-hinnom, translated to the Greek gehenna, the New Testament word for hell.

* 20th century US  
Dumps became centralized burial pits covered with soil.

* Today  
Modern MSW landfills differ from those of just 10 years ago. Today’s waste is enclosed by cover material at the top and a liner at the bottom. Leachate collection systems, groundwater monitoring, gas control and recovery systems, and post-closure maintenance are regulated and implemented.

Managing Waste in the United States

In the U.S., up through the 1960s, solid waste disposal was loosely regulated. Costs for dumping garbage were inexpensive and open dumps accepted materials with few, if any, pollution controls.

But the 1970s and 80s saw the rise of environmental awareness, and with that, a host of stringent regulations affecting landfills and waste management practices. Concern for water quality led to the investigation of leachate and water run-off that contributed to surface and below-ground water contamination. Air quality issues of odor and methane gas generation as well as other health and safety concerns forced the closure of many old dumps. In place of the old town dump came engineered landfills designed to control pollution with plastic liners and daily cover.

But by the 1990s, the number of landfills began to decrease. Some spoke of a “landfill crisis,” as the number of sites slid precipitously from approximately 8,000 in 1988 to 2,514 in 1997. Yet with better management practices and the creation of larger, regional landfills, remaining capacity has been expanded. Nevertheless, more densely populated regions of the country may have ten or fewer years’ capacity remaining. (Jim Glenn, “The State of Garbage in America,” BioCycle, May 1998, 32-43)

Municipal solid waste (MSW) generation continues to escalate on a yearly basis. In the last ten years, total tonnage has risen from 250,000,000 tons to over 340,000,000 tons. A declining amount of that waste is being landfilled, however, as recycling and composting now accounts for 30% of the total wastestream being diverted. For the past five years about ten per cent of MSW in the U.S. has been incinerated, mostly in the New England and Mid-Atlantic regions.
Hierarchy of Waste Management Options

Integrated Solid Waste Management

1. Source Reduction: A front-end waste avoidance approach; designing products and packaging with minimum volume and toxic content and with longer useful life
2. Recycling: Collecting, reprocessing, and using resulting products
3. Waste combustion: Waste-to-energy
4. Landfilling

Illustration #1 Use paper cup as illustration of alternatives:

What can we do with this cup?

1. Source reduction: use it over and over instead of single use (or use a cup with longer durability rather than using new cups each time)
2. Recycle – paper can be recycled; composted
3. Waste combustion Waste-to-energy Burn it to produce energy, heat
4. Landfill—Last option

Results of Nicolet Instrument Corp, WI Reusable Mug Program

<table>
<thead>
<tr>
<th>Materials</th>
<th>No. of Cups/yr</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-use cups</td>
<td>216,000</td>
<td>$7,103 annually</td>
</tr>
<tr>
<td>Reusable mugs</td>
<td>950</td>
<td>$2,707 one time</td>
</tr>
</tbody>
</table>

Illustration #2 Grass clippings

1. Source Reduction: Grasscycling
   a. push mower
   b. electric
   c. gas powered

2. Composting
   a. Home (a form of source reduction)
   b. Municipal

3. WTE

4. Landfill 25+ states have banned landfilling yard debris
THE BASIC ELEMENTS OF SOURCE REDUCTION

- Reduced material use in product manufacture
- Increased useful life of a product through durability and repairability
- Decreased toxicity
- Material reuse
- Reduced/more efficient consumer use of materials
- Increased production efficiency resulting in less production waste

STRATEGIES FOR SOURCE REDUCTION

- Bring reusable shopping bags
- Buy concentrates
- Buy in bulk
- Purchase reusable products
- Purchase durable and repairable products
- Buy secondhand items
- Borrow or rent items when possible
- Avoid over-packaged items
- Be aware of products containing hazardous ingredients
### Overview of Solid Waste Management Practices

**SOURCE REDUCTION**

**Strategies:** Education; rate incentives; changes in design and manufacture of products and packaging; selective shopping by consumers; promotion of reuse, repair & rental habits.

| Advantages: | Saves energy and resources; some strategies are low cost and low technology (such as shopping selectively) |
| Disadvantages: | Relies on behavior changes; difficult to measure impact |

**RECYCLING**

**Strategies:** Education; collection and processing programs (both government and private); market development for products made with recycled materials; procurement policies

| Advantages: | Saves energy and resources; reduces pollution; creates jobs; reduces dependency on landfills and incinerators. |
| Disadvantages: | Relies on behavioral changes; collection and processing systems ahead of market infrastructure for some materials; dependent on stable markets |

**MIXED WASTE PROCESSING**

**Strategies:** Materials Recovery Facility where recyclables are recovered and organic matter (food, yard waste and dirty paper) can be composted. Other materials are landfilled/incinerated.

| Advantages: | No behavioral changes required; potentially high recovery rate of recyclables; potential market for compost produced. |
| Disadvantages: | Does not promote conservation ethic; requires large capital investment; still requires use of landfills/incinerators. |

**LANDFILLING**

**Strategies:** Modern landfills are built to meet new Minimum Functional Standards; often located in non-urban areas.

| Advantages: | Commonly used disposal place; no behavioral changes required. |
| Disadvantages: | May not be the best use of resources that are in the waste stream (buried instead of recycled, repaired or reused). |

**INCINERATION**

**Strategies:** Mixed waste burned to generate electricity; recyclables not necessarily recovered.

| Advantages: | No behavioral changes required; ready market for electricity produced. |
| Disadvantages: | Does not promote conservation ethic; requires large capital investment; produces ash classified as hazardous waste; toxic air emissions. |
Concluding Thoughts:

- Modern Waste Management is Big Business
  - Problem solvers needed
- Recycling is an Ethic
- Vermicomposting & Composting are “sister” industries
- Dual source income opportunity is unique
- Knowledge of waste management “side” and soil fertility “side” is vital

To Think About…

1. Waste Management Issues
   a. Depending upon the geographic area and the dollar amount per ton, the tipping fee may serve as a powerful incentive to process waste. How necessary or desirable is it to locate a vermicomposting operation in a particular region to take advantage of tipping fees?
   b. Some areas of the country are experiencing problems in manure management, as USEPA and state regulatory agencies enforce stricter regulations on manure disposal. On the other hand, there is a realization that funding mechanisms (grants, loans) must be made available to farmers facing increased costs. What steps would you take in presenting vermicomposting as a viable option for manure management?

2. Composting Issues
   a. There are approximately 3500 composting facilities in the US. Many of these operations have the permitting, land, equipment, staff, feedstocks, and experience to handle large volumes of organic residuals. Yet very few know much about or engage in vermicomposting. What factors might motivate a composting facility to consider vermicomposting a portion of its residuals on-site?
   b. What are the reasons for the fact that the composting community as a whole has not embraced vermicomposting?
Composting: The Process

Introduction

What are “best management practices?”

A best management practices (BMP) approach to vermicomposting provides recommendations to be used as guidelines for processing organic wastes into marketable products without adversely affecting the environment. Each set of “BMPs” is designed to improve the success of vermicomposting operations in every aspect of business operation, from initial planning to end-product marketing. While the scope of this manual is not exhaustive, the Best Management Practices contained herein provide information, techniques, and resources that should prove to be useful.

In this section…

The biological fundamentals of composting are presented, beginning with a brief history of composting, a look at the carbon cycle in nature, the microbiology of composting, the composting process model, the key process variables, special attention to the critical factors in composting, and other pertinent information about the transformation of organic residues into a marketable product.

Definition

Composting is a managed, aerobic (requiring oxygen) process in which microorganisms decompose biodegradable material into a humus-like substance called compost. Organic matter (leaves, grass, vegetative food, manures, woody materials, etc.) are transformed through thermophilic and mesophilic phases producing carbon dioxide, water and stabilized organic matter. The resulting product is in a state where storage, handling and land application can be done without adversely affecting the environment. The composting rate is governed by nutrient balance, moisture content, aeration and temperature. Benefits of compost are derived from its high organic matter content, which increases its water holding capacity and improves soil structure, and the balanced microbial community compost contains, which helps suppress disease organisms and increase nutrient availability. Compost use decreases the need for watering and application of fungicide and fertilizer.

Contents

History of Composting
Hierarchy of Composting
The Carbon Cycle
The Microbiology of Composting
Composting Methods, Process Model
Critical Factors in Composting
Characteristics of Raw Materials
The History of Composting

- Archaeological evidence suggests that animal manure was used to increase food production shortly after people began cultivating food.

- Clay tablets of the Akkadian Empire in Mesopotamia refer to using manure in agriculture 1,000 years before Moses was born.

- Numerous references in the Bible and the Talmud to the cultivation of the soil and the use of animal manure as fertilizer and as fuel.
  - Talmud: “They lay dung to moisten and enrich the soil; dig about the roots of trees; pluck up suckers; take off the leaves; sprinkle ashes; and smoke under the trees to kill vermin,“
  - Talmud: Use of blood from animal sacrifices as fertilizer.
  - Talmud commentator: “Do not use your manure until some time after the outcasts have used theirs.” Advocates the use of rotted or composted manure instead of fresh animal matter.

- The Roman Statesman Marcus Cato introduced composting as a way to build soil fertility throughout the Roman Empire more than 2,000 years ago.

- During the Middle Ages (ca. 12th century AD) the Arab Ibn al Awam wrote his Kitab al Falahah or Book of Agriculture, in which he went into detail about the processing and use of compost and manure.

- Medieval Church monasteries practiced composting for soil fertility (St. Albans charter, 1258; Priory of Newenham, 1388)

- Renaissance literature references to compost
  - William Caxton, 15th century printer: “dongyng and compostyng the feldes.”
  - Shakespeare: Hamlet: “Do not spread the compost on the weeds, to make them ranker.”
  - Timon of Athens, “The earth’s a thief, that feeds and breeds by a composture stolen from general excrement.”
  - Sir Francis Bacon, Natural History, says that plants degenerate by “removing into worse earth, or forbearing to compost the earth.”
  - Sir Walter Raleigh: “He shall have the dung of the cattle, to muckle or composture his land.”
• Early American Agriculture

• Pilgrims were taught by native Abanaki tribe to add a fish to each hill of corn.
• Colonial farmers in 18th century mixed two loads of muck and one load of barnyard manure.
• Samuel W. Johnson, Professor of Agricultural Chemistry at Yale College emphasized this practice with the words, “this fact should be painted in bold letter on every barn door in Connecticut.”
• Steven Hoyt and Sons of New Canaan, Connecticut, had a large-scale compost operation using 220,000 fish in one season.
• George Washington’s requirements for a farm manager: “Above all, like Midas, one who can convert everything he touches into manure, as the first transmutation toward gold; in a word, one who can bring worn-out and gullied lands into good tilth in the shortest time.”
• Thomas Jefferson used dung in three different stages of decomposition—fresh or long dung, half purified or short dung, and well-rotted dung.
• Jefferson wrote of a “moveable airy cow house, to be set up in the middle of the field which is to be dunged,”
• James Madison, on May 12, 1818 stated: “There is probably a much higher state of agriculture in China and Japan than in many other countries far more advanced in the improvements of civilized life. Nothing is more certain than that continual cropping without manure deprives the soil of its fertility.”
• George Washington Carver advised farmers to “Make your own fertilizer on the farm. Buy as little as possible. A year-round compost pile is absolutely essential and can be had with little labor and practically no cash outlay.”

• Justus von Liebig in 1840 published his monograph on agricultural chemistry. Up until that time, the humus theory had prevailed. Liebig disproved the theory that plants actually ate humus to grow, and demonstrated that plants obtained nourishment from certain chemicals in solution. For the next 100 years, agricultural practice became increasingly chemical.

• Twentieth Century Organic Farming

• Sir Albert Howard, (in India 1905-1935) became father of the organic method of farming and Indore method of compost making—layering material, then turning.
• Rudolf Steiner, founder of biodynamic agriculture in 1924, emphasized composting.
• J.I. Rodale founder of *Organic Farming and Gardening* in 1942 stressed importance of composting.

• Composting since World War II

• The use of chemical fertilizers increased following World War II.

• Landfill space issues, the need to recycle, and deterioration of agricultural soils have stimulated interest in composting.

• US Composting issues have concerned
  • MSW composting
  • On-farm composting
  • Biosolids
  • Diverting yard trimmings from landfills
  • Backyard composting
Hierarchy of Composting Methods

<table>
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<tr>
<th>Hierarchy of Composting Methods</th>
<th>U.S. EPA</th>
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</thead>
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<tr>
<td>1. Grasscycling (source reduction)</td>
<td></td>
</tr>
<tr>
<td>2. Backyard composting (source reduction)</td>
<td></td>
</tr>
<tr>
<td>3. Yard Trimmings Programs (recycling)</td>
<td></td>
</tr>
<tr>
<td>4. Source-Separated Organics Composting (recycling)</td>
<td></td>
</tr>
<tr>
<td>5. MSW Composting Programs (recycling)</td>
<td></td>
</tr>
</tbody>
</table>

Benefits

1. Grasscycling

   a. Reduces lawn maintenance time by 38 percent.
   b. Leaving lawn clippings on the lawn reduces the need to fertilize by 25 to 33 percent, because nutrients in the grass clippings are simply being recycled.
   c. Reduces or eliminates the need for disposal bags.
   d. Reduces or eliminates the need for pick-up service charges.

2. Backyard Composting

   a. Reduces weight and volume of garbage thrown out
   b. Avoided costs of collection, hauling, and processing or disposal
   c. Provides free soil amendment—savings on fertilizer
   d. Retains soil moisture—savings on water usage
   e. Improves yields of fruits, vegetables, flowers and herbs
## Advantages and Disadvantages of Source Separation versus Commingling MSW

<table>
<thead>
<tr>
<th>SOURCE-SEPARATED MATERIALS</th>
<th>COMMINGLED MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages:</strong></td>
<td><strong>Advantages:</strong></td>
</tr>
<tr>
<td>• Less chance of contamination. This can result in a higher-quality compost product</td>
<td>• Usually collected with existing equipment and labor resources</td>
</tr>
<tr>
<td>• Less money and time spent on handling and separating materials at the compost facility</td>
<td>• Convenient for residents because no separation is required</td>
</tr>
<tr>
<td>• Provides an educational benefit to residents and might encourage waste reduction</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages:</strong></td>
<td><strong>Disadvantages:</strong></td>
</tr>
<tr>
<td>• Can be less convenient to residents</td>
<td>• Higher potential for contamination, which can result in a lower-quality compost product</td>
</tr>
<tr>
<td>• Might require the purchase of new equipment and/or containers</td>
<td>• Higher processing and facility costs</td>
</tr>
<tr>
<td>• Might require additional labor for collection</td>
<td></td>
</tr>
</tbody>
</table>
The Carbon Cycle

In nature, “compost happens” as leaves, twigs, needles and other organic materials decompose, becoming transformed into a humus-rich crumbly material through the activity of soil organisms.

1. Photosynthesis—Plants (autotrophs) take in nutrients, sunlight
2. Plants produce oxygen, organic carbon
3. Heterotrophs—Human beings, animals, microbes consume plants (carbon compounds)
4. Heterotrophs produce carbon dioxide, water, energy (heat). Carbon compounds in plant and animal wastes provide food for decomposers.

“I am not sure that composting is the answer to all things, but, in relation to waste management, the environment, and growing plants, compost seems to answer more questions by increasing performance than it does by decreasing performance. It makes us wonder whether or not the cycle depicted below is really coincidental at all.

Plants inhale carbon dioxide and exhale oxygen, while animals do just the opposite. It is obvious that we need each other to survive in the long run. With the world’s rain forests in jeopardy, with compost helping plants grow better, and with the world waste crisis, composting is the only activity that helps solve all three problems at the same time.”

# The Microbiology of Composting

<table>
<thead>
<tr>
<th>MICROBIAL GROUP</th>
<th>DESCRIPTION</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td>Unicellular of multicellular microscopic organisms. Bacteria usually appear as spheroid, rod-like or curved (spiral) entities, but occasionally appear as sheets, chains or branched filaments.</td>
<td>Generally considered the fastest decomposer. They consume simple sugars, starches, fats and proteins. When bacteria break down molecular carbon bonds (catabolism) in this material, considerable heat is generated.</td>
</tr>
<tr>
<td><strong>Fungi (molds)</strong></td>
<td>A group of simple organisms that lack a photosynthetic pigment; individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called <em>hyphae</em>. Individual hyphae can grow together to form a visible body.</td>
<td>More tolerant of low-moisture and low pH conditions, but less tolerant of low-oxygen conditions. They break down lignous material (woody substances) and other decay-resistant (recalcitrant) materials better than bacteria.</td>
</tr>
<tr>
<td><strong>Actinomycetes</strong></td>
<td>A group of microorganisms, intermediate between bacteria and true fungi, that usually produce a characteristic branched mycelium. These organisms are responsible for the earthy smell of compost.</td>
<td>Break down cellulose and hemicellulose. Primarily aerobic, more pronounced after easily degraded compounds are gone and when moisture and temperature are low.</td>
</tr>
</tbody>
</table>
# Compost Technologies (five)

1. **Open Passive Piles**—unmanaged
2. **Open Windrows and Piles**—actively managed and turned
3. **Covered Static Piles & Tunnels**—actively managed but static
4. **Covered Windrows, Bays**—actively managed and turned
5. **Covered Tunnels, Vessel Systems**—actively managed and turned

## Compost Methods, Materials and Time

<table>
<thead>
<tr>
<th>Method</th>
<th>Materials</th>
<th>Time/Range</th>
<th>Time/Typical</th>
<th>Curing Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive composting</td>
<td>Leaves, Well-bedded manure</td>
<td>2-3 years, 6 months to 2 years</td>
<td>2 years, 1 year</td>
<td>-</td>
</tr>
<tr>
<td>Windrow—infrequent turning</td>
<td>Leaves, Manure + amendments</td>
<td>½ to 1 year, 4-8 months</td>
<td>9 months, 6 months</td>
<td>4 months, 1-2 months</td>
</tr>
<tr>
<td>Windrow—frequent turning</td>
<td>Manure + amendments</td>
<td>1-4 months</td>
<td>2 months</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Passively aerated windrow</td>
<td>Manure/bedding, Fish wastes + peat moss</td>
<td>10-12 weeks, 8-10 weeks</td>
<td>-</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Aerated static pile</td>
<td>Sludge + wood chips</td>
<td>3-5 weeks</td>
<td>4 weeks</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Rectangular agitated bed</td>
<td>Sludge + yard waste or Manure + sawdust</td>
<td>2-4 weeks</td>
<td>3 weeks</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Rotating drums</td>
<td>Sludge and/or solid wastes</td>
<td>3-8 days</td>
<td>-</td>
<td>2 months</td>
</tr>
<tr>
<td>Vertical silos</td>
<td>Sludge and/or solid wastes</td>
<td>1-2 weeks</td>
<td>-</td>
<td>2 months</td>
</tr>
</tbody>
</table>

Source: On-Farm Composting Handbook
The Composting Process Model: Seven Steps

Materials Collected and Delivered to the Composting Facility

Step 1 Feedstock Recovery

Inspection at the facility. Separation of physical and chemical contaminants from the feedstock to guarantee quality of finished product. Initial sampling and testing takes place here. Odor generation must be controlled.

Step 2 Feedstock Preparation

Establish conditions for composting: Set particle size; set C:N ratio; set initial moisture content; initiate microbial diversity (inoculant)

Step 3 Composting

Pathogen treatment; turning and mixing; porosity control; monitoring oxygen; moisture control; manage odor generation.

Step 4 Odor Treatment

Prevent release of objectionable odor to atmosphere.

Step 5 Compost Curing

Develop the level of compost biological stability for marketing

Step 6 Compost Screening and Refining

Remove oversize material (stones, bulking agents, inert contaminants)

Step 7 Compost Storing and Packaging

Prepare compost for seasonal demands; adding amendments; bagging

The Finished Product that is produced for distribution must be tested for compliance with governmental regulatory standards and for market attributes and specifications. Care must be taken to assure attributes of the finished product are consistent with those needed by target markets, that accurate disclosure is made, and directions for use provided.
Management of Key Process Variables

1. Pile Porosity

Porosity means provisions to ensure pile access to oxygen (free airspace) and the ability to retain moisture (water holding capacity). Initial porosity must be established usually using a bulking material and sometimes through sizing particles of the feedstock material. In open windrow and closed agitated systems, pile turning may renew porosity periodically. In static pile composting, once initial porosity is set, only the use of blowers affects the composting process.

Terms:
Porosity  Free Airspace  Particle sizing  Bulking agents
Open windrow  Aerated  Static Pile  Positive, negative aeration
Agitated bed

2. Nutrient Balance

Assuring a carbon to nitrogen (C:N) balance of approximately 30:1 helps ensure rapid decomposition without releasing ammonia odors.

Terms:
C:N ratio

3. Pile Oxygen Percent

The oxygen needs of the microorganisms are provide by convective aeration and turning, or through the use of blowers. Aerobic decomposition of organic matter by microorganisms produces carbon dioxide and water as by-products with little odor.

Anaerobic decomposition of organic matter by microorganisms occurs in the absence of air producing methane gas, alcohols, and other organic compounds. Odor generation is noticeable.

Terms:
Aerobic  Anaerobic

4. Pile Moisture Percent

Initial pile moisture percent should be established at a level that allows a film of moisture to surround each biodegradable particle but not so much water that free airspace between particles is blocked and oxygen is prevented from reaching the microorganisms.
To overcome significant moisture loss during composting, the capability should be provided to make up moisture as required, usually with clean water free of pathogens.

5. Pile Temperature

Pile temperature can be controlled with positive ventilation or with turning and mixing. Pile temperature must be allowed to exceed 55°C (131°F) long enough to destroy pathogens and weed seeds.

Terms: PFRP Pathogens Thermophilic Mesophilic

6. Retention Time

Sufficient time must be provided for three purposes:

a. Time at temperatures in excess of 55°C for pathogen reduction and weed seed destruction
b. Time at mesophilic temperatures (less than 45°C) to achieve the biological stability level needed by customers
c. Time to degrade inhibitors of seed germination and plant growth (organic phytotoxins), and for some markets time to consume fungal substrate

Recommended Conditions for Rapid Composting

<table>
<thead>
<tr>
<th>Condition</th>
<th>Reasonable Range (^a^)</th>
<th>Preferred Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon to nitrogen (C:N) ratio</td>
<td>20:1—40:1</td>
<td>25:1—30:1</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>40-65%</td>
<td>50-60%</td>
</tr>
<tr>
<td>Oxygen Concentrations</td>
<td>Greater than 5%</td>
<td>Much greater than 5%</td>
</tr>
<tr>
<td>Particle size (diameter in inches)</td>
<td>1-3”</td>
<td>Varies</td>
</tr>
<tr>
<td>pH</td>
<td>5.5-9.0</td>
<td>6.5-8.0</td>
</tr>
<tr>
<td>Temperature (°F)</td>
<td>110-150</td>
<td>130-140</td>
</tr>
</tbody>
</table>

\(^a^\)These recommendations are for rapid composting. Conditions outside these ranges can also yield successful results.

\(^b^\)Depends on the specific materials, pile size, and/or weather conditions.
Critical Factors in Composting

1. Set Particle Size

Particle-sizing is usually performed after recyclables and contaminants have been removed manually or with trommel screens and before other preparation steps such as setting the carbon-to-nitrogen ratio, adding moisture and mixing.

Microbes work on the surface of decomposing material. The larger the surface area, the more time is needed for decomposition. Small particles, on the other hand, present more surface area to microbes and contribute to faster decomposition. However, if particles are too small, they will pack together tightly and obstruct the passage of air through the material. This may lead to anaerobic conditions in the pile.

One- to two-inch particle size of organic feedstock is considered optimum. Material passing through a 1 to 2 inch screen or shredder will be small enough to promote vigorous microbial activity, but large enough to provide structure to the composting mass.

Smaller particles tend to settle and pack, increasing the energy needed to maintain correct aeration (thus additional expense). Larger particles, on the other hand, decompose slowly and unevenly, leading to an unstable compost with more oversize rejects to be screened out of the final product. Large particles are also hard to wet uniformly.

Materials that fall through a screen or have been forced through a die are usually about the same size as the screen or die opening or smaller. For example, materials that fall through a 2-inch screen are usually called “2 inch minus” to indicate contents 2 inches and smaller. Long, slender materials can also pass through a screen even though they are longer than the width of the screen opening. For example, a 4-inch nail can readily pass through a 2-inch screen.

Reducing particle size is generally the norm and equipment may consist of drum screens (trommels), rotating drums that use knives or spikes to lift and crush the material, hammermills, and shear shredders. However, some incoming feedstocks may need bulking agents that provide larger particle size and promote pile porosity.

2. Set Recipe

Getting the recipe right means balancing the carbon-nitrogen ratio (C:N), moisture content and porosity (free airspace around particles). The C:N ratio indicates the nutrient balance in a compost mix, providing the food source for microbes. The optimal initial C:N ratio for effective composting is generally 30:1.
A ratio is a number that identifies a proportional relationship between two components. For example, a feedstock having a C:N ratio of 20:1 has, by weight, twenty times more available carbon than available nitrogen. The terms “high” and “low” reflect the relationship of the first element to the second. That is, a high C:N ratio expresses a greater percentage of carbon; a low C:N ratio indicates a relatively greater percentage of nitrogen.

Recipe Example: Fresh grass is high in nitrogen (C:N = 20:1), while dry leaves may average between 40:1 and 80:1. One recipe calls for two parts of leaves (carbonaceous source) to one part of grass clippings (nitrogenous source).

If the carbon content in the recipe is higher than 30:1, not enough nitrogen is available to support microbial need and the rate of degradation will slow. On the other hand, if the initial C:N ratio is below 30:1, more nitrogen is present than needed and the excess will volatilize and be lost as ammonia from the pile, and may become a source of odor. Excess ammonia contributes to odors and irritates the eyes and respiratory tract. Further, loss of nitrogen to the atmosphere in the form of ammonia represents a loss of the nitrogen resource that could have been useful during the composting process or in the final product as fertilizer value.

Not all carbon found in products like woody materials is available to the microbial colonies during the composting cycle. High-carbon materials may resist decomposition, and their carbon may be bound in compounds that are resistant to biological breakdown. Carbon may also appear in physical forms that make it unavailable. If some of the carbon is unavailable, a high C:N ratio may be desirable so that the carbon available to the microorganisms is in the appropriate range. Wood waste and newsprint are nearly 50 percent carbon, but the high lignin content in these materials may reduce their available carbon by less than half. Because the microbes may not be able to access the total volume of carbon in lignous wastes, adjusting the recipe may be necessary.

Recommendations:

<table>
<thead>
<tr>
<th>Target Range: 30:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Control Limit: 40:1</td>
</tr>
<tr>
<td>Lower Control Limit: 25:1</td>
</tr>
</tbody>
</table>
PROBLEM:

How do you determine the C:N ratio in feedstocks?

Formula

\[
\text{C:N Ratio} = \frac{\text{Wt. of “OC” in material A + “OC” in B + “OC” in C, etc.}}{\text{Wt. of “N” in material A + “N” in B + “N” in C, etc.}}
\]

Example: Chicken Manure and Sawdust Feedstocks

<table>
<thead>
<tr>
<th>Feedstock Materials:</th>
<th>Chicken Manure</th>
<th>Sawdust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content:</td>
<td>70%</td>
<td>35%</td>
</tr>
<tr>
<td>Nitrogen, dry weight basis</td>
<td>6%</td>
<td>0.11%</td>
</tr>
<tr>
<td>C:N Ratio</td>
<td>10:1</td>
<td>500:1</td>
</tr>
</tbody>
</table>

Determine C:N Ratio on a blend of one part chicken manure to one part sawdust

<table>
<thead>
<tr>
<th>Contents of one pound of material</th>
<th>Chicken Manure contains</th>
<th>Sawdust contains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.7 lbs.</td>
<td>0.35 lbs.</td>
</tr>
<tr>
<td>Dry Matter</td>
<td>0.3 lbs.</td>
<td>0.65 lbs.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Dry matter weight x percent (0.3x0.06)=0.018 lbs dw</td>
<td>Dry matter weight x percent (0.65x0.0011)=0.00715 lbs dw</td>
</tr>
<tr>
<td>Organic Carbon (OC)</td>
<td>Carbon ratio x dw of N (10x0.018)=0.18 lbs dw</td>
<td>Carbon ratio x dw of N (500x0.00072)=0.3575</td>
</tr>
</tbody>
</table>

\[
\text{C:N Ratio} = \frac{\text{c chicken manure} + \text{c sawdust}}{\text{n chicken manure} + \text{n sawdust}}
\]

\[
\text{C:N Ratio} = \frac{0.18 \text{ lb/lb.} + 0.3575 \text{ lb/lb.}}{0.018 \text{ lb/lb.} + 0.000715 \text{ lb/lb.}}
\]

\[
\text{C:N Ratio} = \frac{0.5375}{0.018715}
\]

\[
\text{C:N Ratio} = 28.72:1, \text{ or approximately } 29:1
\]

This is close enough to an ideal C:N ratio of 30:1 and the two feedstocks may be blended on a one-to-one ratio.
3. Set Moisture

Moisture is added to assist in particle sizing to establish a hospitable environment for biological activity during composting. All living things, including the microbes involved in composting, need water, nutrients, and air. Correct moisture will provide the microbial colonies adequate water for efficient metabolism.

Both air and water can occupy and compete for the pore spaces within the feedstock material. The moisture content must be high enough to establish and maintain a high rate of metabolism, but not so high that it blocks the supply of air to the microbes.

The rate of decomposition decreases rapidly and may stop when there isn’t enough moisture. However, too much moisture creates anaerobic conditions, essentially “drowning” aerobic microbes by limiting oxygen availability, and may cause odors, inhibit the rate of decomposition, and produce byproducts that are phytotoxic (toxic to plants).

Moisture is increased by adding water or by mixing dry materials with materials having a high moisture content such as biosolids or food waste. Water must be uniformly distributed throughout the feedstock material so that no part of the material is too dry or too wet. (Some materials such as leaves, may be hydrophobic, i.e., resistant to wetting.)

Spray water on material while turning a mixing to assure consistent, uniform distribution of moisture throughout the material. During initial preparation of the recipe, additional moisture may come from leachate containing diverse microbial communities. However, it is not recommended to use leachate as make-up water during the composting process, particularly after PFRP has been performed, since pathogens in the leachate may recontaminate the material.

Moisture content falls naturally during the composting process as water evaporates, particularly during turning and mixing as hot, wet materials are exposed to ambient air.

Ideally, fresh water should be used to raise the moisture content, particularly in open systems where evaporation is greater.

**Formula for Determining Moisture Content:**

**Moisture content is discovered by:**

1. Obtaining field samples in the feedstock
2. Drying them in an oven, and
3. Comparing the weight of the wet feedstock sample with the weight of the oven-dried material
Moisture content is defined as follows:

\[
\frac{\text{Weight of water}}{\text{Total weight (water + solids)}} = m
\]

Moisture content can be calculated as follows:

\[
\frac{FF + W}{F + W} = m
\]

Where

- \( F = \) Feedstock weight in tons, prior to adding water (includes the weight of the solids and any moisture in the feedstock)
- \( W = \) Added water weight in tons
- \( f = \) Initial feedstock moisture content, percent total weight expressed as a decimal (as determined from a representative sample)
- \( M = \) Desired moisture content, percent total weight expressed as a decimal

Solving this equation for water addition required gives:

\[
W = F \frac{(m-f)}{(1-m)}
\]

As an example, for 100 tons of feedstock with a 30 percent moisture content as received, and a desired moisture content of 55 percent, the water addition is calculated as follows:

\[
W = 100 \text{ tons} \times \frac{(0.55 - 0.30)}{(1 - 0.55)}
\]

\[
W = 56 \text{ tons}
\]

Therefore, 56 tons of water would need to be added to the 100 tons of feedstock to raise its moisture content from 30 percent to 55 percent. At 8.4 pounds per gallon, 56 tons of water equals about 13,000 gallons.

**Control Points**

<table>
<thead>
<tr>
<th>Target moisture content:</th>
<th>55%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal lower limit:</td>
<td>50%</td>
</tr>
<tr>
<td>Upper Control limit:</td>
<td>60%</td>
</tr>
<tr>
<td>Lower Control limit:</td>
<td>45%</td>
</tr>
</tbody>
</table>

**Rule of Thumb**

Use the “squeeze” test: A firm squeeze will produce several drops of water from a handful of composting material with the right amount of moisture.
4. Biological Activation

Microbes are normally present in the feedstock and will perform the decomposition process naturally during the composting process. However, instead of waiting for the natural build-up of the microbial population, active composting materials can be recycled into the feedstock to biologically activate it. Biological activation can increase the speed of the decomposition process by providing a diverse microbial population at the beginning of the composting process instead of relying on the natural build-up over time.

Some feedstocks, like manures, contain a relatively large number of microbes. Where no manure is present as an inoculum, the addition of compost materials from later in the process into a new batch of compost can “kick-start” the new pile with an active assortment of microbes.

Some operators have successfully provided biological activation by incorporating 10 to 15 percent recycled material into the feedstock. Commercial inoculants are available that may provide biological activation. However, operators have found that recycling their own materials is less costly and provides similar or better benefits than commercial inoculants.

5. Initial Turning and Mixing

Mixing feedstocks together evenly distributes the various materials. A load of wet produce might be mixed with dry leaves to achieve uniformity throughout the mixture. Adding and blending water occurs in this phase. Further breakdown of materials into smaller particles occurs as the mix is agitated and blended together. The goal is to expose each particle of compost to favorable conditions.

Compost users want a consistent, predictable product with uniform appearance, stability and moisture content. The proper blending of materials assures product consistency and market value of the product.

Lack of attention to this phase of the process may result in slowed or stopped biological activity. It may take several days to restore the compost mix environment for biological activity to resume. Lost time means that compost quality may be adversely affected and that more space and additional labor will be needed to manage incoming materials.

6. Temperature

Temperature rises quickly at the beginning because easily digestible material is abundant for microbes to consume. Thermophilic (heat-loving) organisms thrive in elevated temperatures (45-75°C or 113-167°F). Mesophilic organisms thrive in a mid-range of temperature (20-45°C or 68-113°F), but both types of organisms coexist
in a narrow temperature range centered at approximately 45°C (113°F). In this range, both types of organisms contribute to maximum decomposition. Below approximately 40°C (104°F), thermophilic organisms are inhibited, and above approximately 50°C (122°F) mesophilic organisms are inhibited.

**Units of Measure:** Composting regulations commonly refer to temperature in degrees Celsius, but temperature can be measured on either the Celsius or Fahrenheit scales. The correlation between Celsius and Fahrenheit degrees is:

\[
\text{(Degrees Celsius} \times 1.8) + 32 = \text{Degrees Fahrenheit}
\]

or

\[
\text{(Degrees Fahrenheit} - 32) \div 1.8 = \text{Degrees Celsius}
\]

### Comparing Celsius & Fahrenheit Temperature Measurements

<table>
<thead>
<tr>
<th>Celsius</th>
<th>Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°</td>
<td>Water Boils 212°</td>
</tr>
<tr>
<td>55°</td>
<td>PFRP 131°</td>
</tr>
<tr>
<td>37°</td>
<td>Body Temperature 98.6°</td>
</tr>
<tr>
<td>25°</td>
<td>Optimum for <em>E. fetida</em> 77°</td>
</tr>
<tr>
<td>20°</td>
<td>Room Temperature 68°</td>
</tr>
<tr>
<td>0°</td>
<td>Water Freezes 32°</td>
</tr>
</tbody>
</table>

Thanks to Mary Appelhof for suggesting this visual aid
Temperatures are allowed and encouraged to climb during the initial composting phase, after all materials have been properly set and mixed. Since both mesophilic and thermophilic organisms are active around 45°C, the maximum rate of decomposition takes place at this temperature range and is the “target” temperature for high-rate composting. However, higher temperatures are needed to destroy pathogens and weed seeds.

Pathogens are disease-causing organisms, including bacteria, viruses, fungi, helminths, and protozoa. Pathogens are found within living organisms and at background levels in the environment. Healthy humans and animals are immune to pathogens at background levels, but they may be susceptible to disease when pathogens are present in greater quantities. Elevated pathogen levels may be found in some composting materials, where human and animal feces are present, and biosolids.
Sufficient heat generated in the composting process will reduce pathogen levels to eliminate the danger of transmitting disease through the finished product. The resulting product may be considered “sanitized,” where pathogens, although not totally eliminated, are reduced to background levels.

PFRP is the Process to Further Reduce Pathogens, a federal standard of achieving pathogen reduction in organic materials through time, temperature and turning. Composting materials must remain at 55°C (131°F) or hotter for 3 to 15 days, depending on whether the system is in-vessel or outdoor windrow. In windrow systems, the compost must be turned at least five times over the 15-day period to ensure that all particles have been exposed to the required high temperature.

The objectives of PFRP are to, 1) reduce human and animal fecal pathogens to below background levels; 2) establish conditions that inhibit regrowth of pathogens; 3) kill weed seeds; and 4) destroy plant pathogens.

Fecal coliform bacilli and fecal streptococci are often used as indicator species to assess pathogen destruction because these species are more resistant to heat than many other organisms. In general, coliform bacteria and fecal streptococcus will survive below a certain temperature threshold (50°C, or 122°F). However, after about 20 minutes at 55°C (131°F), the surviving fraction is only 0.01. This means that 99 percent of the pathogen population has been destroyed.

7. Turning and Mixing

Turning and mixing help distribute water, nutrients, and air uniformly to the microbes. If water is added and the material is not mixed, the added water may concentrate in certain areas, making some parts too wet or leaving other parts too dry. By turning and mixing, each part of the composting material is exposed to oxygen and porosity may be restored.

The objectives of turning and mixing are:

- blend make-up water uniformly throughout the compost
- distribute various feedstock materials throughout the pile
- break up clumps that can become anaerobic, too wet, or too dry
- break up air channels between clumps that can leave over-dry areas and starve other areas of oxygen
- aid physical breakdown of materials
- kill fly larvae that may grow on the surface of the pile
- speed the entire composting process
- aid in creating a consistent, marketable product

It can be assumed that composting materials lose about 5 percent of their moisture content per day, although this can vary in amount, either higher or lower, depending upon the system being used and other variables. In a dry, hot climate, piles that are...
short and wide tend to lose moisture faster than narrow, tall piles that contain the same amount of material. A five percent daily moisture loss will dry the material from 60 percent to 45 percent moisture in five to six days, and would go as low as about 42 percent in seven days. Moisture loss will be greatest during high-rate composting when the temperatures in the pile are at their highest. Moisture loss is increased during turning as heated composting materials are exposed to ambient air.

8. Compost Stabilization

As the rate of biological activity slows down, temperatures decrease as thermophilic organisms give way to organisms within the mesophilic range. Bacteria that have dominated in the initial phase of composting are less prevalent. Fungi and actinomycetes appear and continue the process of biological decomposition.

During compost stabilization, the rate of decomposition slows down. This phase can take from 20 to 60 days, depending on the technology used. Conditions must continue to be monitored, ensuring that proper moisture and aeration are present so that odors are not generated and that compost will continue to stabilize toward maturity. Areas having excessive moisture may contain phytotoxic byproducts of fermentation.

9. Compost Curing

Curing involves long-term, low-level microbial activity, predominantly by fungi, in processes called mineralization and humification. During this phase, organic carbon converts to carbon dioxide and humus, and organic nitrogen converts to nitrate. Humus, the term for the dark brown to black organic fraction of soil, is both the product of microbial action and source of food for microbes and plants in the soil. Humus is composed of organic matter, including humic acids, and consists of both remains and transformations of the original organic matter and the microbes themselves.

Curing continues the aerobic decomposition process to increase biological stability of the product to levels that may be required for bagging or bulk distribution.

During this phase, reintroduction of pathogens must be avoided by handling compost with clean equipment and by using only fresh water for make-up needed to control moisture content.

A consistent balance of both air and moisture is important to maintain low-level microbial activity as decomposition of more chemically complex substances such as hemicellulose, cellulose, and lignin continues. Actinomycetes and fungi are particularly active during this stage.
10. Screening and Refining

Screening is the separation of physical contaminants from compost based on size, while refining is the separation of contaminants based on density. Refining is usually performed immediately after screening, although screening alone may be the only operation needed to satisfy market requirements.

Oversized items (wood) and physical contaminants (man-made inerts, rocks) are removed from compost during this process to meet safety and product standards.

The Composting Council has established at least two standards:

- Compost may contain no man-made inerts that are potentially injurious to humans and animals, such as glass shards and metal fragments greater than 4 mm. Specific limits may be developed in the future.
- Compost may contain no film plastic greater than 4 mm that would pose a health risk to some animals if ingested. Specific limits may be developed in the future.

Materials targeted for separation during Compost Screening typically include wood, glass, metals, film plastic, stones, bones, leather, hard plastic, and sharps. Sharps include steel sewing needles and straight pins, and stainless steel hypodermic needles. Equipment used includes rotary screens (trommels) and oscillating deck screens.

The moisture content of materials to be screened has a significant impact on the effectiveness of the screening equipment. If moisture levels are too high, clogging the screens with clumps becomes a factor. Optimum moisture content for screening is approximately 40-45%. Because the moisture level during the Curing phase may be higher than what is desirable for Screening, the moisture content should be reduced by drying for one to several days before screening.

Moisture below 35% causes dusting which can irritate eyes and lungs, accumulate on equipment, and become a fire hazard. Excessively dry material can also resist re-wetting (hydrophobic), a negative product characteristic. A lower moisture content can result in dusty operating conditions that promote Aspergillus fumigatus.

*Aspergillus fumigatus* is fungus present universally in all environments. However, it is known to develop large populations in materials with high cellulose, so its presence in composting facilities may be greater where there is a higher density of spores. Humans with weakened immune systems become more susceptible to opportunistic organisms that are capable of causing disease. Oral infection is the predominant route for primary pathogens, and secondary pathogens are typically inhaled by breathing air that has a high density of spores. People with pre-existing conditions, such as asthma, emphysema, tuberculosis, diabetes, and positive skin tests, or who may be taking medication, such as corticosteroids, broad-spectrum antibiotics, or immunosuppressive drugs, or who may be prone to severe allergies, may be more susceptible to secondary infections.
## SUMMARY

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>Proper particle-sizing of feedstocks, turning and mixing are used to ensure pile access to oxygen and allow uniform distribution of moisture.</td>
</tr>
<tr>
<td>Moisture</td>
<td>The right balance nourishes microbial organisms. Target range is 55% by weight. Excess moisture tends to limit oxygen availability.</td>
</tr>
<tr>
<td>Oxygen and Carbon Dioxide</td>
<td>Microorganisms need O₂ to oxidize carbon which is released as CO₂. When aerobes die, anaerobes flourish, resulting in offensive odors. Oxygen concentrations in the compost air greater than 5% are recommended for rapid composting.</td>
</tr>
<tr>
<td>Temperature</td>
<td>Heat is the result of microbial activity. 110-140°F indicates an active pile. Most weed seeds are killed at 145°F. Temperatures above 160°F effectively stop the composting process.</td>
</tr>
<tr>
<td>C:N ratio (recipe)</td>
<td>A carbon to nitrogen (C:N) balance of 25:1 to 40:1 helps ensure rapid decomposition. Target range: 30:1</td>
</tr>
<tr>
<td>Time</td>
<td>C:N ratio, oxygen availability, moisture, particle size, mixing and temperature affect the time it takes to reach stable compost. C:N ratios below 20:1 tend to generate foul odors. C:N ratios above 40:1 increase composting times.</td>
</tr>
</tbody>
</table>

### The Composting Process

- Microbial breakdown of organic matter
- Reduction in particle size
- C:N ratio decreases due to carbon loss
- pH nears neutral
- Volume reduction of 60-80%
- Weight reduction of 40-80%
## Characteristics of Raw Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Type of Value</th>
<th>% N (dry weight)</th>
<th>C:N ratio (weight to weight)</th>
<th>Moisture Content % (wet weight)</th>
<th>Bulk Density (lbs. per cubic yard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple pomace</td>
<td>Typical</td>
<td>1.1</td>
<td>48</td>
<td>88</td>
<td>1,559</td>
</tr>
<tr>
<td>Coffee grinds</td>
<td>Typical</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Corn cobs</td>
<td>Range Average</td>
<td>0.4-0.8</td>
<td>56-123</td>
<td>9-18</td>
<td>-</td>
</tr>
<tr>
<td>Corn stalks</td>
<td>Typical</td>
<td>0.6</td>
<td>98</td>
<td>15</td>
<td>557</td>
</tr>
<tr>
<td>Cottonseed Meal</td>
<td>Typical</td>
<td>0.6-0.8</td>
<td>60-73</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>Cull potatoes</td>
<td>Typical</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fruit wastes</td>
<td>Range Average</td>
<td>0.9-2.6</td>
<td>20-49</td>
<td>62-88</td>
<td>-</td>
</tr>
<tr>
<td>Rice hulls</td>
<td>Range Average</td>
<td>0.4-0.6</td>
<td>113-1120</td>
<td>7-12</td>
<td>185-219</td>
</tr>
<tr>
<td>Tomato-processing waste</td>
<td>Typical</td>
<td>4.5</td>
<td>11</td>
<td>62</td>
<td>-</td>
</tr>
<tr>
<td>Vegetable produce</td>
<td>Typical</td>
<td>2.7</td>
<td>19</td>
<td>87</td>
<td>1,585</td>
</tr>
<tr>
<td>Cattle manure</td>
<td>Range Average</td>
<td>1.5-4.2</td>
<td>11-30</td>
<td>67-87</td>
<td>1,323-1,674</td>
</tr>
<tr>
<td>Horse manure</td>
<td>Range Average</td>
<td>1.4-2.3</td>
<td>22-50</td>
<td>59-79</td>
<td>1,215-1,620</td>
</tr>
<tr>
<td>Sheep manure</td>
<td>Range Average</td>
<td>1.3-3.9</td>
<td>13-20</td>
<td>60-75</td>
<td>-</td>
</tr>
<tr>
<td>Swine manure</td>
<td>Range Average</td>
<td>1.9-4.3</td>
<td>9-19</td>
<td>65-91</td>
<td>-</td>
</tr>
<tr>
<td>Turkey litter</td>
<td>Average</td>
<td>2.6</td>
<td>16</td>
<td>26</td>
<td>783</td>
</tr>
<tr>
<td>Municipal garbage (food waste)</td>
<td>Typical</td>
<td>1.9-2.9</td>
<td>14-16</td>
<td>69</td>
<td>-</td>
</tr>
<tr>
<td>Paper from domestic refuse</td>
<td>Typical</td>
<td>0.2-0.25</td>
<td>127-178</td>
<td>18-20</td>
<td>-</td>
</tr>
<tr>
<td>Straw-general</td>
<td>Average</td>
<td>0.7</td>
<td>80</td>
<td>12</td>
<td>227</td>
</tr>
<tr>
<td>Cardboard</td>
<td>Typical</td>
<td>0.10</td>
<td>563</td>
<td>8</td>
<td>259</td>
</tr>
<tr>
<td>Paper mill sludge</td>
<td>Typical</td>
<td>0.56</td>
<td>54</td>
<td>81</td>
<td>-</td>
</tr>
<tr>
<td>Sawdust</td>
<td>Average</td>
<td>0.24</td>
<td>442</td>
<td>39</td>
<td>410</td>
</tr>
<tr>
<td>Grass clippings</td>
<td>Average/loose</td>
<td>3.4</td>
<td>17</td>
<td>82</td>
<td>300-400</td>
</tr>
<tr>
<td>Leaves</td>
<td>Average/dry</td>
<td>0.9</td>
<td>54</td>
<td>38</td>
<td>100-300</td>
</tr>
<tr>
<td>Tree trimmings</td>
<td>Typical</td>
<td>3.1</td>
<td>16</td>
<td>70</td>
<td>1,296</td>
</tr>
</tbody>
</table>

Source: On-Farm Composting Handbook
Summary of common raw materials for farm composting

<table>
<thead>
<tr>
<th>Bark</th>
<th>Livestock manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardboard</td>
<td>Paper mill sludge</td>
</tr>
<tr>
<td>Cattle manure</td>
<td>Peat moss</td>
</tr>
<tr>
<td>Crop residues</td>
<td>Poultry manure</td>
</tr>
<tr>
<td>Fertilizer and urea</td>
<td>Sawdust and shavings</td>
</tr>
<tr>
<td>Finished compost</td>
<td>Seaweed and other aquatic plants</td>
</tr>
<tr>
<td>Fish processing wastes</td>
<td>Septage and sewage wastes</td>
</tr>
<tr>
<td>Food processing wastes</td>
<td>Slaughterhouse and meat packing wastes</td>
</tr>
<tr>
<td>Fruit &amp; vegetable wastes</td>
<td>Spoiled hay silage</td>
</tr>
<tr>
<td>Grass clippings</td>
<td>Straw</td>
</tr>
<tr>
<td>Horse manure</td>
<td>Swine manure</td>
</tr>
<tr>
<td>Leaves</td>
<td>Wood ash</td>
</tr>
<tr>
<td>Lime</td>
<td>Wood chips</td>
</tr>
<tr>
<td>Newspaper</td>
<td></td>
</tr>
</tbody>
</table>

Source: *On-Farm Composting Handbook*

Common Raw Materials For Composting

**Bark**  Qualities are similar to that of wood chips except, for a given tree species, bark contains slightly more nitrogen and easily degradable compounds. May be composted alone for use in potting media or for mulch. Good bulking agent but poor as a general amendment. Good material for specialty compost products (mulch, potting media) though the composting time is relatively long.

**Cardboard**  Dry and high carbon content. Good degradability. Good moisture absorption and structure. Large quantities available for little or no cost, or a tipping fee may be available. Shredding, storage, and some sorting may be needed. Staples in cardboard boxes may need to be removed. Glues in corrugated cardboard may contain high boron levels. Good to fair amendment.

**Cattle manure**  Nitrogen-rich and very wet. Moisture content and C:N ratio depend on the amount of bedding used, management practices, type of operation, and climate. Generally requires a large amount of dry, high-carbon amendment, often two to three volumes of amendment per volume of manure. Relatively low odor risk if composted within a few weeks. Decomposes quickly. *Bedded pack* manure is moderately dry with goo C:N ratio. *Liquid manure* or slurries must be screened or dried unless only small amounts are used in the composting mix. Some trash may be present. Overall, a very good composting material.

**Crop residues**  Variable characteristics depending upon the material but generally moderate to high moisture and moderate C:N ratio. The C:N ratio and moisture content...
depend on the age and the amount of fruit and seeds present. Generally older vegetation is drier and contains less nitrogen. Usually very good structure and good degradability. Some residues may be dry and high in carbon (corn stalks). Plant pathogens are a concern if compost does not reach high temperatures in all parts of the pile. Excellent to good composting amendment depending on the material.

**Fertilizer and urea** Fertilizers, urea, or other concentrated nitrogen sources are sometimes considered as additives to lower the C:N ratio of high carbon materials such as leaves. Although such materials do reduce the initial C:N ratio, the benefits are short-lived. Nitrogen from such sources tends to be available much more quickly than the carbon in the organic materials. Initially the available carbon and nitrogen are in balance; but as the easily available carbon in depleted, a surplus of nitrogen soon develops. Eventually the excess nitrogen is lost as ammonia.

**Finished compost** Compost can be recycled as an amendment for wet wastes, either alone or in combination with other amendments. Moderately dry. Moderate to low C:N ratio. Provides a good initial supply of microorganisms. Frequent recycling may potentially lead to high salt concentrations, but otherwise, no significant disadvantages. Loss of compost product after recycling is small. Good amendment, especially for lowering the mix moisture content without raising the C:N ratio.

**Fish processing waste** Racks, frames, heads, tails, shells, gurry. Variable characteristics depending on waste, but generally moderately to very wet and high in nitrogen. Lobster, crab, shrimp, and mollusk shells provide good structure. All but mollusk shells decompose quickly. The high risk of odor along with the high moisture requires large amounts of dry amendment and/or special handling. More restrictive regulations may apply. Potential for tipping fee. Wet materials—racks or gurry—are troublesome, and composting should be considered after other options. Shells are moderate to good composting materials if managed properly.

**Food processing waste** Variable characteristics depending upon the process. Filter press cakes generally are moderately dry and have high to moderate carbon content. Other food processing by-products are generally wet with moderate to low C:N ratios. Possible problems include high risk of odor; vermin (rats, mice, flies); contaminants from machinery and cleaning solutions used at the processing plant; and poorly degradable components such as pressing aids. A major advantage is the opportunity to receive a tipping fee. Good to poor composting material depending upon the nature of the waste.

**Fruit and vegetable waste** Peels, tops, trimmings, culls, damaged/spoiled fruit. Moderate to wet with a moderate to low C:N ratio, depending upon the nature of the waste. Except for pits, good degradability. Poor to fair structure. Standing piles of many fruits and some vegetable wastes quickly collapse into a wet mess once decomposition begins. The potential for tipping fees exists. Slight to moderate risk of odor problems. Possible trash from packing operations and markets. Good to fair composting material.
**Grass clippings**  Moderately wet to dry.  Slightly low C:N ratio.  Decompose quickly.  Moderate to high odor potential depending upon management.  Good source of nitrogen for leaf and yard waste mixtures.  Usually available free, or a tipping fee may be available.  Good composting material, if mixed with coarse materials.  Alone, grass clippings tend to compact and become anaerobic.

**Horse Manure**  Usually contains large amounts of bedding; therefore, dry with a high C:N ratio.  Composts well alone or as an amendment for wet cattle manure.  Low odor potential.  Decomposes quickly, especially if bedding is straw.  Often available at little or no cost from local stables, racetracks, pleasure horse owners, fairs, and schools.  Some stable wastes contain medication containers, soda cans, and other trash.  Excellent composting material.

**Leaves**  Relatively dry.  High in carbon.  Good degradability if shredded.  Moderate moisture absorption.  Low odor potential.  Composts alone or as an amendment.  Often contains trash, rocks, plastic bags, and so on—especially if collected from streets.  Large quantities available but seasonal supply requires storage and/or special handling/scheduling.  Leaves can be obtained free, or a tipping fee may be available.  Good to moderate composting material.

**Lime**  Like fertilizers, lime is also considered an additive, either to adjust pH or to control odors.  Generally, lime is an unnecessary ingredient and can be detrimental.  pH adjustment is rarely necessary in composting.  If lime is used for odor control, it can raise the pH enough to cause an excessive loss of ammonia.  The same effects should be expected for other concentrated sources of alkalinity, including cement kiln dust and wood ash.

**Newspaper**  Dry.  High carbon content.  Moderate degradability.  Potential for dual use as bedding.  Good moisture absorption but poor structure and porosity.  Black inks are generally non-toxic.  Large quantities of colored inks and glossy paper are best avoided or should be analyzed because of possible heavy metals and other contaminants.  Available in large quantities at little or no cost, or a tipping fee may be available.  May need shredding and some sorting initially.  Possible problems include storage, dust, and trash around the site.  In general, a good to moderate amendment depending upon the structure of the mix.

**Livestock manure**  Sheep, goat, rabbit and other livestock manures are usually good for composting.  They are collected mostly from bedded manure packs and are, therefore, relatively dry with a high C:N ratio.  Without bedding, the manure is nitrogen-rich and wet.  Bedded material may be used as an amendment to other livestock manures.  Relatively low odor potential.  Decomposes quickly.  Good composting material.

**Paper mill sludge**  Wet or moderately wet if pressed.  Moderate to high C:N ratio.  Requires a dry amendment with nitrogen—a difficult combination.  Good degradability but poor structure.  Slight to moderate risk of odor is mismanaged.  Organic contaminants
are occasionally found in paper sludge. Potential for tipping fee. Fair composting material.

**Peat moss** Acidic fibrous material which has resulted from years of anaerobic decomposition. Low in nitrogen. Highly absorbent of water, nutrients and odors. May hold over ten times its weight in water. Except in regions where natural deposits exist, peat moss is expensive, partly because of its competing uses as an amendment for potted plants and other horticultural crops. Peat moss passes through the composting process virtually unchanged, producing a potentially high valued compost. Its odor- and water-absorbing qualities make it an excellent amendment, but cost limits its use.

**Poultry manure** Very high nitrogen content and moderately moist. Needs a high carbon amendment. *Litter* with sawdust or wood shavings is well suited to composting and may be partially composted when removed from the barn. Nitrogen loss and odor from ammonia is a potential problem because of the high nitrogen content and high pH. Low pH amendments may be needed to lower the alkalinity. Decomposes quickly. The high nitrogen content can result in a fertilizer-grade compost. Good to very good composting material.

**Sawdust and shavings** Dry and carbonaceous. Moderate to poor degradability; sawdust degrades faster than shavings. Good moisture and odor absorption. Can also have a dual use as bedding. Usually available at a moderate to low cost. Good to moderate composting amendment.

**Seaweed and other aquatic plants** Water hyacinth, pond cleanings, waste water treatment species. High to moderate moisture content, depending on previous drying. C:N ratios vary from low (seaweeds) to moderate (water hyacinth). Good degradability. Generally poor structure, especially for seaweeds. Good sources of minor nutrients, but salt content of seaweed is a possible problem if used in large quantities. Possible trash and weed seeds included with beach cleanings. Low to moderate odor risk. Good composting material with added structure.

**Septage and sewage sludge** Raw and digested. Nitrogen-rich and very wet. Requires two to four volumes of dry amendment per volume of sludge. *Septage* and raw sludge decompose quickly, digested sludge moderately. Strong odor potential for septage and raw sludge, strong to moderate for digested. Possible contamination from human pathogens and heavy metals. Special regulations apply for pathogen reduction. Restrictions on land use apply for heavy metals. Composting these materials usually involves operational and land application permits, process monitoring, and product analysis. The one advantage is the opportunity to collect a fee for composting these materials. In general, sewage sludge and septage bring many restrictions and regulations. Through exceptions exist, it is best to avoid these materials for farm composting operations.

**Slaughterhouse and meat packing waste** Paunch manure, blood, miscellaneous parts. Wet and low C:N ratio. Good degradability. High risk of odors and vermin. More
restrictive regulations may apply. Large amounts of amendment are required to lower moisture content and control odors. Except for paunch manure, composting should be considered only if direct land application and other options are not practical.

**Spoiled hay and silage** Moderately dry to wet, depending on conditions. Moderate to high C:N ratio. In most cases, available only occasionally. Added to compost mix as a disposal method and not as a reliable amendment. Good structure and degradability. Possible problems include odor and leachate from silage and weed seeds in hay. Moderate composting material.

**Straw** Dry and carbonaceous. Moderate to poor degradability; sawdust degrades faster than shavings. Good moisture and odor absorption. Can also have a dual use as bedding. Usually available at a moderate to low cost. Good to moderate composting amendment.

**Swine manure** Nitrogen-rich and very wet. Needs a dry, high-carbon amendment. Strong potential for odors. High moisture content and odor make composting more difficult than other manures. With bedding, solids separation, and/or odor-control measures, it can be a fair to good composting material.

**Wood ash** Very dry with little or no carbon and nitrogen. Contains a fair amount of other nutrients, particularly potassium. The concentrations of heavy metals may be a concern with some ashes. In a composting mix, wood ash would absorb moisture and raise the pH of the mix. It has also been proposed as an odor adsorbing agent. Handling is difficult as the ash is a fine powder which blows around and creates dust. Particles tend to cement together after they become wet. Tipping fees may be available. Fair to good composting amendment for wet acidic mixes. Should not be used if the pH is high.

**Wood chips** Dry and high in carbon. Large particle size provides excellent structure but poor degradability. Often used as a bulking agent for forced aeration composting. Must be screened from final compost but can be reused. Moderate to low cost. Has a competing use as a mulch product. Chips from preservative-treated wood and painted wood should not be used. Very good bulking agent but poor amendment otherwise.

### Generators of Food Processing Residues

<table>
<thead>
<tr>
<th>Category</th>
<th>Residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supermarkets</td>
<td>Produce trimmings; outdated perishables; prepared foods; large quantities of corrugated cardboard (OCC). Supermarkets typically recycle OCC, but as much as 30% may be waxed or soiled and wet and therefore unrecyclable but compostable.</td>
</tr>
<tr>
<td>Hotels, restaurants, fast food chains</td>
<td>Vegetable trimmings, paper napkins, OCC, cereal boxed, cooked foods, coffee grounds and filters, paper plates and drink containers, paper towels from restrooms.</td>
</tr>
<tr>
<td>Malls, theaters, entertainment complexes</td>
<td>Paper waste, prepared food waste, food wrappers, waxed paper drink containers</td>
</tr>
<tr>
<td>Convenience stores and service stations</td>
<td>Outdated vending machine and prepared foods, OCC, paper napkins, newspaper, paper towels</td>
</tr>
<tr>
<td>Office buildings and schools</td>
<td>Cafeteria or employee lounge waste similar to that generated by fast food outlets, paper towels</td>
</tr>
<tr>
<td>Hospitals, prisons, military bases</td>
<td>Food and paper wastes similar to those generated by hotels and restaurants</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>Commercial kitchens (airlines, caterers); canneries, bakeries, breweries, dairies, fisheries, and any type of food processor. Typically, raw materials are brought in to these manufacturers in cardboard containers and may be another source of compostables.</td>
</tr>
</tbody>
</table>
Compost: The Product

Introduction

Solid waste managers look at the process of composting as a means by which organic material decomposes so that there is considerable volume reduction of material which then becomes stabilized, thus diminishing concerns of odors, attracting vectors and producing leachates. Hence, the very act of effectively processing organic material solves a waste problem. In some municipalities, the resulting compost is considered to have little economic value. It may be used for alternate daily cover on landfills, or given away free to the public. Some composts have been produced where quality has been questionable. MSW compost tends to have low perceived value and biosolids compost may also raise objections because of concerns with heavy metal content. Understanding the value of compost and the characteristics of quality compost will serve to increase both the use and demand for this product.

In this section...

Compost has the unique capacity to improve the properties of soils and growing media in many ways: physically (structurally), chemically (nutritionally), and biologically. Quality compost can be measured and evaluated quantitatively and found to possess qualitative characteristics as well. Application rates help users determine how much compost is needed for their particular project.

Definition

Compost is the product resulting from the controlled biological decomposition of organic wastes. Finished or mature compost has been sanitized (free of pathogens) and stabilized to a degree which is potentially beneficial to plant growth. Compost is largely decomposed organic material and is in the process of humification (curing). It bears little physical resemblance to the raw material from which it originated. The addition of compost improves the physical, chemical and biological properties of soils and potting mixes. It contains plant nutrients but is typically not characterized as a fertilizer. Quality compost possesses many specific characteristics that can be quantified as to its content of nutrients, pH, moisture content, lack of harmful substances, etc.

Contents

Benefits of Using Compost
Compost Quality Characteristics
Typical Characteristics of Compost
Uses and Application Rates
Quality Requirements for Users
Benefits of Compost Use

- Increased organic content of soil
- Improved soil structure and texture
- Increased aeration capacity
- Increased soil fertility
- Increased water- and nutrient-holding capacity
- Increased resistance to erosion from wind and water
- Reduced pollutant load to surface and ground water
- Enhanced plant disease and weed growth suppression
- Increased temperature insulation
- Increased pH in acidic soils


More Benefits of Using Compost

- Quality compost generally helps make almost all plants healthier
- Quality compost helps retain moisture in sandy soils
- It breaks up clay in heavy soils
- Compost adds nutrients
- It helps improve drainage
- Compost helps hold nutrients in the root zone so plants can use them
- Compost helps make most soils more workable for yearly replanting or easy weeding
- Compost attracts and feeds earthworms
- It reduces plant stress from droughts and freezes
- Compost can extend the growing season
- Compost improves the vitamin and mineral content in food grown in compost-rich soils (also taste!)
- It replaces reliance upon petro-chemical fertilizers
Why Your Customers Should Use Compost

Breaks up clay soils
Dark color absorbs heat
Eases cultivation
Helps prevent crusting
High Cation Exchange Capacity (CEC) ties up heavy metals
Increases microbial population
Increases CEC
Increases exchange capacity of many soil types
Increases root structure
Kills weed seeds during processing
Makes weed pulling easier
Promotes growth of mycorrhizae
Versatile in wet weather
Reduces erosion
Reduces soil compaction
Suppresses weeds when used as a mulch
Contains high organic content
Decreases thatch
Helps form soil aggregates
Helps suppress plant diseases
Improves drought tolerance
Improves soil structure
Increases drainage in dense soils
Increases earthworm population
Increases micronutrients
Increases nutrient availability
Increases soil aeration
Lightweight and easy to move
May increase safety on athletic fields
Provides slow release of micronutrients
Reduces leaching
Replaces cover crops
Uniform texture and consistency

The addition of compost improves the physical, chemical, and biological properties of soils and potting mixes. Compost itself has characteristics that are used as indicators or its quality and usefulness.

### Compost Quality Characteristics

<table>
<thead>
<tr>
<th>Physical</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark color</td>
<td></td>
</tr>
<tr>
<td>Uniform particle size</td>
<td></td>
</tr>
<tr>
<td>Pleasant, earthy scent</td>
<td></td>
</tr>
<tr>
<td>Absence of inerts</td>
<td></td>
</tr>
<tr>
<td>Moisture content &lt; 50%</td>
<td></td>
</tr>
<tr>
<td>Near-neutral pH</td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
</tr>
<tr>
<td>Available nutrients (nitrogen, phosphorous, and potassium)</td>
<td></td>
</tr>
<tr>
<td>minimal levels of heavy metals, organic pollutants, pesticides and herbicides</td>
<td></td>
</tr>
<tr>
<td>Low soluble salt content</td>
<td></td>
</tr>
<tr>
<td>Biological</td>
<td></td>
</tr>
<tr>
<td>Sufficiently mature and stable</td>
<td></td>
</tr>
<tr>
<td>High concentration of organic matter</td>
<td></td>
</tr>
<tr>
<td>Absence of pathogenic organisms</td>
<td></td>
</tr>
<tr>
<td>Absence of weed seeds</td>
<td></td>
</tr>
</tbody>
</table>

Source: Compost Marketing: A Planning Guide for Local Governments, 1994
### Characteristics of Quality Compost

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Quality Compost</th>
<th>Poor Compost</th>
<th>Simple Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Odor</td>
<td>Very little, earthy odor</td>
<td>Sour, rancid, musty or ammonia</td>
<td>Sample from 1 foot deep in pile</td>
</tr>
<tr>
<td>Color</td>
<td>Uniform, dark brown to black</td>
<td>May be lighter or off-color</td>
<td>Use standard sample of cured compost</td>
</tr>
<tr>
<td>PH</td>
<td>Usually between 6 and 8</td>
<td>May be low of 4 or high of 9</td>
<td>pH meter</td>
</tr>
<tr>
<td>Pathogens</td>
<td>55°C C for 72 consecutive hrs.</td>
<td>No proof of reaching Temperatures</td>
<td>Temp. logs documenting PFRP*</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>Less than EPA 503 regs.</td>
<td>May be higher than EPA 503 regs.</td>
<td>No simple test, must be lab tested</td>
</tr>
<tr>
<td>Organic content</td>
<td>Within 5% of specified target</td>
<td>Wide variation of range</td>
<td>No simple test, must be lab tested</td>
</tr>
<tr>
<td>Inert contaminants</td>
<td>Usually less than 1%</td>
<td>Some states have max 10%</td>
<td>Weight test manually separated</td>
</tr>
<tr>
<td>Maturity/stability</td>
<td>Will support plant growth</td>
<td>May draw N from soil or plants</td>
<td>Germination, phytotoxicity tests</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>Usually 0-5 mmhos/cm</td>
<td>May be as high as 20 mmhos/cm</td>
<td>Conductivity meter</td>
</tr>
</tbody>
</table>

Source: Composting Council Standards Committee, 1994

*Process to further reduce pathogens*

---

**PHOIMS Quality Control System**

P = Pathogen reduction, Particle size analysis, Porosity, Percolation rate  
H = Heavy Metals  
O = Organic Content  
I = Inert Contaminants  
M = Maturity, Major Nutrients, Micronutrients, Moisture  
S = Soluble Salts

# Typical Characteristics of Municipal-Feedstock Based* Composts


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Range</th>
<th>Preferred Range for Various Applications under Average Field Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.0-8.5</td>
<td>6.0-7.5</td>
</tr>
<tr>
<td>Soluble Salts (mmhos/cm)</td>
<td>1-10</td>
<td>5 dS (mmhos/cm) or below</td>
</tr>
<tr>
<td>Nutrient Content (dry weight basis)</td>
<td>N 0.5 - 2.5%</td>
<td>N 1% or above</td>
</tr>
<tr>
<td></td>
<td>P 0.2 - 2.0%</td>
<td>P 1% or above</td>
</tr>
<tr>
<td></td>
<td>K 0.3 - 1.5%</td>
<td></td>
</tr>
<tr>
<td>Water Holding Capacity (dry weight basis)</td>
<td>75-200%</td>
<td>100% or above</td>
</tr>
<tr>
<td>Bulk Density (lbs/yard³)</td>
<td>700-1,200</td>
<td>800-1,000</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>30-60%</td>
<td>40-50%</td>
</tr>
<tr>
<td>Organic Matter Content</td>
<td>30-70%</td>
<td>50-60%</td>
</tr>
<tr>
<td>Particle Size</td>
<td>-</td>
<td>Pass through 1” screen or smaller</td>
</tr>
<tr>
<td>Trace Elements/Heavy Metals</td>
<td>-</td>
<td>Meet US EPA Part 503 Regulations</td>
</tr>
<tr>
<td>Growth Screening</td>
<td>-</td>
<td>Must pass seed germination, plant growth assays</td>
</tr>
<tr>
<td>Stability</td>
<td>-</td>
<td>Stable to highly stable</td>
</tr>
</tbody>
</table>

*Municipal feedstock-based composts are primarily derived from yard trimmings, biosolids, municipal solid waste, or food by-products, or a combination of one or more of these feedstocks.

## Compost Characteristics

The chemical, physical, and biological data concerning compost help determine its quality and potential use. Some of these characteristics can be *quantified* using numerical equivalents. Other characteristics may be *qualified* with descriptive language providing quality assurance. Still other parameters or characteristics of compost might be termed “unspecified,” since there is no industry consensus or consistent test methodology.

It is suggested that quantitative data (the first eight items listed below) be routinely provided to compost users by producers/marketers to help assure successful compost use and overall satisfaction.

**pH** Compost may possess a pH between 5.0 and 8.5. pH is adjusted through the use of such materials as lime, to increase alkalinity, and sulfur, to increase acidity. Plant species
each have their own specific pH range and application of compost can affect the pH of soil and growing media.

**Soluble salts (salinity)** Many nutrients are supplied to plants in salt form, while some soluble salts, such as sodium and chloride, are more detrimental to plants than others. Most plant species have a salinity tolerance rating and maximum tolerable quantities are known. Excess soluble salts can be phytotoxic (damaging) to plants. Soluble salts are measured in mmhos/cm or dS/m. Compost may contribute to, or dilute, the cumulative soluble salts concentration of growing media or soil. Manure compost tends to be higher in soluble salts, while soluble salt concentrations in biosolids and yard trimmings composts are more variable. Reduction in soluble salts concentration can be achieved through heavy watering (leaching). However, the salinity of the irrigation water will determine whether this practice is advisable.

**Nutrient Content** Nitrogen (N), phosphorus (P), and potassium (K) are the three nutrients used by plants in the greatest quantities (macronutrients), and are the nutrients most often applied through commercial fertilizers. These nutrients are measured and expressed on a dry weight basis as a percent (%). The percent of phosphorus is expressed as P₂O₅ and potassium as K₂O which are the plant available forms. Nitrogen in compost is predominantly in the organic form and must be mineralized to available forms (NO₃ and NH₄) for use by plants, and insoluble nitrogen forms should be known. The content of these nutrients as well as magnesium and calcium, should be known to allow end users to make correct decisions regarding supplemental nutrition and pH adjustment. Calcium (Ca) and Magnesium may be applied through fertilizer application of pH adjustment (e.g., lime, gypsum). Providing data relative to the content of other nutrients can also be helpful, and may be necessary for specific applications. Although large quantities of nutrients are not typically found in compost, in comparison to most fertilizer products, compost is usually applied at greater rates and, therefore, can have a significant cumulative effect.

**Water Holding Capacity** Water holding capacity is the ability of compost to hold water and is measured as a percent of dry weight. It measures the potential benefit of reducing the required frequency of irrigation, as well as gross water requirements for a crop. Users who know the water holding capacity may be able to monitor or estimate the compost’s effect on their watering regime.

**Bulk Density** The weight per unit volume of compost. Bulk density is used to convert compost application rates from tonnage to cubic yards. Typically it is measured in grams per cubic centimeter, then converted to pounds per cubic yard. Most would consider 800-1,000 pounds per cubic yard as preferred, although the range could be from 700-1,200 pounds per cubic yard. In field application, cubic yards would be extrapolated to express an application rate represented as depth in inches (e.g., 1-inch application rate). Bulk density is also used to determine the volume of compost which may be transported on a given occasion, taking into account that most vehicles have a specific maximum gross weight which may not be legally surpassed.
Estimating the bulk density of compost

1. Weigh an empty 5-gallon bucket, then fill with selected compost and weigh again.
2. Subtract the empty bucket weight from the full bucket weight; record this number.
3. Multiply by 40.5 to find the bulk density of your compost in pounds per cubic yard.

Compost Use Estimator

Cubic Yards of Compost Required to Cover 1,000 Square Feet

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Approx. Cubic Yards</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼-inch layer</td>
<td>0.75 cy</td>
</tr>
<tr>
<td>½-inch layer</td>
<td>1.5 cy</td>
</tr>
<tr>
<td>1-inch layer</td>
<td>3.0 cy</td>
</tr>
<tr>
<td>1 and ½ inch layer</td>
<td>4.5 cy</td>
</tr>
<tr>
<td>2-inch layer</td>
<td>6.0 cy</td>
</tr>
<tr>
<td>2 and ½ inch layer</td>
<td>7.5 cy</td>
</tr>
<tr>
<td>3-inch layer</td>
<td>9.0 cy</td>
</tr>
</tbody>
</table>

Cubic Yards of Compost Required to Cover One Acre

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Approx. Cubic Yards</th>
</tr>
</thead>
<tbody>
<tr>
<td>¼-inch layer</td>
<td>34 cy</td>
</tr>
<tr>
<td>½-inch layer</td>
<td>67 cy</td>
</tr>
<tr>
<td>1-inch layer</td>
<td>134 cy</td>
</tr>
<tr>
<td>1 and ½ inch layer</td>
<td>201 cy</td>
</tr>
<tr>
<td>2-inch layer</td>
<td>269 cy</td>
</tr>
<tr>
<td>2 and ½ inch layer</td>
<td>335 cy</td>
</tr>
<tr>
<td>3-inch layer</td>
<td>402 cy</td>
</tr>
</tbody>
</table>

Cubic Yards of Compost Required to Cover a Specific Area

**Formula:** Specific area to cover (expressed as square feet) × amount of compost to apply (expressed as depth in inches) × 0.0031 = equals cubic yards of compost to cover a specific area.

(____ ft² × ____ inches of compost × 0.0031 = ____ yd³)

**Example:** We are interested in determining the amount of compost necessary to cover 5,000 ft² with a one-half inch layer of compost.

(5,000 ft² × 0.5 inches of depth × 0.0031 = 7.75 yd³)
Moisture Content  Moisture content is the measure of the amount of water in a compost product, expressed as a percent of total solids. The moisture content of compost affects its bulk density and, therefore, will affect transportation costs. Moisture content is also relevant because it affects product handling. Compost that is dry (35% moisture or below) can be dusty and irritating to work with, while compost that is too wet can become heavy and clumpy, making its application more difficult and delivery more expensive. Most composts possess a moisture content of 30-60%, while 40-50% is preferred for product handling.

Organic Matter Content  Organic matter content is the measure of carbon-based materials in compost. Organic matter content is typically expressed as a percentage of dry weight. Being aware of a product’s organic matter content may be necessary for determining compost application rates on specific applications, such as turf establishment. In this application, standard agricultural soil tests may be used to determine the recommended application rate of compost. However, these application rates are specified as the quantity of organic matter needed per acre. Therefore, the organic matter content of compost must be known to convert the application rate to a usable form. Most composts possess an organic matter content of 30-70%, with 50-60% being preferred.

Particle Size  Particle size distribution measures the amount of compost meeting a specific particle size range, by using a series of sieves (screens) to capture compost particles of specific size. Particle size distribution figures are expressed as the percent of material retained per sieve size. For most applications, merely specifying the product’s maximum particle size or the screen size through which the compost passes is sufficient. A compost product’s particle size may determine its usability in specific applications. Examples: A yard trimmings compost screened through a ¼ inch screen would probably not be appropriate to use as a mulch, whereas the same product screened through a 1 inch screen could be acceptable. A compost product with a maximum particle size of ½ inch of greater may not be acceptable as a turf topdressing, whereas a product with a particle size of 3/8 inch or less would be acceptable. For specific applications as a potting/nursery media component, a full particle size distribution may be required. The compost’s particle size distribution will affect the porosity of the media to which it is added.

Qualified Data: Trace Elements/Heavy Metals

The Composting Council recommends that a qualitative description be provided to compost customers pertaining to trace elements and heavy metals. This approach is suggested because providing an all-inclusive chemical analysis to most end users is confusing, impractical, and would not be necessary in most situations.

Examples of Quality Assurance Statements: “Our product meets the Federal EPA’s definition for an exceptional quality product,” or “Our product is approved for unlimited distribution and, therefore, can be used on….” Quantitative data describing trace element concentrations may be made available upon a user’s request as in the
Our product contains trace elements at various levels which are necessary for plant growth; quantitative data is available upon request. This data may be necessary to assist specific users to adjust their fertilizer programs to avoid phototoxicity.

**Trace Elements/Heavy Metals**  Heavy metals are so named for their location on the Periodic Table of the Elements. Heavy metals are trace elements whose concentration are regulated due to the potential for toxicity to human, animals, or plants. The quantity of these elements are measured on a dry weight basis and expressed in parts per million (ppm) or milligrams per kilogram (mg/kg). There are federal and state regulations governing the heavy metal content of composts derived from specific feedstocks.

The trace elements, referred to as heavy metals, are arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium and zinc. The mere presence of these elements does not mean that the product is unsafe. Rather, some of these elements are essential in the diets of plants, animals, and humans and many are included in vitamin supplements.

Certain heavy metals and trace elements are known to cause phytotoxic effects in plants, and some plant species are more sensitive than others. These elements are boron, manganese, molybdenum, nickel, and selenium. Although detrimental quantities of these elements are not typically found in compost, some can accumulate in the root zone over time.

**Part 503 Sewage Sludge Regulations**  
**Summary of Limits for Land Application**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>1. Ceiling Concentration (mg/kg)</th>
<th>2. Cumulative Pollutant Loading Rate (kg/ha)</th>
<th>3. Pollutant Concentration (mg/kg) “Exceptional Quality”</th>
<th>4. Annual Pollutant Loading Rates (kg/ha/365-day period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>75</td>
<td>41</td>
<td>41</td>
<td>2</td>
</tr>
<tr>
<td>Cadmium</td>
<td>85</td>
<td>39</td>
<td>39</td>
<td>1.9</td>
</tr>
<tr>
<td>Chromium</td>
<td>3,000</td>
<td>3,000</td>
<td>1,200</td>
<td>120</td>
</tr>
<tr>
<td>Copper</td>
<td>4,300</td>
<td>1,500</td>
<td>1,500</td>
<td>75</td>
</tr>
<tr>
<td>Lead</td>
<td>840</td>
<td>300</td>
<td>300</td>
<td>15</td>
</tr>
<tr>
<td>Mercury</td>
<td>57</td>
<td>17</td>
<td>17</td>
<td>0.85</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>75</td>
<td>18</td>
<td>18</td>
<td>0.97</td>
</tr>
<tr>
<td>Nickel</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>21</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
<td>100</td>
<td>36</td>
<td>5</td>
</tr>
<tr>
<td>Zinc</td>
<td>7,500</td>
<td>2,800</td>
<td>2,800</td>
<td>140</td>
</tr>
<tr>
<td>Applies To</td>
<td>All biosolids that are land applied</td>
<td>Bulk biosolids and bagged biosolids</td>
<td>Bulk biosolids</td>
<td>Bagged biosolids</td>
</tr>
</tbody>
</table>

Applies To All biosolids that are land applied
Bulk biosolids and bagged biosolids
Bulk biosolids
Bagged biosolids
Definitions:

1. Ceiling Concentration—The maximum content of heavy metals allowed if the product is sold, given away, or otherwise land applied. If any one value is surpassed, then the product cannot be land applied.

2. Cumulative Pollutant Loading Rate—The maximum lifetime loading limit of heavy metals permissible in the soil on a given site.

3. Pollutant Concentrations—The maximum allowable heavy metal content for a compost to be called an “Exceptional Quality” product. Exceptional Quality products may be used in any application, including food crops, as far as the USEPA is concerned. Some states, however, do not allow the use of biosolids compost on edible crops.

4. Annual Pollutant Loading Rates—Maximum annual loading limit of heavy metals permissible on a given site.

Unspecified Parameters

Unspecified parameters are compost parameters not classified as quantitative or qualitative because of current lack of industry consensus regarding definitions, test methodologies, or correlation of data. However, these parameters are considered to be important and should be included at a future date.

Growth Screening  The growth screening test is an indicator of the presence of phytotoxic substances, including volatile fatty acids, alcohol, soluble salts, heavy metals, or ammonia. These substances may cause delayed seed germination, seed or seedling damage or death, or plant damage or death. Growth screening tests include germination, root elongation, and pot tests. Compost that passes an initial growth screening test may fail a similar test later if it has been improperly stored. Specific growth inhibitors, such as volatile fatty acids and alcohol, may form in compost stored in anaerobic conditions.

Stability  Stability is the level of biological activity in a moist, warm, and aerated compost pile. Stable compost consumes little nitrogen and oxygen and generates little carbon dioxide or heat. Unstable, active compost demands nitrogen when applied to soil and growing media. This can cause nitrogen deficiency and be detrimental to plant growth, even causing death to plants in some cases.

Other

These are suggested, minimum compost parameters, developed to represent a wide variety of compost end uses. Other data may need to be provided to certain users, such as porosity and weed seed viability, which may be important to nurserymen. Other parameters may be important to landscapers and turf managers. Aside from these other issues, the compost must also be properly composted to assure it has been sanitized, thus destroying any potentially harmful organisms.
### General Uses and Application Rates for Compost

<table>
<thead>
<tr>
<th>Market (who)</th>
<th>Applications (what)</th>
<th>Approximate Usage Rates (how)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail/Homeowners</td>
<td>Common landscape or garden amendment</td>
<td>1” application or 20% of planting mix</td>
</tr>
<tr>
<td></td>
<td>Mulching</td>
<td>2-“ around all landscape plants</td>
</tr>
<tr>
<td>Sports turf</td>
<td>Construction mixes for new golf courses</td>
<td>5-20% depending on application needs</td>
</tr>
<tr>
<td></td>
<td>Topdressing mixes</td>
<td>5-20% of mix or up to 100% compost for athletic fields under aeration</td>
</tr>
<tr>
<td>Landscapers</td>
<td>New turf establishment</td>
<td>1-2” tilled to a 5”depth depending on soil type</td>
</tr>
<tr>
<td></td>
<td>Turf renovation</td>
<td>1/8-1/2” topdressed after aeration</td>
</tr>
<tr>
<td></td>
<td>Planting bed preparation</td>
<td>1-2” tilled into raised beds</td>
</tr>
<tr>
<td></td>
<td>Mulching</td>
<td>2-3” around all landscape plants</td>
</tr>
<tr>
<td></td>
<td>Backfill for tree planting</td>
<td>30% of planting hole volume</td>
</tr>
<tr>
<td></td>
<td>Outdoor planter mix</td>
<td>20-40% by volume</td>
</tr>
<tr>
<td>Nurseries</td>
<td>Field application as a soil amendment</td>
<td>1-2” incorporated 5” deep</td>
</tr>
<tr>
<td></td>
<td>Band application for shade trees</td>
<td>2” applied in 2-foot wide band</td>
</tr>
<tr>
<td></td>
<td>Liner beds—incorporated</td>
<td>1-2” incorporated pre-plant to 5”depth</td>
</tr>
<tr>
<td></td>
<td>Liner beds—mulched</td>
<td>1-2” mulched post-plant</td>
</tr>
<tr>
<td></td>
<td>Container mixes</td>
<td>5-40% of volume depending on plants -less for high pH or salt sensitive plants</td>
</tr>
<tr>
<td>Topsoil blenders</td>
<td>Soil amendment for many blends</td>
<td>10-15% for blends depending on plant family and specifications</td>
</tr>
<tr>
<td>Roadside</td>
<td>New seeding establishment/upgrading of soil</td>
<td>1” disked to 4”-depth</td>
</tr>
<tr>
<td></td>
<td>Erosion control</td>
<td>1-2” as coarse mulch</td>
</tr>
<tr>
<td></td>
<td>Mulch for tree plantings</td>
<td>2-“ evenly applied</td>
</tr>
<tr>
<td></td>
<td>Planting beds at rest stops/interchanges</td>
<td>1-2” tilled into raised beds 5”-deep</td>
</tr>
<tr>
<td>Landfills</td>
<td>Daily cover</td>
<td>Used to replace soil</td>
</tr>
<tr>
<td></td>
<td>Vegetation establishment/closure</td>
<td>1” disked into soil</td>
</tr>
<tr>
<td>Silviculture</td>
<td>New seeding establishment</td>
<td>1-2” disked where possible</td>
</tr>
<tr>
<td></td>
<td>Mulch</td>
<td>1-2” evenly applied</td>
</tr>
<tr>
<td>Agriculture</td>
<td>General field soil amendment</td>
<td>1-2” incorporated to 5-8”-depth</td>
</tr>
<tr>
<td></td>
<td>Specialty crop production</td>
<td>1-2” incorporated to 5-8”-depth</td>
</tr>
</tbody>
</table>

**Source:** *Composting Council Use Guidelines, 1994*
### Quality Requirements for Compost Users

<table>
<thead>
<tr>
<th>USE</th>
<th>REQUIREMENTS</th>
</tr>
</thead>
</table>
| Mushroom production      | Fresh product (heat contribution is required)  
Humidity rate as low as possible, preferably below 35% of gross weight  
Minimal amount of inerts, if the mushroom compost is to be used in agriculture afterwards  
Acceptable levels of heavy metals since they tend to infiltrate mushrooms very easily |
| Vineyards                | Low level of “impurities”  
Importance of maturity and particle size will depend primarily on the intended use of the compost (maintenance or replanting)  
Organic and moisture content values important for comparative costing  
Heavy metal content should be monitored |
| Arboriculture            | Clean product, low level of impurities  
Maturity less important  
Organic moisture content important for comparative costing  
Particle size of little significance  
Heavy metal content should be monitored |
| Small-scale vegetable farming | Free of sharp items since compost spreading is often done manually  
Requires the use of fine or very fine grade compost  
Maturity very important  
Must be absolutely free of any seeds and of any risk of phytotoxicity  
Salinity must be closely monitored  
Metal content must be monitored since metals are readily assimilated by a number of plants and may be concentrated in the edible portion of the plants |
| Large-scale farming      | Level of impurities important, must be free of contaminants such as plastics (visual impact)  
Organic matter content must be high in order to optimize the economic value of the compost  
NPK fertilizing components may also be considered when calculating the economic value of the product  
Coarse particle size not acceptable  
No fresh compost; requirements for product maturity depend on compost spreading periods  
Heavy metal content must be monitored |

Basic Earthworm Biology

Earthworms are nature’s clean-up crew, aiding in the production of lush, humus-rich topsoil from spent plant and animal materials. These elegantly efficient organisms have been on earth for hundreds of thousands of years longer than humankind, largely untouched by evolution due to their nearly perfect adaptation to their role in nature.

Humankind has studied and learned to appreciate the talents of the earthworm, developing systems that capitalize on the natural role it plays in recycling organic matter back into humus. We now use earthworms for the remediation of organic “waste” materials, reducing the pressure on landfills and aiding in the regeneration of our valuable topsoils.

When beginning a foray into the operation of worm driven systems it is important to be clear on the intended goal of the project. Worm systems are typically managed for one of three reasons; waste management, production of worm biomass, and production of castings. While worms are being grown, organic materials are being processed, and castings are being generated in all worm beds, management methods will vary to some degree depending on the focus of the system.

Vermicomposting is defined as the practice of using concentrations of earthworms to convert organic materials into usable vermicompost or worm castings. These systems focus on the waste material at hand and managing it so that it can be successfully and efficiently processed in a worm system.

Castings production systems are worm-processing beds that use feedstocks specially blended so that castings have a specific nutrient value, chemical characteristic or cross section of microorganisms. The focus of these systems is on end product value.

Vermiculture systems focus on producing the maximum level of worm biomass possible in a given space.

The Amazing Earthworm

Researchers have identified and named more than 4400 distinct species of earthworm, each with unique physical and behavioral characteristics that distinguish them one from the other. These species have been grouped into three categories, endogeic, anecic and epigeic, descriptive of the area of the natural soil environment in which they are found and defined to some degree by environmental requirements and behaviors.

Aneic species, represented by the common nightcrawler (Lumbricus terrestris), build permanent vertical burrows that extend through the upper mineral soil layer, which can be as deep as 4-6 feet. These species coat their burrows with mucous that hardens to prevent collapse of the burrow, providing them a home to which they will always return and are able to reliably identify, even when surrounded by other worm burrows. When deprived of this burrow environment anecic worms will neither breed nor grow.

Aneic species feed in decaying organic matter and are responsible for cycling huge volumes of organic surface debris into humus.

Endogeic species build extensive, largely horizontal burrow systems through all layers of the upper mineral soil. These worms rarely come to the surface, spending their lives deep in the soil where they feed on decayed organic matter and mineral soil particles. While most people believe all worms eat soil, it is only the epigeic species that actually feed on significant volumes of soil itself.
These worm species help to incorporate mineral matter into the topsoil layer as well as aerating and mixing the soil through their movement and feeding habits. Epigeic earthworm species, represented by the common red worm (*Eisenia fetida, Eisenia andreii*), are found in the natural environment in the upper topsoil layer where they feed in decaying organic matter. Epigeic worms build no permanent burrows, preferring the loose topsoil layer rich in organic matter to the deeper mineral soil environment. Even in nature these worms are found in highest concentrations in the forest duff layer or in naturally occurring drifts of leaves and organic debris rather than in soil. We can duplicate the preferred environment of these worm species in bin culture, and it is largely for this reason that it is epigeic worms that are used in vermicomposting and vermiculture systems.

**Requirements**

**Oxygen requirements**

Earthworms are oxygen-breathing animals that absorb oxygen directly through their skin. Oxygen is dissolved into mucous coating the worm’s skin and the dissolved oxygen passes through the skin and the walls of capillaries lacing the skin where it is picked up by hemoglobin in the worm blood and carried throughout the body.

**Moisture requirements**

Moisture is critical to the survival of all earthworm species because it is moisture within the worm’s body that gives it shape, enables it to move, and aids in the worm’s ability to absorb oxygen. To facilitate the absorption of oxygen the skin is very thin and permeable, meaning that the moisture within the body cavity is easily evaporated off, particularly in dry environments. The minimum moisture level for optimal activity among most epigeic species is 60% which ensures the worm can absorb as much moisture as may be lost.

**Temperature requirements**

Specific temperature requirements and tolerances vary from species to species, though the ideal range for most epigeic worms is roughly 60-80° F. The worm’s ability to tolerate temperatures outside of ideal is highly dependant on the level of moisture in the system, with hot, dry conditions being the most lethal combination.

**Nutritional requirements**

Earthworms lack teeth and sufficient digestive enzymes of their own, relying instead on microorganisms to begin to rot and soften organic matter so it can be ingested, then relying on naturally occurring bacteria and fungi in their gut to digest their food. In the process of taking in this biologically active predigested organic matter the earthworm also ingests small particles of sand and soil, which lodge in their gizzard. As the organic matter and microbial life coating it move past this gizzard they are ground against the gritty particles lodged there and fragmented into smaller pieces, making them easier for the gut organisms to digest.

Researchers have recently learned that it is not from the organic matter itself, but from the bodies of the microbial life rotting the organic matter that epigeic earthworms derive the bulk of their most vital nutrients. Once thought to be detritus (debris) feeders, we now understand that the earthworm is actually a predator of microbial life, relying on microscopic bacteria, fungi, protozoa and algae as their major sources of nutrition. Thus, anything that will support microbial activity, that is, anything that rots, is potentially suitable food for earthworms. Materials that support the greatest level of earthworm activity are those that tend to support the greatest and most diverse populations of microbial life.
PH requirements

As microorganisms break down organic matter it goes through a series of naturally occurring changes in pH. Because earthworms thrive in environments rich in decaying organic matter they are adapted to tolerate these pH fluctuations with little or no change in their activity levels. In nature worms are found in environments with a pH range from 4-9, with processing and reproductive rates being no different at an acidic 4 than they are at an alkaline 9. In fact, all things being otherwise equal, earthworms actually prefer an environment with a pH of 5 to 5.5, contrary to the popular belief that they prefer a neutral pH.

With a pH tolerance this wide it is highly unusual for pH to be a limiting factor in any worm system. Further, the radical and artificial adjustment of the pH through the addition of buffering agents like lime can actually have a detrimental effect on the system. The organisms present in a given environment of organic debris are there because they are suited to that environment and whatever fluctuation may naturally occur through the process of decay. When the nature of the system is suddenly and radically altered it forces many of these organisms into dormancy and sometimes kills them outright, thus reducing the availability of nutrition to the worms and potentially slowing the processing rate of the organic matter.

The addition of lime to any worm system is generally discouraged except in those extremely rare circumstances where the pH has dropped well below the worms’ level of tolerance.

Ultra-Violet light response

All earthworms are photophobic to some degree, meaning they react negatively to bright light. The severity of the reaction depends on the species of worm, how bright the light and the level of light to which the worm is accustomed. For example, earthworms accustomed to some light exposure will react less negatively to sudden bright light than will worms accustomed to complete darkness. Some species of worm react negatively to bright light but are actually attracted by dim light.

Earthworms sense light through photoreceptive organs along their back and on the prostomium (sensitive lobe of tissue overhanging the mouth that the worm uses to probe and sense its environment).

Reproduction

Earthworms are hermaphrodites, meaning each worm possesses both male and female reproductive organs. Some earthworm species can be self fertile, meaning they can fertilize their own ova to produce young, and some species are parthenogenic, meaning fertilization of the ova by sperm is not necessary to produce young. Most earthworm species, however, require that two worms exchange sperm in order to produce young.

When worms mate they lay side by side with their heads pointed in opposite directions, making close contact along the upper segments of their bodies. They excrete a mucous that coats both worms and binds them together, preventing them from being easily pulled apart and ensuring environmental conditions like rain or dew do not interfere with the exchange of sperm.

The worms exchange sperm, storing the received seed in a pore on the skin surface just above the clitellum (the differently colored or thickened band that encircles the worm body). Once they exchange sperm, a process that may take hours, the worms move apart and eject their own ova into a pore on their own skin surface near the sperm pore. They then secrete a thick mucous around the clitellum, which hardens on the outside but remains sticky underneath, forming a band out of which the worm backs, drawing the band over its head. As the band passes over the pores holding sperm and ova they are picked up and held on the sticky underside. Once the worm has backed completely out of the hardened mucous band the ends
close forming a cocoon with sperm and ova inside where fertilization takes place. Each worm will continue to produce cocoons until they have used all of the sperm received from the mate. The length of time it takes for the baby worms inside the cocoon to mature and “hatch” out, and the number of young in each cocoon depend on the worm species and environmental conditions.

Contrary to popular belief, worms are a closed species, meaning they can produce viable young only with sperm from members of their own species. They cannot be hybridized. In those rare circumstances when two worms from differing species have attempted to mate, the result was either no young being produced or, in very rare circumstances, babies that were always sterile.

The earthworm cocoon is an incredibly tough structure, designed to protect the young inside from environmental extremes and even ingestion by other animals. Cocoons can be frozen, submerged in water for extended periods of time, dried and exposed to temperatures far in excess of what can be tolerated by adult worms without damage to the young worms inside. The cocoon can even be eaten by other animals, provided it can make it past the teeth, surviving the digestive process and passing out of the animals body in the manure! In areas of climatic extremes it’s likely that the adult members of epigeic worm species do not survive, but the cocoons do, repopulating the environment when environmental conditions return to a range that can support worm activity.

Earthworm cocoons are easy to spot in the worm bed. They are roughly the size of a large grape seed and similarly shaped, with one end rounded and the other drawn out to a point. When first dropped from the body of the parent the cocoon is a creamy, pearlescent yellow, darkening to a cola brown as the young worms within mature and prepare to emerge.

**Earthworm species used in vermiculture**

While earthworm taxonomists have identified thousands of individual worm species, only six have been identified as useful in vermicomposting systems to date. These species were evaluated based on their ability to tolerate a wide range of environmental conditions and fluctuations, handling and disruption to the worm bed, and for their growth and breeding rate. Earthworm species with a short generation time, meaning a relatively short life span and rapid growth and reproductive rate, have been identified as most effective due in large part to the high concentration of juvenile worms present in their populations. Juvenile worms, like human teenagers, are voracious consumers, keeping the processing rate of the system high.

The growth and reproductive rates of each worm species listed below are the maximum identified under ideal conditions. These rates decline the further environmental conditions within the system shift from ideal.

Please note the Latin name of each earthworm species. Common names can be very misleading and often vary between different regions of the world and even regions within a country. It is very difficult to be sure which species of worm is being discussed unless the Latin name is being used. Professional worm growers should know and use the Latin names of the worms they culture.

*Eisenia fetida*/*Eisenia andreii* (common name, Red Worm)

There are two worm species listed here because in virtually all cultures of *E. fetida*, *E. andreii* is present. It so closely resembles *E. fetida* in behavior, environmental requirements, reproductive and growth rate and appearance that the only way to distinguish between the two is through molecular scanning. There is no external difference between the two species. For all intents and purposes these worms can be considered identical. *Eisenia fetida* is generally the only
worm mentioned because the two are so closely associated and because *fetida* is typically the more populous of the two.

*Eisenia fetida/Eisenia andreii* are the worm species identified as the most useful in vermicomposting systems and are the easiest to grow in high-density culture because they tolerate the widest range of environmental conditions and fluctuations and handling and disruption to their environment. *E. fetida/E. andreii* are also common to almost every landmass on earth, meaning there is little concern over importing potentially alien species to an environment where they might cause damage.

While this worm species is considered the premier worm for most applications, it is a small worm, not always suited for use as bait.

- **Temperature range:** Minimum; 38° F, maximum; 88° F, ideal range; 70° F-80° F.
- **Reproductive rate:** Approximately 10 young per worm per week under ideal conditions.
- **Average number of young per cocoon:** Approximately 3.
- **Hatching success rate:** Approximately 83%
- **Time to emergence from the cocoon:** Approximately 32-73 days under ideal conditions.
- **Time to sexual maturity:** Approximately 53-76 days under ideal conditions.

*Note: The spelling ‘fetida’ was changed a few years ago to ‘foetida’ then subsequently changed back for reasons clear only to a few earthworm taxonomists. The different spellings do not denote different species. Information on this species can be found under both spellings, though the correct spelling is ‘fetida’.*

*Eudrilus eugeniae* (common name, African nightcrawler)

This worm is a semi-tropical species, meaning it cannot easily tolerate cool temperatures and is usually grown indoors or under temperature controlled conditions in most areas of North America. *E. eugeniae* is a large species, well suited for use as a bait worm, but does not tolerate handling or disruption to its environment.

This species is used in some vermicomposting systems around the Mediterranean region and in some areas of eastern Asia.

- **Temperature range:** Minimum; 45-50° F, maximum; 90° F, ideal range; 70° F-80° F.
- **Reproductive rate:** Approximately 7 young per worm per week under ideal conditions.
- **Average number of young per cocoon:** Approximately 2.
- **Hatching success rate:** Approximately 81%
- **Time to emergence from the cocoon:** Approximately 13-27 days under ideal conditions.
- **Time to sexual maturity:** Approximately 32-95 days under ideal conditions.

*Amynthas gracilus* (common name, Alabama or Georgia jumper)

*A. gracilus* is another large worm species well suited for use as bait. It is also a tropical species with a poor tolerance for cold temperatures. This worm tolerates handling and disruption
to the worm bed as well as does *E. fetida* and is generally considered an easy worm to culture provided appropriate temperatures can be maintained.

*A. gracilus* is used in a few vermicomposting systems in Malaysia and the Philippines.
- **Temperature range:** Minimum; 45-50° F, maximum; 90° F, ideal range; 70° F-80° F.

- **Reproductive rate:** Undetermined, though believed to be similar to *E. eugeniae*.

- **Average number of young per cocoon:** Undetermined, though believed to be similar to *E. eugeniae*.

- **Hatching success rate:** Undetermined, though believed to be similar to *E. eugeniae*.

- **Time to emergence from the cocoon:** Undetermined, though believed to be similar to *E. eugeniae*.

- **Time to sexual maturity:** Undetermined, though believed to be similar to *E. eugeniae*.

Perionyx excavatus (common name, Indian Blue worm)

*Perionyx excavatus* is a beautiful worm with an iridescent blue or violet sheen to its skin clearly visible under bright light. It is a very small worm, poorly suited as fishing bait, but has an impressive growth and reproductive rate far in excess of the other species grown in bin culture.

This is another tropical worm species with a very poor tolerance for low temperatures, fluctuations in the bin environment, handling or disruption to the system. *P. excavatus* is often referred to as “the Traveler” for its tendency to leave the bin en masse for no apparent reason.

Due to its temperamental nature this species is rarely used in vermicomposting systems in North America, though it is naturally occurring in systems in contact with the soil in the southeastern US and most tropical regions of the world.
- **Temperature range:** Minimum; 50° F, maximum; 90° F, ideal range; 70° F-80° F.

- **Reproductive rate:** Approximately 19 young per worm per week under ideal conditions.

- **Average number of young per cocoon:** Approximately 1.

- **Hatching success rate:** Approximately 91%

- **Time to emergence from the cocoon:** Approximately 16-21 days under ideal conditions.

- **Time to sexual maturity:** Approximately 28-56 days under ideal conditions.

Eisenia hortensis (European nightcrawler)

*E. hortensis* is a large worm species well suited for use as a bait worm. Its ideal temperature range is a bit cooler than that of *E. fetida* and it requires higher moisture levels than do the other species tested for use in bin culture and vermicomposting, but the species tolerates handling and disruption to its environment and environmental fluctuations very well.

Because this worm has a very low reproductive and growth rate, relatively speaking, it is considered the least desirable species of those tested for either bin culture or vermicomposting systems. It is used in a few vermiprocessing systems in Europe for the remediation of very wet organic materials.
- **Temperature range:** Minimum; 45° F, maximum; 88° F, ideal range; 55° F-65° F.
- Reproductive rate: Just under 2 young per worm per week under ideal conditions.
- Average number of young per cocoon: Approximately 1.
- Hatching success rate: Approximately 81%.
- Time to emergence from the cocoon: Approximately 40-126 days under ideal conditions.
- Time to sexual maturity: Approximately 57-86 days under ideal conditions.

A Simple Organism

There are many animals on our little planet without which we could not survive. Chief among them are bees, the major pollinators that aid plants in reproduction; bats, which control insect numbers that even under healthy conditions far outnumber mammalian species; and earthworms, nature’s cleanup crew, which cycle wastes back to soil nutrients. So elegantly efficient are earthworms that they have lived largely unchanged for millions of years, practicing their particular brand of alchemy, turning “waste” materials into food. Management of a worm system is our chance to participate in a miracle, to consciously benefit the circle of life on planet earth.
Vermicomposting

Introduction

The process of vermicomposting organic residues is comparable to the composting process in many ways. Key process variables, such as C:N ratio, aeration, and small particle size are necessary to both systems. But, whereas microorganisms are responsible for the breakdown of organic matter in composting, earthworms in conjunction with microbial activity takes place in vermicomposting. Earthworms require higher moisture content and are sensitive to high ammonia and salt levels. Vermicomposting, performed according to best management practices, is faster than thermophilic composting, produces fewer odors, and may produce a better product.

In this section…

The mesophilic process of vermicomposting is carried on outdoors in temperate regions or safeguarded from temperature extremes in indoor or in-vessel systems. Principal feedstocks vary from site to site. Particular species of earthworms are best-suited for vermicomposting and differ from one another in reproductivity, temperature tolerance and durability. Plant growth trials demonstrate the unique value of vermicompost as a superior soil amendment.

Definition

Vermicomposting is the managed, aerobic process of utilizing earthworms for the stabilization of organic residuals and the production of a marketable soil amendment (earthworm castings, vermicompost). Organic matter is transformed by the activity of microorganisms and earthworms into a humus-like product, much of which has passed through the earthworm's digestive tract. The resulting material is similar to compost in many ways, but may contain increased microbial activity, plant growth regulators, and other as yet unidentified substances that make it a unique soil amendment.

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An Introduction to Vermicomposting

The role of earthworms in the management of organic residues and the production of earthworms and earthworm by-products may be characterized by emphasis or purpose of the operation, by feedstock (e.g. sources and types), by region, by system, and by use of earthworm species.

Vermicomposting vs. Vermiculture

When earthworms are used in waste management, stabilization of organic residuals and the production of a marketable soil amendment (earthworm castings, vermicompost) are generally the chief goals. When the focus is upon breeding earthworms for bait, as a protein source, or for stocking a vermicomposting project, there is often a declining emphasis on the value of earthworm by-products. Thus, vermicomposting facilities tend to utilize earthworms as processors in resource recovery and look for markets in the soil amendments sector. Vermiculture facilities, on the other hand, principally concentrate upon the production of earthworms for sale. Due to the increasing awareness of the value of earthworm-worked material, however, more vermicultural operations are seeking to market their earthworm castings as an adjunct to their earthworm sales.

Some earthworm businesses that harvest indigenous species to sell as fishbait are not generally concerned with optimizing breeding conditions. Thus, the term vermiculture may not accurately describe these harvesting operations, although their marketing structure puts them into the larger category of what may be called an earthworm industry.

Feedstock as Income vs. Expense

The largest vermicomposting facilities typically follow the model of large organics recovery operations that practice conventional composting. Tipping fees collected for incoming feedstocks usually comprise the largest part of any facility’s income stream, and may consist of 80% or more of total revenues. Sales of vermicompost add to the profit margin of a company, but have not yet been significant. Large vermicomposting operations process organic residuals that include yard debris, pre-consumer vegetative food waste, manure from herbivorous animals, cardboard and paper waste, the biodegradable fraction of municipal solid waste (MSW), and, in some limited instances of short-lived pilot projects, biosolids. Pre-composting some residuals, such as yard debris or biosolids blended with bulking agents, has been reported. Sales of earthworms by such vermicomposting facilities occurs only rarely. For most vermiculture operations, on the other hand, feedstocks are purchased or arrangements...
must be made in order to procure feedstocks at some cost to the earthworm grower, such as delivery charges. These vermiculture facilities tend to be smaller in scale, handle lesser volumes of organic materials, are less mechanized and are more labor intensive than vermicomposting sites.

**Temperate Regions Predominate**

While interest continues to grow throughout the United States and Canada, temperate regions seem to predominate in managed earthworm activity. Large outdoor windrow systems are in common use in West Coast operations from the southernmost border of California to Washington State. The Atlantic seaboard, extending from North Carolina to Florida and moving throughout much of the southeastern United States, occupies the second major region for vermicultural activity. Covered systems are more common here, affording greater protection from the elements. Scattered throughout the remainder of the U.S. and Canada are a smaller number of sites with greater provision made to control the adverse effects of extreme temperatures. Indoor and in-vessel systems are required for effective management in regions where climate is seasonally cold.

Earthworms that are harvested for bait, however, are obtained from cooler climate regions. One company reportedly purchases in excess of 50 million Canadian nightcrawlers (*Lumbricus terrestris*) from dealers throughout Canada, Michigan, Pennsylvania and New York. The majority of this harvested crop is from Toronto, Canada.

**Factors for Differences in Systems**

Earthworms are raised in beds, pits, bins, trays, windrows, and continuous flow reactors. Managed systems include outdoor piles of organic matter either on the ground (windrows, pits), or in containers (beds). Beds may be on the ground or elevated to allow space for harvesting vermicompost and capturing leachates. Indoor systems which may be in permanent buildings or polyethylene structures on soil, asphalt or concrete, may include windrows, beds, trays or bins. Various designs of in-vessel reactors have been manufactured and vary according to their ability to control temperature, moisture, aeration, feedstock application and separation of earthworm-worked material from incoming feedstocks. Factors accounting for differences in systems include geography, amounts of feedstock to be processed, availability of capital investment, land and labor, availability of or concern for conservation of water, and whether the operation’s emphasis is upon vermicomposting or vermiculture. While applying feedstocks, maintaining proper moisture content in the worm bed, and separating earthworms from vermicompost are three ongoing activities of any size operation, techniques for performing these duties differ markedly from one facility to another.
Earthworm Species

*Eisenia fetida* (most typically called the redworm or “red wiggler”) used throughout the U.S. and Canada, in both vermicomposting and vermiculture operations, seems to occupy the leading role among earthworm species. Factors for this species’ dominance may be due to its ability to withstand temperature extremes, its capacity to process a variety of feedstocks, its high reproductive potential, and its general durability and hardiness. In general, most vermicomposting facilities use and recommend *Eisenia fetida* over other species. Vermiculture operations, on the other hand, may breed or collect more than one species, particularly if sales are made to bait dealers. *Lumbricus terrestris* (the common nightcrawler) is generally harvested by hand from orchards or golf courses at night. This particular species is not a surface-dwelling earthworm but creates deep burrows and requires soil as well as organic matter. Creating optimum conditions for enhancing reproduction in bins is generally considered difficult to do. *L. terrestris* belongs to the *anecic* category, a group commonly known as *earthworkers*. The *epigeic* or surface-dwelling *Eisenia fetida* feeds on microorganisms within decomposing organic matter and is often referred to as a *composting* earthworm. Vermicomposting facilities in North America use earthworm species of the latter category. Vermiculture operations may raise *composting* earthworms and harvest *earthworkers* as well.

Some interest has been shown in the commercial cultivation of species other than *E. fetida* for vermicomposting. *Eudrilus eugeniae* (African nightcrawler) shares some characteristics of *E. fetida* such as high rate of reproductivity and an effective processor of organic wastes. But unless winter temperatures can be controlled indoors or in-vessel to reach no lower than 16° C, *E. eugeniae* is limited to tropical or subtropical regions where outdoor systems are in use (*Biology and Ecology of Earthworms*, C.A. Edwards and P.J Bohlen, 1996). Similarly, *Pheretima hawayana* and *Perionyx excavatus* while found to be useful in vermicomposting, are limited to warmer climate regions due to their inability to withstand cooler temperatures.

Nearly one hundred vermiculture operations in the United States and three in Canada are found in the bi-annual edition of *Earthworm Buyer’s Guide* (1998-1999). Eschewing scientific nomenclature, this directory lists vendors who market several species of earthworms that are described by their popular names: Red worms, African nightcrawlers, Native nightcrawlers, Grey nightcrawlers, Jumpers, Brown Nose Worms, and others. It is impossible to estimate from this directory alone the magnitude of the earthworm industry in the United States and Canada. Nevertheless, it provides a rudimentary overview of the regions where vermiculture is practiced and is suggestive of some of the practices, products, and markets in the earthworm industry.

Commercial Vermiculture as Private Enterprise

Whereas composting facilities in North America may be owned either privately, by a municipality, or by a joint-partnership of the two entities, vermiculture and vermicomposting activities have not yet attracted the kind of funding to operate long-
term municipal-scale projects beyond the occasional “pilot project” phase. Pilot-scale biosolids vermicomposting has been successfully reported in Lufkin, Texas (Green and Penton, 1981), Fallbrook, California (Harris et al., 1990), and the City of Ocoee, Florida (Riggle, 1996 c). Metro, the municipal waste management authority for Portland, Oregon, has contracted with Oregon Soil Corporation to process food residuals in a six-month pilot project that is scheduled to close in late 1998 (Bogdanov, 1998 b). But these anomalies illuminate the fact that it has been an entrepreneurial spirit that has driven most efforts in promoting the value of both earthworms and earthworm by-products. While municipal-scale and municipally funded waste management is concerned with stabilization of the organic fraction of solid waste, vermicomposting entrepreneurs must focus upon the profit-making potential of their endeavor. Choosing and acquiring optimum feedstocks and giving attention to product quality motivate the entrepreneur. Municipal waste managers and many compost facility operators do not usually enjoy the luxury of choosing a preferred wastestream and may not be able to provide the same attention to quality control as the entrepreneur. If the goal of product sales drives the entrepreneur, then products must be promoted and marketed.

In some glaring instances, gross misrepresentation of potential earthworm reproductivity coupled with phenomenal forecasts of future demand has meant that a few business promoters have been able to dupe investors. Optimistic projections of earthworm multiplication rates have tempted some to promote various and dubious kinds of futures markets. There have been numerous reports of “buy-back contracts” that are sold to investors who are promised exorbitant rates of return. Claims of exaggerated earthworm reproductivity (“earthworms can double their population every month”) and booming worldwide markets have been made to induce would-be earthworm growers to invest their money. Reports of these questionable activities have come from California, Florida, Ohio, Idaho, Nevada, New Mexico, and other states.

While scientists have demonstrated odor reduction and a decrease in time needed to stabilize organic residues through earthworm activity, it remains to be demonstrated by entrepreneurs how large-scale vermiconversion of organic wastes can be made profitable. Instances of failure of some large-scale facilities whether due to undercapitalization, difficulties with regulators, or unstable markets, have been reported.

Sales of Vermicompost

The marketing of earthworm-worked material, described as vermicompost by some, and labeled as earthworm castings (and, more commonly, worm castings) on bags of finished product by others, has some way to go before it becomes as accepted as peat moss, steer manure, or other commercially available horticultural products found in nurseries and garden centers. Even compost, which must compete with other types of soil amendments, currently has greater market recognition than earthworm castings. An example of the lack of vermicompost as a widely available product may be found by referring to Rodney W. Tyler’s Winning the Organics Game: The Compost Marketer’s Handbook (1996). In this work, Tyler surveys the current status of compost marketing in the U.S., but makes no mention of the availability of vermicompost as a soil amendment.
Vermicomposters believe they produce a superior product to the compost produced by their “thermophilic brethren,” but a huge gap in marketing exists between the approximately 4,000 compost facilities in North America and the few hundred earthworm growing and vermicompost producing operations in the same geographic area. This gap may likely shrink as the “blend trend” in compost marketing continues, as compost becomes a basic, but proportional ingredient in a products mix specially formulated for certain applications. There are instances of joint-venture partnerships with compost facilities linking up with vermicomposting technology to create blended products for sale. Some soil blenders have also added vermicompost in small quantities with other soil amendments to create unique product combinations. There is scant evidence of the amounts, production, and sales of the percolate or leachate from the process, commonly known as “worm tea,” and only anecdotal reports of its value as a foliar or liquid soil amendment.

Vermicompost or Earthworm Castings?

The terms vermicompost and earthworm castings have been used interchangeably to identify earthworm-worked material. Castings seems to be the term of choice among industry personnel throughout North America, while vermicompost tends to be the accepted designation within the scientific community. An informal survey of purveyors of vermicompost in the United States finds the terms worm castings and earthworm castings in most frequent use on labeling of soil amendment products containing vermicompost. Some bagged products have been labeled only with the words worm castings, or earthworm castings, and may contain anywhere from ten to one hundred percent vermicompost. In most states, regulations have not been enacted to monitor or control the production, testing, labeling, and promotion of vermicompost, as has been done with other types of soil amendments. Even statewide composting organizations that seek to promote the use of compost are mostly silent on the issue of vermicompost. This lack of attention has meant that there may be uncertainty in knowing the percentage of vermicompost present or its horticultural value in a bagged product that only bears the description earthworm castings.

A number of purveyors of vermicompost, particularly in California, but in other regions as well, insist that labeling their product earthworm castings rather than vermicompost has at least two distinct advantages. First, in the state of California, an agricultural exemption currently exists in favor of vermiculture operations excluding them from composting regulations. As an agricultural activity, the practice of vermiculture (and vermicomposting) results in production not only of earthworms but earthworm by-products, i.e., earthworm castings. In the sense that cows produce milk and bees produce honey, earthworms produce castings as a marketable product. To call the earthworm-worked material vermicompost could associate the material with compost, a product produced for sale by state-regulated facilities. Secondly, some vermicompost marketers believe that the term earthworm castings is more descriptive and better understood in the marketplace than the term vermicompost which may contribute to the perception that the material somehow contains compost.
North American Interest in Vermiculture and Vermicomposting

In 1978 an article appeared in *The Wall Street Journal* concerning securities regulators in several states who were investigating earthworm “breeding schemes.” The story, which many say led to the eventual demise of a then-burgeoning industry, quoted the Arkansas securities commissioner who said, “Millions of dollars are being ripped off from the public across the country because of the flimflam in worm growing arrangements” (Machalaba, 1978). The article sounded the death knell for earthworm growers throughout North America. The collapse of Ronald Gaddie’s network of hundreds of growers in association with North American Bait Farms, Ontario, California, which has been mentioned above, is indicative of the nadir the earthworm industry was later to reach.

Perhaps ironically, R. Hartenstein and his associates, at about the same time in the late 1970s, began researching the use of earthworms in the stabilization of sewage sludge at the State University of New York in Syracuse (Edwards and Neuhauser, 1988). In 1980, a Workshop on the Role of Earthworms in the Stabilization of Organic Residues was held at Western Michigan University. Here a balance of background and opinion was sought in a forum of 22 academic scientists, 2 public sector representatives, and 14 entrepreneurs (Carmody, 1981).

As scientific efforts grew apace, albeit deliberately, popular interest in earthworms and vermicomposting did not resume until the 1990s, and then perhaps due to a confluence of factors. Mary Appelhof’s *Worms Eat My Garbage* (1982, 1997) grew in sales to reach 15,000 copies per year, as *Newsweek* reported (Rogers and Annin, 1996). While sales were moderate when the book was first published, popular interest in vermicomposting (if it may be measured by sales of one book) began to escalate noticeably in the 1990s. *Worm Digest*, a quarterly periodical published in Eugene, Oregon, launched its first issue in the summer of 1993. Within three years it grew in size to printing 10,000 issues of its 32-page newsprint journal. In July of 1994, the International Symposium on Earthworm Ecology (ISEE 5) was held in Columbus, Ohio. More than 220 scientists from 38 countries gathered to hear 165 research presentations (Edwards, 1998). *BioCycle*, the Journal of Composting and Recycling, infrequently published articles about vermicomposting in the early 1990s. But by October 1994, its cover story proclaimed, “New Horizons for Commercial Vermicomposting.” Since then, although its chief focus centers in the 3,500 composting facilities in the U.S. (with growing international coverage), articles on vermicomposting have appeared more regularly. During the past four years, *BioCycle* Conferences, held four times per year, almost regularly feature presentations by vermicomposting experts. In 1996, a cadre of five individuals in southern California formed the short-lived International Worm Growers Association, a non-profit corporation that successfully held a well-attended “Worm Summit,” and published one newsletter before its eventual demise. The urge to establish a “Global Vermiculture Association” (G.V.A.) was passionately discussed on Internet Vermicomposting Forums, later to be scrapped by a steering committee. In spite of the lack of an organized, formal association, popular interest in vermicomposting can
be assessed by visiting the numerous Internet websites and forums dedicated to this subject. *U.S. News & World Report* in a 1997 article pointed to the resurgence of interest in vermicomposting: “Vermiculture ventures, the biggest of which involve 50 million worms chowing down on almost 90 tons of waste per week, have boomed over the past few years” (Koerner, 1997). Whether this boom period will be followed by a cyclical “bust” period remains to be seen.

**Conclusions**

In order for vermicomposting to assume a place of importance on par with the composting industry and its efforts in both stabilizing organic residues and providing a worthwhile soil amendment, several factors merit attention.

First, vermicomposting facilities, to be successful in the long run, must have a waste management focus in which vermicomposting is presented as a viable alternative in managing difficult, problematical residues, such as biosolids and food residuals. If vermicomposting, as it has been shown, is a low odor process that speeds the rate of organic residue stabilization, then it must merit attention from the appropriate levels within the solid waste management sector. If it is demonstrable to be a viable alternative in organic waste management, it deserves not only the funding available for pilot projects, but also longer-term support through tipping fees or other funding mechanisms within municipal solid waste management.

Second, vermicomposting facilities, to enjoy long-term success, should focus greater attention on marketing vermicompost. Here the income potential may be the greatest, although there is much work to do. Recent plant growth trials, conducted at The Ohio State University (Subler, *et al.*, 1998) demonstrate the horticultural value of vermicompost in container media. Compost marketers now have a limited but useful arsenal of data to support their efforts in promoting the advantages of vermicompost.

Third, evidence that up to just 10% (by volume) vermicompost in a blend of potting media produces substantive plant growth vitality, suggests that vermicompost may have a future indelible effect on both the composting industry and soil blenders. Where compost marketers may be looking for an edge to distinguish their product from the competition, and where soil blenders may be looking to produce a “value-added” product, the addition of vermicompost to their products may provide the means to secure a greater fraction of the marketplace.

Fourth, composting facilities, in order to maintain or increase market share, may consider on-site vermicomposting on a limited scale. Since nearly all composting facilities have the available resources in place to practice vermicomposting (feedstocks, equipment, labor, utilities, permitting, etc.), all that would remain would be to inoculate earthworms into a portion of the composted material and to manage key process variables in a vermicomposting system. Such a foray into limited-scale vermicomposting might be arranged through a joint partnership with a vermiculture or vermicomposting facility nearby, as has been reported (Bogdanov, 1997 a). In the future, existing composting facilities...
facilities may be the most likely candidates to advance large-scale vermicomposting in North America.

Fifth, in-vessel vermicomposting systems for institutional and municipal-scale waste management offer the greatest promise as a future growth industry. Due to the necessity of maintaining temperature and moisture requirements in vermicomposting, in-vessel systems are a necessity in most regions of North America, considering the seasonal variation in weather. On-site vermicomposting of food and other organic residuals makes economic sense for institutions such as prisons, military bases, hospitals, schools, nursing homes, and virtually any business or institution where organic residuals are generated. Reduction in collection costs, hauling, and tipping fees would help in amortizing the costs of an in-vessel vermicomposting system, as would the decreased costs for soil amendments otherwise purchased for on-site landscaping. Systems such as the OVS Vermi-Organic Digester have been installed in schools, a military base, a hotel, and a municipal cafeteria. The continuous flow reactor, in use on both the East and West Coasts of the U.S., has been demonstrated to be effective in handling municipally-generated wastes, but has been limited to pilot-scale operations.

Sixth, increasing research efforts in the effects of vermicomposting to reduce pathogens may help establish vermicomposting as a valuable and preferable means of processing biosolids and other pathogen-contaminated organic waste.

Seventh, identifying the biological mechanisms present in vermicompost that may be responsible for the noticeably increased growth and vitality of many plants, is a challenge facing researchers in horticulture and crop science. Future publication of the results of university-conducted plant growth trials that investigate various types of vermicompost (i.e., from pig solids, from food waste, etc.) will serve to promote wider use for this product in agricultural and horticultural settings.

Finally, there may be reason to hope that a concomitant decrease in the proliferation of dubious investment schemes will result from an increase in the dissemination of factual information about the realities of vermicomposting in waste management.

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Vermicomposting and Solid Waste Management

The role of earthworms in waste management has been a significant discovery not only for the practice of vermiculture, but for the solid waste industry as well. Whereas earthworms were once cultivated or harvested principally for fish bait, vermiconversion of organic wastes now promises new opportunities for waste reduction as well as improving soil fertility.

The State of Solid Waste in America

In spite of our growing awareness of the effects and costs of waste, increasing amounts of garbage are produced every year. In the United States alone, more than 340 million tons of municipal solid waste (MSW) were generated in 1996, up 13 million tons from the previous year and representing about a 36% increase over a ten-year period. During the same decade, the number of landfills decreased from nearly 8,000 to 2,514. Costs to handle the growing wastestream are reflected in the tipping fees collected at waste sites that have increased by over 300% in the past ten years. There is reason to believe the trend will continue: More waste. Fewer landfills. Higher costs.

Recycling and Waste Reduction

Nationwide efforts in recycling have helped to decrease by 30% a portion of the waste that would otherwise end up in landfills or become incinerated. Now over half the states have instituted bans on landfilling yard debris and several have plans to increase their recycling rates to 50%. Assembly Bill 939 in California, for example, mandates that communities must reduce their waste by 50% of 1994 levels by the year 2000 or face penalties of up to $10,000 per day.

A significant portion of MSW is organic and may be recovered. The United States Environmental Protection Agency (EPA) estimates that 39 percent of MSW is made up of paper and paperboard products, together comprising the largest component. Yard trimmings amount to 14% of MSW (the second largest material component), and food waste adds another 6.7%.2 At least 60% of all waste, therefore, need not be buried along with glass, metals, plastics, rubber, and the other materials in the wastestream. Organic wastes may be recovered and, through composting or vermicomposting, converted into a valuable soil amendment.

Composting Facilities Divert Organic Waste

As of this writing, there are approximately 3,500 yard trimmings composting sites in the United States. Composting may be defined as “a managed process that controls
biological decomposition and transformation of biodegradable material into a humus-like substance called compost.” Composting facilities divert organic waste that might otherwise end up in landfills. Materials or feedstocks composted include yard trimmings, soiled paper, manure, food scraps, the organic fraction of MSW, and the sludge from wastewater treatment plants (biosolids). Processing these materials may take from three to six months, sometimes longer. Depending upon the facility, the region of the country and the demand for the product, compost is either sold (by the cubic yard, or in bags), used as daily cover for landfills, used by the municipalities who run the compost facility, or given away free. In general, composts from MSW and biosolids are far less in demand than compost produced from yard trimmings or manure. Again, depending on a wide array of factors, compost prices vary from a high of $30.00 per cubic yard for yard trimmings compost in the Northeast and Midwest, to a low of zero, $2.00 or $3.00 per yard for compost in the same regions as well as the rest of the country.

Compost Marketing

Composting facilities, whether privately or municipally owned, rely heavily on tipping fees to pay for their debt service, overhead, daily operations and maintenance costs. Sales of finished compost may help either to offset costs or to achieve greater profitability, but the emphasis on compost marketing differs according to the management priorities of each site. As marketing efforts increase, so does an awareness of compost quality, as customers and producers of compost evaluate the value of the product. In order to make unique, distinctive products that set them apart from other compost producers, some compost managers have created custom blends for their customers. This “blend trend,” as it has been called, reflects the competitiveness of the marketplace and the efforts some compost makers are willing to take in order to increase their profitability. In this regard, some composting facilities are looking at the addition of vermicompost to their blends in order to create a value-added product.

Vermicomposting and Waste Management

Vermicomposting may supply important solutions to waste management problems. Principal issues in organic waste management faced by compost facilities concern odor generation, pathogen control, time and space requirements, economic viability of their operations, and marketability of the final product. Vermicomposting systems, although closely related to composting systems, offer an alternative means of stabilizing organic compounds that is faster and, in the opinion of many, produces a better product. Many scientists and field workers alike, having researched and tested earthworms in waste conversion projects, are optimistic about the future of commercial vermiculture. John R. Sabine of the University of Adelaide, Australia, opened the First International Conference on Earthworms in Waste and Environmental Management, held in Cambridge, U.K., with a vision:

The basis for a legitimate vermiculture industry is no different in principle, from that of any other industry, namely the provision of goods and/or services in sufficient quantity and quality and in such a manner that all those who invest in
the industry, at whatever level, can expect to make a reasonable return on their
time or money or expertise so invested. So, what goods and services can be
provided by vermiculture, and are they needed? As I see it the need at least is not
only indisputable, but often massive, especially with regards to potential services.
And in the context of vermiculture ‘services’ generally equates with ‘waste and
resource management.’

Today, large-scale, commercial vermcomposting is, admittedly, still in a state of
infancy, if compared with commercial composting. There are, perhaps, many reasons to
account for this, not the least of which is the lack of understanding about the process and
the benefits of the final product. If the need for a greater vermiculture industry is truly
“indisputable,” and “often massive,” as J.R. Sabine believes, wider dissemination of the
findings of researchers and field workers may help to catapult the present state of affairs
to new heights.

Four Classes of Vermicomposting

Vermicomposting activity falls into four principal areas. There are residential,
educational, institutional, and commercial systems that have been designed to handle the
appropriate needs of each situation. Home vermicomposters take their kitchen scraps out
to a worm bin that can be easily constructed or purchased from a vendor. Vermicompost
may be separated, periodically, from the earthworms, and used in the home garden.
Educational projects range from classroom worm bins to larger-scale bins that can
accommodate the cafeteria waste of an entire school. Fund-raising projects involving the
sale of earthworms and vermocompost teach students the commercial as well as
ecological values. Municipal food-banks, office buildings, and military bases have
instituted on-site vermcomposting of food and paper waste. Potentially, any business or
institution generating food or other types of organic waste may find it economical not
only to minimize waste collection costs, but also to produce an excellent soil amendment
for landscape use on the same property. Finally, commercial systems vary widely in size
but have the goals of waste conversion, marketing vermocompost, and, in some cases,
marketing other products, including earthworms.

A Commercial Vermicomposting Model

All commercial vermiculture operations are not alike. Differences in local
conditions and management goals account for the varieties of systems now in use.
However, it is possible to draw together from a few of the larger operations certain
emphases, which may permit the construction of a “model” plan. Taken together, the
following areas illustrate a comprehensive plan to generate income from a variety of
sources.
1. **Feedstock Acquisition.**

Tipping fees (sometimes shortened to “tip” fees) are charged for disposing waste material at landfill or composting sites. (Dump trucks “tip” their loads, emptying the contents to the ground.) Such fees range from $15 per ton of waste to as high as $85 per ton, depending upon the region of the country. Franchise waste haulers who contract with cities to collect garbage from residential, commercial and industrial customers must account for these disposal fees in addition to their own costs for collection. Waste generators, *i.e.*, those creating waste, pay fees for collection and disposal, either directly to the hauler or to the municipality serving in the oversight and control of solid waste management.

Tipping fees collected by a composting site usually account for the greatest and in several cases the only source for income, particularly if compost is not sold. (Vermicomposting may offer greater revenue potential—see below.) Tipping fees are used to pay for all aspects of the operation: property fees, utilities, fuel, equipment, labor, maintenance, and administrative costs. A successful commercial vermicomposting operation may offer an attractive alternative to landfiling, incinerating, or even composting organic material by offering lower tip fees than competing systems of organic waste disposal, where such an option may be permitted and where there are no exclusive franchise agreements. For example, one vermicomposting operation, Oregon Soil Corporation, has contracted with a chain of supermarkets to collect pre-consumer food waste from their produce departments. By undercutting the collection fees other haulers charge, Oregon Soil Corporation acquired a choice feedstock for its vermicomposting system and saved the supermarket as much as 40% of the cost of disposal. As a further bonus to Oregon Soil, the same supermarket chain markets Oregon Soil Corporation’s Worm Castings in their garden department.

2. **Feedstock Variety.**

Canyon Recycling of San Diego, California discovered the benefits of utilizing organic waste from a variety of sources. These feedstocks include municipal green waste (yard trimmings), manure from San Diego Wild Animal Park and the Del Mar Racetrack, wood waste from construction and demolition (C&D waste), as well as other types of organic residues. Some materials were composted, others were processed into mulches. To produce soil amendments, their plan called for thermophilic composting in tandem with vermicomposting, which is an exclusively mesophilic process, where temperatures do not exceed 90° F.

By accepting a diversity of feedstocks, Canyon determined to create a variety of marketable products. Bulky materials, such as yard debris and C&D waste, must be shredded to achieve appropriate particle size. Once shredded, the material is screened to produce various grades of uniformly sized material. Canyon found that its shredded C&D waste could be sold to a particleboard manufacturer. Other bulky wood waste has been purchased by “cogen” facilities that burn it as fuel to produce...
electricity. California’s Department of Transportation has purchased mulch products for roadside landscaping. Altogether, nine different products, including vermicompost, have been produced by Canyon.

Conceivably, a vermicomposting site may choose to specialize in certain organic wastestreams in order to produce a consistent, uniform product. Some have specialized in manure from herbivorous animals, others in paper or cardboard fiber waste and still others in food waste. In some cases there is a need to blend various feedstocks together to achieve a proper carbon to nitrogen ratio and to allow for needed porosity. Thus, nitrogen-rich vegetative food wastes are typically blended with paper waste or other carbon-rich materials prior to application to the worm bed. Thus, not all organic residues, sometimes defined as materials that were once living, are necessarily ready for immediate composting or vermicomposting.

3. Composting.

Few vermicomposting facilities seem to engage in composting, but there are some that combine both activities where it is advantageous. There are three principal reasons for composting: a) to achieve pathogen and weed-seed kill; b) blending materials to create optimum feedstocks for earthworms; and c) creating compost to blend with vermicompost to produce a “value-added” product.

a. Where the same material passes through two phases, the first phase may be called “pre-composting,” followed by vermicomposting. Pre-composting assures that pathogens and weed-seeds will be killed as temperatures reach 131 F. A pre-composting stage might be required by local regulatory agencies for certain types of waste, such as biosolids, and possibly, post-consumer food waste where pathogen destruction must be assured. However, research that earthworms contribute to pathogen destruction is forthcoming and someday may influence the removal of regulatory requirements for pre-composting.

b. Pre-composting also allows for bulky, carbonaceous material (straw, leaves, sawdust, paper, woody materials) to be blended with wet, more nitrogenous material (fresh grass clippings, food waste, or bio-solids), with the resulting compost used as a feedstock for earthworms. In other words, a facility that accepts large quantities of leaves or sawdust would not be able to directly vermicompost these materials because of their high carbon content. More “green” or high nitrogen feedstocks would be needed. Similarly, very “wet” feedstocks such as biosolids or food waste (usually tending also to be high in nitrogen) need “bulking agents” such as sawdust or other “dry” feedstocks—which tend to be high in carbon. By blending high carbon, “dry” material with high nitrogen “wet” material an optimum feedstock for earthworms may be created.

c. A facility producing both compost and vermicompost generally finds it advantageous to blend the finished products and market a “value-added” product.
Such a premium product is not only distinctive in the marketplace but has been found to be more profitable as well.

4. Vermicomposting.

Depending upon factors such as geography, financial resources, labor, volume of material to be processed, and other considerations, vermicomposting systems vary from low-tech to high-tech. Low-tech systems tend to be less costly, more labor-intensive and less efficient than high-tech systems that require greater capital, but less labor.

There are, however, successful examples for each type of system in use.

a. Three types of vermicomposting systems

1) **Outdoor windrow systems** are found in temperate climates and are considered “low tech.” A windrow is a row of organic material placed on the ground, usually 3-6 feet in width, and of any length. Such systems may be shielded from rain, covered with shadecloth, or completely exposed. Water may be applied from a truck or by sprinkler irrigation. Material may be applied by hand, with a front-end loader, or a manure-spreader. In colder climates, indoor windrow systems have been used where space is available.

2) **Batch systems** may consist of stacking trays, maximizing vertical space where horizontal space may be at a premium. Such trays or bins, due to the weight of the material, are heavy and must be relatively small if moved by hand. Systems using larger, 4’ x 6’ wooden trays with four legs at the corners have been created. A forklift is used to stack these trays from four to six levels high. Other systems in use include containers made of metal, concrete, plastic, or wood. Some in-vessel systems have been created that monitor and control moisture and temperature.

3) **Raised, gantry-fed beds**, also known as “continuous flow reactors,” are high-tech systems requiring greater capital outlay but less labor. One system in use can handle three tons of material per day in a reactor that is 128 feet long, 8 feet wide and 2 ½ feet deep.

Vermicomposting offers certain advantages over composting that make it attractive, not only from a waste management perspective, but also from a product marketing point of view.

b. Three advantages of vermicomposting: Fewer odors, faster process, better product.

1) **Fewer odors.** Odors are caused in composting due to *anaerobic* (“without oxygen”) conditions, as lack of porosity restricts oxygen from reaching
anaerobic microorganisms. Anaerobic conditions result in odors that may smell like vinegar (acetic acid), sour milk (lactic acid), rotten eggs (hydrogen sulfide), or ammonia. More frequent turning during the composting process usually restores aerobic conditions to the pile, but other factors such as too much moisture inhibit porosity and anaerobic conditions may return. Vermicomposting is also an aerobic process but calls for the addition of feedstocks in small layers (1-2 inches in depth) so that anaerobic conditions (and odors) are not created.

2) **Faster process.** The process of composting organic residues generally takes no less than three months to produce a stable, mature product ready for use. Depending upon the technology used, some composts take six to twelve months to produce. In contrast, vermicomposting can take as little as three to four weeks to produce a marketable product. While not all those producing vermicompost experience results within this time frame, it is, nevertheless, possible to produce finished vermicompost faster than thermophilic composting.

3) **Better product.** Prices for compost may reach as much as $30 per cubic yard, depending upon region of the country, the quality of the compost, and factors of supply and demand. In a number of places it is given away free or sold at very low cost. Vermicompost prices fall into a range of $25 to $120 per cubic yard, also depending upon similar factors that affect compost. Where vermicompost is sold in bags or boxes, prices of $1.00 per pound ($2,000 per ton) have been reported. In general, however, most of those who would purchase either one or both products would be willing to pay a premium for vermicompost because of its perceived and inherent value.

c. **Marketing Vermicompost.**

Vermicompost has been marketed in various ways. Oregon Soil Corporation produces one-pound boxes of its Worm Castings with instructions to add a couple teaspoons of the material to a quart of water and used as plant food. The product can be found on some supermarket shelves in the Pacific Northwest next to name-brand plant fertilizers. Worm castings in one-cubic-foot bags weighing 40 pounds are also produced by Oregon Soil for the same supermarket. Canyon Recycling of San Diego produced its *Vermigro™* bags in sizes of one cubic foot and one-quarter cubic foot. Nurseries, garden centers, and other retail outlets paid $3.50 wholesale for the larger bags, retailing the product for $7.00. The same product was sold to landscapers by the cubic yard at bulk rates. The Yelm Earthworm and Castings Farm in Washington, Vermicycle Organics in North Carolina, and Rainbow Worm Farm in California also sell vermicompost in bags and in bulk.
d. Product Standards and Labeling

Most states have not set product standards for vermicompost or compost. Generally, these products are sold as soil amendments and may not be sold as fertilizer. Labeling requirements for nutrient content vary from state to state, but these tend to affect sales of fertilizer more than soil amendments. Proportions of ingredients in blended soil amendment products are considered proprietary information. Thus, some products have been sold as “worm castings” when, in fact, there may be only a small portion of vermicompost in the product. The rest may contain mostly compost. Labeling on most blended products will provide the types of ingredients contained within (for example, “This product contains compost, peat moss, kelp, guano, and worm castings”), but nearly all blended products do not (and are not required to) reveal the amount or percentage of each ingredient.

5. Compost tea and Worm tea.

Compost tea and worm tea are produced by steeping finished compost or vermicompost in water to concoct a liquid organic fertilizer (LOF) for plants. Such teas have been made by suspending a woven bag (such as burlap) containing compost in a container of water, much like one would use a tea bag in a cup of water. As water percolates through organic matter, nutrients are extracted in the resulting leachate.9 There is some question whether the runoff from the composting/vermicomposting process may be considered a “tea” like that concocted by immersing finished material in water. Some test results seem to indicate that there is considerable value in compost runoff.

A study conducted in Washington State on runoff from yard trimmings compost facilities compared three strengths of leachate tea with a well-known commercial fertilizer (MiracleGro). Marigold plants and radish plants were chosen to test flower production and root growth respectively. Preliminary results of the plant growth trials showed that compost tea outperformed both the commercial fertilizer and the control group of plants receiving water only. A 1:1 dilution of runoff with water produced the best results. One project engineer in the study suggested that higher levels of potassium, micronutrients and humic acids in the leachate were responsible for the increased growth in the plants.10

Compost tea has been used successfully in Maine to prevent potato blight, the fungus that caused the Irish potato famine in the 1800s. Wood Prairie Farm in Bridgewater, Maine, applies 700 gallons of compost tea per week, 10 times per season, on 10 acres of potato plants. It supplies certified organic seed potatoes to all 50 states, and in 21 years has not yet had a problem with late blight which continues to trouble farmers in the same region where cool, wet weather conditions are conducive to the growth of the fungus.11
Foliar sprays from compost tea have also been used. The idea of foliar feeding is that plants above ground are able to absorb nutrients as readily or even more readily than through their root systems. Ralph Jurgens of New Era Farm Service in California claims that “foliars can’t substitute for a good soil fertility program, but they can provide supplements for short periods where rapid nutrient absorption is critical to crop production.” Jurgens suggests using compost tea as a foliar to help plants against powdery mildew and brown rot, and compost tea in drip systems or flood irrigation to build early root development. He claims applications of tea will promote mycorrhizal fungi, control nematodes and fight disease organisms.12

Worm tea is thought to have similar, if not superior properties to compost tea. Some have reported seeing dramatic results in plant growth and vitality after applying worm tea to struggling or diseased plants. Such teas have been used at full strength or diluted with water. Unfortunately, published scientific studies have not yet confirmed or explained these phenomena. Anecdotal evidence from enthusiastic users of worm tea remains the principal source of information at the present. Staff from Canyon Recycling in San Diego, California, reported that 12,000 gallons of runoff from their vermicomposting beds had been sold for $1.00 per gallon, providing them with yet another income source from their diversified operations.


Earthworms in a vermicomposting operation represent the workforce, the processors of organic materials. Having a surplus of earthworms may allow a vermicomposting facility the luxury of either selling off the surplus or expanding the operation, whether on-site or at another location. At least two large vermicomposting operations have sold surplus earthworms at prices that range from $5 per pound to $20 per pound. Canyon Recycling of San Diego reported that it planned to establish nine satellite facilities, stocking them with either the increasing progeny of earthworms from the original site or purchasing earthworms from other growers. Canyon also created an earthworm “nursery” operation in Yelm, Washington, at a former mushroom production facility. Earthworm populations were expanded and entire beds of up to 5,000 pounds of earthworms were shipped to San Diego and as far away as Texas via a trailer equipped with a “moving floor.” Today, this site has become the Yelm Earthworm and Castings Farm under the management of Sound Resource Management of Seattle, Washington.

Surplus earthworms may become available when earthworm beds are divided and fed without harvesting earthworms. The technique of periodically dividing beds to increase earthworm biomass is used to expand a vermicomposting operation’s capacity to process organics. John Beerman, General Manager of Canyon Recycling, reported that earthworm populations were allowed to multiply for several years in order to process increasing amounts of feedstock. Later, the emphasis on vermiculture, i.e., increasing the earthworm inventory, shifted to an emphasis on vermicomposting, i.e., transforming the incoming organics into a marketable product. In operations that must frequently harvest vermicompost for sale, a loss of earthworm
cocoons and juveniles occurs and earthworm populations tend to remain fairly constant. Thus, not all vermicomposting facilities find that they have surplus earthworms to sell. But there are a few sites that maintain a type of “nursery” operation, which may serve a number of purposes. A plentiful supply of earthworms can be used as a form of insurance, should the need arise to re-stock any part of the operation which might suffer a decline in the population. A number of experienced vermicomposters have reported suffering an “earthworm kill,” either through negligence, through the introduction of toxic materials to the worm bed, or due to some unforeseen natural or human cause. A vermiculture “nursery” at a vermicomposting site would serve to replenish low earthworm inventories, expand an existing operation, or simply to produce surplus earthworms for increased revenue.

4 National compost prices for bulk and bagged products from five U.S. regions are reported monthly in Composting News, published in Cleveland, OH.
6 The term thermophilic (heat-loving) means that certain microorganisms, adapted to living at high temperatures, are responsible for “cooking” compost in its initial phase where temperatures may range between 45° and 75° C (113° and 167° F).
7 The mesophilic temperature range is between 20° to 45° C (68° to 113° F).
8 Pathogen destruction is achieved through the Process to Further Reduce Pathogens (PFRP), required by federal regulations and many state regulations. Composting material temperatures must be maintained above 55° C (131° F) for 3 days (in-vessel or aerated static pile) or 15 days (windrows, turning the material at least five times during the 15 days).
9 The term “leachate” is sometimes used broadly to include “percolate” or “tea,” but some prefer to restrict its usage to a negative context such as “harmful leachates” that might contaminate groundwater.
Vermicomposting and the Breakdown of Organic Wastes

Conferences on Earthworms, Earthworm Ecology, and Earthworms in Waste Management

- 1978 Syracuse, New York  *Utilization of Soil Organisms in Sludge Management*
- 1980 Kalamazoo, Michigan  *Workshop on the Role of Earthworms in the Stabilization of Organic Residues*
- 1983 Rome, Italy  *International Symposium of Agricultural Prospects in Earthworm Farming*
- 1983 Grange-over-Sands, U.K  *International Symposium on Earthworm Ecology (ISEE 1)*
- 1985 Bologna, Italy  *ISEE 2*
- 1987 Hamburg, Germany  *ISEE 3*
- 1990 Avignon, France  *ISEE 4*
- 1993 Georgia, U.S.  *Earthworm Ecology in Forest, Rangeland and Crop Ecosystems in North America*
- 1994 Columbus, Ohio  *ISEE 5*
- 1998 Vigo, Spain  *ISEE 6*
- 2000 Kalamazoo, Michigan  *The Vermillennium*
- 2002 Cardiff, Wales UK  *ISEE 7*

Breakdown of Sewage Wastes By Earthworms

- In the late 1970s, Dr. Roy Hartenstein’s laboratory research at State University of New York (SUNY) Syracuse demonstrates that aerobic sewage sludge can be decomposed and stabilized (i.e., rendered innocuous) by *E. fetida* about three times as fast as non-earthworm ingested sludge.
- E.F. Neuhauser *et al* called the process *vermicomposting*, or *vermistabilization*
- They found optimum worm growth in sludge for *E. fetida* occurred at 25°C with 84-91% moisture content
- Sewage sludge was mixed with bulking agents (garden wastes, paper pulp sludge, etc.)
- Objectionable odors disappear quickly
- A marked reduction in populations of pathogenic microorganisms (*Salmonella enteriditis, Escherichia coli*, and other pathogens)
- Sewage sludge projects with earthworms conducted in U.S., U.K., and Italy
- No full-scale successful system has been achieved
Breakdown of Animal, Vegetable, and Urban Organic Wastes

- In 1980, Clive A. Edwards conducts massive research project at Rothamsted Experiment Station in the U.K. on both laboratory and field scale
- Feedstocks included animal manures (pig, cattle, horse, rabbit, poultry), vegetable wastes (mushroom, potato, brewery) and paper pulp
- Two aims:
  - Turn wastes into useful agricultural, horticultural products
  - Process earthworms into protein supplement for animals
- Five earthworm species, ten feedstocks were studied
- Study microbial nutrition of earthworms
- Evaluate worm biomass processing rate
- Develop systems of production for worm protein and processing waste
- Conduct trials on animals using earthworm protein
- Plant growth trials on vermicompost

Characteristics of different wastes

1. **Cattle solids** The easiest manure to grow earthworms; only unfavorable when fresh; must be separated from slurries first
2. **Horse manure** An excellent material; needs little modification
3. **Pig solids** Probably the most productive waste for growing earthworms; solids may have to be separated first; pre-compost to stabilize; vermicompost is high in nutrients
4. **Poultry wastes** Fresh wastes are high in inorganic salts and ammonia; after composting, leaching or aging, earthworms grow well in this material and vermicompost is high in nutrients
5. **Potato waste** Ideal growth medium needing no modification
6. **Paper pulp solids** Excellent growth material needing no modification
7. **Brewery waste** Needs to modification; earthworms process it quickly
8. **Spent mushroom compost** A good medium; earthworms break down the straw into finer material; may be low in plant nutrients
9. **Urban wastes** Yard trimmings and pre-consumer food waste are good media after being macerated.

Suitable Earthworm Species for Vermicomposting

1. **Eisenia fetida** (Redworm, red wiggler, brandling, tiger worm) Ubiquitous; eventually predominates in mixed cultures; wide temperature tolerance; wide moisture range; adapts to many types of organic wastes; tough, readily handled; most commonly used in commercial vermicomposting operations; closely related to *Eisenia andrei*; many worms sold as *Lumbricus rubellus* are actually *E. fetida* or *E. andrei*
2. *Eudrilus eugeniae* (African nightcrawler) Large worm; grows rapidly; poor temperature tolerance; poor handling; difficult to harvest; high rates of reproduction; capable of decomposing large quantities of organic waste; does not survive below 10°C.

3. *Dendrobaena veneta* A large earthworm that can survive in soil but is not very prolific and does not grow rapidly. It can be bred in organic wastes for transfer and use in agricultural soils.

4. *Perionyx excavatus* Extremely prolific; easy to handle and harvest; tropical earthworm, unable to withstand temperatures below 5°C; high reproductive rate; common in Asia, sued in vermiculture in the Philippines, Australia, India

5. *Polypheretima elongata* Tropical, used in India; capable of processing wide variety of wastes including human, animal, and vegetable. May not survive in winter conditions

6. *Lumbricus rubellus* Common species found in moist soils where manures have been applied. Yet to be proven as a species suitable for vermicomposting

### Cocoon Production and Growth Rates

**Maximum reproduction rate of earthworms in animal and vegetable wastes—cocoon production**

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of cocoons</th>
<th>% Hatch</th>
<th>No. of hatchlings</th>
<th>Net reproductive rates per week</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eisenia fetida</em></td>
<td>3.8</td>
<td>83.2</td>
<td>3.3</td>
<td>10.4</td>
</tr>
<tr>
<td><em>Eudrilus eugeniae</em></td>
<td>3.6</td>
<td>81.0</td>
<td>2.3</td>
<td>6.7</td>
</tr>
<tr>
<td><em>Perionyx excavatus</em></td>
<td>19.5</td>
<td>90.7</td>
<td>1.1</td>
<td>19.4</td>
</tr>
<tr>
<td><em>Dendrobaena veneta</em></td>
<td>1.6</td>
<td>81.2</td>
<td>1.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Productivity of earthworms in animal and vegetable waste—length of life cycle**

<table>
<thead>
<tr>
<th>Species</th>
<th>Time for cocoons to hatch (days)</th>
<th>Time to sexual maturity (days)</th>
<th>Time egg to maturity (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eisenia fetida</em></td>
<td>32-73</td>
<td>53-76</td>
<td>85-149</td>
</tr>
<tr>
<td><em>Eudrilus eugeniae</em></td>
<td>13-27</td>
<td>32-95</td>
<td>43-122</td>
</tr>
<tr>
<td><em>Perionyx excavatus</em></td>
<td>16-21</td>
<td>28-56</td>
<td>44-71</td>
</tr>
<tr>
<td><em>Dendrobaena veneta</em></td>
<td>40-126</td>
<td>57-86</td>
<td>97-214</td>
</tr>
</tbody>
</table>
Composters vs. Earthworkers

<table>
<thead>
<tr>
<th></th>
<th>Composters</th>
<th>Earthworkers</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Food</td>
<td>litter</td>
<td>soil</td>
</tr>
<tr>
<td>*Pigmentation</td>
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</tr>
<tr>
<td>*Size of Adults</td>
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</tr>
<tr>
<td>*Burrows</td>
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<td>Large, permanent</td>
</tr>
<tr>
<td>*Longevity</td>
<td>Relatively short-lived</td>
<td>Relatively long-lived</td>
</tr>
<tr>
<td>*Generation time</td>
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Comparison of Vermicomposting and Composting

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<th>Composting</th>
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<td>Ammonia</td>
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<td>Conserve nitrogen</td>
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<td>Particle Size</td>
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Vermicomposting Projects

West Coast Operations—The Early Days

Interest in vermiculture on the West Coast of the United States can be dated as early as 1936 when Thomas Barrett, physician and “Renaissance man” of many interests, established his Earthmaster Farms in El Monte, California. Here he conducted experiments in raising earthworms and recorded his recommendations in a book, *Harnessing the Earthworm* (Barrett, 1947).

In 1967, Ronald E. Gaddie, Sr. started a vermiculture business after a disabling back injury. By 1972, Gaddie’s North American Bait Farms in Ontario, California was approaching $100,000 in gross sales and grew to over $600,000 in 1975. Gaddie co-authored *Earthworms for Ecology and Profit*, Vols. I and II, along with Donald E. Douglas. Over 750,000 copies of the first volume, subtitled *Scientific Earthworm Farming* (1975), were printed and some 250,000 copies of Volume II, subtitled *Earthworms and the Ecology* (1977), were later published. Gaddie’s vermiculture and book publishing business grew wildly throughout the second half of the 1970s, and an extensive network of earthworm growers was established throughout the United States. He reported that his network exceeded 1,100 in California alone. Earthworms were shipped to Italy, France, Korea and Japan. His *Bookworm Publishing Co.* earned tremendous profits from the sale of his writings and earthworm books written by others. His own books were translated into Japanese, French and Spanish. Just as the foreign markets began to surge further in sales (an order for $170,000 of earthworms to be sent to Italy was received), Gaddie was forced to close his doors in early 1980 (Bogdanov, 1996a).

The closure of North American Bait Farms was the result of costly litigation Gaddie faced as the alleged “kingpin” of a pyramid scheme. In 1974 the Securities and Exchange Commission began informing North American Bait Farms that a price guarantee offering to buy back earthworms from potential investors could be construed as a sale of a security that would have to be registered under the Securities Act of 1933 (Gaddie and Douglas, 1975). In spite of all attempts to warn away others from violating SEC regulations, Gaddie became caught in litigation accusing him of participating in illegal “pyramid schemes.” The great cost of having to defend himself and others eventually took its toll. The once million-dollar-per-year business in earthworms alone (not counting book sales) collapsed. Along with it, perhaps tens of thousands of other earthworm growers, by the estimate of one person who was active both then and now, found themselves in an industry locked in a tailspin (Bogdanov, 1996a). Nearly twenty years later the memory of this boom and bust cycle remains in the minds of those still associated with vermiculture in California and throughout portions of the U.S. Today this story’s almost mythic proportions serve as a reminder of both the immense opportunity available in vermiculture as well as the dire consequences that may befall even the most circumspect.
Vermicomposting Bio-Solids in Fallbrook, CA

In 1986, after conducting a successful pilot-scale vermicomposting program, the Fallbrook Sanitary District embarked on a full-scale program to use earthworms (*Eisenia fetida* and *Lumbricus rubellus*) for stabilization of bio-solids. The District produced approximately 0.6 dry tons (544 kg) of sludge per day on its 43-acre site in a community of about 16,000 people located in Northern San Diego County. The two-stage process included pre-composting the material to comply with USEPA’s standards to reduce pathogens. After approximately 30 days in a static pile, material was removed to vermicomposting beds where it was applied at the rate of four to six inches (10-15 cm) per week to the 8-foot (2.4 m) wide windrows of varying length. To maintain porosity, straw bulking material was added about once per month. In about six months, windrows reached a height of approximately three feet (.9 m) and were ready for harvesting. The top six to eight inches (15-20 cm) of material, containing the greatest concentration of earthworms, was removed and used to establish new windrows. The remainder, stabilized vermicompost, was screened and placed in storage where it was allowed to cure for an additional 30 days. The District sold its static pile compost for $15 per cubic yard (.76 m³) and its vermicompost for $35 per cubic yard (.76 m³). It reported that it could not keep up with local demand (Harris, *et al.*, 1990).

Many aspects of this project were deemed successful. Fallbrook Sanitary District’s directors reported evidence that vermicomposting could serve to remove heavy metals from bio-solids. They were also encouraged by the plant growth potential of vermicompost stating that “earthworm excreta (castings) are an excellent soil-conditioning material with a high water holding capacity and ‘natural time release’ for releasing nitrogen into the soil” (Harris, *et al.*, 1990). But other factors, such as increased requirements for production and processing, an increase in time required for vermicomposting, and an increase in surface area, meant that vermicomposting made greater demands than conventional composting.

Canyon Recycling Takes Over

The Fallbrook vermicomposting project was forced to close as local residential development increased. The once rural community became a suburban community. However, interest in vermicomposting continued in San Diego County as Resource Conversion Corporation (RCC) obtained some 5,000 lbs. (2,268 kg) of earthworms from Fallbrook and brought them to Canyon Recycling in San Diego. On an eight-acre site, Canyon Recycling established twenty-two 250-foot (76.2 m) long windrows, ten feet (3 m) in width. A landfill diversion site, Canyon received tipping fees for municipal yard trimmings, manure from San Diego Zoo, San Diego Wild Animal Park and the Del Mar Race Track, and construction and demolition (C&D) debris. In the early 1990s, Canyon concentrated on vermiculture, building up its earthworm population. Earthworm beds were fed and split continuously until the time came to shift from vermiculture to a vermicomposting operation (Bogdanov, 1996 b). By March of 1996, John Beerman, General Manager of the facility reported that he provided his 75,000 pounds (34,020 kg) of earthworms about 15 to 20 tons (13.6 to 18.1 metric tons) of green waste every day.
Three to four inches (8 to 10 cm) of feedstock were applied with manure spreaders twice a week to each windrow. Water usage amounted to between 40,000 and 50,000 gallons per day. Earthworms were sold only rarely. After growing its earthworm inventory for about five years, harvesting vermicompost began in earnest and sales of Vermigro™, a blend of earthworm castings with compost, were made to nurseries, landscapers, organic farmers, and the general public. The blended product was sold in bulk ($35/cu. yd.) and in bags ($7.00 retail for one cu. ft. (.028 m³)). In one instance, Canyon negotiated a contract to produce 5,000 bags per month for a large retailer, but the deal never materialized. Canyon Recycling also sold recycled wood-fiber products to particleboard manufacturers and co-gen facilities, and produced compost and mulch used for roadside application by California’s Department of Transportation (CalTrans). However, the early creation of burdensome and unmanageable indebtedness pressured RCC’s directors to put Canyon Recycling up for sale in 1997. In spite of the fact that Canyon reported it could not make enough Vermigro™ to satisfy the demand, other factors contributed toward the need for restructuring this facility.

**Vermicomposting Organic Residuals from MRFs**

Pacific Southwest Farms, a 54-acre vermicomposting facility in Ontario (San Bernardino County), California began its operation in 1994 with eleven tons (10 metric tons) of earthworms transported from the failed Worm Concern project in Simi Valley, California. Owner Barry Meijer steadily built his operation into what may have been the largest project of its kind up until its closure. PSF received the biodegradable fraction of municipal solid waste (MSW) or “green material” (as defined by California’s compost regulations) from up to three different material recovery facilities (MRFs) for a tipping fee. Initially, PSF took in about 75 tons (68 metric tons) per day and increased that amount to approximately 100 tons (90.74 metric tons) per day. Earthworm-stocked windrows measuring eight feet (2.4 m) in width and 100 feet (30.48 m) in length were fed at the rate of four tons (3.63 metric tons) of material per row per week. Situated east of Los Angeles in an arid climate, PSF’s water usage amounted to 120,000 gallons per day. Sources for water included residential sprinkler runoff and barn water from local dairies. While the water was abundant and free, pumps, irrigation lines and use of electricity added significant expense. At it zenith, PSF estimated that more than 100 tons (90.74 metric tons) of earthworms processed organic residuals in 360 windrows. Finished vermicompost was reportedly sold to agricultural users in central California. Due to the mixed quality of feedstocks which contained a significant portion of inert material (especially glass shards), the final product had to be screened to 1/8 inch and was not acceptable for retail sales to the public (Bogdanov, 1997 c).

PSF’s feedstocks were non-traditional in comparison to other vermicomposting sites. From the beginning of its operation, MRFs in nearby Orange County processed the commingled material they received and sent the biodegradable fraction to PSF. This material was approximately 95% organic but contained enough bits of plastic to cause a problem with site and product appearance. The particle size of the incoming product was later reduced from four inches to 1-1/4 inches, which proved to work better and contained less visible and unsightly plastic. PSF also received ground paper that had come into
contact with food material or other green waste. That which was fed to earthworms is specified as “green material,” defined by the California Integrated Waste Management Board (CIWMB) as “any plant material that is either separated at the point of generation, or separated at a centralized facility [a MRF] that employs methods to minimize contamination. Green material includes, but is not limited to, manure, untreated wood wastes, paper products, and natural fiber products. Green material does not include treated wood waste, mixed demolition or mixed construction debris” (California Integrated Waste Management Board, 1997a). During the time of its operation, Meijer believed PSF was the only project using MSW for vermicomposting in California.

**Current Legal Status of Vermicomposting in California**

The San Bernardino Local Enforcement Agency (LEA) effectively shut down PSF in November, 1996 by issuing a Notice and Order requiring PSF to obtain a solid waste facilities permit as a transfer/processing station. PSF was also told it could not “process” any of its incoming feedstock. Processing would include either blending with manure or pre-composting the incoming feedstock. PSF appealed this Notice and Order. In February, 1997 the San Bernardino County Independent Hearing Panel issued a decision which specified that the earthworm bed activity was excluded from regulation by the CIWMB’s compost regulations and that PSF was not required to obtain a solid waste facilities permit.

But PSF’s problem continued. San Bernardino County attempted to close down PSF because of its location in a dairy zone, saying that it needed a conditional use permit and did not possess one. PSF filed an appeal of this ruling and, in April 1997, the Court of Appeal, State of California, Fourth Appellate District, determined that PSF could continue its vermicomposting operation. Citing California’s Food and Agricultural Code, the court agreed that vermiculture is an “agricultural use” and that PSF was in operation for the purpose of producing an “animal product” (Bogdanov, 1997d).

At least two victories for PSF and the practice of vermiculture in the state of California were won by these decisions. First, vermiculture continues to enjoy an agricultural exclusion from California’s composting regulations by virtue of the fact that the Food and Agriculture Code identifies vermiculture and its by-products as agriculture. And, secondly, pre-composting of feedstock prior to application on earthworm beds does not fall under the CIWMB’s compost regulations. Critics have complained that these exclusions do not allow for a “level playing field” for composters and vermicomposters alike. Additionally, the exclusions open the door for disguising a composting operation by allowing it to possess a small quantity of earthworms and call it vermicomposting. To discourage the possible abuse of vermiculture exclusions, CIWMB is amending its regulations to clarify what it will allow. In its Initial Statement of Reasons, CIWMB wrote: “A revision of the term ‘vermicomposting’ is necessary to clarify that worm castings, not compost, are the primary product of vermicomposting activities” (California Integrated Waste Management Board, 1997b). CIWMB maintains that an enforcement agency has the flexibility to determine whether an activity is or is not a vermicomposting activity. Incidental earthworm activity, in which significant amounts of biological
decomposition occurs which is not related to earthworm activity, would not constitute “vermicomposting.” Therefore, according to the CIWMB, the presence of a few earthworms in a compost pile would not qualify the operation as a “vermicomposting activity.”

Meijer’s Pacific Southwest Farms won only a Pyrrhic victory, however, as time-consuming litigation during the Cease and Desist order forced haulers to locate other sites to transport their organic waste. Without tipping fees and feedstocks to continue his operation, Meijer was forced into shutting down the facility.

Rainbow Worm Farm, Davis, CA

For twenty-one years Al Cardoza’s Rainbow Worm Farm has seen steady growth, largely due to Cardoza’s talents and persistence in single-handedly creating a full-service operation. Cardoza obtains dairy manure from Dixon, a small community located a few miles from his vermiculture facility in Davis, west of Sacramento, California. In addition to the expense of trucking this material to his own farm, Cardoza periodically visits the dairy farm to turn the manure, speeding up the pre-composting phase of the feedstock. Four-foot wide windrows, called “ricks,” cover some 3 acres of his twenty-acre farm. Sprinkler irrigation is used to spray a fine mist on the unshaded beds where temperatures frequently hit triple digits in summer. The exclusively outdoor vermiculture operation currently has 30 ricks approximately 200 feet (61 m) long. “That’s over one mile (1.6 km) in length,” reports Al’s son Dan Cardoza, who now manages Rainbow after Al’s recent retirement.

The rows receive about one inch (2.54 cm) of material every two weeks, amounting to about 40-50 cubic yards (30-38 m³) per row. Earthworms (Eisenia fetida) are harvested in a trommel designed and built by Al. Custom-made earthworm harvesters and blueprints are available for sale. Harvested earthworms are packaged in wax-coated cardboard boxes and shipped by ground carrier and by air freight all over the world. Cardoza applies wax to the interior of the boxes, perforates each one with enough holes to allow ventilation, and applies a red-ink stamped warning: “Alive! Earthworms. Do not expose to heat or cold.” A specially blended bedding mix of peat moss, shredded paper and oyster shell flour is used in packaging earthworms for shipment. The senior Cardoza has designed a heavy-duty blender for mixing earthworm castings with other ingredients to create custom potting soils for nurseries. He also has designed bagging and sealing machines that are used for packaging Rainbow Worm Castings, available in one-quarter and one cubic foot (.028 m³) bags. Cardoza’s video thoroughly covers all aspects of his operation: sprinkler set-up, creation of ricks, feeding, harvesting earthworms and vermicompost, making wax-coated cardboard boxes, and shipping procedures that include preparation of bedding and bagging. Two-day seminars and consultation services are also available. (Bogdanov, 1998 a).
Ecology Farms, Temecula, CA

In February 1995, George Bodlak, together with several partners, started Ecology Farms in Temecula, California. The ten-acre site raises *Eisenia fetida* on pre-composted yard trimmings adding 10-15% steer manure in the winter. Three different systems for raising earthworms are in use. Shade-cloth covered breeding beds are used to raise earthworms in a closely monitored environment. Moisture content of 80-85% and a temperature of 72°F (22°C) are maintained. From these beds, earthworms are then moved to a second system, fully exposed windrows for “conditioning” where the key process variables are not as ideal and earthworm reproductive activity slows. A third system uses fiberglass bins that were formerly used in trucking agricultural produce. A two-tier design in these bins allows for the collection of “earthworm tea” which Bodlak claims has restorative properties when used as a foliar on plants, although this has not been validated. Demonstration gardens showcasing the benefits of both vermicompost and “earthworm tea” are in use at Ecology Farms as they are at several other vermiculture sites in California.

Earthworms have been shipped in large quantities of 5,000 lbs. (4.53 metric tons) or more. Trucks equipped with a “walking floor” trailer expedite the shipping of entire windrows. But this vermiculture operation has also put strong emphasis on its sales of vermicompost as well. Under the “All-In-One” product label, earthworm castings are blended with compost, sea kelp, gypsum, bat guano and saponin from yucca trees. Screening and bagging are done on site by some of the ten employees. Expansion of Ecology Farms to include additional large-scale vermicomposting projects has been reported (Riggle, 1996 b).

Compost Site Sells Vermicompost before Producing It

Joe Lundstrom, site manager for Cascade Forest Products in Novato, California, took the experience he gained as site manager at Canyon Recycling in San Diego and added a vermicomposting emphasis to the conventional composting performed at the Novato site. But in this case, sales of vermicompost actually preceded the production of vermicompost. Initially, since there was no on-site vermicomposting, Lundstrom searched his own Marin County as well as adjoining counties in Northern California for earthworm castings that could be included in his product blends. Knowing that the addition of vermicompost created a “value-added product,” Lundstrom contacted vermiculture operations to purchase their earthworm castings. Once obtained, castings became part of the several blends Cascade has created under its own name and used in the custom blends it makes for others (Bogdanov, 1997 a). Offering an extensive line of soils, amendments and mulches, at least six products, appended with the words “with worm castings,” are sold in bulk by Cascade: Super-Premium Planting & Container Mix, Planter Mix, Amended Loam, Premium TopSoil, Super Compost, and Garden Compost. Within these blends, and in addition to vermicompost, are found fir bark fines, perlite, peat moss, lava rock, poultry manure, redwood fines, sand, bio-solids, composted yard trimmings, and forest humus. In addition to their own bulk sales and the custom blends
they prepare for local distributors such as Shamrock Earth Blends, Cascade provides ingredients for the Gardner and Bloome line of retail bagged products.

Soon after his arrival at the Novato site, Lundstrom inoculated five windrows, one hundred feet (30.5 m) long and ten feet (3 m) wide, with approximately 5 tons (4.53 metric tons) of earthworms. Cow manure and co-composted bio-solids were used as feedstocks. Situated next to a lagoon that continues to accept bio-solids under a grandfathered arrangement made many years ago, Cascade Forest Products finds that the compost made with bio-solids adds a darkness of color to the finished products that their customers find appealing. Earthworms (*Eisenia fetida*) thrive on the combination of co-compost and manure in the outdoor windrows. Lundstrom finds he still cannot make enough vermicompost to satisfy the demand for his blends. Cascade Forest Products continues to purchase earthworm castings from vermiculture operations many miles away, but freight costs have made some transactions prohibitive.

**Airline Pilot Raises Earthworms in Wine Country**

In 1992, Jack Chambers, a commercial airline pilot purchased a five-acre farm in Sonoma, California from a chicken rancher who also raised earthworms on poultry manure. Chambers expanded his Sonoma Valley Worm Farm by adding outdoor windrows to the existing covered row system, by obtaining dairy manure, by installing an irrigation system, and by purchasing equipment (tractor, trommel screen). Today, earthworms and vermicompost are sold at wholesale and retail prices. Earthworms (*Eisenia fetida*) are most commonly sold in 1,2,5, and 10-pound units, but larger amounts have been sold to bait dealers. Vermicompost is sold at $40 per cubic yard (.76 m³) (retail) and $30 per cubic yard wholesale.

Chambers has experimented with feedstocks such as alfalfa and has discovered variations in earthworm activity according to the amount of moisture applied to earthworm beds (Riggle, 1996 b). Seasonal predators, robins, have caused problems by removing earthworms from windrows over a period of a few weeks before migrating. To facilitate harvesting vermicompost, Chambers covers a three-foot (.9m) section on one end of a windrow, (thereby withholding food and water), which encourages earthworms to move laterally in search of food. The cover is removed several days later to harvest vermicompost.

Chambers sold about 2,000 pounds (907 kg) of earthworms, most in one and two-pound (.45-.9kg) orders, through a voucher program offered in the City of San Jose in 1996. This was in connection with earthworm bin sales by another vendor in the municipally-sponsored program and accounted for nearly one-half the entire amount of earthworms Sonoma Valley Worm Farm sold for the year.

The seasonal nature of earthworm sales is clear to Chambers who speaks of a “bell-curve” in the annual cycle. “The phone starts ringing in late March and [continues] fairly steadily in April. Things really go until the Fourth of July, when there’s a little dip, then they start soaring up again to the top of the bell-curve until about October, and that’s
when it starts to cool down,” he says. Sonoma Valley Worm Farm’s advertising is limited to a few listings in Bay Area Yellow Pages. Having a toll-free number stimulates sales, Chambers says, and association with Master Gardeners and Master Composters has also been advantageous (Bogdanov, 1997 b).

**Cocoon Production Holds Promise**

Environmental Recycling Systems (ERS) of Alpine, California is located on a five-acre parcel of land east of San Diego. Founder Sherrel Hall has been an active proponent of vermiculture for the past twenty years and claims to have developed an intensive, mass production breeding system whereby earthworm cocoons may be harvested and shipped in significant quantities for inoculation of earthworm beds to produce a substantial number of hatchlings.

Hall claims that his earthworm breeding facility can produce 50 million baby earthworms every 30 days. After 75 days, the approximate weight of young earthworms would total 25 tons (22.68 metric tons). He says his building space allows for an earthworm population of up to 400 million young hatchlings (200 tons) per month (White, 1996). Most of the earthworm production from ERS as of Spring 1996 was going to a ten-acre site in East San Diego County that received 40 tons (36.3 metric tons) per day of municipal green waste along with dairy and horse manure. ERS also reported that it would “provide earthworms of a different species” to be inoculated into soil of a planting area in a land reclamation project in San Diego (Riggle, 1996 a).

**Continuous Flow Reactor Processes Food Residuals**

Dan R. Holcombe is the founder of Oregon Soil Corporation, established in February 1988. His continuous flow reactor, designed and developed by Dr. Clive Edwards of The Ohio State University, has been in use in Clackamas County, just outside of Portland, Oregon since the early 1990s. The raised vermicomposting bed measures 128 feet (39 m) in length, 8 feet (2.4 m) in width and is 3 feet (.9 m) deep. A manually operated, two-ton capacity gantry feeder, riding on rails fixed to the top of the plywood sides, disburses up to six tons (5.4 metric tons) of blended organic materials daily. About 80% of the feedstock is pre-consumer food waste picked up from over 20 Portland-area supermarkets and food processors. Composted yard trimmings and shredded paper are blended in as bulking agents along with the wet organics (Riggle and Holmes, 1994). A chain-driven breaker bar mechanically scrapes vermicompost from the raised mesh floor, allowing the finished material to fall to the floor under the unit. A recovery scraper then moves the vermicompost from one end of the reactor for collection at the other end. One of the advantages of the continuous bottom discharge is that few earthworms are lost from the greater biomass working in the upper level.

Daily applications of thin layers of organics allow earthworms to work in the upper level of the reactor as earthworm-worked material descends toward the mesh floor. Total time from feedstock application to harvesting vermicompost can take from three to four weeks. Vermicompost is packaged in 1 lb. cardboard boxes and 1 cu. ft. (.0283 m³)
bags and labeled as Oregon Soil “Earthworm Castings.” The one-pound product is sold as plant food with directions recommending that one-teaspoon of castings should be added to a quart of water and used with every watering. One tablespoon of castings may also be mixed in for each quart of other potting media. The one cubic food bag is described as an all-purpose planting mix. It contains the admonition, “Use no concentrated plant food in conjunction. Our castings are a complete and balanced plant food. The pH balance of this product is 6.8.”

In 1991, Oregon Soil Corporation received a grant for $93,300 from Portland Metro’s “1% for Recycling” program which allowed Holcombe to put up a greenhouse-type structure and procure some equipment to build a pilot reactor. In February 1993, Oregon Soil began doing business with the Fred Meyer chain of “one-stop shopping” stores in the greater Portland area. Of the 20 stores with food departments, Fred Meyer’s estimates that each store produces an average of 45 tons (40.8 metric tons) of garbage per month. OSC’s staff continues to make daily pick-ups of organics and delivers them to the vermicomposting site.

In 1997, Holcombe disassembled his unit from a farm in Clackamas County and moved it to an existing compost facility within Portland’s city limits. The current plan is to continue to work in conjunction with Metro on vermicomposting food residuals while also taking advantage of the pre-composted yard trimmings available from the compost facility (Bogdanov, 1997 f).

From Mushroom Farm to Earthworm Farm

The Yelm Earthworm & Casting Farm, formerly the site of a mushroom-producing operation, was converted to an earthworm farm in 1991 under the ownership of Resource Conversion Corporation (RCC) of San Diego, California. RCC used the Yelm farm for R&D experiments with the hope of stocking other vermicomposting projects it had planned to start in addition to its Canyon Recycling project. Earthworms bred in Yelm were sold in quantities of up to 5,000 pounds (2.26 metric tons) and were shipped as far as Texas. In 1997 the farm came under the ownership of Sound Resource Management, an environmental consulting firm based in Seattle, Washington (Bogdanov, 1997 e).

Nestled in Smith prairie southwest of Mt. Rainier, the farm is located approximately 20 miles (33.86 km) east of Olympia, Washington. Jim Jensen, a principal and consultant with SRM, oversees the Yelm project. No stranger to vermicomposting, Jensen provided planning, development and implementation for the Food Lifeline Waste Reduction Demonstration Project in Washington’s King County from the end of 1991 to the beginning of 1994. During the 18-month active vermicomposting phase, Food Lifeline diverted nearly 50 tons (45.37 metric tons) of food scraps and yard debris by utilizing earthworms in pallet-box bins. Unsalvageable food collected by Food Lifeline that could not be vermicomposted was distributed to pig farms (Sound Resource Management Group, 1992).
The Yelm operation uses two systems to grow earthworms and convert treated dairy manure to vermicompost. The Yelm farm pays for delivery of manure that has been separated after sitting in a lagoon. The solids are removed and the manure passes through a heating process. The farm’s vermiculture system utilizes 4’x6’ (1.2 m by 1.8 m) wooden trays formerly used for mushroom production. The fairly shallow trays (6 inches—15.24 cm—deep) are stackable and maximize floor space in the covered portion of the facility estimated to be 33,000 square feet. Periodically, perhaps every two months, half the contents of the trays (earthworms, castings and manure) are removed and used to start a new tray or bin. The second system uses sprinkler-irrigated windrows, located both indoors and outdoors. Typically, rows are fed until about 30 cubic yards of material is ready to be harvested. Jensen estimates each row contains about 1,500 pounds (.68 metric tons) of earthworms (Eisenia fetida). Overall, he figures his operation currently has about 38,000 pounds (17.24 metric tons) of earthworms (Bogdanov, 1997e).

Managing one of the largest vermiculture operations of the West Coast, Jensen says the Yelm farm is adequately prepared to make large, bulk sales of earthworms and vermicompost (Jensen, 1998). Smaller quantities of products are also packaged and sold. Earthworms are packaged for shipment in wax-coated cardboard boxes, but Jensen has also experimented with shipping small quantities of earthworms in breathable plastic bags. Vermicompost is sold in 8-quart and 1 cubic foot (.0283 m³) labeled “Earthworm All Purpose Potting Soil; Natural Castings and Bedding.”

With some ten acres available, Jensen anticipates using the extra land for processing leaves and wood chips. By combining these materials with dairy manure, a darker-looking vermicompost may be produced. Adding more windrows outdoors and using “floating” row covers will help create additional indoor space for product development, packaging and warehousing. The potential also exists, says Jensen, for establishing in-vessel systems and becoming a testing ground demonstration center where people can come to see different technologies in operation.

**Vermiculture in the Southern and Eastern United States**

A search for earthworm-growing businesses in the United States will find the highest concentration in the more temperate regions. In the southern U.S., Alabama, Arkansas, Louisiana, and Texas are principal vermiculture locations with Kentucky, Missouri and Tennessee also well represented. North Carolina, South Carolina, Georgia and Florida predominate along the Atlantic coast, but vermiculture is also practiced in parts of Pennsylvania, New York, and even into some New England states. It appears that most growers in these regions use a business name such as “XYZ Worm Farm” and advertise to those interested in using earthworms for bait. Here are found many species of earthworms offered for sale, with scientific nomenclature supplanted by descriptive or common names. African nightcrawlers, native nightcrawlers, gray nightcrawlers, jumpers, red wigglers, brown nose worms, swamp worms, tiger worms, and a host of other names are used promoting earthworms for sale.
In some instances, vermiculture in the southeastern United States differs from West Coast operations in terms of feedstock and design. Today, reportedly hundreds of rabbit breeders throughout the southeastern U.S. use earthworms to convert manure dropped from rabbit hutches. Vermiculture represents a secondary industry in many of these instances. The construction of covered pits, both above ground and in-ground is fairly common. Earthworm growers speak in terms of creating “bedding” and may use peat moss and topsoil mixed with manure. While manure from herbivorous animals is a common feedstock, pulverized grain feeds are also in popular use. Poultry mash, alfalfa meal, and other finely ground high-protein feeds are added in thin layers or applied in trenches. Problems with “sour beds” occur when too much of this material accumulates in the bed. Concern with developing “fatter,” larger earthworms for the bait industry prompts earthworm growers to experiment with a variety of feedstocks. Bait producers distinguish between large “breeder” or bait-size earthworms and a mixed variety they call “bed-run,” consisting of a mixture of sizes that includes juveniles and hatchlings. Many growers sell earthworms in Styrofoam cups to fishermen or may sell larger quantities to bait dealers. Since the smallest unit (cup) usually contains a certain count of earthworms (e.g. one dozen nightcrawlers), sales of larger quantities of earthworms have adopted the earthworm-count system as well (e.g. 10,000 breeders for $80). Since earthworm counts are nearly always converted to weight amounts (e.g. 1,000 breeders weigh approximately one pound), many farms show their prices in earthworm weight as well. But this is less typical where a number of different species are sold and earthworm weights differ according to the type and size of earthworm sold.

**Tennessee Project Uses Disabled Workers**

In February 1995, Goodwill Industries of Chattanooga, Tennessee, along with consultant Larry Martin, constructed two 50-foot (15.24 m) long earthworm beds placed on a concrete floor. The 6-foot (1.8 m) wide beds, 2 feet (61 cm) in height, each have a capacity for about 22 cubic yards (16.8 m³) material, mostly cow and rabbit manure, along with some shredded paper and produce. Also known as the “Goodworms” project, the system is tended by disabled workers who also make bags for selling earthworms and vermicompost (Riggle, 1996 a).

By heavily watering the earthworm beds, excess liquid percolates through the system and forms puddles between the two beds. “Earthworm tea” is collected with a 10-gallon shop-vacuuming device, strained twice and sold for $1 per two-liter plastic container. Larger quantities, such as 5-gallon buckets and 55-gallon drums are also planned to be sold.

Larry Martin of Vermitechnology Unlimited, Inc. in Orange Lake, Florida is chief consultant for the project and has been involved in the vermiculture industry for over two decades. Martin began experimenting with earthworms in 1974 from an initial 2-pound (.9 kg) purchase made from Ronald Gaddie’s North American Bait Farms. Martin claims that since his original purchase, made over 20 years ago, he has never bought additional earthworms to expand his operation (Martin, 1996). Martin’s company manufactures modular, insulated earthworm beds, four feet (1.2m) wide by 18 inches (45.7cm) high
with varying lengths from 45 to 65 feet (13.7 to 19.8m). These are prefabricated units and can be set up in about four man-hours. A unit set up for a Chattanooga school used R-30 insulation, heavy duty shade cloth on the bottom of the bin to keep out moles, and shade cloth as a cover (Bogdanov, 1997 h).

Martin is also active on a vermicomposting project for a 2,500-acre hog farm in North Carolina. Swine manure is flushed out of a hog barn twice a week and then passed through a solids separator. The solids are applied to low technology earthworm beds and converted to vermicompost (Riggle, 1996 a).

*U.S. News & World Report* wrote in September 1997 that Martin’s company “sells around 100 tons of worm droppings—also known as castings—to local organic growers” (Koerner, 1997). Later Martin said, “what I’ve sold isn’t a drop in the bucket to what I could have sold” (Bogdanov, 1997 h).

**Vermicycle Organics, Inc.**

In 1994 Tom Christenberry, son Chris Christenberry, and partner Michael Edwards formed Vermicycle Organics, Inc., based in Charlotte, North Carolina. Having experimented with vermiculture for 20 years, the partners were ready to tackle large-scale projects vermicomposting hog manure in eastern North Carolina. In this region of the state are located many huge corporate hog farms, some with as many as 5,000 to 10,000 animals per acre. On most of these farms, swine manure is usually flushed into open lagoons and the liquid fraction is later sprayed on fields of Bermuda grass. Concern over the environmental impact of these long-in-use practices is serving as motivation to explore alternative means of handling this wastestream. After evaluating several pilot projects, the team settled on the use of an automated solids separator installed between the swine house and the lagoon at a hog farm. After separation, the material is placed on a concrete pad and the remaining effluent is piped into a lagoon. Thereafter, the manure solids are taken to earthworm beds measuring 190 feet (58m) long by 2 feet (.6m) wide (Riggle, 1996 b).

Vermicycle Organics, working with a group of hog producers, is constructing a series of greenhouses to accommodate more waste. Each 220-foot (67m) by 35-foot (10.7m) greenhouse provides shelter for three earthworm beds. On one site alone a total of 16 greenhouses are scheduled to process about 7,500 tons (6,806 metric tons) of manure per year (Riggle, 1997).

The company is now moving toward the installation of continuous flow reactors designed by Dr. Clive A. Edwards to increase the volume of material it can handle while minimizing labor costs. Another part of the operation is called the “nursery,” where earthworms (*Eisenia fetida*) are grown prior to their introduction into the vermicomposting systems. Earthworm castings have been sold in 2 lb. (.9kg), 10 lb. (4.5kg), and 25 lb. (11.3kg) bags since 1995 under the name Vermicycle™. Local markets such as garden centers, supermarkets, and organic farmers have been very receptive to the product that costs twice the price of compost. Vermicycle Organics is
also looking to export its vermicompost to foreign countries such as Japan, and is considering vermicomposting feedstocks other than swine manure in order to market earthworm castings to certain Muslim countries.

**Vermicomposting in Canada**

Original Vermitech Systems, Ltd. (OVS) of Toronto, Canada was founded in 1990 by Al Eggen. While at one time the bulk of company sales came from the manufacture of small, household vermicomposting bins, Eggen’s larger in-vessel systems, capable of handling from 50 to 850 pounds (23-386 kg) of organics per day, are now the company’s chief focus (Bogdanov, 1997 g).

In 1992 OVS began marketing vermicomposting units capable of processing 50 to 100 lbs. (23-46kg) of organics per day from restaurants, schools, and institutions with food waste. In 1993, the Brockville Psychiatric Hospital in Ontario, Canada installed an OVS unit with 600 lbs./day (272kg) capacity. The system was equipped with heat panels and temperature sensors to maintain the proper climate for earthworms (Riggle and Holmes, 1994).

In March 1996, an OVS unit known as the Vermi-Organic Digester was installed at Metro Hall in Toronto. Metro Hall is the head office of the Municipality of Metropolitan Toronto, a 28-story, 953,000 square foot building located in the heart of downtown Toronto. It houses two thousand employees and has a 325-seat cafeteria with an additional 200-seat patio. It produces almost 14 metric tons of food waste and almost 30 metric tons of paper towel waste annually (Bogdanov, 1997 g).

The Vermi-Organic Digester uses a shredder/mixer for volume reduction and feedstock preparation. It is a motor-driven, high-speed unit that can shred and mix organics such as fruits, vegetables, paper, cardboard and leaf mulch. Combinations of paper products and food waste can be shredded and mixed simultaneously to produce the food mix. The operator then transfers the organics manually to the vermiculture system in the required proportions. The feed is then consumed and converted to vermicompost by the earthworms. From time to time, vermicompost must be harvested. This is accomplished by moving a lever to disturb the lower layer of finished earthworm castings causing them to fall through a grate. Collection of vermicompost is made possible by removing doors at the bottom of the unit.

The School Cafeteria Model (V-50) measures 4’x8’x3’ (1.2x2.4x.9m) high, comes with a baked enamel finish and is provided with hinged, locking lids for security. Ventilation is thermostatically controlled by forced air into the bottom chamber and an exhaust outlet is found in the upper chamber. At 30-50 lbs. (13.6-23kg) of organic waste per day, the V-50 unit has the capacity to process 9 tons (8.17 metric tons) of material per year. It is estimated that the average cost per day for electricity for the fan and heater can be as little as 25 cents per day. Maximum water usage is estimated to be one gallon per day. Operating time for a staff person is estimated to be just 30 minutes per day. It is recommended that the unit be stocked with 100 lbs. (45 kg) of earthworms (Eisenia
*fetida*). Nine other models, similar in design but different in capacity, are also available. Units capable of handling 70-850 lbs. (32-386 kg) per day are advised to add the optional overhead automated food distribution system. The largest units are capable of handling 100 tons (90.7 metric tons) of organic waste per year.
Vermicompost Use in Plant Growth Trials

A. General observations

1. Anecdotal evidence is abundant; scientific documentation is relatively sparse.
2. “A little goes a long way.” and “More is not always better.”
   “A consistent and interesting trend for trials with plants grown in container media is for the best responses to occur when worm castings constitute only 10 percent to 20 percent of the volume of the mix, with greater proportions of castings not always improving plant growth as well. In some cases, even as little as five percent of castings in the mix is enough to cause a dramatic response.” S. Subler, C.A. Edwards, and James Metzger, “Comparing Vermicomposts and Composts,” BioCycle, July 1998, 63-64.

3. Such small amounts to produce such dramatic results suggests there is more to the value of castings than mineral content.
   a. micronutrients
   b. plant growth regulators
   c. microbial activity

B. Vermicompost and Compost Compared

Vermicompost has:

1. Slightly lower pH value than compost
2. Slightly higher nutrient concentrations, particularly N, than compost
3. Very low concentrations of ammonium-nitrogen compared to compost
4. Very high concentrations of nitrate nitrogen compared to compost
5. A buffering capacity that composts may not have

But:

6. There is a great deal of overlap in nutrient contents
7. It’s not always easy to tell one from the other
8. It’s difficult to predict the relative growth responses.

C. Tests with Raspberries, Marigolds, and Tomatoes

1. Enhanced microbial activity in pig solids vermicompost may explain increased micronutrient availability and plant growth. (raspberries)

2. Pig solids vermicompost, food waste vermicompost, and biosolids compost (10% by volume) led to significantly increased total weights of plants over a commercial growth medium. (marigolds)

3. Food waste and pig solids vermicompost at 10% and pig solids vermicompost at 20% led to “significantly greater tomato seedling weights after 3 weeks” than the Metro Mix 360 control alone.

4. “More is not necessarily better.” High N concentrations in biosolids compost made tomato plants grow too rapidly—“overly succulent and spindly,” not desirable for subsequent transplanting.

D. Conclusions

1. Pig solids vermicompost consistently outperformed other vermicomposts and composts tested.

2. Researchers are still trying to identify the biological mechanisms responsible for “the unique and remarkable plant growth responses that continue to be widely observed and reported.” [Emphasis added]

*Outline is from material reported in:
Characteristics of Vermicompost

“The nutrient content of vermicomposts differs greatly depending on the parent material. However, when their nutrient content is compared with that of a commercial plant growth medium to which inorganic nutrients have been added, they usually contain more of most of the necessary mineral elements for plants, although there is often a deficiency of magnesium.” C.A. Edwards, *Earthworm Ecology* (1998).

Major plant nutrient elements in earthworm-processed animal wastes

<table>
<thead>
<tr>
<th>Waste Material</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separated cattle solids</td>
<td>2.20</td>
<td>0.40</td>
<td>0.90</td>
<td>1.20</td>
<td>0.25</td>
<td>0.02</td>
</tr>
<tr>
<td>Separated pig solids</td>
<td>2.60</td>
<td>1.70</td>
<td>1.40</td>
<td>3.40</td>
<td>0.55</td>
<td>0.03</td>
</tr>
<tr>
<td>Cattle solids on straw</td>
<td>2.50</td>
<td>0.50</td>
<td>2.50</td>
<td>1.55</td>
<td>0.30</td>
<td>0.05</td>
</tr>
<tr>
<td>Pig solids on straw</td>
<td>3.00</td>
<td>1.60</td>
<td>2.40</td>
<td>4.00</td>
<td>0.60</td>
<td>0.05</td>
</tr>
<tr>
<td>Duck solids on straw</td>
<td>2.60</td>
<td>2.90</td>
<td>1.70</td>
<td>9.50</td>
<td>1.00</td>
<td>0.10</td>
</tr>
<tr>
<td>Chicken solids on shavings</td>
<td>1.80</td>
<td>2.70</td>
<td>2.10</td>
<td>4.80</td>
<td>0.70</td>
<td>0.08</td>
</tr>
<tr>
<td>Commercial plant growth medium</td>
<td>1.80</td>
<td>0.21</td>
<td>0.48</td>
<td>0.94</td>
<td>2.20</td>
<td>0.92</td>
</tr>
</tbody>
</table>

“An important feature of vermicomposts is that, during the processing of the various organic wastes by earthworms, many of the nutrients that they contain are changed to forms that are more readily taken up by plants, such as nitrate or ammonium nitrogen, exchangeable phosphorus, and soluble potassium, calcium, and magnesium.” C.A. Edwards, *Earthworm Ecology*, (1998).

Effect of earthworm activity on nutrients in organic wastes

<table>
<thead>
<tr>
<th>Organic Waste</th>
<th>Nitrate Nitrogen (ppm)</th>
<th>Readily soluble P (% d.m.)</th>
<th>Exchangeable (% d.m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K</td>
<td>Ca</td>
</tr>
<tr>
<td>Cattle waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unworked</td>
<td>8.8</td>
<td>0.11</td>
<td>0.19</td>
</tr>
<tr>
<td>Worm-worked</td>
<td>259.4</td>
<td>0.18</td>
<td>0.41</td>
</tr>
<tr>
<td>Pig waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unworked</td>
<td>31.6</td>
<td>1.05</td>
<td>1.49</td>
</tr>
<tr>
<td>Worm-worked</td>
<td>110.3</td>
<td>1.64</td>
<td>1.76</td>
</tr>
<tr>
<td>Potato waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unworked</td>
<td>74.6</td>
<td>0.19</td>
<td>1.94</td>
</tr>
<tr>
<td>Worm-worked</td>
<td>1428.0</td>
<td>0.22</td>
<td>3.09</td>
</tr>
</tbody>
</table>
1998 Results of Plant Growth Trials
Ohio State University
Oregon Soil Corporation

Leaf Area (cm²) of Marigold Seedlings
Grown in Premium Soilless Media (Metro Mix 360)
With and Without Addition of Vermicompost

<table>
<thead>
<tr>
<th>Days Growth</th>
<th>7 day*</th>
<th>8 day</th>
<th>9 day</th>
<th>10 day</th>
<th>11 day</th>
<th>12 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>MetroMix 360</td>
<td>1.6</td>
<td>1.9</td>
<td>2.01</td>
<td>2.3</td>
<td>2.54</td>
<td>2.98</td>
</tr>
<tr>
<td>10% Vermicompost/90% MM 360</td>
<td>3.6</td>
<td>4.25</td>
<td>6.75</td>
<td>7.79</td>
<td>9.25</td>
<td>9.75</td>
</tr>
<tr>
<td>20% Vermicompost/80% MM 360</td>
<td>1.85</td>
<td>2.10</td>
<td>2.35</td>
<td>2.84</td>
<td>3.21</td>
<td>3.35</td>
</tr>
</tbody>
</table>

* Days after Germination

“Clearly the marigold leaf area expanded much more quickly after substituting 10% or 20% of the commercial medium with vermicompost. There have been consistent indications that the addition of 10% vermicompost can have just as good or better effects than addition of 20% vermicompost.”

“…similar data are available for the other crops listed.”
Selected Bibliography


Appelhof, Mary; Webster, Katie; and Buckerfield, John. “Vermicomposting in Australia and New Zealand.” BioCycle, June, 1996, 63-66.


______. “Putting It All Together.” Remineralize the Earth, Spring, 1998, 54-56.


Marketing

Introduction

Effectiveness in compost marketing separates companies that are just “getting by” from companies that realize great profits when the latter create value added products. Compost markets fall into two areas: dollar markets, where high quality compost commands the best prices and volume markets, where the decision to use compost is used based upon obtaining it for the lowest possible price. In the latter case, agricultural use of compost, while able to absorb large volumes, is probably not the compost marketer’s first choice. These markets may object to compost use based on low nitrogen values, particularly if it is more costly than competing fertilizers. Dollar markets, on the other hand, consisting of retail garden centers, nurseries, landscapers, and other specialty uses, offer more profit potential.

Due to the weight of the product and costliness of transporting it over great distances, compost markets are best developed within a 100-mile radius or less.

In this section...

The compost facility, even as it is being designed, must look ahead to marketing its products. What types of incoming raw materials and production processes will determine the quality of the product? Can this product be produced consistently? In order to make sales and keep customers, increasing the product knowledge of compost sales staff and educating compost customers must be two ongoing activities.

Product marketing must keep pace with production. Techniques for increasing sales should be constantly explored. Compost marketers need to be alert for new markets, innovative uses, and key partnerships in widening their distribution base as well as keeping regular customers satisfied.

Contents

The Compost Factory Paradigm
Retail Markets
Volume Markets
General and Specific Structure
Compost Industry Growth
Packaging and Labeling
Marketing and Education
COMPOST MARKETING

Source: Rodney W. Tyler, Winning the Organics Game, 1996

I. The Compost Factory Paradigm

A. Understanding the Flow

1. General Structure: Production & Sales (see Figure 1)

![Diagram of compost factory paradigm]

**General Structure**
Production & Sales

- **Production**
  - Incoming Raw Materials
  - Production Processes
  - Product Quality

- **Sales**
  - Marketing Emphasis

- Need for Control
- Need for Consistency
- Product Knowledge (input)  
- Product Education (output)

Figure 1
2. Specific Structure: Vermicomposting Production & Sales (see Figure 2)

Figure 2
B. The Natural Market Hierarchy
   1. Dollar Markets
   2. Volume Markets
C. The Compost Industry Life Cycle Curve

Estimated compost industry life cycle curve (Figure 3)

![Figure 3]

Time
Overdevelopment of the market (Figure 4)

![Figure 4]
Underdevelopment of the market (Figure 5)

Parallel development of production and marketing programs...just in time for inventory. (Figure 6)
D. Understanding Markets

1. Market (Geographical area)
   Defines the geographic customer base—i.e., Sacramento, CA, compost market
2. Market Sector (Customer base)
   Customer bases within geographic markets, i.e., Landscape market segment in Sacramento, CA
3. Use (How they use it)
   Defines how the product is used, independent of customer base—i.e., topdressing can be done by homeowners, golf courses, and landscapers (each are market segments).

E. Benefits of the Compost Factory Paradigm (see Figure 8)

1. Allows the industry to be identified, segmented, quantified, and understood based on natural division in the marketplace.
2. Increases research and development projects that will be based on the needs of the marketplace.
3. Improves communication about markets, uses, and the differences between them.
4. Helps educate decisionmakers so that correct compost facilities are built after appropriate market assessment.
5. Helps marketers keep profits in mind that should positively affect their bottom line.
6. Provides a mode of interaction between the marketplace and manufacturers of compost products to increase awareness of needs on both ends.

The Compost Factory Diagram
II. Retail Markets  
(see Figure 9)

- **Definition:** The retail market is the final stop in a long or short chain of purchases that creates demand for a specified product or service.
- **The 20-80 Rule:** Approximately 80% of the population in the U.S. lives in 20 major cities.
- **Education:** As the general public becomes more educated about the benefits of using compost, the retail market segment will grow.
- **Demographics:** The greatest market for soil amendments in the retail markets appear to be households with 30- to 49-year-old college-educated members, professional business people, households with married people and children, suburban households, and people with incomes more than $40,000 per year (National Gardening Association Inc., 1993).

III. An Overview of the Green Industry Markets

A. Landscapers

1. New turf establishment  
2. Turf renovation  
3. Planting bed preparation  
4. Mulching  
5. Backfill for tree planting  
6. Outdoor planter mix

B. Nurseries

1. Field application as a soil amendment  
2. Band application for shade trees  
3. Liner beds—incorporated  
4. Liner beds—mulched  
5. Container mixes

C. Sports Turf, Golf Courses, Athletic Fields

1. Construction mixes for new golf courses  
2. Topdressing mixes  
3. New turf establishment  
4. Turf renovation  
5. Amendment for flower beds

D. Grounds Maintenance
E. Topsoil Blenders—Soil amendment for many blends

1. Topsoil amendment
2. Additional product to sell directly to market
3. Special mixes for contractor work

IV. An Overview of Volume Markets

A. Sod Production
B. Silviculture

1. Forest Reestablishment
2. Erosion Control

C. Mine Reclamation

1. Vegetation Establishment
2. Erosion Control

D. Roadside (DOT/DNR)

1. Vegetation Establishment
2. Erosion Control

E. Landfill Daily Cover
F. Crop Agriculture
“The One Page Marketing Plan for Compost Marketers”
Dollar Markets and Most Popular Uses

- **Any Major Market**
  - **Landscapers**
    - **Grounds Managers**
      - Turf Establishment
      - Topdressing
      - Flower Bed Amendment
      - Backfill for Planting Trees & Shrubs
      - Mulching All Landscape Plants
  - **Nurseries**
    - Greenhouses
    - Field Application as an Amendment
    - Ingredient in a Container Mix
    - Liner Bed Production (as Amendment)
    - Mulch for Many Types of Nursery Stock
    - Band Application for Shade Trees or Row Crops
  - **Topsoil Blenders**
    - Material Yards
    - As a Topsoil Amendment & Extender
    - As an Additional Product to Sell Directly to Market
    - Special Mixes for Contractor Work
  - **Sports Turf, Golf Courses, Athletic Fields**
    - As a Replacement for Peat in Construction and Topdress Mixes
    - As a Poor Man's Topdress for Athletic Fields
    - Amendment for Flower Beds
    - New Turf Establishment
    - Mulch for All Landscape Plants
  - **Garden Centers** (Retail Trade)
    - Additional Product to Offer Retail Customer (Bulk and Bag)

Figure 9
Packaging and Labeling

Distribution Information to Consider

Packaging Considerations

- Bulk or bags
- Use recycled, reusable or compostable bags when possible

Labeling Considerations

- Your company name
- Your company address
- Your company phone and fax #s
- Maximum temperature of this batch and # of days
- pH
- C:N ratio
- Particle size distribution
- Soluble salt level
- Original ingredients
- Recommendations for application
- List any certification criteria
- Major nutrients (N-P-K)
- % organic matter

Delivery Considerations

- Your truck should be neat and labeled with company name
- Check with customer before delivery
- All paperwork should be neat and accurate
- Deliver label and instructions for use with all bulk loads
Marketing and Education

Information and Activities to Consider

Educational Information
- Scientific evidence of quality/performance
- Instructions for use
- Economic or other benefits
- Join Composting Council, local composting organizations

Research & Development
- New formulations and technologies
- Continuous finished product testing
- Plant responses in various soils

Testimonials
- Where has it been used?
- Who has used it?
- How have they used it?
- What are the results?

Demonstrations
- City parks
- Roads strips
- Major theme parks
- Compost demonstration site sponsorship
- Community gardens
- Schools and campuses
- Open houses

Pricing Strategy
- Available substitutes
- Penetration pricing
- Market-share pricing
- Long-term considerations

Adapt Project Specifications to Allow Compost Use
- Work with landscape architects
- Work with building specification departments
- Work with DOT/DNR agencies
Advertising
• Magazines
• Direct Mail
• Newspaper
• Radio and TV
• Trade Shows
• Associations
• Conferences
• Word of mouth

Product Refinement & Market Targeting
• Niche products for new markets
• Superior service
• Equipment rental for applications

Promotions
• Specials
• Campaigns
• Giveaways
• Contests
• Meeting sponsorships
• Community projects
• Talks at schools and civic groups

Sales Skills
• What’s in it for your customer?
• Understanding product features and benefits

**Benefits identified by purchasers of compost products:**
Helps reduce compaction…it makes the soil more spongy and helps it spring back more
Helps increase water retention…also like a sponge holding water, compost increases available water
Helps hold onto nutrients…the “magnetic charge from the high CEC associated with compost holds nutrients so that plants can use them
Helps reduce chemicals needed…compost helps promote healthy plants…healthy plants need less help from chemicals and fertilizers
Reduces erosion…by dispersing the force of raindrops, compost helps reduce erosion
Increases filtration…the spongy nature of compost helps small channels open for water to drain quickly through until the “sponge” swells with water absorbed by compost
Reduces some diseases…compost provides a natural habitat for colonization of beneficial microflora capable of outcompeting some of the bad diseases that cause plant losses.
Increases porosity…because compost is lighter than soil and has more air voids, it provides most soils especially heavy clay soils, with an increase in total porosity.
Financing

Introduction

Financing a composting facility, whether public or private, involves creating partnerships with individual and corporate lenders, management, and public agencies. Financing strategies involve the participation of results-oriented problem solvers who know how to obtain the resources it will take to bring a project to fruition.

Much depends upon the credibility of the project developer who is seeking the approval of the public, regulators, politicians, and sources of funding. Good developers are team builders, forging together the energies of individuals and groups who can help get the project moving in the right direction.

Various funding source options are available for financing capital costs. Operating costs that depend upon revenue sources such as tipping fees and product sales must be accurately forecasted.

In this section…

Establishing the developer’s credibility and the qualifications of the project team is important for garnering community and agency support. Political acceptance and regulatory approval will depend to a large extent upon the developer who can present a plan that will benefit all parties concerned. Thus, the first step to be taken in order to obtain facility financing is the presentation of a comprehensive plan that will convince key decision-makers, detailing the qualifications of the project leaders, the technical soundness of the plan and demonstrating an understanding for regulatory and zoning issues that may be involved. Seven funding sources are presented for financing capital costs and four revenue sources are presented for financing operating costs.

Contents

Establishing Project Credibility

Financing Capital Costs: Seven Funding Sources

Financing Operating Costs: Four Revenue Sources

Developing a Business Plan
Facility Financing

I. Establishing Project Credibility

Before a financial institution or investor puts equity into a composting operation, the developer must have addressed the following questions:

<table>
<thead>
<tr>
<th>Key Elements of a Successful Operation:</th>
</tr>
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<tbody>
<tr>
<td>• Developer Credibility</td>
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<tr>
<td>• Technical Expertise</td>
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<tr>
<td>• Political Acceptance</td>
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<td>• Regulatory Approvals</td>
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<tr>
<td>• Comprehensive Business Plan</td>
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<tr>
<td>• Adequate Revenues</td>
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</tbody>
</table>

A. Developer Credibility

The developer should have a project team that has the necessary management and technical skills. The team should be ready to sell the project to bankers, government officials and the public.

<table>
<thead>
<tr>
<th>The Management Team should have:</th>
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<tbody>
<tr>
<td>• Knowledge of the Industry</td>
</tr>
<tr>
<td>• Experience</td>
</tr>
<tr>
<td>• Management skills</td>
</tr>
<tr>
<td>• Capability to “sell the project”</td>
</tr>
<tr>
<td>• Financial Strength</td>
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<tr>
<td>• Perseverance</td>
</tr>
</tbody>
</table>
Key Questions:

Past Performance
What experience do you bring to the project?
What is your history of success?
Do you repay debt?

Knowledge of the industry
What is your expertise in the solid waste industry?
How does this project fit into the regional plan?
Can you assess past and current facilities’ problems and successes?
Are you aware of what future trends might bring to the industry?

Project Management Skills
Can you put a team together to make the project work?
Do you have staying power?

B. Technical Experience

For the 90% of compost facilities that use basic windrow technology, substantial resources are not needed to create a technically sound facility. Thus, elaborate designs and reports should not be required.

Team members should possess:
- Understanding of compost processing
- Material management skills
- Access to experts
- Ability to explain to the public
- Knowledge of other projects—what works and what doesn’t

Key Questions:

Knowledge of the Science
Do you have a grasp of compost science?
Can you manage the organic waste stream competently?

Understand the Technologies Available
Can you assess the technology options, and select the most appropriate?
Can you explain to the public exactly what your process entails? Can you assure investors that your technology will work?

Link with Research Institutions
Have you set up a networking channel with university personnel? Do you have the best technical advisors on your team?

Professional Associations
Have you joined your state and national associations?

C. Political Acceptance

Gaining site and political approval may be the toughest of all steps and usually hinges on where the site will be built. Before financing a composting facility, the project team should seek a letter of support from the host community and the necessary planning and zoning agencies.

**Positive Community Relations Means:**

- Sharing development plans and listening to objections
- Creating measurable project benefits for the community
- Showing care for the project’s impact on business and personal lives

Key Questions:

Prepare the community
Are you prepared to educate the public? Can you show the need for the project in your area? Have you chosen a site you can show is a good property use? What type of kick-off program can you do to promote positive attitudes?

Obtain contracts for inputs
Have local communities agreed to bring their municipal waste stream? Have you sought other forms of organic waste? Have citizens and commercial generators bought into your program?

Address the Problems
Have you addressed the potential problem of odor with the community? What about noise and traffic? Have you stressed good management and contingency plans?
Stress the Positives

Have you explained the benefits the project can bring the community?
  - Recycles former waste to a great, salable product cost effectively
  - Saves valuable landfill space
  - Perfect opportunity for public/private partnership—everyone wins
  - Creates jobs

D. Regulatory Approvals

The regulatory requirements for compost facilities vary dramatically from state to state and are based on the types of materials being composted. Since more than half the states have banned yard debris from landfill disposal, this has created a significant demand for composting in many areas.

The most important regulatory and permitting requirements can come at the local level. Here, regulations can be developed to deliberately encourage or directly impede the development of composting facilities.

It may be necessary to retain legal counsel and a reputable environmental consultant, but only if necessary.

Key Questions:

Know your state and local restrictions
  Have you read local zoning and permitting rules in your area?
  Have you explained to the regulators exactly what you want to build?

Get Proper Zoning

Involve Your Solid Waste District
  Have you attended any of the Solid Waste District meetings?
  Have you determined how your project fits the Waste District’s plan?

Obtain State Permits
  Are you familiar with your state’s requirements for compost facilities?
  What are the building and operational requirements they have set?
E. Comprehensive Business Plan

Key Questions:

Inputs
Have you made accurate estimates of the anticipated materials?
Do you have the municipal contracts?
Have you sought other sources of organics to ensure year round inputs?

Assets
What assets do you have in place?
What are you willing to put into the project?

Revenue Sources
Tip fees—Are the fees you project in line with the local economics?
Compost sales—Are you meeting highest market demands?
Equipment Rental—Can your equipment be rented for income?

Expenses
Have you done a good job projecting expenses?
Can you match the facility expenses with potential revenues?

Funding needs
Have you determined your immediate and ongoing capital needs?

F. Revenues and Markets

The business plan must include a projection of income as well as a market evaluation for the products of the facility. Typically a compost facility relies on two sources of revenue: tipping fees and material sales.

Key Questions:

Size of Service and Product Area
Have you developed a plan to advertise your product?

Know the Trends
Is “compost” a household word in your area?
Do your potential customers understand “designer soils?”
Is peat moss available and inexpensive?
Where are local landscapers getting comparable materials?
Do you anticipate more material on the market soon?

Anticipate Changes
Competitive Advantages
  Do you have staying power?
  Can you meet customer demands quickly, with top quality product?
  Are your prices in line? Can you demand more for your quality?

Disadvantages
  Don’t underestimate the importance of your markets to your competition

G. Guarantees

The bottom line is: the lenders want to know how they will get their money back. Thus, there must be some guarantees.

Key Questions:

  What kinds of guarantees can you provide?

  Project Success
  Sale of Assets
  Small Business Administration Guaranteed Loan
  Mortgages
  Contracts
Seven Crucial Points to Remember:

1. **Be prepared before going to the bank.**

   Have your homework done. Be prepared to answer general, technical, political and financial questions. While having all the answers immediately is not important, it is the overall impression of competence you reflect that determines your success. Go to the lenders with more than an idea.

2. **Educate the bankers (or other lenders).**

   Chances are the compost industry will be new to them. Impress them with your knowledge of solid waste trends, composting technologies, and equipment you are considering. Invite them to equipment demos or to visit other facilities. The more they know the easier it will be for you to explain exactly what you need from them.

3. **Surround yourself with people smarter than you.**

   Network with the key players in the industry. Join the professional associations. Go to professional meetings. Hire good consultants and research professionals. Read everything you can find. All the knowledge and experience you can absorb makes you look good.

4. **The size of the project is directly proportional to the politics you’ll play.**

   When a project involves a large community or more than one municipality, complicated technologies and large contracts, count on spending enormous amounts of energy and money in siting and approvals.

5. **Nothing is ever final.**

   Rules, technologies, contracts, approvals, markets, or equipment—situations never remain static. Anticipate change.

6. **Bigger is better.**

   It is hard to build a small compost facility and be financially successful. Because the capital costs of starting a facility are extensive, they must be spread over long commitments and volume to make a profit.

7. **Don’t put all your eggs in one basket**

   Cultivate the contracts that get you started. Seek out new sources, new technologies, and new contracts. Don’t be tricked into thinking that throwing a lot of money into the project is paramount to success. Many high-tech, multimillion-dollar facilities have closed. Great flows of material and money are not enough—you must know how to use them together. Continually upgrade and improve your quality. If you can do this, the lenders will seek your business.
II. Financing Capital Costs: Seven Funding Sources

<table>
<thead>
<tr>
<th>Facility Financing</th>
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<tbody>
<tr>
<td>1. Solid Waste Management Fees</td>
</tr>
<tr>
<td>2. District Tax Levies</td>
</tr>
<tr>
<td>3. Bond Financing (General Obligation, Revenue)</td>
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<tr>
<td>4. Lease Financing</td>
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<td>5. Agency Funds</td>
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<tr>
<td>6. Public Grants and Loans</td>
</tr>
<tr>
<td>7. Private Sector Equity and Bank Financing</td>
</tr>
</tbody>
</table>

A. Solid Waste Management Fees

To fund publicly-owned solid waste projects like composting facilities, public agencies may levy a solid waste management fee on property owners. The public agency may use these fees to pay for the facilities, for their operation and maintenance, and for paying off bonds.

Fees can be assessed based on the following:

- Flat charge for each residence or building
- Weight or volume of the refuse received
- Average number of containers or bags of refuse received
- Relative difficulty of collection or management of received solid waste
- Other criteria related to the service provided

This approach is best suited to small, cohesive communities that perceive composting as beneficial and worthy of public funding.

B. District Tax Levies

- Advantages
  - Very predictable revenue stream
  - Works well with long-term costs such as bond payments
- Disadvantages
  - As a flat tax, it is not based on actual use of services. Individuals have no
    incentive to use compost facility
  - Public acceptance; tax-funded public services have become politically
    unpopular

C. Bond Financing

There are two types of bonds that may be issued by a public agency: General
Obligation Bonds and Revenue Bonds

<table>
<thead>
<tr>
<th>General Obligation Bonds</th>
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<tbody>
<tr>
<td>are issued against the financial stability of a state, city, or district. Proceeds from the sale of the bonds must be kept as a separate fund to pay for the facilities or services.</td>
</tr>
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</table>

Bond-financed facilities usually must accept public bids for the facility or adopt a
resolution approving a request for proposals.

<table>
<thead>
<tr>
<th>Revenue Bonds</th>
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<tbody>
<tr>
<td>are special obligations of the public agency and are payable only from dedicated facility revenues. They are funded based on the strength of potential income from the project. The revenues may include monthly user fees, disposal fees, or sales of materials.</td>
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</tbody>
</table>

The service provider usually provides additional credit support through
construction, performance and operating guarantees, and the government provides “put or pay” contracts. These contracts commit the district to guarantee delivery of a minimum tonnage of solid waste and pay a tipping fee whether or not the guaranteed waste is delivered and the facility is operating.

D. Lease Financing

Capital purchases can also be funded through lease financing. This method is
frequently used to obtain either fixed equipment to be installed in the facility (mixers, agitators, compactors, conveyors, etc.), or rolling stock equipment (forklifts, wheel loaders, containers, collection vehicles, or windrow turners). Leases typically last for shorter periods (3-5 years) than bonds, and the cost of financing is typically higher. In many cases, however, the security on the lease is provided by the equipment itself.
Lease financing is most useful when other capital financing is not available. It can be a useful approach for small equipment purchases between major capital projects or as a means of starting a project when there are few alternatives.

E. Agency Funds

Public service organizations, whether county, city, or district, have access to ongoing agency funds from their annual operations. Larger operations have an equipment/capital replacement line item in their budget and an annual capital appropriation mechanism that guides long-term capitalization and capital replacement.

This allows local units of government to enter the composting business. It also works well where the local unit of government funds equipment purchases and site development of a facility that can then be operated by a private firm. This sort of assistance from the public sector makes private responsibility for composting a reality.

F. Grants and Loans

Many states have developed solid waste management grants, loans and funding for waste reduction, recycling, and management. They have gained popularity as a source of funding for recycling, including composting programs. In many cases, inexpensive loan financing makes a project possible. Many of the loans are offered at rates equal to or below the prime rate.

The obvious advantage of grants and low interest loans is that they lower overall project costs. Loans, while requiring a payback, may still be advantageous at low interest rates. Some grants have drawbacks, such as the uncertainty of receiving a grant, the timing of the application, and the actual funding award that can disrupt project development. The effect of any waiting period on project development must be weighed.

G. Private Sector Equity and Bank Financing

Private financing does not place an administrative tax burden directly on the local units of government. It is often secured sooner since the approval process may be much simpler. Also, private sector financing is available in smaller amounts that can be timed to the project’s needs, rather than bundled into a large public bond issue.

Lack of public control is an argument against private capitalization. Private financing has an element of uncertainty and unpredictability. A company that has planned a compost facility and announced that it will be available at a certain date, may, for any of several reasons, delay or reverse that decision. Typically, the public sector will require some type of contractual commitment for approval.
III. Financing Operating Costs: Four Revenue Sources

Most facilities generate revenues using a combination of means, such as material sales and tipping fees. The following section summarizes each source of revenue and helps determine which is appropriate.

<table>
<thead>
<tr>
<th>Four Revenue Sources</th>
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<tbody>
<tr>
<td>1. Facility Tipping Fees</td>
</tr>
<tr>
<td>2. Collection Fees</td>
</tr>
<tr>
<td>3. Landfill Tipping Fee Surcharge</td>
</tr>
<tr>
<td>4. Material Sales</td>
</tr>
</tbody>
</table>

A. Facility Tipping Fees

Facility tipping fees, paid at the gate of a compost facility, are the most common method used in the solid waste and material recovery industry to cover the operating and maintenance costs (O&M costs) of the facility.

Facility Tip Fees

- Should be set lower than rates charged for landfilling (so haulers have an incentive to take material to composting site)
- Can be collected on the basis of weight or volume
- Small facilities usually collect by volume because of the expense of a scale
- Variable tip fees may be used to charge more for some materials (bagged) and less for desirable materials (clean, dry wood chips)
- Apply equally to all facility users
- Can be easily increased or decreased to cover costs

B. Collection Fees

Collection fees usually take the form of a subscription service. The user pays the collection agent a regular payment, monthly or quarterly. Haulers collect this fee to cover both collection and disposal costs.
If the subscription service is standard, all users pay the same fee. In such a case, there is no incentive to recycle or reduce the organic waste stream.

Variable-rate fees allow the user to pay for refuse actually collected. It encourages waste reduction through home composting or self-hauling. Variable rate fees should be used if collection fees are a major revenue source for composting operations.

The main disadvantage of variable-rate fees is that they cost more to administer.

C. Landfill Tipping Fee Surcharge

Communities that own or host a site may add a surcharge to landfill tipping fees to raise funds for composting and to favor reduction and recovery over disposal.

Private landfills may legally challenge such a fee if it is imposed by local legislation and the landfill does not agree to participate. These surcharges are generally negotiated with the landfill operation in exchange for government support of the facility.

If the community increases its efforts in waste diversion, the composting facility that is dependent on the surcharge as a major revenue source, may find a decreasing revenue stream.

D. Material Sales

Markets for compost are becoming stronger as research reveals the increased benefits of compost use. Competitive products, such as topsoil and peat, may be more expensive or in short supply, which helps the compost market. Based upon some reports of the market revenues for compost in some parts of the country, it appears that some facilities may enjoy considerable success from product sales.

Sales are directly related to the facility’s success in producing a high quality product. Strong product sales create incentives for operators to continue to produce value-added products.

The variability of markets means that no facility can consider product sales the sole or even the primary source of revenue. Supply and demand may fluctuate and revenues may be difficult to predict. But over time, many predict that as the marketplace becomes better educated, and as the quality of compost becomes more consistent, markets will expand and revenue streams will become more stable and predictable.
Developing A Business Plan: Sample Outline

A business plan provides a “vision” for a composting facility. This vision is important for the operators, managers, and potential investors. Make sure that the business plan for the proposed facility is up to date and accurate as possible. The following should be included in a thorough business plan:

Cover Sheet

- List the business name, address, phone number, owner(s) name(s), and date

Table of Contents

- Provide a specific list complete with page numbers

Executive Summary

- Summarize your business plan in a maximum of two to three pages. This might be your only opportunity to sell your business to a potential investor.

Business Description

- Give a brief history of the business
- Present a vision of how the business will make profits by meeting the needs of your customers for the next five to 20 years.
- Describe the company’s legal structure, location, and facilities

Management and Personnel

- Describe how the business will be organized. Provide an organization chart.
- Show how the skills and experience of the owner(s) and staff will help make the business succeed.
- Describe the means and methods for staff training.

Operations

- Prepare a facility management plan that addresses volumes for processing, types of materials, location of site, design of facility, capital equipment
descriptions, staffing levels, troubleshooting techniques, and transportation routes.
• Describe the operation and its associated operating costs. Make sure that tip fees take account of seasonal fluctuations.

Marketing

• Describe the market positioning as a function of processing services, tip fees, price of finished product, and likely place and form of product sale.
• Describe customers and explain why they will send material to the site and/or buy the finished product(s).
• Describe how the finished product(s) compares with competitive composts and topsoil products.

Finance

• Prepare an operating pro forma that includes all capital replacement, interest, labor, utilities, fuel, administrative and maintenance costs.
• Prepare a sales projection that estimates desired and minimum annual and monthly sales. Make sure projection accounts for seasonal fluctuations.
• Create a cash flow budget for the next three years based on operating pro forma and market projections
• Use cash flow statement to develop a balance sheet and income statement for each year
• Describe what the projected financial statements say about the facility’s ability to be profitable.

Appendix

• Three years financial statements or personal income tax records
• Resumes of all owners and key staff
• Include all licenses and registrations pertinent to development of the facility, or provide status report of pending application for license or registration.

Source: Composting Council, Composting Facility Financing Guide
Site Design

Introduction

The choice of a composting or vermicomposting site depends upon a number of factors. As in all real estate acquisitions, the first rule is always “location, location, location.” But two major considerations of site selection are contradictory to one another. First, in order to minimize trucking costs and maximize accessibility to both incoming feedstocks (for the sake of obtaining vital tip fees) and the sale of outgoing products, the ideal site should be close to waste generators and compost users. However, the perennial issues of odors, dust, noise and traffic associated with composting sites invite criticism from neighbors who prefer not to have composting activities nearby. The cry of NIMBY (“Not in my back yard”) has been heard all too often. Even when compost sites have been started in outlying areas, developers have built communities that bring neighbors (and complaints) closer to sites that were once unnoticed. Following best management practices for siting and site design will improve the chances of an operation to find success in both minimizing processing costs and generating higher revenues.

In this section…

Factors for determining a good location not only include the proximity of neighbors but the quality of the land surface itself in order to sustain the movement of heavy equipment. Permitting requirements must be considered and careful attention must be paid to environmental impact issues such as water run-off and air quality. The use of natural and man-made buffers not only help to “hide” the operation, making it less noticeable, but serve as a barrier to diminish odors, noise and dust from impacting neighbors. The construction of a compost pad and maintenance of surfaces for the movement of heavy equipment is of major importance. And the orderly flow of materials is enhanced by a site layout that is designed for receiving, processing, storage and distribution with minimal distance and moving requirements between stages.

Contents

Site Planning
Site Layout and Design
Site Surface Design
Site Planning

Site development involves finding an acceptable location for operating a compost processing facility that will have a minimal impact on the surrounding community and environment.

Location

The ideal location would be as close as possible to generators of organic materials as well as close as possible to end-user markets. However, this very proximity to populated areas is also the greatest threat to the composting facility, where complaints about noise, dust, odors and traffic may be raised. In some cases, formerly remote composting sites have heard greater numbers of complaints as new community developments are built nearby. Due to increased traffic, the use of heavy equipment, noise, dust, and possible odors, facilities are best located close to agricultural, public utility, or industrial areas. Facilities near residential areas face more stringent operational controls in order to avoid complaints from neighbors. Sites near sensitive locations, such as schools, hospitals, and nursing homes should be avoided. FAA regulations prohibit the existence of compost facilities within 10,000 feet (almost 2 miles) of any airport.

Site Selection Criteria

- Proximity to waste generators
- Proximity to customers
- Proximity to transportation corridors
- Opportunity for expansion
- Buffer from neighbors (schools, hospitals, etc.)
- Drainage, runoff control
- Firm surface to support vehicles under varying weather conditions
- Cost of space, utilities

Permitting Requirements

Many states, particularly in the central and western U.S., do not have specific permitting or siting requirements for facilities that process yard debris. Two states, Delaware and Michigan, have expressly exempted yard debris processing facilities from permitting or siting requirements. Pennsylvania has yard waste composting guidelines that exempt facilities from permitting if they comply with the guidelines.

Specific permitting requirements for composting vary from community to community. Many local government units require compost sites to adhere to specific zoning and land use regulations that regulate where composting can take place. Requests for zoning or special use permits may be required before a site plan can be approved.
Some counties and cities have environmental review agencies that must approve applications and site plans. Before beginning the planning process, check local and state requirements in your area.

### Siting Checklist

- Check zoning
- Identify public officials with jurisdiction over the proposed facility
- Review state and local composting regulations
- Check prevailing wind direction
- Identify critical surface and ground water resources
- Identify nearby “sensitive receptors”
- Detail pre-existing buffers such as woods, roads, walls, hills, etc., between site and its neighbors
- Identify possible areas for future facility expansion
- Detail surrounding transportation routes

### Setbacks

A setback is a prescribed distance separating the area of a particular activity and a neighboring boundary. In order to protect the surrounding community from noise, dust and odors, setback requirements have been imposed in some areas. Some examples include:

- 500 feet from a sensitive receptor (hospital, church, school, nursing home)
- 300 feet from residences
- 500 feet from active wells
- 200 feet from natural or artificial wetlands

Other setbacks may prescribe the distance between the composting pad and the property line.

### Buffers

Buffers serve to block the effects of noise, odor, and the visual impacts on the site’s neighbors. Types of buffers include distance, rows of trees, berms, walls, and bodies of water. Taking advantage of natural buffers such as wooded areas and hills can effectively prevent the complaints and opposition of neighbors. Visual screens should be considered at facilities in urban or suburban settings. During site design, the direction of prevailing winds should be noted and the buffer zone extended in that direction.

The buffers needed will depend on the location, materials received, and site management. Following best management practices will significantly reduce the distance needed for buffers.
Entrance and Exit Requirements

The facility should be easily accessible from major transportation routes. Travel through a residential neighborhood should be avoided. Entrance and exit roads should not create any major pedestrian or vehicular conflicts. The approach to the entrance and exit should be from a road with adequate capacity and turning capabilities. The site entrance should be clearly marked with signs.

Road design should support any anticipated high traffic volume or heavy vehicles. A traffic study may be performed to determine anticipated traffic volume.

The entrance road should be designed to avoid delay and back-up of vehicles entering the site. This can be accomplished by designing a circular traffic flow, along with adequate turning and dumping areas. The entrance and internal road network should provide access for fire trucks and other emergency vehicles. The facility should have direct access to hard surface roads. The preferred access road should be one that is able to be used during we weather, especially in the rainy season.

Vehicles leaving the compost facility should not track mud or compost from the site to public roads.
Site Layout and Design

Land Area Requirements

The type and quantity of incoming feedstocks are key factors in determining the amount of land needed for a composting facility.

<table>
<thead>
<tr>
<th>Potential Sources of Compostable Inputs</th>
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<tbody>
<tr>
<td>Food Processing Residue</td>
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<tr>
<td>Agricultural Residues</td>
</tr>
<tr>
<td>Forestry and other residuals</td>
</tr>
<tr>
<td>Biosolids (sewage sludge)</td>
</tr>
<tr>
<td>Leaves, brush, yard trimmings</td>
</tr>
<tr>
<td>Source-separated MSW</td>
</tr>
<tr>
<td>MSW</td>
</tr>
<tr>
<td>Biodegradable packaging</td>
</tr>
<tr>
<td>Animal Mortalities</td>
</tr>
<tr>
<td>Soiled Paper Products</td>
</tr>
</tbody>
</table>

Estimate the Total Potential Volume of Compostable Inputs and their processed value:

<table>
<thead>
<tr>
<th>How Many Tons Are Expected</th>
<th>Convert Raw Tons to Yards</th>
<th>Account for Shrinkage</th>
<th>Total Yards Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>____________Tons</td>
<td>3 Yards in 1 ton in X</td>
<td>1 Yard Out = _______ Yards</td>
<td></td>
</tr>
</tbody>
</table>

1 Yard Out = _______ Yards

Other factors include:

- Level of processing technology (height of windrows, space between rows, rate of volume of reduction
- Rules for setbacks, storm water control and land use
- Storage time before grinding
- Market demand for products
- Buffers
- Internal traffic circulation
The land area of a composting facility must be large enough to handle present and future volumes. Ideally, a facility should have enough acreage to accommodate an entire year’s projected volume of incoming feedstock. One informal national survey found that processing site capacities range from 1,500 to 3,000 tons per year per acre. Most sites cannot efficiently handle more than 5,000 cubic yards per acre per year.

Compost facilities should be designed to assign land areas to the three operational phases:

- Staging/Receiving
- Processing
- Curing, Storage and Screening

Approximate percentages of total area needed for site layout have been proposed based upon surveys of composting facilities. Area requirements for efficient material movement from station to station are approximately as follows:

- 20-30% for Staging and Receiving
- 55-65% for Processing
- 10-20% for Curing, Storage and Screening

**Material Flow and Site Configuration: A typical layout**
Staging Area

The staging area is dedicated to receiving, weighing, unloading, inspecting, debagging, grinding and mixing incoming materials. The size of the staging area is related to the volume received and the period of storage before grinding.

The volume of incoming yard trimmings may be reduced substantially by grinding equipment. Typically, a volume reduction of two-thirds is achieved by grinding brush, tree trimmings and shrubbery.

Processing Area

Windrow construction and turning occur in the processing area, which occupies half or more of the total area in use. Windrows should run parallel to the slope to prevent runoff from ponding on the uphill side of the windrow.

The processing area should be close to the staging area with rows perpendicular to the staging area to reduce transfer distance.

Storage and Curing Area

Activities in the storage and curing area include screening, stockpiling finished product, and loading for shipment. The size of this area is determined by the estimated length of time between seasonal market demand. Some areas have two peak seasons, spring and fall. Storage space should allow for approximately six months’ capacity. As a result of 75-80% volume reduction caused by the composting process, only 10-20% of the total area in use is needed to store large quantities of finished product.
Site Surface Design

A firm surface

While a firm surface is necessary for windrow composting, the necessity of a paved surface depends upon state and local regulations. Moderate to well-drained soils are satisfactory for some lower intensity composting situations.

Compacted sand or gravel

A pad constructed of 6 inches of compacted and graded sand or gravel works well when the existing soil conditions are not acceptable.

Benefits of paved pads

Paved pads of concrete or asphalt are beneficial in reducing problems related to mud, equipment operation, pad maintenance and compost quality. Concrete or asphalt pads make mixing of raw materials with a bucket loader much easier. Year-round access is permitted during all climate conditions. Efficiency in material handling is increased. The chief drawback to paved pads is their high cost.

Typical Site Preparation and Construction Costs (ca. 1995)

<table>
<thead>
<tr>
<th>Pad Type</th>
<th>Average Cost per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Pad (no fill)</td>
<td>$5,000</td>
</tr>
<tr>
<td>Gravel/slag</td>
<td>$29,200</td>
</tr>
<tr>
<td>Asphalt pad</td>
<td>$57,200</td>
</tr>
<tr>
<td>Concrete pad</td>
<td>$129,000</td>
</tr>
</tbody>
</table>

Note: Does not include engineering and construction supervision; cost figures may vary from community to community.

Danger of ponding

Heavy equipment tends to form ruts when there is significant rain or snow. The formation of ruts allows for accumulated water to create “ponding,” a condition that creates added difficulties for the compost operator. Anaerobic conditions may be created if a pile or windrow is located in the standing water.
Clay soils

The presence of clay at a site requires special attention in the preparation of a hardened surface in order to avoid serious drainage and resulting odor problems. Cohesive soils like clay cannot support activity in wet weather. Experience in many states in recent years has clearly indicated that sites located on a clay base without overlying pavement will become inaccessible and extremely muddy after only a month or two of steady operation.

Grading the slope

A pad should be constructed so that its final grade and elevation provides a slope that allows water to flow away quickly from composting materials. Slopes of less than 2% are difficult to maintain, especially when most re-grading is performed only up to the skill level of the operator’s eye. The overall slope of the pad, regardless of the material used in its construction, should be able to consistently maintain flow in the direction of the drainage collection ditches or leachate pond.

Disadvantages of unpaved sites

Constant grading and re-grading needed to maintain an appropriate slope and surface integrity. Additional layer of surfacing material is required annually or periodically to make up for losses due to constant scraping action of metal buckets. The quality of finished compost is adversely affected when gravel becomes mixed with the feedstocks and resulting compost.

Minimum Recommendation

The mixing area and active windrow composting area should be hard surfaced. Additionally, the entry, exit, access roads, and perimeter areas around grinders, debaggers, and screeners should be prepared to handle the movement of heavy equipment.

Managing Drainage

Drainage and retention pond structures should be easily arranged for gravity flow collection. This consideration is imperative at the outset in order to accept or reject the viability of a possible composting site.

The pond inlet and outlet structure should be designed to control flow and minimize erosion of the structure or its surroundings. Retention ponds help control the volume of runoff that might affect surrounding rivers, lakes and wetlands. Usually, off-site flow is restricted to an amount that is equivalent to the runoff volumes under the same storm conditions before development took place.
Stormwater runoff should not be allowed to flow into curing areas, screening areas or storage areas for finished product.

Retention ponds require periodic maintenance including removal of sediment, inlet and outlet cleaning, and prevention of slope breakdown.

Site Design Checklist

- Acquire all necessary permits (building, zoning, business, and solid waste management)
- Prepare a construction erosion control plan to mitigate loss of soil and impact to surrounding water resources
- Identify types, quantity and seasonal distribution of incoming material
- Define incoming quantity limitations based on site size and composting technology
- Define material staging and preparation requirements
- Identify outgoing quantities of finished material
- Estimate need for size reduction/mixing equipment
- Estimate need for turning equipment
- Estimate need for screening and blending equipment
- Estimate need for utility equipment (loaders, dozers, trucks)
- Define site boundaries
- Describe major areas of activities (receiving, pre-processing, grinding, composting, curing, storage)
- Describe major transportation routes to and from facility
- Determine traffic flow on site
- Define buffers necessary to mitigate effects on neighbors
- Design pad and roadway surfaces
- Provide site security (gate, signage, fencing)
- Develop appropriate site erosion control structures (diversion channels)
- Develop appropriate retention pond facilities for storm water control and collection/removal of sediment
Operations

Introduction

Day-to-day composting and vermicomposting operations involve the management of materials, equipment, and personnel. Businesses of all types experience success or failure largely due to their effectiveness (or lack of it) in management. Poor management is directly related to higher costs if materials are not properly handled, equipment is not maintained and staff members are ineffective in carrying out their responsibilities.

Facility managers are often capable technicians with superior knowledge and skills concerning the processes involved to personally manage each step of the operation. However, competency in skill level does not guarantee competency in management responsibility. Effective managers constantly evaluate the entire operation, looking for ways to make improvements, save money, and discover potential problem areas before they become problems.

Operators who strive for maximum efficiency know they have to begin by setting up a system, then training responsible staff to perform their duties according to the operations protocol established.

In this section...

Well-run facilities implement a systematic approach to their operations, defining what must be done at each step of the way and communicating that knowledge to responsible operators. Organics recovery facilities examine incoming feedstocks at the time they are delivered and before they are processed in order to determine what steps must be taken. Storage of some materials is required, whether for short or long term. Equipment must be capable of handling the volumes expected and maintained accordingly. Staff members should be trained in all aspects of the operation, understanding that their role is important in producing, maintaining, and guaranteeing product consistency.

Contents

Incoming Materials
Storage of Incoming Materials
Composting Equipment
Staff Training
Operations Checklist
Operations

Feedstock Recovery: Managing Incoming Materials

Good Neighbor

The goal of every composting facility should be to operate in such a manner that does not create an adverse impact on the environment (air, water quality) or the surrounding community (noise, odors). Additionally, each facility should use procedures to maximize employee safety and health, and limit fire hazards.

Materials Handling

Proper operation of a compost facility requires an effective system of managing incoming materials, use of equipment and trained staff.

The Role of Waste Generators

Even before the material is delivered to the facility for composting, waste generators play an important role in the quality of the incoming feedstocks. While source separated waste implies that care has been taken to eliminate contaminants, experience has shown that anywhere from 3-11% of delivered presorted organic material contains “mistakes.” This is particularly true where the emphasis is upon “cleaning up” waste products rather than on focusing on the quality of the organic material collected.

Education

A public and hauler education program, coupled with an effective community recycling system, should be considered to encourage removal of contaminants at the source of generation (home, business, industry). Because society is accustomed to disposing of all wastes together, source separation programs typically require a change in habits for both generators and collectors. Simple, one-page flyers (perhaps with pictures) can be used to encourage consistent source-separation practices, identifying acceptable compostables and discouraging co-mingling with non-compostables.
Gate Management

Each site should have staff monitoring the receipt of each load of incoming material, inspecting the load for foreign matter or contamination.

Contaminants

Loads need to be inspected for household hazardous waste (HHW) and for other foreign materials such as glass, metal, sharps, hard and film plastic, and other undesirable materials. Storage containers should be provided on-site for removal of contaminants in accordance with state and local requirements.

Recyclables

Some materials not suited for composting may be recyclable. Aluminum, ferrous metals, glass, paper, cardboard and plastics such as HDPE and LDPE may be sorted out from the incoming feedstocks.

Sorting Equipment

Magnetic separators can remove metals that may damage facility equipment and contaminate finished product. Various screening arrangements can sort out objects based on size. Screening during the Feedstock Preparation phase increases the costs of the operation.

Incoming Material Considerations

- Type and number of vehicles delivering material (for high-traffic facility, commercial and residential traffic should be separated)
- Type of material and whether it is in bags
- Site operator control of drop off

Separation by Material Type

Loads should be identified and directed to separate areas for different product streams.

- Wet feedstocks (food waste, grass, manure, wet leaves, etc.)
- Dry feedstocks not requiring grinding (leaves, sawdust, etc.)
- Yard trimmings requiring grinding
- Material too large for the rated capacity of the grinding equipment
Weight and Volume Characteristics

A facility operator needs to know the weight and volume characteristics of different types of feedstock. The density of various components of yard debris is dependent on the degree of compaction, moisture content, and the bulk density of the material. Some yard waste densities are shown below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Loose (lbs./cu.yd)</th>
<th>Compacted (lbs./cu.yd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Grass</td>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>Brush</td>
<td>300</td>
<td>900</td>
</tr>
</tbody>
</table>


A knowledge of the bulk density ranges is important due to their effect on the operational parameters of products, inventory, and shipping.

<table>
<thead>
<tr>
<th>Material Processing Stage</th>
<th>Weight (lbs./cu.yd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed compacted yard trash Before grinding</td>
<td>500-550</td>
</tr>
<tr>
<td>Loose mixed brush Before grinding</td>
<td>100-250</td>
</tr>
<tr>
<td>Mixed yard trash After grinding</td>
<td>350-400</td>
</tr>
<tr>
<td>Mixed logs only After grinding</td>
<td>425-550</td>
</tr>
<tr>
<td>Mulch 60 days old After windrowing</td>
<td>550-650</td>
</tr>
<tr>
<td>Screened compost After windrowing</td>
<td>800-1000</td>
</tr>
</tbody>
</table>

Source: City of St. Petersburg, FL Sanitation Department (1995).

Note: The densities are affected by particle size from processing equipment, age, processing method, moisture content, and compaction.

Plastic Bags

Yard clippings collected and delivered in plastic bags present a major operational concern for compost facilities. Plastic bags are popular with residents because they are inexpensive and hold more material than paper bags. However, plastic bags cause odor problems when grass clippings and food waste turn anaerobic in a matter of hours. Typically, residents bag yard debris on weekends and waste is not collected until one of the following weekdays. By the time it reaches the composting site, anaerobic conditions may be prevalent. Additionally, other contaminants may be hidden from inspection and found later when bags are opened. Plastic debagging systems are available but their ability to remove all of the plastic in a cost-effective manner is still a question for site operators to consider on an individual basis. De-bagging is costly, whether it is done mechanically or by hand.
To save money, some operators rely on equipment to break open bags, compost the contents, and screen unwanted plastic and inerts at the end. However, this method is subject to increasing the on-site nuisance of unwanted plastic particles blowing around as well as contamination of the compost product.

**Control Vectors**

Vectors must be controlled to prevent an environmental nuisance. Rodents and other small animals are often deposited in the receiving area by delivery trucks.

**Gate Management Tips**

- Don’t accept material in plastic bags. If you must, determine an effective means of de-bagging and waste accumulation.
- Reject non-compostable wastes at the gate. Track incoming loads so haulers can be identified and held accountable for contaminants.

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**Best Management Practices: Feedstock Recovery**

- Remove recyclables

- Remove contaminants that can affect finished product (lead, glass, plastic, etc.)

- Remove items that can cause damage to composting equipment or cause injury to workers (metals, rocks, etc.)

- Avoid commingling “clean” feedstocks with other incoming materials

- Match feedstock recovery choices to facility capability to prepare for composting

- Practice Good Housekeeping—Keep a Clean Site
Storage of Incoming Materials

There are several management variables to consider when accumulating material on site:

- The size of the facility—space and equipment available

  The amount of incoming material to be stored on-site may depend upon space available for active composting. Also, it may not be economical to process material without a minimum tonnage build-up prior to bringing the suitable processing equipment on-site. Compaction of yard debris is discouraged because it may cause loading and fire safety problems. One acre of storage area can hold 750 tons if properly managed.

- Type of materials being received—wet, dry, whether or not they need processing

  Loads containing primarily grass and other high nitrogen wet feedstocks (food waste) need to be incorporated into the composting process quickly so as to minimize odor and reduce the loss of nitrogen. Dry, carbon-rich feedstocks (leaves, sawdust, straw, wood chips) may be stored to be commingled with nitrogen feedstocks upon demand. Brush and other woody yard waste requiring size reduction may be stockpiled prior to processing long periods of time without causing odors. This allows the operator the ability to grind material as needed, during slow periods or when leased equipment is used.

- Odor generation—grass clippings, food waste

  Give top priority to managing odor-causing feedstocks.

- Products to be produced—scheduling, processing times, seasonal variations

  In most areas of the country the volume of yard waste generated varies by season. Typically May through September will produce the majority of grass collected. Depending upon weather and landscaping practices, leaves are collected and may arrive at the composting site in a shorter time period. To successfully handle fluctuations, a site must accommodate surges of incoming materials by estimating peak capacity in advance.

- Proximity to neighbors—noise, odors, dust

  The proximity of neighbors may determine management practices where noise, odors and dust may be produced. Odor problems are the single biggest threat to a composting operation.
• Safety and regulatory issues—pile height, moisture content, time, spontaneous combustion

Causes of fires:

• High Porosity—mulch, brush
• Supply of Oxygen
• Low moisture percent 25-45%
• High temperature

Fires can ignite from spontaneous combustion within the pile. However, a rare set of conditions must occur for this type of fire to be possible. First, there must be vegetation with ample nitrogen to fuel bacterial populations that generate heat. The continued heating of vegetation to their ignition temperature is thought to be due to rapid oxidation initiated after bacterial preheating. While most microbes cannot live at temperatures above 160-175°F, rapid oxidation may increase the heat to more than 200°F for an extended period of time. Second, there must be adequate air supply and insulation. One of the ways in which heat loss is limited is through compaction in piles that are too high. In piles over 12 feet high, it is possible for the internal heat of the compost pile to initiate chemical reactions which lead to spontaneous combustion. Third, spontaneous combustion becomes a possibility as the material dries out to a moisture content range of 25-45%.

Operational procedures to minimize spontaneous combustion for storage of organic materials include:

- Incoming unprocessed materials should be stored in windrows or piles with a clear area around each pile that is equal to the height of the pile.
- Mixing new material with older material on the site should be avoided, and an area should be thoroughly cleaned before starting a new pile.
- Storage sites should be level and on firm ground.
- Temperature of older storage piles should be monitored.
- Concentrations of fine materials during pile build-up should be avoided.
- Employees should be aware that vehicle exhaust systems can cause fires.
- Pile compaction should be avoided.
- Keep moisture above 45%
- Keep moisture uniform
- Keep pile height below 12 feet to allow heat dissipation
How to Fight a Compost Fire

Unfortunately, local fire departments generally respond with methods that are counterproductive. They typically apply large quantities of water to storage piles, which has the effect of spreading the fire, generating runoff, and saturating compost that might have been suitable for marketing.

A more appropriate method is to break down the pile or windrow to separate the burning materials, then spread the burning materials out in a layer on the ground. Frequently, the fire will simply go out in the thin layer. However, the use of water is recommended at this time to quickly extinguish the remaining fire to prevent sparks from spreading the fire to other windrows or piles.

Quantity of Incoming Material

In designing a composting facility, decisions and estimates must be made about the type and quantity of feedstocks to handle. Site design, equipment needs, and the amount of compost that will likely be produced can be calculated based on a study of local organic waste generators. A waste characterization analysis will show the anticipated type, source and amount of organic materials generated in a particular geographic region. The amount of compost that can be produced can be calculated once inputs are known.

As an example, consider statistics from a US EPA study (1992) on yard trimmings generated annually in the U.S. Of the total solid waste stream, 35 million tons of yard debris were produced annually. Based on the U.S. population of nearly 250 million people, approximately 280 pounds of yard waste were generated per person per year in the U.S. While this may yield a reasonable number to use for estimating local available yard trimmings, the exact number will vary greatly across the country. Yard trimmings figures for a northern state will be significantly different from a state such as Florida. For other organic materials such as food, however, variations across geographical regions are probably less significant.

Objectives for estimating volumes of incoming feedstocks include:

- Ensuring a sufficient supply of high carbon materials on-site for the anticipated arrival of green/wet feedstocks
- Sizing and equipping the facility for peak volumes during spring and summer months
- Planning operating procedures and staffing requirements
Identify Compost Feedstocks

Potential Sources of Compostable Inputs

<table>
<thead>
<tr>
<th>Food Processing Residue</th>
<th>Bark</th>
<th>Livestock manure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Residues</td>
<td>Cardboard</td>
<td>Paper mill sludge</td>
</tr>
<tr>
<td>Forestry and other residuals</td>
<td>Crop residues</td>
<td>Peat moss</td>
</tr>
<tr>
<td>Biosolids (sewage sludge)</td>
<td>Fertilizer and urea</td>
<td>Sawdust and Shavings</td>
</tr>
<tr>
<td>Leaves, brush, yard trimmings</td>
<td>Seaweed</td>
<td>Fish processing residues</td>
</tr>
<tr>
<td>Source-separated MSW</td>
<td>Fruit/veg. Residues</td>
<td>Septic &amp; sewage wastes</td>
</tr>
<tr>
<td>MSW</td>
<td>Grass clippings</td>
<td>slaughterhouse wastes</td>
</tr>
<tr>
<td>Biodegradable packaging</td>
<td>Leaves</td>
<td>Spoiled hay</td>
</tr>
<tr>
<td>Animal Mortalities</td>
<td>Newspaper</td>
<td>Straw</td>
</tr>
<tr>
<td>Soiled Paper Products</td>
<td>Wood ash</td>
<td>Wood chips</td>
</tr>
</tbody>
</table>

Estimate the Total Potential Volume of Compostable Inputs and their processed value:

<table>
<thead>
<tr>
<th>How Many Tons Are Expected</th>
<th>Convert Raw Tons to Yards</th>
<th>Account for Shrinkage</th>
<th>Total Yards Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tons</td>
<td>X</td>
<td>3 Yards in</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Yard Out</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 Yards In</td>
<td></td>
</tr>
</tbody>
</table>

Volume Reduction During Processing Phases

<table>
<thead>
<tr>
<th>Material</th>
<th>Volume</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoming yard trimmings</td>
<td>100 Cubic Yards</td>
<td></td>
</tr>
<tr>
<td>Fresh mulch after grinding</td>
<td>34 Cubic Yards</td>
<td>66%</td>
</tr>
<tr>
<td>Finished compost</td>
<td>20-25 Cubic Yards</td>
<td>75-80% overall</td>
</tr>
</tbody>
</table>

Materials handling GOLDEN RULE:

Never move something twice if you can avoid it, and then move it as short a distance as possible. Each load should be dumped where it will be initially processed. Costs are incurred every time material is moved. Design the site and material handling as it moves through the stations of activity.
Composting Equipment

Most of the equipment and labor invested in a composting system involve moving, mixing, and manipulating the materials. Equipment necessary for a composting operation will depend upon both volume and type of incoming materials. As the volume of materials to be processed increases, so does the need for larger, more sophisticated, and more expensive equipment. Some types of materials, particularly brush and tree trimmings, need to pre-processed by grinders or shredders.

Four of the most common types of equipment used are:

- **Loaders** The most important piece of equipment for small operations because of their versatility
- **Grinders** Used to reduce size of large, woody materials
- **Turners** Windrow turners are used to more thoroughly mix composting materials than front-end loaders
- **Screeners** Over-sized items are removed from finished compost to produce a marketable product of uniform size

Other equipment may include de-baggers, mixers, and bagging equipment for finished compost.

**Bucket loaders**

Bucket or front-end loaders tend to be the workhorses of outdoor windrow composting facilities. They are used for moving the material through all the phases of operation, from moving incoming feedstocks, to pile formation, to mixing windrows, and then moving material through the final stages of curing and bagging or bulk distribution.

Depending upon the skill and experience of the operator, some loaders are effective in initial mixing of the materials and pile formation. However, one drawback to using loaders for turning windrows is that there is greater potential for creating poorly mixed areas within the pile. To achieve more thorough turning and mixing, windrow turners are employed.
Size Reduction

• Why

Size reduction equipment is needed in order to adequately set the particle size of incoming brushy materials. Optimizing space for composting and producing a standardized, marketable product make size reduction equipment necessary for most yard debris operations, unless only leaves and grass clippings are collected. Composting is enhanced when the particle size of materials is from one to two inches in diameter. Woody materials such as tree trimmings and brush must be broken down by a chipper or grinder before they can be added to a compost mix. By increasing their surface area, woody materials become more accessible to composting microbes.

• How

Many grinders on the market are most effective on dry woody materials and require extensive maintenance when handling green, wet materials. Wear on hammers and knives in grinding equipment is increased by the presence of wet feedstocks. When possible woody materials should be shred separately from grass and leaves.

• Types

• Shear Shredders

Shear shredders may be stationary or trailer-mounted. They reduce the size of material through the action of a cleated belt which forces material against stationary knives.

• Hammer Mills and Tub Grinders

Hammer mills use free-swinging metal hammers mounted on a spinning shaft to break apart material until it is small enough to drop through discharge openings. Hammer mills can be very large and are often stationary, although portable units are available with diesel or gasoline engines that range from 300-550 in horsepower.

A tub grinder requires one person to operate it and another to load materials into the machine. Regular maintenance is necessary. A new set of 96 hammers costs from $900-$1,400 and takes 2-3 hours to
install. Hammers need to be rotated after about 50 hours of operation and replaced after 140-240 hours of operation.

- Chippers, Other Grinders, Shredders

Other shredding, grinding and chipping mechanisms reduce particle sizes with various combinations of rotating and stationary cutters. Chippers slice particles with knives mounted on a cylinder or disc that rotates within a fixed housing.

Mixers and Turners

Mixing equipment is used to prepare materials for composting. Many small compost facilities use only front-end loaders to mix materials, although separate equipment such as pug mills and batch mixers use augers or rotating paddles to produce a good mix of materials.

Windrow turners are specially designed for turning and aerating compost windrows. Small, tractor-driven turners are side mounted on loaders to tractors which are driven in aisle ways beside the windrow. Large turners are self-propelled, straddle the windrow, and allow more intensive use of land. Windrow turners mix piles more thoroughly than front-end loaders, but are less flexible because they cannot be used to move materials from one area to another.

Screening Equipment

Screening is most often performed to remove unwanted particles after composting, but is sometimes used before composting to remove rocks, metal, glass and other unwanted objects that may damage grinders and affect the final compost quality. Glass, for example, is generally easier to remove from composting material before grinding takes place but has a strong negative impact on finished compost if tiny shards are present.

- Trommel Screens

Trommel screens are rotating, inclined drums with holes (screens) that allow material to pass through the screen as it rotates, while larger-sized (overs) pass through the cylinder and are discharged at the end.

- Shaker Screens

Shaker screens are often situated as decks that are stacked to separate materials into different size ranges. The decks vibrate and particles bounce along the screen length. “Blinding” (clogged screens) is reduced by cleaning balls that dislodge materials.
### Costs & Capacity of Composting Equipment

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Cost Range</th>
<th>Capacity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-end loader</td>
<td>$50,000-$100,000</td>
<td>500-750 cy/hr</td>
<td>Necessary for loading, moving</td>
</tr>
<tr>
<td>Tractor-driven turners</td>
<td>$10,000-$90,000</td>
<td>2,000-4,000 cy/hr</td>
<td>Also need a loader or tractor</td>
</tr>
<tr>
<td>Self-propelled turners</td>
<td>$40,000-$200,000</td>
<td>2,000 to 4,000 cy/hr</td>
<td>Large volume systems</td>
</tr>
<tr>
<td>Grinders</td>
<td>$20,000-$700,000</td>
<td>10-500 cy/hr</td>
<td>Hammers, rotating tub</td>
</tr>
<tr>
<td>Hammer mills</td>
<td>$17,000-$250,000</td>
<td>60-450 cy/hr</td>
<td>Use hammers to crush materials</td>
</tr>
<tr>
<td>Chippers, shredders</td>
<td>$5,000-$135,000</td>
<td>5-300 cy/hr</td>
<td>Use knives, blades to cut materials</td>
</tr>
<tr>
<td>Pug mills</td>
<td>$20,000-$50,000</td>
<td>20-2,000 cy/hr</td>
<td>Continuous mixing systems</td>
</tr>
<tr>
<td>Batch mixers</td>
<td>$10,000-$150,000</td>
<td>10-500 cy/hr</td>
<td>Adapted from agricultural uses</td>
</tr>
<tr>
<td>Screeners</td>
<td>$50,000-$180,000</td>
<td>10-200 cy/hr</td>
<td>Screen sizes vary</td>
</tr>
</tbody>
</table>

### Equipment Tips:

- Talk with other operators to find out what equipment they have used and what the service record has been
- Use equipment with a history of high-quality service
- Have equipment demonstrated on-site with your material. If possible, have it demonstrated during adverse weather conditions
- Lease or rent equipment such as grinders and screeners on an “as needed” basis, especially if used infrequently
- Have a reliable backup processing plan for equipment failure
- Purchase equipment with a proven track record
- Purchase equipment that flexibly suits the incoming material and site
- Air conditioning is necessary
- Follow manufacturer checklists for scheduled inspection and maintenance
- Keep spare parts on hand (flails, hammers, bolts)
Staff Training & Safety

Large-scale composting facilities commit a high percentage of resources toward the effective use of heavy equipment to move large quantities of material. The capital investment and operating conditions require that managers concern themselves with training employees in the proper use of equipment and in safety measures.

Hire Qualified Staff

Finding individuals who have composting experience is not as important as hiring mechanically-talented individuals who can be trained to troubleshoot problems in the composting operation. Even unskilled workers can perform jobs such as debagging and site maintenance. The importance of minimizing “down time” should be stressed. Choosing and training staff are a significant part of the work of a composting operator. Individuals who have had on-farm experience may be particularly useful. Staff will be required to operate and maintain equipment, monitor and sample compost piles, administration, gate management, and other tasks.

Principles of Composting

As part of their training, staff members should become familiar with the various aspects of the composting process, from incoming feedstocks to the characteristics of quality compost. Staff members should realize their effectiveness has a critical impact on the daily operations and the overall success or failure of the enterprise. Each staff member should have a basic understanding of the biology of composting and how to avoid problem areas in advance.

Seasonal Workforce

Depending upon the local climate and flow of materials, many composting facilities have seasonal high and low points. For some, the late spring, summer and early fall are when most yard trimmings are generated and processed. In geographical areas where winters are severe, composting activity practically ceases and the need for staff falls as well. Staff members are hired with this understanding.

Equipment Maintenance

The constant flow of materials into the facility means that there is constant pressure on facility equipment to be fully operational. Any breakdown in equipment not only hampers the management of the incoming flow, but serves to increase the workload for the future, in essence, increasing costs. The practice of preventive maintenance is imperative for smooth-running operations, but even diligence in maintaining equipment
is no guarantee that breakdowns will not occur. Obtaining an inventory of hard-to-obtain parts and locating a reliable mechanic will help to minimize lost time when equipment goes down.

**Employee Safety Equipment**

The following uses of employee safety equipment are recommended:

- Hearing protection should be worn at levels of 85 decibels or above. Ear muffs are more effective than ear plugs.
- Safety goggles should be worn to protect the eyes from dust or projectiles.
- Leather gloves should be worn to protect the hands.
- A dust respirator should be worn to protect against airborne dust. A disposable respirator that filter particles down to 1 micron in size is recommended.
- Tub grinder and screening areas may require hard hats and/or protective screens to shield workers from projectiles

Visitors to the site should be restricted from operating areas and should be given standard head and eye protection when they accompany staff into working areas.

**Equipment Hazards**

Employees should be trained with regard to equipment hazards and the potential conditions that cause accidents, including the following:

- Know the safe operation and design of equipment that has pinch points, wrap points, cutting points, and entanglement risks from free-wheeling parts.
- Monitor for pinhole leaks in hydraulic lines.
- Volume reduction equipment has a “hot” zone where projectiles may be thrown. The direction of the rotation and the distance objects travel should be observed. A safety zone of up to 250 feet from the size-reduction equipment is recommended for unauthorized personnel.

Basic common sense standards should apply with regard to safety.

**Continuous Training**

Training at composting facilities should be an ongoing process. Employees come and go and new developments in equipment and practice make for constantly changing conditions at the workplace.

The following safety and operational measures are recommended:
• Conduct regular safety meetings
• Instruct all employees on the safe operation and maintenance of all equipment
• Instruct all employees on proper safety procedures

Encourage staff members to share their experiences and concerns during employee meetings. Share records of tests conducted on-site to inform employees of how their efforts are contributing to the final products. Chart the volumes of material being processed to record the progress of the facility and share this information with staff.

Work on developing a team of employees who have high standards, goals, and incentives to do better. Operators and staff should be encouraged to increase their knowledge and skills by seeking further training that leads to advancement in responsibility and compensation.

Operating Rules

1. Protect your workers
2. Protect the environment
3. Protect yourself from lawsuits
4. Protect your equipment
5. Do your paperwork
6. Follow procedures consistently
Tyler’s Top Ten Business Principles

1. **Be a servant to your employees and managers.** Giving them every single possible resource to succeed will drastically increase both of your chances of success. Become wrapped up in their personal dreams and desires and help them in reaching them. By truly looking out for their best interests, you will be looking out for your best interests.

2. **Match accountability with authority in all management areas.** Highly qualified people will gladly be held accountable for their actions in all areas if they have the appropriate authority to make decisions and move forward with their own judgment. Late intervention from management takes away authority, but leaves accountability, which makes them feel extremely uncomfortable. It is unfair. Authority levels that are breached offer no reward to the manager held accountable and created questions of who is to blame in case of failure.

3. **Keep the rules of the game the same for at least short periods of time.** For quarterly, bi-yearly, or yearly increments, the rules of the game for management must stay somewhat consistent in order to establish management parameters. Constantly changing the rules and parameters creates a moving target syndrome that ends up frustrating everyone from staff to owners. The only thing worse than trying to hit a moving target is shooting at a target that has not yet been set. If the target moves due to insecurities in upper management, the insecurities must be addressed before new targets are set or the problem will be a chronic, repeating nightmare. If upper management does not realize that the moving target exists due to their own insecurities, then someone must boldly tell them.

4. **Trust your managers.** A true manager is one who lives and breathes his or her work 24 hours a day, but is only on the clock for 8 or 10. The instincts that drive managers of this type are truly worth their weight in gold. If these instincts are trusted, rewards will be great. The only reason the instincts should ever be questioned is if the person asking the questions has a complimentary role or better instincts. This is almost impossible unless the questioner lives and breathes the topic more than the manager.

5. **Treat managers as a stable of racehorses.** Feed them the best of opportunities and celebrate their victories with them. Let them write their own ticket in life and stay with your company out of passion for their work.

6. **When you are wrong, openly admit it and take full responsibility** for all implications and errors that exist all the way down the line. Failure to admit errors does nothing but sap personal ego and create suspicion in the eyes of others.

7. **If you are so busy that you cannot remember your promises,** to your employees (who are your customers), then make a promise to yourself to either get better at remembering these promises or write them down. Nothing is more frustrating or less productive than getting into a “you said—he said” argument.

8. **Never skimp on pay.** If managers bring a unique economic opportunity to you, pay them honestly for it. The moment you try to skimp on pay in an effort to be a good negotiator, you lose their trust, confidence, and future employment, as well as their future earning potential for their business. An established pattern of paying the managers less than what they are proven to be worth will only lead to creating competition for yourself someday.

9. **Never, ever cut spending on worthwhile projects or activities in a booming marketplace.** The last thing a booming marketplace needs is a conservatism in spending. Every $100 cut will result in a potential loss of $1,000 profit within 5 years. If you do not have the money to spend on these activities, borrow it. If your bank does not allow you to borrow it, seek financing through other alternatives. If there is not one person to spearhead the search for funding, appoint it as an additional job responsibility to someone already on the payroll and reward them when they hit paydirt.

10. **Get to know your people.** Knowing what your people do for hobbies and fun is one thing, understanding and appreciating why they do it is a completely different thing. It is the understanding and appreciation of them that will enable you to communicate with them on the deepest level on any topic, including work. The return will be a desire for them to learn and understand similar traits about you. When you finally let down your guard and open up to them, all of the stress and anxiety from preconceived or imagined hidden agendas will disappear, paving the way for progress as a team.
# Operations Checklist

<table>
<thead>
<tr>
<th>Time period</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daily</strong></td>
<td>Check material at the gate. Monitor quality, record volumes/weight. (Trash or debris is removed by person who brought it)</td>
</tr>
<tr>
<td></td>
<td>Process (grind or chip) incoming materials.</td>
</tr>
<tr>
<td></td>
<td>Incorporate grass within 24 hours of when it is dropped off</td>
</tr>
<tr>
<td></td>
<td>Check for odors and take action when necessary</td>
</tr>
<tr>
<td></td>
<td>Check site for trash and debris, remove.</td>
</tr>
<tr>
<td></td>
<td>Check equipment, lubricate according to maintenance schedule.</td>
</tr>
<tr>
<td></td>
<td>Maintain pad to provide drainage and access. Keep clear aisles</td>
</tr>
<tr>
<td></td>
<td>Check and treat compost piles if necessary.</td>
</tr>
<tr>
<td><strong>Weekly</strong></td>
<td>Monitor and record windrow temperature, moisture and other conditions.</td>
</tr>
<tr>
<td></td>
<td>Treat windrows based on monitoring (turn, water, add material)</td>
</tr>
<tr>
<td></td>
<td>Combine windrows as volume shrinks</td>
</tr>
<tr>
<td></td>
<td>General clean-up of site</td>
</tr>
<tr>
<td></td>
<td>Staff meeting</td>
</tr>
<tr>
<td></td>
<td>Equipment maintenance</td>
</tr>
<tr>
<td><strong>Seasonal Tasks</strong></td>
<td>Grind accumulated brush and wood waste</td>
</tr>
<tr>
<td></td>
<td>Distribute finished product</td>
</tr>
<tr>
<td></td>
<td>Conduct major equipment maintenance</td>
</tr>
<tr>
<td></td>
<td>Planning and marketing</td>
</tr>
<tr>
<td></td>
<td>Pad resurfacing as needed</td>
</tr>
</tbody>
</table>
Introduction

Formulating a business plan is important for several reasons. First and foremost, a business plan serves as a blueprint for your operation, a document that becomes a roadmap to help you get where you want to go. In short, a well-written business plan is The Masterplan you draft for yourself. But the business plan is also a tool for showing and convincing others. Typically, bankers, venture capitalists and investors want to see how the details fit into the overall plan. Your business plan becomes a valuable sales tool, your best “brochure” for influencing the decisions of others. It also can be an excellent recruiting tool, used to capture the imagination of those with whom you want to work—your future associates.

The Business Plan serves as a constant reminder of What we’re doing and why we’re doing it. But it doesn’t have to be etched in concrete. Most planners revise their goals periodically. The Business Plan should be thought of as a flexible instrument, clarifying and perfecting your objectives.

In this section…

Whether a business is a start-up or is already up and going, poised on the verge of continued growth, a business plan is a necessary instrument for defining and carrying out The Masterplan. Good business plans start by seizing upon ideas and visualizing dreams coming true. That might mean some changes need to be made, personally as well as corporately. Asking questions is fundamental for each step along the way. A cohesive team must be built who will give their commitment to the cause. Composting and vermicomposting operations are built by ecopreneurs who are part of a relatively recent wave of interest in maintaining the quality of our environment. Making the time and taking the time to sit down and perform short and long-range planning are fundamental for success.

Contents

Introduction, Basic Concepts
Change
Asking Questions
Team Building
Becoming an Ecopreneur
Masterplan
Introduction: Basic Concepts

A. IDEAS, DREAMS

“The future belongs to those who believe in the beauty of their dreams.”
Eleanor Roosevelt

“Dream as far as you can see and when you get there, you can see farther.”
Zig Ziglar

“The problem is not typically limited money like most people think… but limited vision.”
John Wimber

“Think so big that you can’t do it alone, so big you can’t do it this year…this decade or even in your lifetime. Have a dream worth dreaming. A challenge so big that even ‘credit’ isn’t necessary.”
Bobb Biehl

“I have been trying all my life, first to see for myself, and then to get other people to see with me. To succeed in business it is necessary to make the other man see things as you see them. SEEING in this broader sense was the objective. In the broadest possible sense I am a visualizer.”
John W. Patterson

B. CRUSADE

“Crusaders commit to something bigger than their business.”
A.L. Williams

C. ACTION

“Don’t wait for your ship to come in; swim out to it.”
Anonymous

“Start by following trails; then become a trailblazer.”
Peter Bogdanov
CHANGE

Change typically represents both possible opportunity and potential loss.

The Fear of Change

“Taking a new step, uttering a new word, is what people fear most.”
Dostoyevski

The Necessity of Change

“Plan change into your plans. You’ll have to anyway.”
John Wimber

“One key to all planning is the word evolution. You start in a direction and your plans keep evolving.”
Gary Weaver

A Sound Set of Beliefs Will Guide Through Change

“It is IBM’s credo that any organization, in order to survive and to achieve success, must have a sound set of beliefs on which it bases all its policies and actions. But more important than having a set of beliefs is faithful adherence to those beliefs. If any organization is to meet the challenges of a changing world, it must be prepared to change everything about itself except those beliefs as it moves through its present to its future. Let me reiterate. The basic philosophy, the very spirit of and drive of an organization, has far more to do with its relative achievements than do technical or economic resources, organizational structure, innovation and timing.”
T.J. Watson, Jr., former IBM Chairman of the Board

Questions:
1. What are the things which never change?
2. Should I allow this change?
3. Are we changing too much too fast?
4. What are the advantages of this change?
5. What negative aspects of this change need creative problem-solving?
6. Is this change temporary or permanent?
ASKING QUESTIONS

Asking questions is essential for gaining knowledge, understanding and wisdom.

   
   Sequence is important

2. Compared to what?
   
   Nothing is meaningful without a context. What is the context?

3. What’s missing?
   
   We’re trained to look at what we see. We must find what is missing.

4. What is the ideal?
   
   What if everyone involved in the situation acted ideally; how would they act?

Additional Questions:

5. Do we need an insider/outsider to give counsel in this situation?

6. How would I look at this situation if I were one of my critics?

7. What questions are still lingering in my mind?

8. How would various aspects of the situation rate on a scale of 1-100?

9. What if we had unlimited time, all the money we need, and all the people to help us?

10. Will it make a difference a week, a month, a year from now?
Mind Stretcher Questions

1. What is the one word, one sentence, one paragraph essence of our idea?

2. WHY are we doing what we are doing?

3. What are the five most fundamental assumptions?

4. What changes would we make if we had unlimited time? …3 years…3 days…3 hours…3 minutes…to accomplish the task?

5. Where will this idea be in 10/15/25/50/100/500 years from now?

6. What if we had unlimited staff? …1/2 staff? …one or two extra people? What would they do? Why?

7. What changes would we make if we had double our current budget? …unlimited budget? …1/2 budget?

8. How can we double the income and cut our costs in half?

9. Which part of the total idea warrants extra funding?

10. Which part could we drop and not really miss?

11. What is the ultimate “Blue Sky” potential of the idea?

12. What 5 things could keep us from realizing the full potential? How can we clear away the roadblocks?

13. What are our greatest strengths and how can we maximize them?

14. If we had to start over…what would we do differently?

15. What if this idea were 100 times as successful as we plan? (Note: Many words could be substituted for ideas, such as program, project, department, etc.)
Team Building

Trying to build your team without a clearly defined and unanimously agreed upon purpose is like trying to build a skyscraper on quicksand.

1. What is our dream? What is our Super Goal?

2. What is our masterplan?

3. What training do we need to maximize each person?

4. What communications system do we need to keep the team on track?

5. Do we have a team attitude? Discipline? Are our strengths complimentary? Do we have the top people available? Do we have a “coach” who makes the final decisions?
Becoming an Ecopreneur

I. **Question:** What one single factor determines every ecopreneur’s success?

   A. Technical working knowledge of environmental science
   
   B. Prior business experience
   
   C. Lots of money
   
   D. High Risk Tolerance
   
   E. None of the above

II. **Success (Failure) Rate in New Businesses**
   (Dept. of Commerce statistics)

   A. Every year over 1,000,000 people start a business in the U.S.
   
   B. By the end of the first year 40 percent of them will be out of business.
   
   C. Within five years, more than 80 percent (800,000) will have failed.
   
   D. More than 80% that survive the first five years fail in the second five.

III. **Questions to ask yourself about starting a business:**

   A. What if I fail outright in the first six months? How will I survive economically? Do I have enough cash reserves to hold me until I can start another business or find another job?

   B. If the business generates marginal profits but shows promise, can I afford to hang on until it takes off?

   C. How will I feel about myself if I fail? Will the failure of my business make me feel like a failure as a human being? What will my family think? What will my friends say?

   D. If I don’t succeed, will I have the nerve to try again?
IV. Techniques to Move Forward

A. Identify Reasonable Risks
B. Separate Your Sense of Self-Worth from Your Business Judgment
C. Accept Failure as a Teacher
D. Apprentice Yourself
E. Seek out Trade Associations
F. Join or Work for Nonprofit Groups
G. Attend Professional Conferences
H. Read Key Business and Environmental Magazines
I. Tap the Government
J. Tap Local Experts
K. Form Innovative Partnerships

Test the Idea, Assess the Competition

A. Are There Any Precedents?
B. Is There a Market for the Product or Service?
C. Whom Are You Competing Against?

Put It on Paper

A. Mission: What will the new business do, and why does the world need it?
B. Market: Who will buy your products or services from the company? (demographics)? How big is the market? How much will it grow?
C. Pricing: What will you charge for your products or services?
D. Competition: Who are your competitors and how successful are they? What are your competitors’ strengths and weaknesses? (e.g., pricing, sales, service, support)

E. Operations: What overhead (office space, equipment, employees, etc.) will you need to get started? How will your product be manufactured and distributed, or your services be sold?

F. Budget: How much will it cost to launch and operate your business? When will you break even? When will you get into the black? What is your projected annual growth rate?

G. Diversification: What spin-off products and services might you develop?

**Finding Capital for Startup and Growth**

A. Invest Brains, Not Bucks

B. Personal Savings vs. Outside Cash

C. Tapping Family and Friends for Cash
   1. Can they handle the risk?
   2. How would they react in the event of a disaster?
   3. Do the funds come with hidden strings attached?

D. Getting Credit from Customers, Clients, and Suppliers

E. Seek Grants from States, Foundations

F. Borrowing Money from the Bank
   1. Get a track record
   2. Provide hard numbers
   3. Develop a personal rapport with your banker
   4. Don’t must mail in a loan application—give a brief presentation

G. Turn Customers into Investors

H. Seek Venture Capital

I. Join Forces with a Larger Friend
1. There’s no way to protect an idea; your only insurance is to become indispensable.
2. Make sure the partner makes a strong contribution.
3. Consider what it will take to dissolve the partnership.

J. Keep Costs Down

1. Buy used, secondhand equipment.
2. Network to obtain products and services (barter, exchange)
3. Independent contractors vs. employees
4. Go easy on supplies—avoid temptation to buy in bulk

Marketing: Combining All Available Options

A. Press Releases: Advertising that “Money Can’t Buy”

1. Challenge the status quo or convention wisdom
2. Describe something outrageous or unusual
3. Present shocking finding from and informal study
4. Stage an event that dramatizes a point
5. Send your release to the right editor
6. The release itself should contain news, not self-serving hype about your product or service. Media will be turned off by thinly-veiled requests for free publicity.

B. Bylined Articles: A published article with a small biographical identification at the end.

C. Newsletters

D. Direct Mail

E. Trade Shows

F. Seminars and Workshops

G. Trade Associations

H. Brochures

I. Space Ads
The Ten Commandments of Ecopreneuring

A. Clarify Your Mission

1. What am I trying to achieve?
2. What distinctive competence do I bring to the endeavor?
3. How will I solve my customers’ needs?
4. How will I differentiate myself from my competitors?

B. Plan, Plan, Plan and Ask Questions

1. How many people, ideally, will buy my products or service?
2. What dollar results can I expect from my marketing efforts in three months? Six months? Twelve months?
3. Who are my competitors and what strengths and weaknesses do they possess?
4. Have I defined my market niche precisely?
5. Why will customers buy from me instead of from my competitors?
6. What new technologies will benefit my operation?
7. What legislation can benefit my business?
8. How will the overall economy affect my business?

Then, ask the tough questions:

9. What if my projected universe of customers turns out to be much smaller than I imagined?
10. What if my projected response to marketing efforts is 10 percent, 20 percent, or even 50 percent below expectations?
11. What if I miscalculated my competitors’ strengths or failed to account for new competitors who have entered the field?
12. What if traditional businesses with deep distribution and marketing channels begin offering my products and services—can I sustain my niche?
13. What if a competitor offers lower prices, higher quality, and greater customer satisfaction?
14. What if a new regulation prevents me from selling my products?
15. What will I do if a new technology makes my current process or product obsolete?
16. What if the economy takes a nosedive—will people consider my products or services too expensive or unnecessary?

C. Be Ultrarealistic

1. If you assume a project will take two weeks to complete, allow four
2. If you think you’ll sell 500 units a week, make sure the business can survive on 250.
3. If you believe it will take 3 months to secure financing, make sure you can go six months without it.
4. Plan for the best; and plan for the worst.

D. Think Total Customer Satisfaction

1. Make Life Easy for the Customer
   a. 800 number
   b. postage-paid envelopes
   c. money-back guarantees

2. Add Value Whenever Possible
   a. See yourself as a consultant to the customer, not just a supplier. A problem-solver.
   b. Serve your customers as a broker of free information.

3. Seek feedback from customers; suggestions for improvements

E. Think Total Quality

1. What defects can I eliminate?
2. What processes can I streamline?
3. What pleases or displeases our customers?
4. How can we encourage suppliers to “do it right the first time?”

F. Study the Competition

G. Develop Company Strengths

H. Emphasize Positive Cash Flow

I. Manage Your Growth
1. Are we still making quality products or offering the quality service on which we founded our business?
2. Do we still cultivate and serve customers totally?
3. Are we still selling solutions to problems rather than pushing goods and services?
4. Does everyone here understand the company’s mission?
5. Have we acquired layers of bureaucracy that thwart accountability?
6. Would I want to work here?

J. Recession-Proof Your Operation: “Think Globally, Act Locally”
MASTERPLAN

VISION,
DIRECTION,
ACTION
Progression of broad planning into fine-tuned marketing action steps

Vision
Direction
Action

1 Mission
2-5 Goals
10-20 Objectives
100's of Action Steps
1,000's of Daily Activities

SSS
Quality Markets
Infrastructure
Policy
MASTERPLAN
For
_____________________
(your business)

Mission Statement (14 words or less)

Examples:

“Our mission is to achieve overall industry leadership and dominant regional market share.”

“Our mission is to serve the recycling needs of our community and region.”

“Our mission is …

Purpose, Goals, Objectives

**Purpose**
Why do I exist? (Personal)
Why do we exist? (Corporate)
Mission Statement

**Goals:**
Written, time-date milestone in the future toward which you are working.

**Objectives:**
What areas will I concentrate my energy in order to reach my goals?
VISION 2000
Exploring Options in Seeking Industry Leadership

Mission Statement:

“Our mission is to achieve overall industry leadership and dominant regional market share.”

Goals:

1. Marketing:
2. Production:
3. Community Outreach:
4. Research & Development:
5. State Center & Model Organics Recovery Facility:

Objectives:

1. Marketing
   a. Assess the local and regional market
   b. Formulate a marketing plan
   c. ______________________
   d. ______________________
   e. ______________________

2. Production
   a. Identify local organic waste generators
   b. Assess current production practices
   c. ______________________
   d. ______________________
   e. ______________________
3. Community Outreach
   a. What links can be formed with various interest groups?
   b. __________________________
   c. __________________________
   d. __________________________
   e. __________________________

4. Research & Development
   a. How can increased R & D maximize sales?
   b. __________________________
   c. __________________________
   d. __________________________
   e. __________________________

5. State Center and Model Organics Recycling Facility
   a. Create an on-site Center for the Study & Use of Compost and Vermicompost
   b. Design a model organics recycling facility for tours, education, and promotion of _____ as a leader in the industry.
   c. __________________________
   d. __________________________
   e. __________________________
Glossary of Terms

Composting, Vermicomposting, Waste Management, Soil Ecology, Soil Fertility

Abiotic  Not biotic; not related to life or specific life conditions. Usually meaning physical or chemical factors, such as temperature, humidity, inorganic chemicals.

Absorption  The process by which a substance is taken into and included within another substance, e.g., intake of water by sol, or intake of gases, water, nutrients by plants.

Acidic  Having a pH value below 7.0 A preponderance of hydrogen over hydroxyl ions in a soil solution. Turns blue litmus paper red. Compare alkaline.

Actinomycetes  A group of microorganisms considered to be intermediate between bacteria and fungi, producing rod-shaped, filamentous, or branched-shaped mycelium. These organisms produce the fragrant, earthy smell of compost, similar to odors produced after a rain in a forested area and said to be especially noticeable after the soil is tilled.

Active Compost  Material that is undergoing or capable of undergoing rapid decomposition, is not sufficiently stabilized for use as a soil amendment, demands biological oxygen and nitrogen, is capable of generating heat, and is not horticulturally or agronomically beneficial in its present form. Synonymous with “green compost.”

Adsorption  The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles. The process by which one substance adheres to the surface of another substance, usually a solid.

Aerate  To expose to the action of air or to cause air to circulate through. In composting, aeration allows for oxygen-deficient air to be replaced by atmospheric air allowing aerobic microbes to flourish. Mixing or turning organic material allows oxygen to reach soil organisms.

Aerated static pile  A composting system using air blown (positive forced aeration) or drawn (negative forced aeration) through perforated pipes under a free-standing compost pile, thus requiring no turning of the pile.

Aerobacter  A specific genus of bacteria, most of which are strictly aerobic bacteria.

Aerobe  Any organism requiring atmospheric concentrations of molecular oxygen as the final acceptor in metabolism.

Aerobic  An adjective used to describe a process or microorganism requiring the presence of oxygen. Aerobic microorganisms consume oxygen, release energy (heat) and produce carbon dioxide and water (called aerobic respiration). For successful
composting and vermicomposting, sufficient oxygen is needed to keep the system aerobic. This ensures that the composting proceeds rapidly and with minimal odor. Compare *anaerobic*.

**Aerobic Decomposition** The oxidation of organic matter into carbon dioxide and water by microorganisms in the presence of air.

**Aestivation** A period of inactivity, or dormancy, induced by unfavorable conditions. During aestivation, the earthworm curls up into a knot and becomes quite pink.

**Aggregate** A group of soil particles cohering so as to behave mechanically as a unit. [See soil aggregation]

**Agitated bed** An in-vessel composting method in which the materials are contained in a bin or reactor and are periodically agitated by a turning machine (such as a top-entering device that is supported on a bridge across the bed which travels the width of the bed) or by augers. Usually some means of forced aeration is also provided.

**Agricultural residues** Organic material produced as by-products from the raising or growing of plants and animals on farms and ranches, including manures, bedding, plant stalks, culls, hulls, leaves and vegetative matter.

**Air classifier** A mechanical device using air currents and air flotation to separate particles in compost according to size, density and aerodynamic drag, producing a heavy fraction, light fraction and ultralight fraction. Inert substances such as plastic and sometimes glass may be separated out from the combined material to produce a cleaner, more marketable product (also called “air knife”).

**Algae** One-celled plants chiefly associated with a water habitat.

**Alkaline** Having a pH value above 7.0. Turns red litmus paper blue. Compare *acidic*.

**Alternate Daily Cover (ADC)** Material other than soil that will function in a landfill as a barrier to the emergence or attraction of vectors, progress of fires within the landfill, escape of odor, and excess liquid infiltration.

**Ambient air temperature** The temperature of the air in the vicinity of the compost pile.

**Amendment (soil)** 1. Any material, such as compost, lime, gypsum, peat moss, sawdust, or other additives that is worked into soil to enhance its characteristics. 2. An ingredient in a mix of composting raw materials included to improve the overall characteristics of the mix or to provide attributes required by customers for certain compost products. Amendments often add carbon, dryness, or porosity to the mix.

**Amoeba** A primitive form of microscopic animal life.
**Ammonia** A gaseous compound formed of nitrogen and hydrogen (chemical formula NH₃), having a pungent odor, and commonly formed from organic nitrogen compounds during composting and released under alkaline conditions (pH>8). High ammonia concentrations (greater than 0.5 mg/g) are toxic to earthworms.

**Ammonium** An ion comprised of nitrogen and hydrogen (chemical formula NH₄⁺). It is readily converted to and from ammonia depending on conditions in the compost pile.

**Anabolism** The process in a plant or animal by which food is changed into living tissue; constructive metabolism; opposed to *catabolism*.

**Anaerobe** Any organism requiring reduced oxygen concentrations, or elevated carbon dioxide concentrations in order to be able to perform metabolic processes. Strict anaerobes typically are killed by even the slightest oxygen concentrations, while facultative anaerobes can function in both aerobic and anaerobic conditions, but use very different metabolic pathways depending on oxygen concentration.

**Anaerobic** An adjective used to describe a process or microorganism that functions in the absence of oxygen. Anaerobic microorganisms do not require air or free oxygen to live. Anaerobic composting proceeds slowly and is odorous.

**Anaerobic decomposition** A type of decomposition that does not use oxygen. Anaerobic decomposition creates odor problems; aerobic decomposition does not. Byproducts of anaerobic decomposition are alcohols and other organic compounds, and most significantly odorous compounds such as amines (fishy smell), sulfides (rotten eggs), and volatile fatty acids (flatulent odor).

**Anecic** A category of earthworm species that form permanent or semi-permanent burrows in the soil down into the mineral horizon. Earthworms of this category emerge to the surface where they feed on dead leaves and other decomposing organic matter. *Lumbricus terrestris* is a major representative of this group. [See also *endogeic* and *epigeic*]

**Anion** An atom or molecule with a negative charge of electricity, e.g., nitrate, NO₃⁻.

**Annelid** Any segmented worm of the phylum Annelida, which includes earthworms and leeches. An organism that has a segmented body, giving it a ringed appearance. The segments are arranged one beside each other symmetrically along the length of the earthworm to form the body.

**Annual Pollutant Loading Rate** The maximum amount of a pollutant that can be applied to a unit area of land during a 365-day period.

**Anterior** Situated before or at the front of (opposed to *posterior*). The prostomium and mouth of an earthworm are located at the anterior region of its body.
Artificial Soil  Growth medium for plants obtained by mixing soil or inert soil substitutes with stabilized organic matter.

Ascaris  A parasitic worm found in contaminated water and lives in the intestines of humans and animals. Ascaris ova are significantly reduced within an hour at 55°C.

Ash  The material left after incinerating organic materials at 550°C consisting of minerals and inorganic matter in compost.

Aspergillus fumigatus  A species of fungus, one of over 900 Aspergillus species, and common in nearly all countries of the world. Aspergillus fumigatus is found in dust in homes, in schools, in libraries, in stores, in hospitals, and in anyplace dust resides, in most bedrooms and bedding, in bathrooms, and in basements. Aspergillus spp. are found outside the home in yards, in parks and playgrounds, in orchards and anyplace that dust is found. Humans can become allergic to Aspergillus spp. Its spores can cause bronchial disease and allergic reactions in some individuals. It can cause complications for people with certain existing health conditions. Some patients in hospitals are particularly susceptible to infection caused by exposure to it. Aspergillus fumigatus appears in compost feedstock that is below the dust threshold level of 35% moisture content, and in composting piles if biomass moisture content is allowed to drop below about 40%. The most likely location for A. fumigatus is storage of dry leaves, and near the compost screening operation if product moisture content is allowed to be below about 40%.

Autotroph  Any organism capable of self-nourishment by using inorganic materials as a source of nutrients and using photosynthesis or chemosynthesis as a source of energy, as most plants and certain bacteria and protists. Compare heterotroph.

Available  In general, a form capable of being assimilated by a growing plant. Available nitrogen is defined as the nitrogen that is water-soluble plus what can be made soluble or converted into free ammonia. Available phosphoric acid is that portion which is water-soluble plus the part which is soluble in ammonium citrate. Available potash is defined as that portion soluble in water or in a solution of ammonium oxalate.

Available Nutrients (in soil)  The part of the supply of a plant nutrient in the soil that can be taken up by plants at rates and in amounts significant to plant growth.

Available Water (in soil)  The part of the water in the soil that can be taken up by plants at rates significant to their growth; usable water; obtainable water.

Bacillus  A specific genus of bacteria, typically Gram-positive, rod-shaped, aerobic, spore-forming bacteria, often occurring in chainlike formations. Use generically, any rod-shaped, chain-forming bacterium.

Back-haul  A transportation option whereby the shipper takes advantage of lower transport costs by using vehicles that are returning to an origin of distribution to carry materials to the markets within the vehicle’s origin area or destination.
**BACT**  Best Available Control Technology

**Bacteria**  Microscopic organisms, usually unicellular or in clustered colonies. Bacteria are usually spherical, rod-shaped or spiral, but may appear as sheets, chains, or branched filaments. Their movement is passive, dependent upon rainfall, root growth, or ingestion by various soil fauna to move about. Flagellants have directed motility in water film. Bacteria exist either as free-living organisms or as parasites, with a broad range of biochemical, often pathogenic properties. Various species of bacteria are involved in infectious diseases, nitrogen fixation, fermentation, or putrefaction. They break down nutrients into forms plants can use.

**Batch**  1. Process of composting that is not continuous-flow. No organic materials are added to a batch once the feedstocks have been prepared and combined to begin composting. Bin composting and windrow composting may be batch systems. 2. An in-vessel vermicomposting system using portable bins, trays or containers, often stacked upon one another to maximize use of vertical space. (Vermicomposting performed in outdoor windrows or in continuous flow reactors are not batch systems.) Unlike thermophilic batch systems, batch systems in vermicomposting may call for the addition of feedstocks until the bin or tray is harvested, either for earthworms, vermicompost, or both.

**Batch Mixer**  A type of mixer that blends materials together indistinct loads or batches. The materials are loaded, mixed, and then unloaded in sequence rather than moved through in a continuous flow. Batch mixers for composting are sometimes modified livestock feed mixers using paddles or augers as the mixing mechanisms.

**Bedding**  1. Moisture-retaining, stabilized organic materials such as shredded newspaper, shredded cardboard, compost, coir, aged manure, or peat moss that serve as a dwelling environment for earthworms. 2. Dry absorbent materials used to provide a dry lying surface for livestock. Bedding materials such as sawdust and straw absorb moisture from livestock wastes the soil and the environment.

**Bed-run**  Vermiculture term for earthworms of all sizes, found mixed together in a worm bed. Earthworms may be sold as “bed-run,” or as mature “breeders.”

**Beneficial organisms**  Non-pathogenic life; often improving the growth of a desired organism in a more-or-less mutualistic association where both organisms benefit from the presence of the other.

**Berm**  Earthen mound with or without vegetation, to attenuate or buffer noise, as well as provide visual screen.

**Bin**  1. Compost bin: A container in which composting materials are placed rather than in freestanding piles (heaps). Bins are considered a form of in-vessel composting and may be constructed with or without forced aeration. 2. Worm bin: A container for
earthworms, bedding and feedstocks allowing protection from many predators and may
protect earthworms from harsh or unfavorable weather.

**Bioaerosols** Microorganisms that may have the potential to cause adverse health effects. Bioaerosols of concern during composting consist of microorganisms (actinomycetes, bacteria, and fungi), arthropods, protozoa, and organic constituents of microbial and plant origin. In January, 1993 a group of international experts on bioaerosols, risk assessment and composting published an executive summary stating that “Composting facilities do not pose any unique endangerment to the health and welfare of the general public.” While some immunocompromised individuals are at increased risk to responses from bioaerosols, “the general population is not at risk to systemic (i.e., whole body, generalized, as in circulatory, lymph etc.) or tissue infections from compost-associated bioaerosol emissions.” [Composting Council Fact Sheet, 1993]

**Bioassay** A laboratory test using a living test organism.

**Biochemical Oxygen Demand (BOD)** The amount of oxygen used in the biochemical oxidation of organic matter in a specified time (usually five days), at a specified time, at a specified temperature (usually 68°F), and under specified conditions. A standard test used in assessing the biodegradable organic matter in municipal wastewater. An indication of compost stability and a tool for studying the compost process.

**Biodegradable** The potential of an organic substance to be broken down into simpler compounds or molecules such as water, carbon dioxide, methane, and inorganic compounds, predominantly by the enzymatic action of microorganisms.

**Biofilter** A system for filtering air or water that is typically comprised of a packed bed with microorganisms attached to a suitable medium such as shredded tree bark or stable compost. One of the technologies applied for bioremediation, a process by which unwanted substances are broken down and removed from air, soil, water and raw materials for industrial processing. Biofiltration is the process by which organic gases are cleaned by passing air through compost or soil containing microorganisms capable of degrading the gases.

**Biogas** A mixture of methane and carbon dioxide produced during the anaerobic decomposition of organic matter by microbes. Biogas may be burned as a fuel. Methane gas generated at landfill sites can be collected and used for heating or power generation purposes. A saturated gas consisting of approximately 55 to 70% methane, 25 to 35% carbon dioxide, and trace amounts of nitrogen and hydrogen sulfide.

**Biological waste** Blood and blood products, excretions, exudates, secretions, suctionings and other body fluids that cannot be directly discarded into a municipal sewer system, and waste materials saturated with blood or body fluids, but does not include diapers soiled with urine or feces.

**Biomass** 1. The amount of living matter in a given habitat, expressed either as the weight or volume of organisms per unit area. (Earthworm biomass in vermicomposting might be expressed as X pounds earthworms per cubic foot of organic material (volume),
X pounds earthworms per square foot of material (area), or the percentage of earthworm weight to total weight of organic matter.  2. Organic matter that can be converted to fuel, such as chopped green waste, regarded as a potential energy source.  3. Any organic matter that is available on a renewable or recurring basis (excluding old-growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, wood and wood wastes and residues, aquatic plants, grasses, residues, fibers, and animal wastes, municipal wastes, and other waste materials.

**Biosolids** 1. Solids derived from primary, secondary or advanced treatment of domestic wastewater which have been treated through one or more controlled processes that significantly reduce pathogens and reduce volatile solids or chemically stabilize solids to the extent that they do not attract vectors. Formerly used for and synonymous with sludge, biosolids are the solid residue component of the wastewater purification process, a product of screening, sedimentation, filtering, pressing, bacterial digestion, chemical precipitation and oxidation. Primary biosolids are produced by sedimentation process and secondary biosolids are the product of microbial digestion. Generic components within biosolids include water, microorganisms, humic substances, undecomposed organic matter, and miscellaneous inorganic salts and minerals. 2. The product of microbially digested sewage sludge. See also sludge.

**Biota** The animals, plants, fungi, etc. of a region. [Greek, biote, life]

**Blinding** Blinding refers to the condition when the screen openings become blocked with material. Most screens include some provision to reduce blinding, like brushes on a trommel, vibration, or bouncing balls on a shaker deck.

**Bone meal** Raw bone meal is cooked bones ground to a meal without any of the gelatin or glue removed. Steamed bone meal has been steamed under pressure to dissolve out part of the gelatin.

**Breeders** Designation for earthworms that are sexually mature.

**Bucket loader** A vehicle that employs a hydraulically operated bucket to lift materials. Includes farm tractors with bucket attachments, skid loaders and large front-end loaders.

**Buck Wall** A short, strong wall often made of concrete or treated wood. It is used primarily as a support to push against when scooping and lifting loose or flowing materials (such as manure).

**Buffer zone** Area between the composting operation and homes or other sensitive land uses.

**Bulk** In nonpackaged form.

**Bulk density** Weight of mass per unit of volume of a material. Bulk density is expressed in pounds per cubic foot or grams per cubic centimeter. For example, the weight of a pile of wood chips divided by the volume of the pile is the bulk density.
**Bulking agent**  A material added to a compost feedstock mixture to improve porosity and structure and reduce bulk density. Bulking material may be carbonaceous such as coarse sawdust or shredded yard trimmings to add carbon to the composting recipe, especially when the initial material is wet, compacted and high in nitrogen, such as food waste. Additionally, some bulking agents (wood chips, chipped rubber tires) may not contribute available carbon, but do provide a stable, porous structure to the pile to maintain airflow by reducing settling and compaction. Bulking agents are usually rigid and dry and often have large particles (for example, straw). The terms “bulking agent” and “amendment” are often used interchangeably.

**Burrow**  A hole or tunnel in the soil mineral horizon made by anecic and endogeic earthworms, creating more pore space and channels for plant roots.

**Butyric Acid**  A volatile organic acid produced through the incomplete anaerobic oxidation of organic matter, typically identified as sour milk smell.

**Byproducts of composting**  Gaseous byproducts include water vapor (H₂O), carbon dioxide (CO₂), and heat, and can include methane (CH₄), hydrogen (H₂), hydrogen sulfide (H₂S), nitrogen (N₂), oxygen (O₂), and other volatile compounds; liquid byproducts can include condensate and leachate.

C  Chemical symbol for carbon.

**Calcareous**  Something that is made of or contains calcium carbonate; in soil, can occur as chalk or limestone.

**Calciferous gland**  Earthworm gland that opens into the esophagus and may regulate calcium levels in earthworm blood by excreting excess calcium.

**Calcium**  A silver-white element, found in limestone, chalk, etc., and occurring also in animals in bone, shell, etc.

**Calcium carbonate**  A white powder occurring in nature as calcite, chalk, etc. In agriculture this product is known as “Ag Lime” and is used to neutralize acidity of soils. May be used safely to reduce excess acidity in worm bins.

**Carbon**  A nonmetallic element found combined with other elements in all organic matter.

**Carbohydrate**  A group of organic compounds composed of carbon, hydrogen, and oxygen that are classified as sugars, starches, and cellulose. Usually the hydrogen and oxygen occur in the proportion of 2 to 1, respectively, such as in glucose (C₆H₁₂O₆).
Carbon Cycle  The cycle in nature by which the carbon molecule is transformed. Carbon dioxide in the atmosphere is utilized by plants that are, in turn, consumed by other organisms that produce carbon dioxide, water and energy.

Carbon dioxide  A colorless, odorless, incombustible gas comprised of carbon and oxygen (chemical formula CO$_2$). Carbon dioxide is present in the atmosphere, is formed during respiration, and is produced by the oxidation of organic carbon compounds during composting.

Carbon to Nitrogen Ratio (C:N ratio)  The numerical ratio of carbon present in organic matter to that of the sum of organic plus inorganic nitrogen. The C:N ratio determines the composting potential of a material which, if nutrients are in balance, provides microbes their necessary food source.

Casting  Material excreted through the anus of an earthworm. Earthworm egesta which contain available nutrients and large microbial populations that are rich in biologically active microbial metabolites and are particularly active in plant metabolism. Earthworm feces; the voided earth and other waste materials that are deposited on the surface of the ground. Not all species form their casts above ground.

Catabolism  The energy-releasing process in a plant or animal by which living tissue is changed into waste products of simpler chemical composition; destructive metabolism; opposed to anabolism.

Cation  An atom or molecule which has a positive charge of electricity, e.g., ammonium, NH$_4^+$.

Cation Exchange Capacity (CEC)  A measure of the nutrient holding power of a soil or soil amendment, such as compost. Indicates a soil’s ability to attract and retain plant nutrients that exist as charged molecules or ions. Soils typically have a negative (anion) charge while fertilizer nutrients typically have a positive (cation) charge. A high cation exchange capacity attracts and retains fertilizer nutrients for slow release.

Cellulose  A carbohydrate (C$_6$H$_{10}$O$_5$) that is a long chain of tightly-bound sugar molecules comprising the chief constituent of the cell walls of plants and of wood, cotton, hemp, paper, etc.

Celsius  After Anders Celsius, who devised a temperature scale in which 0º represents the ice point and 100º the steam point. Composting regulations commonly refer to temperature in degrees Celsius, but temperature can be measured on either the Celsius or Fahrenheit scales. The correlation between Celsius and Fahrenheit degrees is: (Degrees Celsius x 1.8) + 32 = Degrees Fahrenheit
**Clamshell Bucket**  Vessel used with a hoisting device to transport solid materials. Equipped with two jaws that clamp together when the vessel is lifted by specially attached cables.

**Clay**  A minute soil particle less than 0.002 millimeters in diameter.

**Clitellate adult**  Any earthworm with a developed clitellum and genital markings.  (See also *postclitellate adult*)

**Clitellum (pl. clitella)**  The swollen, glandular portion of earthworm epidermis associated with cocoon production appearing about one-third down the body from the anterior portion.  A swelling in the skin near the head that secretes material to form cocoons. The clitellum forms a band that can be flared, non-flared, saddle shaped, or annular. The clitellum is generally found between segments 26-33.

**Co-collection**  Collecting trash at the same time as source-separated recyclables at curbside using the same vehicles and crews.

**Co-compost**  A questionable term, usually applied to compost derived from sewage sludge and yard trimmings and/or mixed organic material from either source-separated organic waste or mixed municipal solid waste.  In reality, every composting operation can produce “cocompost” because more than one single feedstock item is composted.

**Cocoon**  Earthworm ova (fertilized eggs) are contained in cocoons that are formed on the clitellum.  After copulation, earthworms separate and each earthworm clitellum produces a secretion that hardens over the fertilized ova.  Earthworms move backwards, slipping the “tube” containing the ova over their heads.  Each end of the tube closes to form a lemon-shaped cocoon that changes in color from whitish (when formed) to yellow, greenish, and then brownish.

**Coelom**  The cavity between the body wall and the food (alimentary) canal.

**Coelomic fluid**  Milky white liquid (sometimes yellow) in earthworms containing many different kinds of particles in suspension.  Earthworms may eject this fluid through their dorsal pores at times of stress.  The coelomic fluid of *Eisenia fetida* smells of garlic, (fetid) hence the name of this species.

**Cogeneration fuel**  Compostable materials utilized to generate electricity, steam or other forms of energy.

**Coir**  The waste fiber from the coconut having a high water-holding capacity and used successfully as bedding for earthworms.

**Collection franchise**  A franchise, certificate, contract or license issued by a city or county authorized a person to provide collection service.
**Commercial fertilizer**  Plant food that has been manufactured from petroleum.

**Complete fertilizer**  A fertilizer containing all three of the primary fertilizer nutrients (nitrogen, phosphate, and potassium) in sufficient amounts to be of value as nutrients.

**Compost**  The product resulting from the controlled biological decomposition of organic wastes. Finished or mature compost has been sanitized (free of pathogens) and stabilized to a degree that is potentially beneficial to plant growth. Compost is largely decomposed organic material and is in the process of humification (curing). Compost has little resemblance in physical form to the original biodegradable material from which it was made. Compost is valued for its organic matter content and is typically used as a soil amendment to improve soils. Compost also has other uses of value. It is typically not used as a fertilizer unless amended.

**Compostable**  Organic material that can be biologically decomposed under aerobic conditions.

**Compost tea**  1. A liquid consisting of finished compost that has been steeped in water to concoct a “tea” that is applied to either the root zone of plants or sprayed directly upon plants as a foliar.  2. A water extract of compost that is “cold” brewed. The organisms extracted from the compost (bacteria, fungi, protozoa and nematodes) are given foods which result in an increase in number and activity of the beneficial species.

**Composters**  1. Those who practice composting; 2. Compost bins; 3. Of earthworms: A category akin to epigeic species that are heavily pigmented, dwell within organic matter, do not form permanent burrows and have higher reproductive rates and shorter lifespans than other categories of earthworms. *Eisenia fetida* is a major representative of this category. Compare earthworkers.

**Composting**  The managed process of controlled, biological decomposition of organic material into a humus-like substance called compost. The aerobic thermophilic and mesophilic degradation of organic matter to make compost.

**Composting facility**  A site or facility that utilizes organic solid waste or mixed solid waste to produce a useful product through a managed process of controlled biological decomposition. In some states (Oregon, for example), vermiculture, vermicomposting and agricultural composting operations are considered composting facilities.

**Conductivity, electrical**  A physical quantity that measures the readiness with which a medium transmits electricity. Commonly used for expressing the salinity of irrigation waters and soil extracts because it can be directly relation to salt concentration. It is expressed in decisiemens per meter (dS/m), or in millisiemens per centimeter (mS/cm) or millimhos per centimeter (mmhos/cm), at 25°C.

**Construction and Demolition waste (C&D waste)**  Materials resulting from the construction, remodeling, repair, or demolition of buildings, bridges, pavements, and
other structures, and may include debris from the clearing of land. Such waste typically consists of materials including concrete, bricks, bituminous concrete, asphalt paving, untreated or chemically treated wood, glass, masonry, roofing, siding, plaster; and soils, rock, stumps, boulders, brush and other similar material. This term does not include industrial solid waste and municipal solid waste generated in residential or commercial activities associated with construction and demolition activities.

**Consumers (primary, secondary, etc.)** An organism that obtains energy by eating other organisms or plants. Primary consumers (bacteria, fungi, etc.) feed on organic residues. Secondary consumers feed on primary or first level consumers.

**Contaminant** Unwanted material. Physical contaminants of compost can include sharps and metal fragments, glass, plastic and stones; chemical contaminants can include trace heavy metals and toxic organic compounds; biological contaminants can include pathogens. In excessive amounts a contaminant can become a pollutant.

**Continuous flow** A system of composting or vermicomposting in which material is continuously added to the process and the end product is continuously removed. Continuous flow systems in vermicomposting are achieved by raising the bed, adding feedstocks to the top of the system and harvesting castings from under a mesh floor.

**Controlled Composting** A process in which most important operating factors are controlled, such as initial nutrient balance, pile porosity, pile oxygen percentage, pile moisture percentage, pile temperature, and time. The process is controlled to achieve maximum efficiency, reduce process time, sanitize the organic mass, and minimize odors.

**Convection** Heat transfer by fluid motion between regions of unequal density that result from non-uniform heating. In windrow composting, cool air is drawn into the biologically active composting pile from the sides and exits the pile from the top as warm air.

**Crop** The thin-walled storage chamber in the earthworm alimentary canal situated in front of the gizzard. A widened portion of the digestive system that lacks the muscularity of the gizzard. It is located after the esophagus, but before the gizzard. An area where food is digested.

**Cryophilic** Decomposer organisms that thrive at ambient temperature.

**Cubic yard** A unit of measure equivalent to 27 cubic feet or 22 bushels. A box that is one yard wide, one yard long and one yard high has a volume of one cubic yard. A cubic yard is often loosely referred to as a “yard” (for example, a one-yard bucket on a front-end loader.

**Curbside Recovery** The collection of solid waste, recyclables, or other materials placed in front of the property (curbside) by the generator, who then returns the containers to their normal location after they have been emptied. Curbside collection is generally used
in the collection of residential solid wastes, source-separated recyclables, and organic materials or other materials. It is not normally used in commercial, institutional, or industrial solid waste collection.

**Curing** Final stage of composting in which decomposition of organic matter occurs under mesophilic conditions after most of the readily metabolized material has decomposed and stabilized so that turning or forced aeration is no longer necessary. Curing eliminates organic plant phytotoxins, provides additional biological stabilization, especially the decomposition of cellulose, hemicellulose and lignin, provides maturity, and begins a prolonged period of humification and mineralization, lasting nominally about four months or more.

**Damping-Off Disease** The wilting and early death of young seedlings caused by a variety of pathogens.

**Decomposers** The microorganisms and invertebrates that cause the normal degradation of natural organic material.

**Decomposition** The breakdown of organic matter by microbial action. The process of conversion of organic material from one form to another, generally with biomass production by the organism doing the decomposition, production of metabolic waste products and carbon dioxide.

**Degradability** Term describing the ease and extent that a substance is decomposed by the composting process. Materials which break down quickly and/or completely during the time frame of composting are highly degradable. Materials which resist biological decomposition are poorly or even non-degradable.

**Dendrobaena veneta** Large earthworm species with potential for use in vermicomposting that can also survive in soil but is not very prolific and does not grow very rapidly.

**Denitrification** The biological reduction of nitrogen to molecular nitrogen or oxides of nitrogen, resulting in the loss of nitrogen to the atmosphere.

**Density** The weight or mass of a substance per unit of volume. See also *bulk density*.

**Dewatered biosolids** (formerly called dewatered sewage sludge) Municipal wastewater treatment residuals with a total solids content of 12% by weight or greater that can be transported and handled as a semi-solid material.

**Digester** Tank used to contain biosolids during the anaerobic digestion process.

**Digestion** The process in sewage treatment by which organic matter in biosolids is decomposed by anaerobic bacteria with the release of a burnable mixture of gases. Applies also to anaerobic process involving other decomposable organic material.
**Disease suppression** The ability of compost and vermicompost to suppress certain plant diseases when applied to soils. The ability to inhibit, compete with, or consume disease-causing organisms preventing them from causing disease.

**Disperse** To move or scatter in various directions.

**Diversion** A term used to describe the act of inverting one or more designated materials from a solid waste stream. Diversion typically occurs at the point of generation but can also occur at waste transfer and processing facilities. The objective of diversion is to market materials for productive use and hence prevent these materials from being landfilled or otherwise permanently disposed. In recycling, it is the practice of recovering usable resources before they are landfilled.

**Diversion rate** The amount of material being diverted for recycling compared to the total amount that was previously disposed of.

**Dorsal pores** The small holes located in the intersegmental furrows down the middle of the earthworm’s back. These holes lead to the coelomic cavity. The term first dorsal pore 5/6 means that this is the first dorsal pore and it is located between segments 5 and 6.

**Drop-Off Program** A collection program in which householders take recyclable or compostable material to a community pick-up station or recycling center.

**Drum Composting System** Enclosed cylindrical vessel that slowly rotates for a set period of time to break up material and initiate the composting process.

**Dry matter** The portion of a substance that is not comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%).

**Dry weight basis** Calculated on the basis of having been dried at 105°C until reaching a constant mass, i.e., essentially 100 percent solids content.

**Earthworkers** A category of earthworms akin to anecic species that are medium to lightly pigmented, dwell within the soil horizon, form permanent burrows and have lower reproductive rates and longer lifespans than composter earthworms. *Lumbricus terrestris* is a major representative of this category. Compare composters.

**Earthworm** Earthworms are members of the class Oligochaeta, which also includes the Enchytraeids. Oligochaeta are related to the Polychaeta (bristle worms) and the Hirudinea (leeches). Polychaeta and Hirudinea are exclusively marine or freshwater invertebrates, whereas species of oligochaetes inhabit soil or fresh water. Some 20 families of earthworms are usually recognized. See also worm.

**Ecology** The branch of biology dealing with the relations and interactions between organisms and their environment.
**Ecosystem** A mutually dependent system consisting of plant, animal life and inorganic matter.

**Egg** The roundish female reproductive cell capable of developing into an organism when fertilized by a sperm cell. In earthworms, fertilized eggs are encased in a cocoon.

**Eisenia andrei** Earthworm species known also as “tiger worm” or “red tiger worm,” it is closely related to *Eisenia fetida* and does not differ from it in overall reproductive performances and requirements.

**Eisenia fetida** Earthworm species most commonly used in vermicomposting because it is ubiquitous, has a wide temperature tolerance, is tough and readily handled, usually becomes dominant in mixed cultures, and can live in organic wastes with a good range of moisture contents. Common names include: redworm, red wiggler, brandling, manure worm and tiger worm.

**Eisenia hortensis** see *Dendrobaena veneta*

**Electrical Conductivity** Measure of a solution’s ability to carry an electrical current; varies with the number and type of ions contained in the solution. Electrical conductivity is the basis for measuring soluble salt concentration. (See also *soluble salts*).

**Enchytraeids** Known as “potworms,” these small (10-20 mm long) white segmented worms are anatomically similar to earthworms except for the miniaturization of their features.

**Endogeic** A habitat classification term. These earthworms burrow continuously to form a network of channels – some vertical and some horizontal in the rhizosphere. The majority of the burrows are horizontal. [See also *anecic* and *epigeic*]

**Enterococcus** A disease producing bacterium. It is one type of streptococcus that lives in the intestinal tract of humans and animals. It can cause diarrhea, nausea, and fever. Enterococcus in the composting matrix is significantly reduced with a short time at 60°C.

**Entomologist** One who specializes in the study of insects.

**Environment** All external conditions that may act upon an organism or soil to influence its development, including sunlight, temperature, moisture and other organisms.

**Environmentally sound** Describes practices applied to the land that do not harm the soil, surface or groundwater, or air and are safe for plants and animals.

**Enzyme** Any of numerous complex proteins produced by living cells to catalyze specific biochemical reactions.
**Epidermis** Skin; the outer cellular layer of the body wall which secretes mucus.

**Epigeic** A category of earthworm species as described by M.B. Bouché that feeds on decomposing litter on the soil surface, is heavily pigmented, creates no burrows, is relatively short-lived and reproduces faster than anecic or endogeic species. They can form some shallow vertical burrows where they temporarily escape from drought, heat, and disturbances. Compare composters. [See also anecic and epigeic]

**Epilobic** See prostomium.

**Erosion** The wearing away of the land surface by detachment and transport of soil and rock materials through the action of moving water, wind or other geological agents.

**Eudrilus eugeniae** Commonly known as the African nightcrawler, it has high rates of reproduction and is capable of decomposing large quantities of organic wastes. Its main disadvantages are its poor temperature tolerance and poor handling capabilities so that it is easily damaged and can be difficult to harvest. It has a preference for higher temperatures, cannot tolerate extended period below 16º C and does not survive below 10ºC.

**Excavate** To remove by scooping or digging out.

**Exchange capacity** A measure of the nutrient holding power of a soil or soil amendment, such as compost. Indicates a soil’s ability to attract and retain plant nutrients that exist as charged molecules or ions. Cation exchange capacity concerns positively charged ions. Anion exchange capacity refers to negatively charge ions. Cation exchange is usually stressed because most soils have a negative charge and, therefore, attract the positively charged cations typically supplied by fertilizers. (See also nutrient-holding capacity)

**Exempt** Freed from an obligation or duty required of others.

**Exotic** Introduced through human activity to an area; from a foreign location.

**Extended pile** A pile form used in aerated static pile composting in which a large pile is constructed of individual cells, each with an aeration system. Cells are added daily and stacked against the previous cells, giving the overall pile a nearly rectangular cross section.

**Exudates** Simple sugars, proteins, carbohydrates, hormones released by plants into the environment, typically for the express purpose of encouraging the growth of bacteria and fungi which form a biological shield around the plant, preventing disease-causing organisms from detecting the root.
**Facultative anaerobe**  Organisms that can perform metabolism using either oxygen or inorganic molecules as the final electron acceptor in metabolism. These organisms generally switch from aerobic metabolism at low oxygen concentrations.

**Fallow**  Cropland left idle in order to restore productivity, mainly through accumulation of water, nutrients, or both.

**Fecal coliform**  Organisms that may indicate contamination by fecal pathogens. Fecal coliforms in the composting matrix are significantly reduced within approximately 30 minutes at 55°C (131°F).

**Fecal streptococcus**  A pathogen that thrives in anaerobic conditions. Fecal streptococcus in the composting matrix is significantly reduced within a short time by aeration and within about 30 minutes at 55°C.

**Feedstock**  Biologically decomposable organic material used in producing compost or vermicompost.

**Fermentation**  The enzymatically controlled anaerobic transformation of an organic compound that typically involves the production of carbon dioxide. While both aerobic and anaerobic processes can be included as fermentative process, this term usually refers to anaerobic fermentation where alcohol is produced, as in wine or beer fermentation, for example.

**Fermentor**  A vessel used for fermentation processes, such as making beer or wine. Broadly applied, any container in which metabolic processes are being performed.

**Fertigate**  A term to describe the simultaneous application of plant food (fertilize) and water (irrigate).

**Fertility**  The level of plant nutrients and organisms in the soil. A fertile soil has sufficient nutrients and soil organisms for good plant growth.

**Fertilizer**  Any natural or manufactured material, such as chemicals, manure, etc., put on or in the soil to improve the quality or quantity of plant growth.

**Fertilizer Grade**  An expression that indicates the weight percentage of plant nutrients in a fertilizer. Thus, a 10-20-10 grade contains 10% total nitrogen (N), 20% available phosphoric acid (P₂O₅), and 10% soluble potash (K₂O).

**Fertilizer Value**  An estimate of the value of commercial fertilizer elements (nitrogen, phosphorus, and potassium) that can be replaced by manure or other organic waste material. Usually expressed as dollars per ton of organic waste material or as manure or as quantity of nutrients per ton of manure or organic material.
**Ferrous metals**  Metals derived from iron. They can be removed from commingled materials using large magnets at separation facilities.

**Flow control**  A practice under which a municipality requires trash generated within its borders to go to certain disposal sites. Flow control provides a monopoly, in effect, allowing governments to make long-term investments in disposal sites ensured they will have the revenues to pay for the investment. *Regulatory* flow control has been successfully challenged as unconstitutional and is not considered a viable means of ensuring supply. Communities may still employ *economic* flow control, offering favorable tip fees to attract materials to a desired facility.

**Foliar**  Pertaining to leaves. Foliar sprays are liquids, such as compost tea, sprayed directly onto leaves of plants to provide nourishment and/or pest control.

**Food waste (pre, post-consumer)**  Residual food from residential, institutional or commercial facilities. Unused portions of animal, vegetable or fruit material resulting from food production. Post-consumer food waste may differ markedly from pre-consumer food waste in that the former may be cooked, contain table salt, cooking oils, fats, dairy products, bones, meat, utensils and other substances, including pathogens, that may be harmful to earthworms, slow down the vermicomposting process and may also affect handling procedures by humans.

**Foodweb**  In soils, the interactions between soil organisms (bacteria, fungi, protozoa, nematodes, microarthropods, etc.) that form a web of life, just like the web that biologists study above ground. The soil foodweb consists of a set of organism relationships, often based upon which organism will consume another, or which organisms cycle a particular nutrient within an ecological community.

**Forage**  Unharvested plant material that can be used as feed by domestic animals. Forage may be grazed or cut for hay.

**Forced aeration**  Use of blowers or other mechanical devices to move air through composting materials.

**Free Airspace (FAS)**  In composting, the voids between particles that are not occupied by water. At water saturation all voids, or pores, are occupied by water and none by air. As pores become smaller in size, they become capable of holding water more readily. (See also *porosity*).

**Front End Loader**  A wheel or crawler mounted machine with a hydraulically controlled bucket used for handling loose bulk materials.

**Fulvic acid**  A particular fraction of complex humus material composed of medium molecular weight long-chain organic compounds, typically 2000 to 6000 dalton length chains. Of the recalcitrant humic materials, these can be used by bacteria.
**Fungus, fungi** Single-celled or multinucleate organisms of the division Thallophyta, lacking a photosynthetic pigment (chlorophyll) that live by decomposing and absorbing the organic material in which they grow. Includes mushrooms, molds, mildews, rusts, smuts and yeasts. Individual cells have a nucleus surrounded by a membrane and may be linked together in long filaments called hyphae (web-like appearance) that often produce specialized fruiting bodies. Individual hyphae can grow together to form a visible body. Fungi break down the more recalcitrant, or difficult-to-decompose organic matter. Fungal waste products become soil organic matter and these materials are used by other organisms.

**Garbage** Refers specifically to food scraps but is also used to describe any unwanted or useless material. The term is generally understood to include trash, which may or may not contain compostable organic materials.

**Gate volume** The amount of waste, measured by volume, that enters a landfill.

**Genital markings** Glandular swellings, pits or grooves of the epidermis (skin). See *genital tumescences*.

**Genital tumescences** Areas of modified epidermis without distinct boundaries, through which follicles of genital setae open.

**Genus (genera)** A major subdivision of a biological family or subfamily in the classification of organisms, usually consisting of more than one species. Scientific nomenclature, written in italics, uses both genus (capitalized) and species (lower case) to identify organisms; thus *Eisenia fetida*, or *Homo sapiens*.

**Gizzard** In the alimentary canal of earthworms the chamber where food is ground into small particles with the aid of mineral particles taken in with food. The muscular portion of the digestive system where food is digested. It is located immediately after the crop, and just before the intestine.

**Green Feedstocks** Materials used to produce compost. Green feedstocks are low in 1) substances that pose a present or future hazard to human health or the environment and, 2) low in and unlikely to support human pathogens. Green feedstocks include but are not limited to: yard debris, animal manures, wood waste, vegetative food waste, produce waste, vegetative restaurant waste, vegetative food processor by-products and crop residue. (Oregon Dept. of Environmental Quality)

**Green waste** Grass clippings, leaves, twigs, weeds, brush, bushes, shrub and tree prunings, Christmas trees, garden trimmings and other vegetative matter from land clearing and landscaping activities; synonymous with Yard Trimmings and Yard Waste; does not include putrescible material. See also *yard trimmings*. (Compost Facility Operating Guide)
Grinding  Operation that reduces the particle size of materials. Grinding implies that particles are broken apart largely by smashing and crushing rather than tearing or slicing. See also shredding.

Groundwater  Water beneath the earth's surface that fills underground pockets (known as aquifers), supplying wells and springs.

Hammermill  A type of powered crusher or shredder using rotating or flailing hammers to break materials up into smaller pieces.

Hardpan  A hardened or cemented soil horizon or layer. The soil material may be sandy or clayey and may be cemented by iron oxide, silica, calcium carbonate, or other substances. In the composting process, hardpan forms at the bottom undisturbed layer of a turned biomass pile.

Harvest  1. Of earthworms, the process of manual or mechanical separation of earthworms from the organic material (bedding or feedstocks) in which they dwell; 2. Of vermicompost or castings, the process of separating earthworms and feedstocks from the finished material to prepare for use as a soil amendment.

Harvester  A mechanical device used to separate earthworms from their bedding and feedstock. A screened motor-driven trommel, cylindrical in shape, rotates at an angle, allowing organic matter to fall through the screened cylinder, as the larger material (“overs”) travel the complete distance of the cylinder. Earthworms and material too large to pass through the screened cylinder are separated at the lower end of the cylinder. See also trommel.

Hatchling  An earthworm newly hatched from a cocoon.

Hazardous compounds  Any organic or inorganic compound that may endanger life or health at a certain level, including poisons, heavy metals, pesticides, and so on. They are sometimes found in mixed municipal solid waste.

Hazardous waste  Waste material that exhibits a characteristic of hazardous waste (ignitability, corrosivity, reactivity, or toxicity) as defined in the 1976 federal law Resource Conservation and Recovery Act (RCRA).

Heavy metal  Metals of high atomic weight and density; trace elements whose concentrations are regulated because of the potential for toxicity to humans, animals, or plants, and includes arsenic (As), chromium (Cr), molybdenum (Mo), selenium (Se), copper (Cu), nickel (Ni), cadmium (Cd), lead (Pb), mercury (Hg), and zinc (Zn) if present in excessive amounts. Can be found in considerable concentrations in sewage sludge and several other waste materials. High concentrations in the soil can lead to toxic effects in plants and animals ingesting the plants and soil particles. Federal and many state regulations restrict the land application of materials that contain high concentrations of heavy metals.
Hemicellulose  A substance like cellulose but less complex that is extracted from wood or corn fiber by dilute alkalis and consists of sugars and sugar acids.

Herbicides  Agents used to inhibit plant growth or kill specific plant types.

Herbivorous  Feeding on plants.  Manure from herbivorous animals is an acceptable feedstock for composting and vermicomposting, whereas fecal material from carnivorous (meat-eating) animals is not acceptable in vermicomposting.

Hermaphrodite  An organism, such as an earthworm or plant, in which reproductive organs of both sexes are present.

Heterotroph  An organism requiring organic compounds for its principal source of food.  Compare autotroph.

HHW  Household Hazardous Waste.  See definition below.

High rate decomposition  The first stage/step of the composting process characterized by an increasing rate in oxygen consumption and generation of carbon dioxide and heat when the biomass is kept moist and aerated.  During high rate decomposition the temperature-time relationship is achieved to comply with the Process to Further Reduce Pathogens (PFRP) as described in the US EPA 40 Code of Federal Regulations Part 503 Appendix B, item B, page 9404.

Holding pond  Also called retention basin or detention basin.  An earthen basin designed to temporarily store precipitation runoff and other water for later use or disposal.  Holding ponds can be excavated or formed above grade by constructing earthen embankments.

Homogenous  Of uniform composition or structure throughout.

Horizon, soil  A layer of soil, approximately parallel to the soil surface, with distinct characteristics produced by soil-forming processes.

Household Hazardous Waste  Any organic or inorganic compound that may endanger life or health at a certain level, including poisons, heavy metals, pesticides, etc., sometimes found in mixed municipal solid waste.  HHW includes adhesives, batteries, cleaning products, explosives, gasoline, motor oil, paints, pesticides, herbicides, treated wood, and solvents.

Humic acid  The main constituent of humus, composed of proteins and partially degraded lignins.  Humic and fulvic acids are amino acids that emerge as a by-product during the process of decomposition of organic matter.  They operate enzymatically within seed tissue to increase water absorption and respiration, and speed up the rate of germination.  These substances enhance root initiation and act as a growth hormone to
increase development of secondary lateral roots. Humic acids make up a particular fraction of complex humus, composed of extremely recalcitrant, high molecular weight, very long-chain organic compounds typically 6000 to 600,000 daltons in length and highly structured in a three-dimensional manner. They are very resistant to decomposition and highly condensed. Turnover time in soil may be 300 to 3,000 years.

**Humics** The mixture of all recalcitrant, long-turnover time organic compounds in soil, includes both fulvic and humic fractions.

**Humification** The process by which organic material is converted to soil organic matter including humic and fulvic acids.

**Humus** A complex amorphous aggregate, formed during the microbial decomposition or alteration of plant and animal residues and products synthesized by soil organisms; principal constituents are derivatives of lignins, proteins and cellulose combined with inorganic soil constituents; dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter. Humus retains and slowly releases nutrients to plants.

**Hybrid** The offspring of two animals or plants of different breeds, varieties, or species, especially as produced through human manipulation for specific genetic characteristics. While the term “hybrid” to describe earthworms has been made by some who sell earthworms, scientists have found no proof that hybridization exists among worm species.

**Hydrogen sulfide** A gas with the characteristic odor of rotten eggs produced during anaerobic decomposition of organic matter with the chemical formula H_{2}S.

**Hydrophilic** Capable of uniting with or taking up water.

**Hydrophobic** Not capable of uniting with or taking up water.

**Hygroscopic** Capable of taking up moisture from the air.

**Immobilization, nitrogen** Conversion of nutrient compounds from an inorganic form, available to plants, into the organic tissue of microorganisms or other plants. The nutrients are unavailable until the microorganisms die and the microbial tissues containing the nutrients decompose. Nitrogen immobilization occurs when materials with a high carbon-to-nitrogen ratio are land applied. The microorganisms that use the carbon also assimilate the available nitrogen in the host soil rendering it unavailable to plants.

**Impermeable** Not permitting water or another fluid to pass through.

**Incineration** The process of burning solid waste under controlled conditions to reduce its weight and volume, and often to produce energy.
Incinerator  A furnace, boiler, kiln, etc. for burning wastes under controlled conditions.

Indigenous  Belonging to the local area, native and not imported from anywhere.

Industrial waste  Materials discarded from industrial operations or derived from manufacturing processes.

Inerts  Non-biodegradable material such as metal, glass, and plastic that will not break down in the composting process.

Infiltration area  An area or strip of land that contains vegetation (usually grass) where water enters the soil in a controlled manner. In filtration areas can be relatively flat to gently sloping parcels of land, or they can be long, narrow, low-sloping channels. A pasture of haycrop land can serve as an infiltration area. Infiltration areas can be used to treat dilute wastewater and nutrient-laden runoff.

Infiltration rate  The amount of time required for a known amount (volume or weight) of water to soak through the soil.

Inoculate  To introduce organisms into surroundings suited to their growth.

Inoculum, pl. inocula (inoculant)  The substance used to make an inoculation. Living organisms or material containing living organisms (such as bacteria or other microorganisms) that are added to initiate or accelerate a biological process (for example, biological seeding). In composting, during feedstock preparation, the material added to ensure that appropriate microorganisms are present to “activate” the feedstock. May include recycled compost product or manure.

Inorganic  Substance in which carbon-to-carbon bonds are absent; mineral matter.

Inorganic waste  Waste composed of material other than plant or animal matter, such as sand, dust, glass, and many synthetics.

Insect  Any animal of the class Insecta, comprising small, air-breathing arthropods having the body divided into three parts (head, thorax, and abdomen) and having two antennae, three pairs of legs, and usually two pairs of wings.

Institutional waste  Waste materials originating in schools, hospitals, prisons, research institutions, and other public buildings.

Insulating Material  Material used to prevent the loss of heat from an active compost pile. Insulating material includes but is not limited to foam, soil, or compost that has undergone the Process to Further Reduce Pathogens (PFRP).

Integrated Pest Management (IPM)  An ecological approach to managing pests using pesticides only when and where necessary to reduce economic losses and minimize adverse side effects.

Integrated Solid Waste Management  A practice using several alternative waste management techniques to manage and dispose of specific components of the municipal
solid waste stream. Waste management alternatives include source separation, recycling, composting, energy recovery, and landfilling.

**Intersegmental furrow** In earthworms, the area between two consecutive segments. It is here where the skin is thinnest and where, in pigmented species, color is lacking.

**In-vessel** A diverse group of composting and vermicomposting methods in which materials are contained in a building, reactor, or vessel.

**Iridescence** Shimmering colors on the surface of the earthworm's skin as a result of refracted light. Green and blue are common iridescent colors.

**IPM** Integrated Pest Management

**Juveniles** Those earthworms without genital markings such as the clitellum, tubercula pubertatis, or genital tumescence. This stage of the life cycle is located between the hatchling phase and the appearance of genital markings (adult stage).

**K** Chemical symbol for potassium. Potassium is a primary nutrient as soluble potash (K₂O) marketed in fertilizer material.

**Kelp** Any of several species of seaweed sometimes harvested for use as a fertilizer. Dried kelp will usually contain 1.6 to 3.3% nitrogen, 1 to 2% P₂O₅ and 15 to 20% potash (K₂O).

**Land application** Application of manure, sewage sludge, municipal wastewater, and industrial wastes to land either for ultimate disposal or for reuse of the nutrients and organic matter for their fertilizer value.

**Landfill** A facility for the disposal of solid waste involving the placement of solid waste on or beneath the land surface. Term for a garbage dump which is located in a cavity in the ground so that, when full, it may be covered up and look like part of the land. Today’s landfills are sanitary and require special technology to eliminate the methane gas and toxic leachate produced by the garbage.

**Leachate** 1. Liquid has come into contact with, percolated through, or condensed out of composting feedstock or compost containing extracted, dissolved and suspended materials. Liquid that drains from the mix of fresh organic matter. Leachate from an aerobic compost pile is typically full of plant nutrients and can be an excellent liquid fertilizer (Compost Facility Operating Guide). Also called *percolate*. 2. Compost leachate, produced when water drains from over-saturated compost, is not necessarily anaerobic, but quite often is since if organisms in the compost are growing rapidly, they will consume all the oxygen during passage of the water through the compost. This then can result in phytotoxic compounds in the leachate. (Ingham, *Compost Tea Brewing Manual, 4th ed*, 1). 3. Liquid that has come into direct contact with solid waste and contains dissolved, miscible and/or suspended contaminants as a result of such contact.
Because leachate may include potentially harmful materials, leachate collection and treatment are crucial at municipal waste landfills.

**Leaching**  The removal of materials in solution by the passage of water through a parent material.

**Leaf mold**  Decomposed or mostly decomposed leaves.

**Lignin**  Complex organic substance that acts as a binder for the cellulose fibers in wood and certain plants; adds strength and stiffness to the cell walls. A hard, woody substance embedded in the cellulose of plant cell walls to provide support. Lignins decompose very slowly by microbial activity (recalcitrant).

**Lime**  Also known as “agricultural lime,” or “Ag-lime,” it refers to ground limestone (calcium carbonate) used as an amendment to reduce acidity in soils or worm bins. Hydrated or slaked lime is caustic and toxic to earthworms.

**Litter**  1. The layer of slightly decomposed organic material on the surface of the floor of a forest. 2. Poultry litter is the dry absorbent bedding material such as straw, sawdust, and wood shavings that is spread on the floor of poultry barns to absorb and condition manure. Sometimes the manure-litter combination from the barn is also referred to as litter.

**Loading rate**  1. The optimum weight or volume of feedstock that can be applied to an earthworm bed at regular intervals for efficient processing. 2. The maximum amount of a pollutant that can be applied to a unit area of land during a 365-day period. (see annual pollutant loading rate).

**Loam**  The textural class name for soil having a moderate amount of sand, silt and clay. Loam soils contain 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand.

**Lumbricus rubellus**  A common species of earthworm found in moist soils, particularly where animal manure or biosolids have been applied. It is frequently confused with *Eisenia fetida* and both species have been known simply as “redworms.” Its suitability for vermicomposting systems has yet to be substantiated.

**Lumbricus terrestris**  Major representative of the anecic category, this soil dwelling earthworm creates deep burrows, mates on the surface and pulls organic matter into its burrow.

**Macronutrient**  Nutrients that plants require in relatively large amounts, including nitrogen, phosphorus, potassium (the familiar N-P-K of fertilizer labels), as well as calcium, magnesium and sulfur.

**Macroorganism**  Organisms that are visible to the eye without magnification.
**Make-up water**  Liquid added to replace moisture loss during composting.

**Manure**  Generally, the refuse from stables and barnyards, including both animal excreta and straw or other litter. In some countries outside the U.S. the term is used more broadly and includes both farmyard or animal manure and “chemical manures,” for which the term “fertilizer” is nearly always used in the U.S.

**Material Recovery Facility (MRF)**  A solid waste management facility which separates materials for the purposes of recycling from an incoming solid waste stream by using manual and/or mechanical methods, or a facility at which previously separated recyclables are collected. A “clean” MRF generally refers to a facility to recover commodity resources segregated by generators through “curbside recycling” programs, and a “dirty” MRF refers to recovery from mixed waste collection practices. “Material recovery facility” includes composting facilities in Oregon. (DEQ)

**Mature compost**  The stabilized and sanitized product of composting that 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.

**Meat**  The flesh of animals as used for food, generally best avoided in vermicomposting systems.

**Medical waste**  Generally defined as any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals.

**Mesophilic**  The mid-range (Gk., mesos, middle) of temperature in composting. A phase that occurs between 20 to 45°C (68 to 113°F) [according to the *Compost Facility Operating Guide*], or “generally accepted as between 50 and 105°F (10 and 40°C)” [according to the *On-Farm Composting Handbook*]. Also used to describe the soil organisms that are found within this temperature range.

**Metabolism**  1. The chemical and physical process continuously going on in living organisms and cells, comprising those by which assimilated food is built up (anabolism) into protoplasm and those by which protoplasm is used and broken down (catabolism) into simpler substances or waste matter, with the release of energy for all vital processes. 2. The exchange of matter and energy between an organism and its environment and the transformation of this matter and energy within the organism.

**Metabolites**  Organic compounds produced by metabolic processes.

**Methane**  Colorless, odorless, flammable gaseous hydro-carbon, CH₄, present in natural gas and formed by the decomposition of vegetable matter under anaerobic conditions, as in marshes and mines. It may be used as a fuel.
**Microbe** An organism that can be seen with the aid of a microscope (Gk., *mikros*, small + *bios*, life). This is the short terminology for microorganisms (microscopic animals and plants).

**Microfauna** Populations of microscopic animals including protozoa and nematodes.

**Microflora** Populations of microscopic plants including bacteria, actinomycetes, fungi, and algae.

**Micronutrient** Stimulators of the enzymatic function necessary to sustain microbial metabolism. Micronutrients are required in small quantities by plants for growth, but can be toxic at high levels. Essential micronutrients are boron, chlorine, copper, iron, manganese, molybdenum and zinc. Stimulators can also include macronutrients, nickel, and sodium.

**Microorganism** Any organism too small to be viewed by the unaided eye, (thus requiring magnification for observation) such as bacteria or some fungi and algae.

**Middens** The castings of anecic earthworms (i.e., *Lumbricus terrestris*) which serve as a lid to their burrows; the mound of soil surrounding the burrows of soil dwelling organisms.

**Mineralization** To convert into mineral or inorganic form.

**Mixed Municipal Solid Wastes (MMSW)** Includes various discards from residential, commercial, and institutional sources, which are commonly disposed at incinerators or landfills. The largest components of mixed municipal solid waste are typically paper and paper products, leaves, brush and yard trimmings, wood, food scraps, glass, plastics, and metals.

**mmho (pl. mmhos)** A millimho. One thousandth of a mho (pronounced mo with a long o). A mho is a unit of measurement for electrical conductivity that is the basis for measuring soluble salt concentration (mho is the backward spelling of ohm, the unit of measurement for electrical resistance). One mho is equal to 1 siemens (S).

**Moisture content (wet basis)** Weight of water in a material divided by the sum of the weight of water plus solids in the material. Moisture content is sometimes reported on a dry basis. Dry –basis moisture content equals the weight of the water divided by the weight of the dry matter.

**Monoculture** The cultivation of a single species of organism, e.g., earthworms, or an agricultural crop.

**Most Probable Number (MPN)** An index of the number of coliform bacteria that, more probably than any other number, would give the results shown by the laboratory examination.
MRF  Material Recovery Facility

MSW  Municipal Solid Waste

Muck  Highly decomposed organic soil material developed from peat. Generally, muck has a higher mineral or ash content than peat and is decomposed to the point that the original plant parts cannot be identified.

Mucus  A viscous, slimy solution secreted by body cells for protection and lubrication.

Mulch  A benign organic or nonorganic soil surface cover used to: 1) help retain moisture longer in the soil by retarding evaporation; 2) discourage weed growth; 3) help maintain constant winter and summer temperature providing insulation to the soil; and, 4) discourage water runoff and soil erosion by shielding the soil surface from water abrasion and promoting water absorption and retention. Organic mulches may include chopped leaves and grass, shredded and chunk bark, coarse compost, organic peat, peat moss, shredded hardwood, shredded paper, straw, and wood chips. Non-organic materials may include stone, rock, lava rock and film plastic.

Municipal Solid Waste (MSW)  1. All solid waste generated in an area except industrial and agricultural wastes. Sometimes includes construction and demolition debris and other special wastes that may enter the municipal waste stream. Generally excludes hazardous wastes except to the extent that they enter the municipal waste stream. Sometimes defined to mean all solid wastes that a city authority accepts responsibility for managing in some way. 2. Discarded materials from which compostable organic material may be recovered for feedstock to make compost, and other recyclable material recovered for sale, such as aluminum, ferrous, paper, etc. Municipal solid waste originates from residential, commercial, and institutional sources within a community.

Muscles  Earthworms travel by coordinating two kinds of muscles: circular and longitudinal muscles. Both are located under the epidermis. When the circular muscles contract, the segments become thinner (decrease in segment diameter), the earthworm lengthens and moves forward. When the longitudinal muscles contract, the segments become thicker (increase in segment diameter), and the earthworm shortens.

Mycelium  The collective term for fungus filaments or hyphae.

Mycorrhizal fungi  Vesicular-arbuscular mycorrhizae (VAM) are a set of mycorrhizal fungi that form arbuscules and vesicles within the roots of plants, while ectomycorrhizal fungi form a net, called the Hartig net, within the first one-to-two cell layers of feeder roots and send rhizomorphs along the root surface. Host ranges of row crops for VAM are quite broad. The important factor to understand in choosing species of VAM is climate. When growing conifers, ectomycorrhizal fungal experts should be consulted.

N  Chemical symbol for nitrogen. Total nitrogen is a primary nutrient marketed in fertilizer material. See nitrogen below.
**Natural Organic Fertilizer** Materials derived from either plant or animal products containing one of more elements (other than carbon, hydrogen, and oxygen) that are essential for plant growth. These materials may be subjected to biological degradation processes under normal conditions of aging, rainfall, sun curing, air-drying, composting, rotting, enzymatic action, anaerobic/aerobic bacterial action, or any combination of these. These materials are not mixed with synthetic materials or changed in any physical or chemical manner from their initial state, except by physical manipulations such as drying, cooking, chopping, grinding, shredding, or pelleting.

**Nematode** Also “roundworms,” are among the most numerous of the multicellular organisms found in any ecosystem. They are primarily inhabitants of water films or water-filled pore spaces in soils. The overall body shape is unsegmented, threadlike, cylindrical, and tapering at the ends and may be viewed under moderate magnification (ca. 100x) binocular microscope. Nematodes feed on a wide range of foods including bacteria, fungi, plants, and may be predators and omnivores. The four major functional groups in soil include bacterial-feeding, fungal-feeding, predatory (eat other nematodes) and root-feeding.

**Nightcrawler** A term used to describe various earthworm species such as Canadian nightcrawler, i.e., *Lumbricus terrestris*, the African nightcrawler, i.e., *Eudrilus eugeniae*, and the Belgian or European nightcrawler, i.e., *Eisenia hortensis* (also known as *Dendrobaena veneta*). *Lumbricus terrestris*, is called a “dew worm” in Canada. It comes to the surface at night or in conditions of low light and relatively high moisture on the surface.

**NIMBY** Acronym for “Not In My Back Yard,” an expression of resident opposition to the siting of a perceived undesirable facility based on a particular location proposed.

**Nitrate-Nitrogen** A negatively charged ion comprised of nitrogen and oxygen (NO$_3^-$). Nitrate is a water soluble and mobile form of nitrogen. Because of its negative charge, it is not strongly held by soil particles (also negative) and can be leached away. Nitrate has the potential of being readily leached from compost piles by water and carried to local surface water bodies (streams, rivers, lakes) or through underlying soils into groundwater aquifers.

**Nitrification** The biochemical oxidation of ammonia nitrogen to nitrate.

**Nitrogen** A nonmetallic element that constitutes nearly four fifths of the air by volume, occurring as a colorless, odorless, almost inert diatomic gas, N$_2$, in various minerals and in all proteins and used in a wide variety of important manufactures, including ammonia, nitric acid, TNT, and fertilizers.

**Nitrogen fixation** Generally, the conversion of free nitrogen to nitrogen compounds. Specifically in soils, the assimilation of free nitrogen from the soil air by soil organisms and the formation of nitrogen compounds that eventually become available to plants.

**Nocturnal** Active at night (opposed to diurnal).
Non-point-source pollution  A catchall term for contaminated runoff from a large number of miscellaneous sources such as fields, streets, and lawns rather than discharge from the pipe of an industrial facility or sewage treatment plant (see point source discharge). The most common pollution include fertilizers and pesticides from farmers’ fields and residential lawns, sediments from eroding fields, ditches, and construction sites, used motor oil poured into sewers or dumped onto the soil, and toxic pollutants from city streets. Composting reduces non-point source pollution through use of its process and/or product. For example, livestock manures can be managed by the composting process to reduce non-point source impacts. This is particularly important if otherwise the manure would enter the water directly, if not enough land is available for the manure to be applied directly to the soil, or if land application of the manure would supply excess nutrients to the soil.

N-P-K  Primary plant nutrients, which are, plant foods including total nitrogen (N); available phosphoric acid (P₂O₅) or phosphorus (P); and soluble potash (K₂O) or potassium (K). In the chemical philosophy, these three elements are considered important to force crop production (as opposed to the organic philosophy goal of improving the biodiversity of the soil). US law requires that the ratio of these three elements be specified on every bag of commercially-available fertilizer. A ratio of 3-1-2 or 4-1-2 is considered good.

Nutrient Availability  The relative proportion of a nutrient in the soil that can be absorbed and assimilated by growing plants.

Nutrient cycling  A biogeochemical cycle. The process of conversion of organic and inorganic material from one form to another, generally with the production of biomass by the organism doing the cycling, production of metabolic waste products which serve as the next step in the nutrient cycle, and carbon dioxide.

Nutrient-Holding Capacity  The ability of a soil or soil product to absorb and retain nutrients so they will be available to the roots of plants. (See also exchange capacity)

Nutrient retention  The opposite of leaching, extraction or loss of nutrients. The least mobile nutrients will nearly always be the organic forms, and the most mobile, or leachable, are the mineral forms. Retention requires nutrients to be physically immobilized by inclusion in organic matter (in organisms or organism waste-products such as bacteria, fungi, plants or plant detritus) or by chemically binding on the surface of clay, sands, silts or organic matter.

Odor  A sensation resulting from adequate stimulation of the olfactory organ. The property of quality of a thing that stimulates or is perceived by the sense of smell.

Odor Concentration  The dilution level required to produce an odor intensity level, which 50% of a population will detect. Below this concentration a volatile compound is not a perceived odor, although the compound may still be present in the air.
**Odor Detection Threshold**  The threshold at which a receptor is able to distinguish a dilute odor sample from odor free air.

**Odor Detection Panel**  A group of individuals who, with “certified average noses,” are used in place of analytical tests to conduct sensory evaluations of odors that may be emanating from a composting site.

**Oligochaeta**  One of the taxonomic classes in the phylum Annelida. Members of this class have segmented bodies, setae on all segments (except the peristomium and periproct), a true coelom, a closed vascular system, and crawl using circular and longitudinal muscles.

**Operator**  The designated individual(s) in substantial control of process operations at a compost facility.

**Operating and Maintenance (O&M) Costs**  Ongoing expenses that include such items as equipment leasing and maintenance, utilities, labor, administrative expenses, licenses, supplies, insurance, residue disposal, marketing fees, contract fees, and publicity programs. Sometimes O&M costs are broken down into four basic categories: 1. Collection; 2. Processing and Marketing; 3. Administration; and 4. Education and Publicity.

**Order**  The usual major subdivision of a class or subclass in the classification of organisms, consisting of one of more families.

**Ordinance**  A statute or regulation, especially one enacted by a local government.

**Organic**  1. Noting or pertaining to a class of chemical compounds that formerly comprised only those existing in or derived from plants or animals, but that now includes all other compounds of carbon. Substance which includes carbon-to-carbon bonds. All compounds whose molecules contain carbons, with a few exceptions such as carbon dioxide. 2. Of or relating to or derived from living organisms. 3. Also refers to organic foods, or foods raised according to standards of organic agriculture, including the use of crop rotation to control plant diseases and pests and to allow rejuvenation of soil nutrients; additionally, the use of nonsynthetic fertilizers such as to build soil structure and microbial life as the basis for strong plants. Where necessary, nonsynthetic pesticides may be used according to standards adopted by committees established at the state and national levels to certify foods as “organic”. 4. A fertilizer that is derived from vegetable or animal matter.

**Organic matter content**  Organic matter is composed primarily of carbon, oxygen, hydrogen and nitrogen. The organic matter content is the portion of an organic material that is volatilized at 550°C (1022° F). It is usually expressed on a dry weight basis. It is used to describe the quality of the soil environment to support and sustain vegetative production.
**Organic Soil Conditioner**  Stabilized organic matter marketed as a soil amendment for improvement of soil structure. It also improves certain chemical and biological properties of the soil.

**Organism**  A plant or animal. A system regarded as analogous to a living body.

**Ovum**  (egg): A mature reproductive cell of female animals.

**Oxygen**  A colorless, odorless, gaseous element constituting about one-fifth of the volume of the atmosphere and present in a combined state in nature.

**P**  Chemical symbol for phosphorus. Total phosphorus is a primary nutrient marketed in fertilizer material as phosphoric acid ($P_2O_5$).

**Pad, Composting**  The surface or area occupied by actively composting windrows and piles.

**Parthenogenesis**  Development of an egg without fertilization (Gk., *parthenos*, maiden, virgin + *genesis*, origin) Most earthworm species reproduce by cross-fertilization, although some species can also produce cocoons parthenogenetically.

**Passively-Aerated Windrow Composting**  A composting method in which windrows are constructed over a series of perforated plastic pipes that serve as air ducts for natural aeration. There is no use of forced-air blowers. Windrows are not turned.

**Pathogen**  An organism or microorganism, including helminths, bacteria, mold, fungus, virus and protozoa capable of producing an infection or disease in a susceptible host. Often found in waste material, most pathogens are killed by the high temperature of the composting process. Measures to control pathogens include effective industrial hygiene and worker hygiene practices, effective design, and operation of biodegradation of pathogen nutrients and for adequate and uniform aeration and temperature/time to assure pathogen destruction and process and product monitoring for quality control.

**Peat**  Partly decayed fibrous vegetable matter of natural occurrence resulting from years of anaerobic decomposition. It is composed chiefly of organic matter that contains some nitrogen of low activity. Peat is unconsolidated soil material accumulated under conditions of excessive moisture and low pH. Highly absorbent of water, nutrients and odors, it may hold over ten times its weight in water. Canadian sphagnum peat moss is mined from bogs and sold as an organic mulch. It is commonly used as bedding for shipping harvested earthworms. Due to its acidity, calcium carbonate or oyster shell flour is added to raise the pH. It is not recommended as a medium for growing earthworms since it is a limited resource.

**Percent Moisture**  The weight of water in a material divided by the sum of the weight of water plus solids in the material, multiplied by one hundred. (See also moisture content)

**Percolate**  Liquid which has come into contact with, percolated through or condensed out of composting feedstock or compost and contains extracted, dissolved and suspended materials; liquid that drains from the mix of fresh organic matter. See also leachate.
**Perionyx excavatus**  An ideal earthworm species under tropical conditions, it is used extensively in vermiculture in the Philippines and Australia. Its inability to withstand adverse temperature conditions is its chief drawback.

**Periproct**  The last segment of the earthworm’s body; contains the anus.

**Peristomium**  The first segment of the earthworm’s body; contains the mouth.

**Perlite**  Volcanic mineral used as an amendment in potting soil.

**Permaculture**  The conscious design and maintenance of agriculturally productive ecosystems. It is the harmonious integration of landscape and people, providing their food, energy, shelter and other needs in a sustainable way. The philosophy behind permaculture is to work with, rather than against nature. (A hybrid of permanent and agriculture).

**Permeability, soil**  The quality of a soil horizon that enables water or air to move through it. It can be measured quantitatively in terms of rate of flow of water through a unit cross section in unit time under specified temperature and hydraulic conditions.

**Persistence**  Refers to a slowly decomposing substance, which remains active in the natural cycle for a long period of time.

**Pest**  An insect or small animal that harms or destroys garden plants, trees, etc.

**Petrochemicals**  Commercially manufactured fertilizers and pesticides made from the nonrenewable petroleum resource.

**PFRP**  The Process to Further Reduce Pathogens, defined below.

**pH**  A measure of the concentration of hydrogen ions in a solution (potential Hydrogen). pH is expressed as a number between 0 and 14; a pH of 7 is considered neutral; a substance that has a pH of 8 has ten times fewer hydrogen ions than a substance with a pH of 7; the lower the pH, the more hydrogen ions present, and the more acidic the material is; the higher the pH, the fewer hydrogen ions present, and the more basic it is. pH is measured on a logarithmic scale, which means that each unit represents a ten-fold change in the acidity or alkalinity of the material measured. Thus a compost at a pH level of 4.0 is 10 times more acidic than one having a pH of 5.0, 100 times more acidic than a compost having a pH of 6.0 and 1,000 times more acidic than compost at 7.0.

**Phenols**  A benzene carbon ring structure with hydroxyl groups at various positions attached to the carbons in the ring, typically resistant to enzyme attack and therefore considered relatively resistant to decomposition. Many phenols have antibiotic or toxic capabilities.
**Pheretima hawayana** A tropical earthworm species used in vermicomposting.

**Phosphorus** Necessary for photosynthesis, for energy transfers within plants, and for good flower and fruit growth. Unlike nitrogen, phosphorus has more to do with plant maturation than with plant growth. Excess soluble phosphates are subject to loss thorough leaching and synthetic phosphates are among the five major pollutants measured to determine water quality.

**Phosphoric acid** A term that refers to the phosphorus content of a fertilizer, expressed as phosphoric acid (P\(_2\)O\(_5\))

**Photophobic** An abnormal sensitivity to or intolerance of light.

**Photosynthesis** The process by which green plants combine water and carbon dioxide to form carbohydrates under the action of light. Chlorophyll is required for the conversion of light energy into chemical energy.

**Phytophthora** A group of fungal plant pathogens, which cause a serious root, crown, and sometimes foliar (leaf) disease on a large number of plants. These fungi are most active under conditions of high soil moisture.

**Phytotoxic** Adjective describing a substance that has a toxic effect on plants, resulting in the death or impaired growth of the plant. Phytotoxic elements may inhibit plant growth and seed germination due to excessive salt content, pH, the presence of organic acids and other factors. Immature or anaerobic compost may contain acids or alcohols that can harm seedlings or sensitive plants.

**Plow layer** A depth of about 13-15 centimeters (6 inches) that is broken and turned in preparation for planting seed, and which is the root zone for many crops and plants. This is the approximate depth that soil amendments such as compost are tilled into the soil.

**Point source discharge** A discharge from any discernible, confined, and discrete conveyance, including, but not limited to, any pipe, ditch, channel, tunnel, or conduit.

**Pollutant** An organic substance, an inorganic substance, a combination of organic and inorganic substances, or a pathogenic organism either directly from the environment or indirectly by ingestion through the food chain, could, on the basis of information available to the Administrator or the U.S. EPA, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunction in reproduction), or physical deformations in either organisms or offspring of the organisms.

**Polymorphism** The occurrence of slightly different looking individuals within the same species; slight variations within one species.
**Pore space**  Open space in soil allowing air and water to move through. Earthworms develop pore space in spoils through their burrowing activities.

**Porosity**  The fraction of soil or compost volume not occupied by soil or compost particles; porosity is the measure of the pore space of a material or pile of materials. Porosity is equal to the volume of the pores divided by the total volume. In composting, the term porosity has sometimes been used loosely, referring to the volume of the pores occupied by air only without including the pore space occupied by water (see also *Free Airspace*).

**Postclitellate adult**  Earthworms who have passed their reproductive period. They no longer have a clitellum, but do show a discoloration where the clitellum and genital markings were once located. (See also *clitellate adult*)

**Potash**  A term for potassium oxide (K₂O) marketed in fertilizer material.

**Potassium**  A primary nutrient as soluble potash (K₂O) marketed in fertilizer material.

**Pot worms**  See *enchytraeids*.

**Predator**  An organism that consumes other living organisms, as opposed to a decomposer, for example, which consumes dead plant material.

**Prey**  An organism, which is eaten by a predator.

**Primary Plant Nutrients**  Plant foods including total nitrogen (N), available phosphoric acid or phosphorus (P), and soluble potash or potassium (K).

**Process to Further Reduce Pathogens**  PFRP was originally developed for composting sewage sludges but has been widely applied to solid waste composting. Compost safety standards specify that compost be subjected to PFRP, a *process* standard, not a *product* standard that can be measured by testing finished compost. Composting PFRP is defined in the federal regulations as: “Using either the within-vessel composting method or the static aerated piled composting method, the temperature of the sewage sludge is maintained at 55 degrees Celsius or higher for three days. Using the windrow composting method, the temperature of the sewage sludge is maintained at 55 degrees or higher for 15 days or longer. During the period when the compost is maintained at 55 degrees or higher, there shall be a minimum of five turnings of the windrow.” The Process to Further Reduce Pathogens is found in “Standards for the Use and Disposal of Sewage Sludge,” 40 Code of Federal Regulation Part 503, dated February 19, 1993, Appendix B to Part 503-Pathogen Treatment Process, item (B) page 9404.

**Profile, soil**  A vertical section of the soil extending through all its horizons and into the parent material.
Proprietary Rights  All formulae, know-how, patents, patent rights, patent applications, letters patent, trade secrets, inventions, models, processes, designs, licenses, business rights, rights to exclude others, pricing policies, information as to the identities of requirements of customers or potential customers, market information, market analyses, marketing plans, operating or management policies, procedures and forms, computer software and computer operating procedures and all other information used or useful in developing and operating a unique business or enterprise.

Prostomium  In earthworms a lobe overhanging the mouth, and in some worms so small that it cannot be distinguished. The lobe of skin that projects out in front of the first body segment (peristomium). It is located above the mouth, and there are three formations as seen in dorsal view.

Protein  Any of a group of high-molecular-weight nitrogen-containing compounds that yield amino acids on hydrolysis. Protein is a vital part of living matter and is one of the essential food substances of animals. The protein content of earthworms ranges from 60-80%.

Protozoa  Various one-celled organisms that usually obtain nourishment by ingesting food particles rather than by photosynthesis. Their major prey group is bacteria. Three major groups of protozoa that occur in soil are the flagellates, the amoebae, and the ciliates. Amoebae can be separated into naked amoebae and testate amoebae. Because bacteria contain much more N per unit C, N is released as ammonium, a plant available form of N.

Pseudomonas  A genus of bacteria. Some species in this genus are plant-pathogens while some are extremely beneficial to the growth of some plants. Taxonomic revision of this group of species is underway.

Psychrophiles  Organisms that prefer colder temperatures, below the mesophilic range (Gk., psychros, cold) This group of bacteria species works to break down organic matter under “cold conditions” of 0 to up to over 55 degrees. They generate low levels of heat.

PTO  Power take off. Drive shaft and coupling on a tractor, which transmits power from the tractor engine to implements and secondary equipment (for example, pumps, grinders, and windrow turners).

Putrefaction  Bacterial or fungal decomposition of organic matter with resulting obnoxious odors; rotting.

Putrescible waste  Solid waste containing organic material that can be rapidly decomposed by microorganisms and which may give rise to foul smelling, offensive products during such decomposition or which is capable of attracting or providing food for birds and potential disease vectors such as rodents and flies.
**Pythium**  A fungal plant pathogen, which causes seed, seedling, and root, rots on a large number of plants. These fungi are most active under conditions of high moisture.

**RDF**  Refuse Derived Fuel

**Recalcitrant**  Resistant to biological decomposition.

**Recipe**  The ingredients and proportions used in mixing together several raw materials for composting.

**Recyclables**  Items that can be reprocessed into feedstock for new products. Common examples are paper, glass, aluminum, corrugated cardboard, and plastic containers.

**Recycle**  Any process by which solid waste materials are transformed into new products in such a manner that the original products may lose their identity.

**Recycled waste**  Discarded products and packaging materials recovered for reuse and/or processing into new products.

**Reduced or Conservation Tillage**  A tillage system where a portion of the previous year’s plant residue is left on the surface after planting seeds. The residue is food for earthworms and less tillage means less disturbing of earthworm borrows and their food supply.

**Redworm**  A common name for both *Eisenia fetida* and *Lumbricus rubellus* because of their heavy pigmentation. The term redworm has been used interchangeably with red wiggler.

**Regenerate**  To restore or revive a lost body part by the growth of new tissue. Some earthworm species can regenerate either the anterior or posterior portions of their bodies, but may not if too many segments are removed.

**Remedial**  Supplying a remedy. Intended to correct or improve deficient skills in a specific subject.

**Remediation**  The correction of something defective or deficient.

**Renewable resource**  A resource such as plants that can be grown all year and which can be recovered quickly if lost. In contrast, soil in nonrenewable, as it takes hundreds of years for soil to develop naturally.

**Renewable Energy**  A form of energy which is regenerative or virtually inexhaustible. Typical examples are wind, geothermal, and water power. Energy can also be generated from biomass fuels such as wood and forest residues, animal manure and waste, grains, crops and aquatic plants.

**Residue**  Dead plant materials (stems, stalks, and leaves) left after harvest.

**Resource recovery**  The extraction and use of materials and energy from the waste stream. The term is sometimes used to denote solid waste incineration with energy
recovery, also called waste-to-energy incineration. Synonymous with “material recovery” and “recycling.”

**Respiration** The physical and chemical processes by which an organism supplies its cells and tissues with the oxygen needed for metabolism and relieves them of the carbon dioxide formed in energy-producing reactions.

**Respirometry** A method for measuring the oxygen uptake rate of compost.

**Reuse** The return of a commodity into the economic stream for use in the same kind of application as before without change of its identity.

**Rhizosphere** The area immediately around plant roots, including the roots itself. This is an area of intense microbial activity, where plants, microorganisms, other soil organisms, and soil structure and chemistry, interact in complex ways.

**Rock dust** Finely ground rock particles having the consistency of flour or powder. One form of rock dust recommended calls for 90% to pass through a 200-mesh screen (200 holes per square inch). Soil remineralization (SR) proponents advocate the addition of rock dust to soils that have become severely demineralized by erosion and cultivation. See soil remineralization.

**Run-off** Any rainwater, leachate or other liquid that drains over land from any part of the facility. Water originating from rainfall and other precipitation that is found in drainage facilities, rivers, streams, springs, seeps, ponds, lakes and wetlands as well as shallow ground water.

**Salmonella** Disease-causing bacteria that affect humans and warm-blooded animals, and can cause allergic reactions in susceptible humans and sickness including severe diarrhea with discharge of blood. *Salmonella* exhibits no growth beyond 46°C (115° F), and death occurs within one hour at 55°C (131° F).

**Salt** 1. A crystalline compound, sodium chloride (NaCl) occurring chiefly as a mineral or a constituent of seawater, and used for seasoning food and as a preservative. 2. Any of a class of chemical compounds formed by neutralization of an acid by a base, a reaction in which hydrogen atoms of the acids are replaced by cations supplied by the base. Thus, the products, other than water, of the reaction of an acid with a base. Salts commonly found in soils break up into cations (such as sodium and calcium) and anions (such as chloride and sulfate) when dissolved in water. Earthworms will die in wastes with high amounts of inorganic salts (must be less than 0.5%).

**Sand** Individual rock or mineral fragments in soils having diameters ranging from 0.05 to 2.0 millimeters. Usually sand grains consist chiefly of quartz, but they may be of any mineral composition. The textural class name of any soil that contains 85% or more sand and not more than 10% clay.
Sanitary Landfill  A landfill permitted to accept household and commercial waste (solid and liquid non-hazardous waste).

Sanitization  The reduction of disease-producing organisms below the level of health risk.

Screen  One of a family of devices, which vibrate, oscillate, or rotate for the purpose of sorting materials by size through a perforated plate or open mesh fabric.

Screening  The sifting of feedstocks, compost or vermicompost through a screen to remove large particles and/or contaminants and to improve consistency and quality of the product. Screening feedstocks such as yard trimmings prior to composting is performed to set an optimum particle size to maintain porosity during composting. Finished products, (compost and vermicompost) are best kept in curing piles and screened just prior to bulk sales (screened to order) or prior to bagging.

Secondary annulation  The small furrows (wrinkles) that occur in-between the intersegmental furrows of earthworms.

Secondary Plant Nutrients  Those nutrients other than the primary nutrients that are essential for the normal growth of plants and that may need to be added to the growth medium. Secondary plant nutrients include calcium, magnesium, and sulfur; micro plant nutrients include boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sodium, and zinc.

Secrete  To discharge, generate, or release by secretion (the process of releasing a substance that fulfills some function within the organism).

Segment  1. A division or band along the length of the earthworm body divided by furrows or intersegmental grooves. The segments vary in width, usually being widest in the anterior and clitellar regions. 2. The small rings that surround the length of the earthworm’s body. They are simply folds in the skin.

Self-heating  Heat generation caused by the microbial oxidation of organic matter, which leads to a temperature rise.

Seminal fluid  Fluid produced by prostatic glands in earthworms in which sperm cells can be transferred between worms during copulation.

Septage  The pumpings from septic tanks, cesspools, holding tanks, chemical toilets and other sewage sludges not derived at sewage treatment plants.

Setae  Bristle-like structures on the exterior of the earthworm body wall used to grip surfaces as an aid to locomotion and assist the physiological processes, which take place at copulation. They help the earthworm to move and act to sense the environment.
**Setal pairings** The arrangement of the setae on the earthworm’s body. Three arrangements exist: closely paired, widely paired, and separate.

**Setback (or buffer)** Prescribed distance separating the area of a particular activity and a neighboring boundary (for example, the distance between the composting pad and the property line).

**Sewage sludge** See sludge

**Sexually mature** The phase of earthworm development when the clitellum becomes prominent. (The earthworm becomes *clitellate*). The overall time earthworms take to reach sexual maturity from hatching differs greatly between species and has been investigated in detail only for a few species, mostly in culture. *Eisenia fetida*, for example, takes 53-76 days to reach sexual maturity from the time it hatches from a cocoon.

**Sharps** Needles, IV tubing with needles attached, scalpel blades, lancets, glass tubes that could be broken during handling and syringes that have been removed from their original sterile containers. Also sewing needles and straight pins.

**Shredder** A powered mechanical device used to break waste materials into smaller pieces. Shredding implies that the particles are broken apart by tearing and slicing. See also grinding.

**Silt** 1. Individual mineral particles of soil that range in diameter from the upper size of clay, 0.002 mm, to the lower size of very fine sand, 0.05 mm. Soil of the textural class silt contains 80% or more silt and less than 12% clay. 2. Sediments deposited from water in which the individual grains are approximately the size of silt, although the term is sometimes applied loosely to sediments containing considerable sand and clay.

**Siting** To situate or locate on a site.

**Sludge** Any solid or semi-solid waste and associated supernatant generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant or air pollution control facility or any other such waste having similar characteristics and effects. *Activated sewage sludge* is an organic fertilizer made from sewage freed from grit and coarse solids and aerated after being inoculated with microorganisms. The resulting flocculated organic matter is withdrawn from the tanks, filtered with or without the aid of coagulants, dried, ground and screened. (See also biosolids.)

**Slurry** Wastewater containing significant amounts of dung, urine and bedding derived from intensively housed cattle, pig and poultry, and/or wastewater containing other biodegradable waste materials.
**Soil**  Soil is composed of a variable combination of minerals (in the form of sand, silt and clay) organic matter, water, air and living soil organisms. It provides mechanical support and sustenance for plants.

**Soil aggregation**  Soil particles (sand, silt, clay parent material) are bound together through the actions of microorganisms, and the space between these particles formed through the bonding action, and by the larger faunal organisms in the soil. The more aggregated the soil, in both small and larger ped structures, determines in part how water, roots and nutrients will be held by that soil.

**Soil amendment/soil conditioner**  A soil supplement which physically stabilizes the soil, improves resistance to erosion, increases permeability to air and water, improves texture and resistance of the surface to crusting, eases cultivation, or otherwise improves soil physical quality. Matter that, when added to the land, will make the soil healthier by such means as balancing and adding nutrients, balancing the pH, encouraging the process of microorganisms. Does not include commercial fertilizers, agricultural liming materials, unmanipulated animal manures, unmanipulated vegetable manures and pesticides. From a legal standpoint a soil amendment (such as compost or worm castings) is different than “fertilizer” and is not governed by laws that regulate fertilizers.

**Soil erosion**  Soil being displaced by water or wind due to poor surface cover, steep and/or long slopes, and poor soil structure.

**Soil mantle**  Soil surface of the Earth, normally thought of as the top, fertile layer of soil.

**Soil remineralization (SR)**  The application of rock dust to soils demineralized by erosion and cultivation. Advocates of SR claim that the application of rock dust to soil increases the growth of microorganisms, increases the nutrient uptake of plants, counters the effects of soil acidity, prevents soil erosion, increases the storage capacity of the soil, contributes to the building of humus complexes, has anti-fungal properties, and when sprayed on plants repels insects. It is also claimed that remineralization also enhances and speeds up the process of composting.

**Soil structure**  The physical and chemical makeup of the soil as they relate to supporting plant growth. Earthworms will help provide the internal space between soil particles, allowing for sufficient air and water movement for plant and animal use.

**Soil texture**  A characterization of soil type, based on the relative proportions of sand, silt and clay in a particular soil.

**Soil tilth**  The physical condition of a soil with respect to its fitness for growth of plants.

**Solid waste**  All putrescible and non-putrescible solid and semisolid wastes, including but not limited to garbage, rubbish, ashes, industrial wastes, swill, sewage sludge, construction and demolition wastes, abandoned vehicles or parts thereof, and recyclable materials.
**Solid Waste Management**  Prevention or reduction of solid waste; management of the storage, collection, transportation, treatment, utilization, processing and final disposal of solid waste; or resource recovery from solid waste; and facilities necessary or convenient to such activities.

**Solid Waste Management Plan**  A plan developed by local government to manage solid wastes which includes descriptions of existing facilities and collection systems, plans for developing new facilities, comprehensive waste reduction and recycling programs, cost analyses, long range projections for solid waste management needs, and programs for surveillance and control.

**Soluble**  Capable of being dissolved in water; in solution.

**Soluble salts**  Soluble salts concentration is the concentration of soluble ions in a solution, which is measured by electrical conductivity, that is the ability to carry an electrical current. Electrical conductivity varies both with the number and type of ions contained in the solution, which can indicate potential for phytotoxicity. Soluble salts in compost will determine its ultimate end use. Each user group, e.g., vegetable growers, nursery industry, etc., has its own set of salinity standards for growing specific plants or crops. (See also *electrical conductivity*)

**Source reduction**  Waste prevention; that is, avoiding waste generation. As applied to solid waste, reducing the generation of waste in the first place, as opposed to later reusing or recycling.

**Source separation**  Segregation of recyclable materials or yard waste from mixed waste on the household or business level (at the place where such waste originates) to facilitate recycling and composting these materials. Source separation refers to separating newspapers, glass, yard wastes, plastic bottles, etc. into separate containers or piles for waste processing.

**Subsoils**  Soils that lie under the topsoil, containing fewer nutrients, organic matter, and soil development than the darker-colored topsoil.

**Subtitle D**  Solid, non-hazardous waste section of the federal Resource Conservation and Recovery Act (RCRA).

**Species**  The major subdivision of a genus or subgenus, regarded as the basic category of biological classification, composed of related individuals that resemble one another, are able to breed among themselves, but are not able to breed with member of another species. For example, the scientific name for North American earthworms typically called “nightcrawlers,” is *Lumbricus terrestris*. The last part of the name, *terrestris*, (always italicized and lower case) is the species name. *Lumbricus* (always started by upper case Italics) is the genus name.

**Sperm**  A male reproductive cell.
Spermathecae  An organ in which sperm are stored.

Spontaneous combustion  Self-heating and ignition of a combustible substance because of chemical reactions that occur within the substance. In composting, this can occur at moisture contents between 25 and 45%. If a biologically active compost pile dries out, temperature at the boundary layer between moist, biologically active areas and dry dormant areas can cause temperature to build up to the point of auto-ignition.

Stability of compost  The degree to which the composted material can be stored to used without giving rise to nuisances or can be applied to the soil without introducing phytotoxins and will not deplete soil nitrogen. A stable compost continues to decompose at a very slow rate and has a low oxygen demand.

Stabilization  1. The conversion of organic material to compost.  2. To convert to a form that resists change. In the waste industry this term is used to refer to heavy metals, pathogens, nutrients, and other substances present in organic waste which become inert and unlikely to be taken up by plants or leached into the water table or air.

Starch  A carbohydrate composed of the sugar glucose chemically bonded together in long, usually branched chains. Starch is an energy storage molecule produced by plants. It is used in adhesives, foods, cosmetics, medicines, and other materials. Starch is a granular solid and chemically a complex carbohydrate \((C_6H_{10}O_5)_n\).

Static pile system  A pile of organic matter that may or may not be aerated, left to stand in place without turning while undergoing decomposition.

Stormwater  Rainfall and snow melt runoff.

Strict anaerobe  An organism that performs metabolism using oxidized forms of nutrients (carbon dioxide, nitrate, nitrite, sulfate, sulfite, etc.) as the final electron acceptor in metabolism. Strict anaerobes will be destroyed when they come in contact with di-oxygen, or ozone, as their membrane structure is broken down by these compounds.

Subgrade  The layer of earthen materials upon which the pavement of a road, compost pad, or leachate collection pond is laid.

Subsoil  The bed or stratum of earth immediately under the surface soil. Often referred to as the mineral horizon. Roughly, that part of the soil below plow depth.

Substrate  The carbon source in composting material.

Sugar  Any of a class of sweet, soluble, crystalline carbohydrates, as the disaccharides (sucrose, lactose, and maltose) and the monosaccharides (glucose and fructose). Sugars are found in many plants—especially sugar cane, sugar beets and other vegetables, melons, berries, and fruits—and in the sap from certain trees such as some maple trees.

Suspended solids  Particles in leachate or wastewater that are large enough to settle out of solution or be filtered out.
**Sustainable agriculture**  An agriculture that is continuously productive and profitable; conserves natural resources and enhances the health and safety of people, domestic animals and wildlife.

**Swale**  A low place in a tract of land, usually producing ranker vegetation than the adjacent higher ground.

**Swill**  Liquid or partly liquid food for animals, specially kitchen refuse given to swine; slop.

**Taxonomist**  One who practices the science dealing with the description, identification, naming and classification of organisms into hierarchical groups or *taxa*. These groups are kingdom, phylum, class, order, family, genus, and species. Genus and species names are used together for clarity, such as *Homo sapiens* and *Eisenia fetida*, the genus being capitalized and the species written in lower case. *E. fetida* belongs to Kingdom *Animalia*, Phylum *Annelida*, Class *Oligochaeta*, Order *Haplotaxida*, Family *Lumbricidae*, Genus *Eisenia*, Species *fetida*.

**Thermophile**  An organism adapted to living at high temperatures, as some bacteria and algae.

**Thermophilic**  Heat-loving microorganisms that thrive in high temperatures. The thermophilic phase in the composting process occurs between 45 and 75°C (113 and 167°C). It is associated with specific colonies of microorganisms that accomplish a high rate of decomposition.

**Tillage systems**  The mechanical means of preparing a seed bed and caring for seeds and plants, including moldboard plowing, discing, and cultivating; and the use of conservation tillage, such as no-till or mulch tillage (leaving last year’s plant residues on the surface of the soil) to reduce erosion and increase water infiltration of the soil.

**Tilth**  The physical condition of a soil with respect to its fitness for the growth of plants.

**Tipping fees**  Fees charged to haulers, usually in dollars per ton, for unloading or dumping waste material in a landfill, transfer station, recycling center, waste-to-energy facility, or composting site. Sometimes shortened to *tip fees*. Also called a disposal or service fee.

**Top dressing**  Applying a layer of compost or other material to the surface of the soil.

**Topsoil**  The darker-colored soil on the earth’s surface containing the highest amount of organic matter and nutrients (needed for food production).

**Total coliform**  An indicator for pathogens. Total coliform in a composting matrix is significantly reduced within a short time at 140°F.
Total solids  The material in biomass that remains as residue when the biomass is dried in a forced-air over at 70±5°C for 18-24 hours to the point of no further weight (moisture) loss.

Toxicity  Adverse biological effect due to toxins and other compounds.

Toxin  Compounds that cause a reduction of viability or functionality in living organisms.

Trace Elements  Elements whose concentrations are a concern because of their potential to cause toxicity in humans, animals, or plants—including copper, nickel, cadmium, lead, mercury, and zinc present in excessive amounts. Trace elements also include metals that are essential for growth, such as copper and nickel.

Transfer Station  A permanent, fixed, supplemental collection and transportation facility used by persons and route collection vehicles to deposit collected solid waste from off site into a larger transfer vehicle to transport to a solid waste handling facility.

Transpiration  Loss of water vapor to the atmosphere from the leaves and stems of living plants.

Trommel  A rotating cylindrical screen essentially horizontal with a slight downward incline from the feed end to the discharge end. The tumbling action assists in size reduction and in the separation of incoming materials. See also harvester.

Tubercula pubertatis  Glandular swellings that occur on both sides of the clitellum. They are not always present, and they can be continuous or discontinuous with the clitellum. Their size and shape may vary from long narrow bands, triangles, or sucker-like shapes, depending on the species.

Tub grinder  A special type of shredder or hammermill generally used for size reduction of brush, tree limbs, and wood pallets.

Turning  A composting technique that mixes and agitates material in a windrow, pile, or vessel. Its main effect is to increase the porosity of the windrow to enhance natural pile aeration. It can be accomplished with bucket loaders or specially-designed turning machines.

Valeric acid  A volatile organic acid produced through the incomplete anaerobic oxidations of organic matter, typically identified as vomit smell.

Vector  A carrier such as an animal, air current, and/or water stream that ingests or conveys garbage, odor, microorganisms, and/or pathogens from one location to another. Most common usage of the term “vector” refers to animals, insects, or other organisms that carry pathogens from one host to another, such as rats, flies, birds, and mosquitoes.
Such pests are frequently carried into composting facilities by delivery trucks and are attracted to compost facilities by the odor of decomposition. Vectors need to be controlled for public health and aesthetic reasons.

**Vegetative** Feedstocks used for composting which are derived from plants including but not limited to: fruit and vegetable peelings or parts, grains, coffee grounds, crop residue, waxed cardboard and uncoated paper products. Vegetative material does not include oil, grease or dairy products such as milk, mayonnaise or ice cream.

**Vermicast** 1. Earthworm casting. 2. According to *Worms Eat My Garbage*, author Mary Appelhof defines it as “A single worm casting or a quantity of worm castings. Worms ‘work’ material by ingesting, excreting, and re-ingesting it. Vermicast is extensively worm-worked and re-worked. It may be overworked and has probably lost plant nutrients as compared to vermicompost. Vermicast has a fine, smooth texture which may dry with a crust on the surface.” 3. Term for earthworm castings used in Australia and India.

**Vermicompost** 1. Worm-worked material, containing both earthworm castings and other organic materials not ingested by earthworms. 2. Often used synonymously with “worm castings.” 3. “Mixture of partially decomposed organic waste, bedding, and worm castings. Contains recognizable fragments of plant, food, or bedding material, as well as cocoons, worms, and associated organisms.” [*Worms Eat My Garbage. 2nd ed.*]

**Vermicomposting** The process by which earthworms convert organic matter into earthworm castings.

**Vermiculite** A natural mineral used as an amendment in potting soil.

**Vermiculture** The raising of earthworms under controlled conditions.

**Vermimicrobedaphic** A term invented by Dr. Michael S. Bisesi to describe the biotechnology of converting organic matter by earthworms. *Vermi* is Latin for “worm,” *microb* is a shortened form for “microbes” and *edaphos* is Greek for “soil.”

**Vermin** Noxious or objectionable animals, especially those of small size that appear commonly and are difficult to control, as flies, lice, cockroaches, mice and rats.

**VOC** Volatile organic compounds.

**Volatile Compound** A compound of substance that vaporizes (“evaporates”) at relatively low temperatures or is readily converted into a gaseous by-product; examples include alcohols and ammonia; volatile compounds are easily lost from the environment of a compost pile.

Volatile Fatty Acids Organic acids produced during anaerobic decomposition of organic matter that contribute to offensive compost odors.
Waste  Rejected as useless or worthless; refuse, garbage, trash; something left over or superfluous and left unsalvaged; something destroyed; something neglected rather than used; anything unused, inadequately used or unproductive.

Waste audit  An inspection, examination, evaluation and/or verification of a waste stream. It is a detailed accounting of the amount of materials purchased, used, recycled, and disposed of. An audit identifies the proportions of various materials within the waste stream such as glass, plastic, aluminum, paper, ferrous metal, food waste, etc. and may identify volumes generated at regular intervals (daily, weekly, monthly, annually). Audits help identify the points at which changes in purchasing, consumption, and use can reduce or eliminate material. A waste audit includes quantifying current disposal costs and discarded material; identifying and quantifying materials that are unnecessary, reusable and recyclable; estimating cost savings; and implementing and monitoring the program.

Waste reduction  All means of reducing the amount of waste that is produced initially and that must be collected by solid waste authorities. This ranges from legislation and product design to local programs designed to keep recyclables and compostables out of the final waste stream.

Waste stream  A term describing the total flow of solid waste from homes, businesses, institutions and manufacturing plants that must be recycled, burned, or disposed of in landfills; or any segment thereof, such as the “residential waste stream” or the “recyclable waste stream.”

Waste-to-energy system (WTE)  A method of converting MSW into a usable form of energy, usually through combustion.

Water infiltration  The moving of water through the open spaces of the soil. Earthworms develop pore space in soils through their burrowing activities.

Water Table  The upper surface of groundwater.

Windrow  A long, relatively narrow, and low pile. Windrows have a large exposed surface area which encourages passive aeration by chimney effect and drying. In composting, windrows are turned mechanically with a front-end loader or specially designed windrow-turning equipment. In vermicomposting, windrows are not turned, but feedstocks are continually applied to the surface until such time that earthworms are separated and vermicompost is harvested.

Windrow turner  One of a series of devices either self-propelled or driven through a tractor power take-off for the purpose of forming and turning windrows of composting material. Windrow turners may be either wheeled or tracked mechanisms that move through the pile, forming a new windrow either directly behind or beside the original pile. Two common designs of windrow turners convey material upward, mix it, and drop it back into a windrow; or use rapidly rotating flails to move material up and backward, forming a new windrow behind the machine.
Wood waste  Chemically untreated wood pieces or particles generated from processes commonly used in the timber products industry. Such materials include but are not limited to used wooden pallets and grates, post-consumer wood wastes, sawdust, chips, shavings, stumps, bark, hog-fuel and log sort yard waste, but do not include wood pieces of particles containing or treated with chemical additives, glue resin or chemical preservatives, such as creosote, pentachlorophenol, or copper-chrome-arsenate.

Worm  Any of numerous long, slender, soft-bodied, legless, bilaterally symmetrical invertebrates, including the roundworms, platyhelminths, acanthocephalans, nemerteans, horsehair worms, and annelids. Worms include leeches, grubs, parasitical intestinal worms, and marine worms. All earthworms are worms, but not all worms are earthworms. See also earthworm.

Worm bin  A container specially prepared for earthworms to live in and process organic residues. Bins may be constructed of wood, metal or plastic, are situated indoors or outdoors, and are representative of the batch method of vermicomposting. Depending upon the size and weight of the contents, a bin may or may not be portable. Generally allowing for aeration, most worm bins also allow for drainage of leachate.

Worm tea  1. A liquid consisting of finished vermicompost that has been steeped in water to concoct a “tea” that is applied to either the root zone of plants or sprayed directly upon plants as a foliar. 2. The leachate or percolate collected from a functioning vermicomposting system.

Yard Trash  1. Vegetative matter resulting from landscaping maintenance or land clearing operations and includes materials such as tree and shrub trimmings, grass clippings, palm fronds, trees and tree stumps. [Florida Administrative Code] 2. Yard trash can include any of the following materials: chunks of asphalt and concrete, bricks and tiles, clay and plastic flower pots, wood trimmings, building demolition debris, nails and screws, pipe, wire, tools, used lawn mower blades, empty motor oil cans, used motor oil, used oil filters, used air filter, other used car, lawn and garden equipment parts, bicycle parts, empty pop containers, plastic cups, plastic plates and tableware, paper cups and plates, paper napkins, empty beer bottles and cans, gloves, caps, children’s toys, tennis balls, golf balls, discarded sports equipment, lawn furniture, water hoses, sunglasses, jewelry, light bulbs and broken glass, plastic bottles and lids, plastic banding, plastic grocery bags, plastic newspaper bags, plastic leaf bags, foil wrapping paper and ribbon, rope and string, paint brushes, can and lids, spray cans. [Compost Facility Operating Guide]

Yard Trimmings  Grass clippings, leaves, twigs, weeds, brush, bushes, shrub and tree prunings six inches or less in diameter, Christmas/Holiday trees, garden trimmings, and other vegetative matter from land clearing activities, and from residential, commercial, institutional, business, and public lands and parks landscaping activities; does not include putrescible material. See also green waste.

Zero discharge  Containment of all leachate from a facility, or the prevention of the production of leachate.