1.7

Making and Using Compost

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Introduction: Making & Using Compost

UNIT OVERVIEW

High-quality compost is one of the essential organic matter inputs, along with green manures, used to manage soil health in organic farming and gardening systems. In this unit students will learn the fundamental concepts and practices used to produce quality compost with aerobic high-temperature composting techniques, with a focus on garden-scale practices.

The lecture introduces the biology of the composting process and the critical elements involved in successful compost production. Demonstrations provide instructions on the materials, suggested content, and activities for teaching students the basic skills and knowledge needed to produce high-quality compost on both field and garden scales. Using step-by-step instructions and a suggested hands-on exercise, students will build and track the progress of a garden-scale compost pile. Field-scale considerations are briefly reviewed and a case study included, along with an example of a successful urban composting program that also addresses healthy food access.

MODES OF INSTRUCTION

> LECTURE (1 LECTURE, 1.5 HOURS)
> The lecture reviews the benefits of composting and the biology of the composting process, emphasizing the key factors required for quality compost production and its use at the garden and farm scale.

> DEMONSTRATION 1: GARDEN-SCALE COMPOST PRODUCTION (1–1.5 HOURS)
> The garden-scale compost demonstration details how to construct, troubleshoot, and assess aerobic hot compost piles, including a step-by-step outline for students to follow.

> HANDS-ON EXERCISE FOR STUDENTS (3 HOURS INITIALLY; MONITORING OVER 6 MONTHS)
> This exercise takes students through the process of building and monitoring a garden-scale compost pile over several months.

> DEMONSTRATION 2: FIELD-SCALE COMPOST PRODUCTION (1 HOUR)
> The demonstration outline details how field-scale compost windrows are made and monitored.

> ASSESSMENT QUESTIONS (1–2 HOURS)
> Assessment questions reinforce key unit concepts and skills.

> POWERPOINT
> See *casfs.ucsc.edu/about/publications* and click on Teaching Organic Farming & Gardening.

LEARNING OBJECTIVES

CONCEPTS

- The benefits of aerobic hot composting and the benefits of compost in soil
- The different stages of the biological composting process and the key composting organisms responsible at different stages
- The key factors for aerobic hot composting including carbon-to-nitrogen ratio, moisture, aeration, and volume

SKILLS

- How to assess compost materials
- How to build a compost pile
- How to troubleshoot, turn, and track a compost pile
- How to assess finished compost for various uses

Lecture 1: Making & Using Compost

Pre-Assessment Questions

1. What is compost?
2. What are some examples of composting systems and how do they differ?
3. Why is aerobic high-temperature composting favored for agricultural /horticultural purposes?

A. Compost and Types of Composting Defined

1. Composting defined
   a) Composting is a biological, chemical, and physical, highly aerobic process that transforms large, bulky, coarse materials (mostly plants and animal manures) to a homogenous, stable end product that is: uniform, brown/black in color, crumbly in texture (slightly greasy), sweet smelling, and particulate. Finished compost is a source of nutrients for plant growth and a feedstock for soil organisms.
   b) The process is biological as it is achieved by organisms. The actual decomposition is chemical via acids and enzymes. The physical aspect involves macroorganisms (mostly arthropods) and their chewing, shredding, and mixing actions. See Supplement 1, Making Quality Compost at a Garden Scale.
   c) Compost can be used in two ways: As a soil builder/conditioner that improves the physical properties of a soil (especially structure and bulk density), and as a fertilizer, with both immediate and long-term effects
2. Examples of composting systems
   a) Indore windrow method: The classic high-temperature aerobic composting method featuring animal manures and green waste, popularized by Sir Albert Howard. Growers and commercial producers use this method and its variations (e.g., the Luebke method)
   b) UC Rapid Composting: Features frequent turning of the pile (daily or every other day) to rapidly produce compost (see Resources)
   c) The UCSC Farm & Garden method: A variation of the Indore method; hand-built scale, high-heat aerobic piles for garden use
   d) Sheet composting: Spreading and burying organic material (leaves, greens, etc.) over a garden bed or landscape, then digging it in to decompose. Additional nitrogen is sometimes applied.
   e) Vermicomposting: Also known as worm composting, vermicomposting systems rely on earthworms (often "red wigglers", *Eisenia fetida*) to digest and decompose organic material, resulting in nutrient-rich "castings" used as a fertilizer and soil conditioner
   f) In-vessel composting: Features a closed system such as a building or large metal containers in which temperature and airflow can be controlled. Often used to compost municipal wastes.

B. Benefits of Aerobic Hot Composting

1. Advantages of aerobic hot composting process
   a) Stabilizes volatile nitrogen. Composted organic matter contains nitrogen in a more stable form (nitrate) that is more usable by plants.
   b) Kills most pathogens, e.g., *E. coli* and Salmonella, and weed seeds (if piles are above 131˚F for 15 days)
   c) Introduces a wider population of microbes than found in the raw ingredients
   d) Reduces volume of wastes (by approximately 50%)

e) Allows for use of raw materials that shouldn't be put directly in soil (e.g., sawdust, raw manure)

f) Degrades many contaminants since most pesticides are petroleum- (carbon)-based and thus digestible.

g) Recycles organic matter on farm and reduces off-farm inputs (nutrient cycling)

h) Improves bulk density, a measurement of a weight of a volume of soil including both the solids and the pore space. In general, a lower bulk density number means better soil conditions. Bulk density increases with compaction; soils with a high bulk density can restrict root growth.

2. Benefits of compost in the soil

   a) Improves soil structure and soil aggregate stability, resulting in better drainage, aeration, air/gas exchange, erosion resistance, tilth (workablity), and the soil's ability to recover from compaction. Microbes in compost secrete glue-like compounds that help bind soil particles together.

      i. Microbes, particularly bacteria, have a thick, mucilaginous capsule surrounding them that helps attach them to soil particles, and in turn to encourage individual soil particles to bind together into aggregates

      ii. Soil microbes live within and between the micropores in soil aggregates, thus binding them into more stable aggregates. Bacteria do this by sticky exudates, fungi by the binding action of their hyphae.

      iii. Soil microbes as well as plant roots exude sugar-like polysaccharides (non-sweet sugars) and other compounds that bind individual soil particles together

      iv. The thread-like hyphae of fungi secrete a gooey protein called glomalin that also aids in aggregation

      v. As organic residues decompose, gels and other viscous microbial byproducts are secreted into the soil and encourage a crumb or granular type of aggregation

   b) Increases moisture retention

   c) Provides a slow-release source of nutrients and increases availability of minerals. Increases Cation Exchange Capacity (CEC) and percent base saturation, thus increasing availability of Ca, Mg, and K. Also, humic and fulvic acids in finished compost help dissolve minerals in the soil, making phosphorus, calcium, magnesium, potassium, and other nutrients available to plants. See Unit 1.11, Reading and Interpreting Soil Test Reports, and Unit 2.2, Soil Chemistry and Fertility, for more information on CEC.

   d) Increases the population and diversity of microbes in soil that continually make nutrients available to plants. Provides food for microbes.

   e) Helps buffer soil pH by neutralizing both acid and alkaline soils and bringing the pH levels to the optimum range for nutrient availability to plants. Compost pH is optimally 6.0–7.0.

   f) Compost organisms promote disease suppression by various tactics (competitive interactions):

      i. Predation: E.g., fungi predate on detrimental nematodes)

      ii. Competition: Outcompete pathogens for niches and resources

      iii. Suppression: Produce acids and antibiotics that suppress or kill pathogenic organisms

   g) Plays key role in soil fertility management in organic systems

3. Potential disadvantages of composting (see also L. Field Scale Compost Considerations, below)

   a) Cost and time: Many farmers and gardeners don't make their own compost because of equipment needs, materials costs, and labor expenses

b) Space needed for composting can take up available production land

c) Odor or other impacts on neighbors can create challenges in urban/suburban areas

d) Rules governing compost production methods must be strictly followed if operating a certified organic farm (see National Organic Program, *www.ams.usda.gov/nop* for composting regulations)

C. Biology of the Composting Process

1. Compost ecosystem overview

   a) What makes composting happen? A wide range of decomposers are naturally present in most soils and on organic matter. Microbial decomposers can account for 60%–80% of total soil metabolism. See the discussion and depicition of "Process and Participants" in Supplement 1 and Appendix 1, Compost Time/Temperature Curve.

   b) Decomposer organisms play different roles in a complex compost food web (see Appendix 2, Compost Food Web). Microscopic organisms such as bacteria, fungi, actinomycetes, and yeasts are mostly primary consumers of compost materials. Macroscopic organisms such as mold mites, nematodes, springtails, centipedes, beetles, and earthworms feed on the primary and secondary consumers.

2. Key compost organisms

   a) Bacteria are primarily responsible for the first stages of decomposition in the composting process

      i. Feed on succulent plant materials such as simple sugars, plant saps, proteins and some starches. As their populations can double hourly, the initial rate of decomposition is rapid.

      ii. Use primarily enzymes, manufactured from the N-rich material in the pile, to decompose the organic matter.

   b) Fungi

      i. Also decompose simple sugars, plant saps, proteins, and starches, but their primary role is to decompose the most resistant carbonaceous compounds in the pile, such as chitin, lignin, and cellulose

      ii. Improve soil structure by physically binding soil particles into aggregates

      iii. Suppress disease

   c) Actinomycetes

      i. Filamentous bacteria, some of which grow as segmented hyphae (strands) that resemble fungi. Actinomycetes give compost its earthy smell.

      ii. Produce long, grayish, thready or cobweb-like growths that are most commonly seen toward the end of the composting process

      iii. Can decompose complex carbon, including lignin, chitin and cellulose. Enzymes enable them to break down woody stems, bark, and newspapers.

      iv. Responsible for some disease suppression (produce enzymatic compounds and antibiotics)

   d) Macroorganisms: Earthworm and other later compost pile immigrants (see discussion of Process and Participants in Supplement 1)

      i. Though not always present in finished compost, macroorganisms feed on the pile's earlier inhabitants

      ii. Examples: Nematodes, mold mites, springtails, wolf spiders, centipedes, sow bugs, earthworms, ground beetles (for more information, see Unit 2.3, Soil Biology and Ecology)

3. Compost temperature curve and bacteria (see Appendix 1)
   a) 50˚–113˚F: Mesophilic (mid-temperature loving) bacteria and other organisms populate the pile in the first 24–48 hours, multiplying quickly and causing temperatures to rise with increased metabolism. As internal pile temperatures rise above 113˚F, mesophilic organisms start dying out and thermophilic bacteria populations rise.
   b) 113˚–150˚F: Thermophilic (heat-loving) bacteria, which are present as dormant spores at lower temperatures, multiply quickly in the heating compost pile. Temperatures can be sustained at 130˚–150˚F for two weeks or more. Turning the pile can help sustain high temperatures by reducing density of material and reintroducing oxygen for aerobic bacteria.
   c) 150˚F and above: May be too hot for thermophilic organisms to survive and biological activity may slow as a result. Temperatures optimally should remain at 150˚F or below.
   d) 120˚F and below: After the first month, a compost pile will cool to the point where mesophilic organisms will populate the pile. Mesophilic bacteria repopulate, but fungi, actinomycetes, yeasts, and molds dominate this stage of composting.

D. Overview of Key Environmental Conditions for Aerobic, Hot Composting

Successful composting requires creating the right environmental conditions for decomposers to function optimally. Key conditions include:

- Carbon-to-nitrogen (C:N) ratio of materials
- Moisture
- Aeration
- Surface area of compost materials
- Volume of compost pile
- Turning and troubleshooting

E. Compost Materials: Key Considerations

1. Carbon-to-nitrogen (C:N) ratio (see Appendix 3, C:N Ratio of Common Compost Materials)
   a) The carbon-to-nitrogen ratio refers to the proportion of carbon to nitrogen by weight in any organic matter. Different types of organic matter have different carbon-to-nitrogen or C:N ratios. For example, wood, which is very high in carbon, has a C:N ratio of 500:1 while grass clippings have a C:N ratio of 17:1.
   b) C:N ratio of a material can change due to many factors: Plant growth, storage, how fertilized, what an animal was fed. Numbers on a chart are approximations.
   c) The optimum C:N ratio for biological activity is between 25:1 and 30:1. Compost piles should ideally start with an overall C:N ratio in this range. The C:N ratio of finished compost will be 14:1 to 17:1. Much of the carbon in the pile is released as CO_2 as decomposers metabolize organic matter.
2. Nitrogenous materials
   a) Compost materials with low C:N ratios are often called nitrogenous, sometimes "greens"
   b) There is a range of nitrogenous materials as demonstrated on the C:N ratio charts (see Appendix 3)
   c) C:N ratio of a material can change: As a growing plant ages it develops more carbon (e.g., young green grass growing into tall brownish-greenish stalks)
   d) Storage/treatment: Use greens when fresh. If necessary, make a concentric pile of greens; tarp to preserve N and use as soon as possible.
3. Carbon materials
   a) Compost materials with high C:N ratio are called carbonaceous, sometimes "browns"

b) Carbon materials can be more or less complex as shown on C:N chart (e.g., wood chips can have C:N ratio of 400:1, straw 70:1, brown leaves 40:1; see Appendix 3)

c) High carbon materials can be stored easily to use later (e.g., store brown leaves or straw stubble from fall to mix with the abundance of greens in the spring)

d) Carbon materials can be bulkier and thus can provide aeration in a pile

e) High carbon materials often are dry and can be difficult to properly moisten (can be spread out and soaked or left out in rain)

4. Animal manures

a) Manures are considered nitrogenous, but can have a wide range of C:N ratios depending on type of animal manure, feed source, bedding material, and age. See Appendix 4, Calculating C:N Ratios for Compost—A Rough Guide, for examples.

i. Poultry manure (approximately 6–12:1 C:N ratio) is high in nitrogen as well as phosphorus

ii. Horse manure (approximately 20:1 C:N ratio) mixed with bedding material (straw or woodchips). Bedding absorbs urine well, and half the N is in urine, half in manure. Manure can vary widely in its overall C:N ratio due to type and quantity of bedding material (e.g., is the "horse manure" pile mostly dry wood shavings? Think high carbon). Although not particularly high in nutrients (other than K), it is a great "tool" for building soil structure, whereas chicken manure is a more effective fertilizer.

c) In general, manures are more biologically active than plant residues due to having passed through an animal's digestive system

d) Raw manures can carry weed seeds, pathogens, pesticide residues, and antibiotics, so should be composted properly. If applied directly to the soil, National Organic Program regulations dictate raw (uncomposted) animal manures must be incorporated a minimum of 120 days prior to the harvest of crops "whose edible portion has direct contact with the soil surface or soil particles, (e.g., leafy greens) or 90 days prior to the harvest of crops with no direct soil surface or soil particle contact."

5. Balancing the carbon and nitrogen in a pile (see Appendix 4)

a) Consider approximate C:N ratio of each ingredient as a reference in deciding on quantity. Larger compost operations may test the C:N ratio of each ingredient and come up with formulas for quantities.

b) For smaller, hand-built piles, layering is a good way to estimate proportions and "homogenize" the pile. Thin layers are recommended to put the diversity of ingredients in closer proximity. The aim here is to meet all necessary criteria (C:N ratio, water content, oxygen content, particle size) uniformly throughout the pile. Examples of proportions, by volume (see also Supplement 1):

- 3 inches of fresh horse manure/bedding
- 3 inches of loose succulent greens
- 1/2 inch of loose oat straw (pre-wetted)

Another option is a plant-based recipe:

- 2 wheelbarrows of straw or deciduous leaves such as sycamore, oak
- 1 wheelbarrow of loose succulent greens or packing shed scraps (carrot tops, beet tops, overgrown zucchini, etc.)
- 1.5 five-gallon buckets of fresh, crumbly soil (from a recently turned bed

c) For large-scale composting, materials are often laid out along a windrow to gauge proportions and then turned with a mechanized compost turner. See discussion of large-scale compost production, below, and Supplement 2, Field-Scale Compost Production—A Case Study.

d) Trial and error: Make observations and keep records about what works, what doesn't (see Appendix 5, Compost Materials and Temperature Chart). Note that the quality of feedstocks directly influences the composting process, and thus the quality of the end product.

6. Other components some advocate adding to compost
   a) Clay soil: Those who use the Luebke method of compost think it's beneficial to use 10% clay soil in the pile because it reduces N losses, makes end-product more stable. Clay acts as a "colloidal trap," retaining nitrogen where microbes can convert it from a gaseous form into a useable form. Thin, repetitive layers of clay soil work best.
   b) Rock phosphate can increase usable phosphorus by making P more available to crops and help reduce volatilization of NH_3. By layering rock phosphate next to animal manures in a compost pile, the result is an increase in *Pseudomonas* spp. bacteria as well as nitrifying bacteria. These organisms immobilize both P and N in their bodies; when they die and decompose, those nutrients are liberated in a form available for plants to use.
   c) Inoculants (purchased biological "activators"): May be useful for dealing with some problems, e.g., high oil content plant residues, but considered unnecessary by most because compost organisms are present in manures, soils, and on plant materials. Some use aged compost as an inoculant if the composting area is new or on concrete.
   d) Wood ash: Using small amounts of wood ash in compost eliminates possible negative effects of high pH of ash when added directly to soil and adds potassium
   e) Rock minerals (to help speed their availability through chemical breakdown)
7. What not to compost
   a) Though often discouraged, composting manure of humans or other carnivorous or omnivorous animals (dogs, cats, pigs) is possible, but you must be very careful about pathogens (see EPA and World Health Organization guidelines, and *www.jenkinspublishing.com/humanure.html*). Food safety and organic certification regulations may prohibit the use of these materials in compost; check current guidelines.
   b) Perennial weeds that are resistant to decay such as Bermuda grass, oxalis, mint, bindweed
   c) Some diseased plants, e.g., fire blight on pear/apple wood, *Phytophthora infestans* (late blight) on potatoes and tomatoes
   d) Meat and dairy (if worried about attracting pests). Small amounts okay in center of pile.
   e) Large quantities of fats and oils: Compost organisms can't readily break these down
   f) Leaves of eucalyptus, walnut, and other trees with tannins or known allelochemicals; conifers (acidic, slow to break down). Small amounts of these materials are okay.
8. Particle size of materials
   a) Shredding or chopping materials, especially large, woody stalks, will speed the composting
   b) The greater the surface area to volume ratio, the faster the rate of potential decomposition. Decomposers work on surfaces, so the more surface exposed, the more decomposers can work.
   c) Compaction can occur if particle size is too small, and material is wet and nitrogenous (e.g., all lawn clippings), leading to loss of aeration and anaerobic conditions
   d) Layering sequence and thickness can be adjusted to avoid compaction and maintain aeration; alternate large with small particle sizes
   e) Waxy coated leaves decay very slowly because of coated surface

f) Municipal compost tub grinders reduce materials to 1 inch or less. A sharp spade or machete can be used to chop materials by hand.

F. Moisture

1. Moisture needs of decomposers
   a) All decomposers involved in composting need water
   b) Aerobic microbes, similar to marine mammals, need water around them all the time, but also need oxygen to survive. They live and move around on a film of water.
2. Moisture content in compost pile should be 50%–60% (moist as a wrung-out sponge)
   a) First consider the moisture of the materials to be composted
   b) Add water as pile is built, watering dry layers especially. More water should be put on layers in top half of pile, as much will trickle down (apply approximately two-thirds in top half, one-third in bottom half).
   c) Excess moisture will cause compaction, loss of air (you shouldn't be able to squeeze water out of compost)
   d) Insufficient moisture will cause a pile to decompose slowly
   e) If you're going to turn a pile frequently, you can add more water as you turn
   f) Turn pile, troubleshoot—add water if too dry, aerate and add dry material if too wet
   g) Seasonal moisture considerations: Tarp piles in winter to keep rain off; use compost covers, tarps or straw cap to conserve moisture in summer

G. Aeration

1. Aerobic bacteria, which make hot composting happen, require oxygen and respire carbon dioxide (CO_2)
2. Anaerobic bacteria populate portions of the pile where the oxygen content is low. They create methane gas and sulfur compounds (the rotten eggs smell) and can be harmful to soil life (commercial compost made in anaerobic digesters are often finished aerobically in windrows).
3. Oxygen is often the limiting factor when compost temperature goes down after first weeks
4. CO_2 can be monitored with special equipment—at 10–12% CO_2, need to turn the pile if possible
5. Turning the pile reintroduces oxygen, stimulating new growth of aerobic bacteria and further breaking down material, making it easier for microbes to decompose them. You can also break up anaerobic pockets within the pile as you turn it.

H. Volume and Temperature

1. Minimum pile size recommended is 5 feet x 5 feet x 5 feet to achieve the benefits of the hot composting process (although any almost any size can work, smaller piles will not heat up and will take longer to decompose)
2. At this volume the pile is self-insulating and can reach 130–150˚F for 10 days to 3 weeks
3. 131˚–145˚F = optimal temperature range. Turn if reaches 150˚F.
4. Maximum height and width should be 6 feet so as not to limit aeration or increase compaction of pile; air does not move more than 3–4 feet into a static pile
5. Compost fabric, straw cap, or soil cap can help retain some heat

I. Maturation and Turning

1. Most windrow piles take about 6 months minimum (spring into fall) to mature if not turned; longer in winter depending on climate. Note that National Organic Program (NOP) standards requires that windrows be turned five times, and remain at a temperature between 131˚–170˚F for 15 days, for use on certified organic farms. Be sure to check current regulations, as changes to these standards may occur.
2. Advantages of turning include:
   a) Speeds composting process by aerating the pile
   b) Achieves more thorough composting by moving outer materials to pile center
   c) Allows for troubleshooting and adjustments to pile (great learning opportunity)
   d) Additional mixing of ingredients
   e) Physical (mechanical) breakdown of particle size of materials
3. Disadvantages of turning include:
   a) Time, energy, expense
   b) Loss of nitrogen as pile is turned
   c) Additional space needed unless turning out and back
4. Turn at least once (more speeds process but is labor intensive by hand)
   a) If you turn compost only once, ideally do so at 3 weeks or when temperature curve has clearly started back down. After turning at this stage, temperature curve will go up again. At this point oxygen is the limiting factor—turning reintroduces oxygen for aerobic organisms to continue using as they digest the still relatively fresh materials.
   b) If you turn the pile twice, ideally turn at about 3 weeks and 6 weeks, again referring to heat curve for information

J. Assessing Compost Maturity and Stability

1. Parent material should be largely indistinguishable, texture should be crumbly
2. Temperature has cooled down to ambient temperature
3. Signs of macro life (e.g., redworms, sowbugs, springtails), though may not be present in large-scale operations
4. Dark brown to blackish-brown color
5. Earthy smell (no ammonia or anaerobic odor)
6. Feels "greasy" or slick when squeezed between fingers
7. Maturity vs. stability: A set of 7 quantitative indicators are used to define the maturity and stability of compost –
   - pH: 6.5 to 8.0
   - Sulfides: zero to only trace
   - Ammonia = <0.05 ppm
   - Ammonium: 0.2 to 3.0 ppm
   - Nitrites: <1.0 ppm
   - Nitrates: <300 ppm
   - CO_2: <1%

   Quantitative indicators adapted from "Quality Guidelines for Compost Chart," *compiled by Jon Nilsson (East Coast Compost) and Autrusa Compost Consulting criteria (George Leidig, Blue Bell, PA)*

K. Applying Compost

1. Timing
   a) Spring, prior to planting
   b) Mid season, as "side dress": Placed around established plantings and worked into the top 1–4 inches of soil
   c) Fall, with a planting of cover crops
2. Application rates
   a) Application rates vary with intensiveness of cropping system and use of cover crops
   b) Field scale: ~4–10 tons/acre on an annual basis
   c) Garden scale: ~ 0.5–2 lbs/square foot (this = 10–20 tons/acre annually). 1–2 lbs/square foot for soil development, 0.5–1 lb/square foot for maintenance.
3. Placement
   a) Field-scale: Incorporate into top 8–12 inches of soil
      i. Side dress: In the root zone of the crop
   b) Garden-scale
      i. Initial stages of soil development: Incorporate into top12–24 inches of soil (see Unit 1.2, Garden and Field Tillage and Cultivation, Appendix 3, French Intensive/Double Digging Sequence)
      ii. Soil fertility maintenance: Incorporate into top 4–8 inches via side forking

L. Field-Scale Compost Production (see also Supplement 2, Field-Scale Compost Production—A Case Study)

Many growers buy commercially produced compost, and some make large volumes of compost on site using a windrow system and compost turner or front-end loader

1. Advantages of making compost on site
   a) Quality control: Can monitor and maintain control, ensure quality end product
   b) Effective use of culls, other on-farm waste materials that would otherwise have to be disposed of
   c) Compost available when needed; commercial supplies not always available
   d) Potential cost savings in making compost on site vs. buying from commercial source
   e) Key part of soil health and fertility program; high quality compost helps ensure healthy soil
2. Challenges of making compost on site
   a) Up-front costs for equipment—compost turner, appropriate tractor/bucket loader, and irrigation infrastructure, etc.—can be high
   b) "Learning curve" involved: May take several years of fine tuning system to ensure reliable results
   c) Requires reliable sources of quality feedstocks, e.g., green waste, manure. Materials and delivery costs can be high.
   d) Requires labor inputs
   e) Requires dedicated space for delivery of feedstock and windrowing
   f) Requires water source
   g) Must comply with local and state ordinances re: leachates, odors, other considerations
   h) Certified organic operations must meet federal National Organic Program regulations; weather conditions (e.g., extended rainy periods), labor and time constraints can make requirements for 5 pile turnings in a 15-day period challenging

3. Recommendations if "buying in" compost from commercial producers
    a) Monitor quality; ask for records of inputs and nutrient analysis
    b) Visit the composting operation to inspect materials, practices used
    c) If certified organic, make sure product is approved by the Organic Materials Review Institute (OMRI, *www.omri.org*)
    d) Ensure adequate space available for deliveries

Demonstration 1: Garden-Scale Compost Production

for the instructor

OVERVIEW

Key to the process of building quality compost is the ability to assess the materials that will make up the pile. Before starting the pile-building demonstration, spend time discussing the materials you've gathered for the pile's construction. Providing a range of compost materials for discussion will enhance students' understanding of and skills in assessing carbon-to-nitrogen ratios, moisture content, and other variables of compostable materials. Variety also brings a wider range of nutrients and different feedstock for different types of microorganisms.

Useful comparisons for discussion include:

- green young weeds/grass clippings vs. older carbonaceous plants (same plant, different life stage)
- fresh manure vs. aged manure (horse, cow, chicken, other examples if possible)
- horse manure with straw bedding vs. horse manure with wood chips or shavings
- food scraps vs. crop residues

Spend time assessing various materials at the beginning of the demonstration and then review each as they are layered on the pile. Let students know that there is no one recipe for compost; each pile will differ based on the materials available, time of year, and the composter's own experience.

PREPARATION AND MATERIALS

1. At the compost site mark a 5 feet x 5 feet to 6 feet x 6 feet or longer area as the desired base of the pile.
2. Gather compost materials such as straw, greens (cover crops, crop residues, weeds), fresh horse manure, food scraps, chicken manure, brown leaves, older dried-out weeds or crop residues, etc. Make sure to have materials in sufficient quantities to complete at least a 5' x 5' x 5' pile. Keep each material in its own distinct pile (for comparison).
3. Gather tools, materials, and handouts: hose with sprayer, wheelbarrows, manure forks, spades, compost thermometer, compost materials and temperature record sheet (see Appendix 5, Compost Materials and Temperature Chart) and assignment sheet (see Hands-On Exercise).
4. Assess existing compost piles for examples of various stages of decomposition, piles built with different techniques or materials, and piles that may be too wet, too dry, etc. As an option, bring in some different compost samples. Include good examples of finished compost. Plan which to visit at end of demonstration.

PREPARATION TIME

1–2 hours

DEMONSTRATION TIME

1–1.5 hours

A. Plan the Pile with Students

1. Compost materials assessment

   Ask students to assess each compost material in terms of:

   a) Carbon-to-nitrogen ratio
   b) Moisture content
   c) Particle size
   d) Aeration

2. Pile location, size, shape

   Discuss considerations for:

   a) Location
   b) Size
   c) Shape of pile

3. Considerations for layering

   Plan how the pile will be built by discussing:

   a) Thickness of layers (as per material)
   b) Order of layers
   c) Amount of water to add to which layers (with more added in top layers than bottom)

B. Demonstrate Pile Building

1. Demonstrate proper tool techniques for safety and efficiency

   a) Discuss which tools are used and why
   b) Demonstrate proper use of each tool

2. Pile base

   a) Mark area for base size and discuss size parameters
   b) Demonstrate and discuss loosening soil within area
   c) Make first layer with manure or greens

3. Demonstrate layering (ask for 2–3 students to help)

   Map out layering sequence and for each layer:

   a) Review considerations for each material to make appropriate thickness
   b) Show how to judge layer thickness, uniformity
   c) Demonstrate how to "cinch" or "scratch" each layer slightly into layer below. This can be done with long handled forks or pulling forks. The objective is to slightly mix together (homogenize) the layers differing in C:N ratio.
   d) Show how to keep pile square (mind corners and edges)
   e) Demonstrate how to add water as needed

4. Review layers and sequencing as pile progresses

   a) Ask students to build a several-layer sequence and explain their process
   b) Are there new considerations as pile progresses or as materials available change?
   c) Assess pile shape and size

5. Demonstrate finishing a pile

   a) 5 feet high = maximum
   b) Finish with a carbon layer (e.g., straw cap) or soil as a sealant to prevent volatilizing of N in top layer
   c) Show use of tarp or compost cloth
   d) Show how to label pile with date, materials used, other information

C. Monitoring the Composting Process

1. Why monitor and why keep records
2. Demonstrate/discuss compost thermometer (and other monitoring devices if available)
3. Demonstrate how to use materials and temperature record sheet (Appendix 5, Compost Materials and Temperature Chart); show examples of record sheets from past, including timing of turning/aeration with temperature dip

D. Demonstrate Turning a Pile

1. Review the pros and cons of turning
2. Review when to turn, how often to turn
3. How to turn—outside materials to inside
4. Troubleshooting as you turn

E. Assess Existing Piles or Compost Samples

1. Examine piles at different stages of decomposition looking for:
   a) Heat, temperature curve examples (record book)
   b) Odor, color, texture
   c) Moisture
   d) Recognizable parent materials
   e) Different materials or techniques used
   f) Show examples in continuum from coarse to finished
   g) Examples of good, finished compost
2. Look for examples of problems to have students troubleshoot

F. Give students their compost-building and monitoring assignment

(see Step-by-Step Instructions and Hands-On Exercise)

Demonstration 1: Garden-Scale Compost Production

step-by-step instructions for students

INTRODUCTION

Use this set of instructions as a reference as you build and monitor compost piles

A. Planning the Pile

1. Compost materials assessment

   Assess each of the gathered compost materials in terms of:

   a) Carbon-to-nitrogen ratio
      - i. Is the material high in carbon? High in nitrogen? Or nearer to the ideal composting range of 25:1 to 30:1 carbon-to-nitrogen (C:N) ratio?
      - ii. How might age and storage have affected its C:N ratio?
      - iii. If manure, how would the quantity and type of bedding affect its C:N ratio?

   b) Moisture content
      - i. How much moisture is coming in with material? (e.g., lawn clippings can be 70% moisture)
      - ii. How much water should be added given time of year, ambient temperatures, rainfall?
      - iii. Aiming for 50%–60% moisture content—"moist as a wrung-out sponge"

   c) Particle size
      - i. How will the particle size of the material affect the pile's compost process?
      - ii. Should something be chopped up? How?

   d) Aeration
      - i. How will this material affect the overall aeration of the pile?
      - ii. If it might tend to compact, what can be done to lessen this effect?

2. Plan pile location, size, shape

   a) Location considerations
      - i. Proximity to use area, water source, materials source
      - ii. Ease of construction and access around pile
      - iii. Shaded area best to reduce drying in summer
      - iv. Compost piles located beneath trees may lose nutrients to tree roots

   b) Size considerations
      - i. Width and height—5 to 6 feet (for aeration and for easier access as building)
      - ii. Length: 5 feet (minimum) to any length
      - iii. Assess quantity and quality of usable material. How long a pile can you plan to make?

   c) Shape of pile
      - i. Aim for vertical sides to maximize volume of pile
      - ii. To retain moisture through summer, build pile with a flat top and a thick "cap" of straw

iii. Piles built to overwinter should have a more rounded top to shed rain (with straw cap)

3. Considerations for layering
   a) Thickness of layers (as per materials)
      Use thin layers for materials at either extreme of the C:N ratio range. Examples:
      i. Approximately 1- to 3-inch layers for things that are high C (straw)
      ii. Approximately 1- to 3-inch layers for things that are high N (fresh horse manure)
      iii. Approximately 4- to 6-inch layers for mid-range C:N materials (mixed weeds/ crop residues)
      iv. Use thin layers if particle size and/or moisture content make compaction likely
   b) Order of layers
      i. Some say you can speed decomposition by putting the manure layer (with its high population of microorganisms) on top of the green layer (with the most readily available food source in the form of plant saps)
      ii. Mixing or scratching layers slightly together helps homogenize pile, avoid compaction
   c) Amount of water to add (to which layers; top vs. bottom)
      i. Consider the material of each layer—moisture, particle size
      ii. Water each layer that needs additional moisture
      iii. Add more water to layers in top half of pile (some will trickle down to lower layers)

B. Building the Pile

1. Review proper tool techniques for safety and efficiency
2. Establish the pile base
   a) Mark off area for base size (5 feet x 5 feet or longer)
   b) Loosen soil in area with a spading fork to enhance aeration and migration of organisms
   c) Make first layer with manure or greens (enhance migration of soil organisms to higher N food source)
   d) Pile will be most compacted and thus least aerated at bottom. Bulky materials in base can aid in aeration but may make pile harder to turn.
3. Building layers
   As each layer is made:
   a) Review key considerations for each material to make appropriate thickness (relative C:N, particle size, moisture, aeration)
   b) Make layer uniformly thick
   c) Scratch (mix) each layer slightly into the next using spading fork or manure fork
   d) Keep pile square by pulling/adding material to corners and edges and tamping walls with fork
   e) Use hose sprayer to add water to layers that need it, paying attention to the corners and edges. Some materials (straw, dry manure) should be scratched with forks as watered to allow more even distribution of water.
4. Review key considerations as pile progresses
   a) Build a several-layer sequence and review key considerations as you go
   b) Assess new considerations as the pile progresses or as materials change (e.g., the weed pile first had fresh green weeds on the top, but now it’s just older, brownish weeds)
   c) Assess the pile shape and size as you progress

5. Finishing a pile
   a) 5 feet high = maximum for access/ease of building and for aeration
   b) Finish with a carbon layer (if pile is not to be finished that day, end with carbon)
   c) Use a tarp or compost cloth as protection from rain and from drying. Compost cloth "breathes"; tarps can limit aeration so some just use for rain.
   d) Label pile with date, materials used, other information

C. Monitoring and Recording the Composting Process

1. Monitor temperature with compost thermometer
   a) Take temperature daily for first month and after turning; then weekly
   b) Temperature should be taken at several points in the pile and averaged
   c) Thermometer should be inserted 18 inches to 2 feet into pile
   d) Hold thermometer by probe while inserting and removing
2. Record temperature and observations on record-keeping sheet (see Appendix 5)
   a) Track pile through decomposition process, creating heat curve graph as you go
   b) Use heat curve graph to assess pile performance, indicate when to turn

D. Turning a Pile

1. Review the pros and cons of turning
2. Turn at least once (more often speeds process but is labor intensive by hand)
   a) If only turning once, ideally do so at 3 weeks or when temperature curve has clearly started back down. At this point oxygen is the limiting factor—turning reintroduces oxygen for aerobic organisms to continue using as they digest the still relatively fresh materials.
   b) If turning twice, ideally turn at about 3 weeks and 6 weeks, again referring to heat curve for information (e.g., dip in temperature)
3. Turn outside materials to inside and inside to outside
   a) Pull outside materials off pile (outer foot of material will be drier, less decomposed). Set aside.
   b) Water outer layer of materials
   c) Spread a base layer of inner materials in space next to original pile
   d) Mix outer materials into center of new pile as you rebuild with inner materials (don't try to recreate original layers)
4. Troubleshoot any problems as you turn the pile
   a) Break up dry pockets or compacted clumps
   b) Water if too dry
   c) Leave overly-wet materials spread out to dry.
   d) Add nitrogenous materials if pile has not heated up and moisture is fine
   e) Low heat piles will still compost with time if you can't "fix" problem(s)
   f) "Failed" piles can be used as material for a new pile

E. Assessing Piles and Documenting Observations

1. Examine piles at different stages of decomposition for:
   a) Heat, temperature curve
   b) Odor
   c) Moisture
   d) Recognizable parent materials
   e) Different materials or techniques used
   f) Examples of good, finished compost
2. Look for trouble signs
   a) Too wet (can squeeze water out)
   b) Too dry (usually doesn't heat up properly, may have dry pockets)
   c) Anaerobic conditions (smells like sulfur, usually wet and compacted)
   d) Didn't heat up (could be lack of moisture, improper C:N ratio)
3. Make written recommendations for achieving desired rate of decomposition and implement them
   a) Heat, temperature curve examples (record book)
   b) Odor, color, texture
   c) Moisture
   d) Recognizable parent materials
   e) Different materials or techniques used
   f) Show examples in continuum from coarse to finished
   g) Examples of good, finished compost

Hands-on Exercise: Build & Monitor a Compost Pile

step-by-step instructions for students

SUMMARY

In groups of 2 to 3, you will build a group compost pile, and monitor its progress over the next 6 months. The step-by-step outline (pages 1-313–1-316) can serve as a guideline as you build the pile and later as you turn it. Use the Compost Materials and Temperature Chart (Appendix 5) to list materials and the sequence of layers, and to record temperatures, observations, and other data.

GROUP RESPONSIBILITIES INCLUDE:

- Assessing the available compost materials
- Planning compost layering
- Building the pile
- Keeping records on the pile (see record sheet in appendices) including labeling (name of pile, ingredients, date); record observations; daily temperature readings for first month; weekly temperature readings for subsequent months
- Turning the pile at least once (at 3 weeks or so)
- Troubleshooting any problems
- Answering the questions below after 1–2 months

QUESTIONS ABOUT YOUR PILE

1. How hot did your pile get and how long did it sustain this heat?
2. How does the heat curve on your pile compare to others you have seen? What assumptions can you make based on this heat curve?
3. When you turned your pile, what was your assessment of it? What if any troubleshooting did you need to do?
4. When you dig into your pile now, what recognizable materials remain? How does the pile smell, feel, look?
5. What other observations have you made about your pile?

Demonstration 2: Field-Scale Compost Production

for the instructor

OVERVIEW

This demonstration introduces the considerations, techniques, and mechanical equipment used in on-farm production of compost for use on a multi-acre scale. Students will first review the characteristics of compost feedstock, the importance of adequate moisture during the composting process, and be provided with examples of the temperature changes occurring in previously built compost piles. The instructor should also discuss optimal and necessary temperature ranges for organic certification, materials and techniques used to maintain optimal conditions for aerobic decomposition, and the various indicators used to determine compost maturity. In the second part of the demonstration, the instructor presents the specific techniques and equipment used in combining materials, monitoring and turning large compost piles, and factors to consider in applying finished compost. This exercise requires access to a commercial composting operation or farm that makes its own compost. See also Supplement 2, Field-Scale Compost Production—A Case Study.

PREPARATION AND MATERIALS

1. At the compost site mark a 5 feet x 5 feet to 6 feet x 6 Preparation and Materials

Ideally, materials for this demonstration would include mature compost, immature compost, an active compost pile, sample feedstock, and compost turning and application equipment, as well as temperature, turning, and feedstock records from recent compost piles. A laboratory nutrient analysis of compost should also be available.

DEMONSTRATION RESOURCES

- California's CalRecycle program, *www.calrecycle.ca.gov/organics*. Website offers extensive information on compost use in agriculture, including case studies of compost use and scientific research on compost's effects, as well as a list of compost and mulch suppliers.
- Magdoff, Fred, and Harold van Es. 2009. Chapter 13: Making and Using Composts in *Building Soils for Better Crops: Sustainable Soil Management, 3rd Edition*. Sustainable Ag Network Series Handbook #10. Produced by the Sustainable Agriculture Research and Education Program (SARE) and the US Department of Agriculture. Available free online: *www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*
- *Field Guide to On-Farm Composting*. 1999. Available from Natural Resource, Agriculture, and Engineering Service (NRAES) Cooperative Extension, 152 Riley-Robb Hall, Ithaca, New York 14853-5701, *www.nraes.org*.
- Rynk, Robert (editor). 1992. *On-Farm Composting Handbook*. NRAES 54. Ithaca, NY: Northeast Regional Agricultural Engineering Services

PREPARATION TIME

1 hour

DEMONSTRATION TIME

1 hour

DEMONSTRATION OUTLINE

A. Field-Scale Compost Making

1. Review compost-making process
   a) Examine feedstocks
   b) Discuss C:N ratios of various feedstocks
   c) Discuss importance of supplying adequate moisture during the composting process
2. Review temperature curves from past piles
3. Discuss National Organic Program definition of compost and requirements for compost production and use
4. Discuss importance of monitoring CO_2 levels as a guide for turning
5. Discuss optimum and required temperatures
6. Examine breathable tarp used for covering pile
7. Review and discuss nutrient profile of laboratory analysis of finished compost
8. Discuss indicators of compost quality and maturity (see J on page I-304 of the Lecture)

B. Equipment and Techniques for Windrowing, Turning, and Field Application of Compost

1. Explain and demonstrate how feedstock is layered for initial mixing
2. Explain and demonstrate how water is applied as necessary during the mixing process
3. Explain and demonstrate how feedstock is run through spreader to form windrow
4. Explain and demonstrate how compost pile is turned
5. Demonstrate and discuss techniques used in field application of compost
6. Discuss application rates of compost

Assessment Questions

1) List four benefits of aerobic, high temperature composting.

2) List four improvements to soil quality that would result from regular incorporation of compost into the soil.

3) Name the key decomposer organisms and describe their role at the various composting stages/ temperatures.

4) What temperature range is considered best for composting and why? What is too hot?

5) List the key conditions necessary for aerobic, high temperature composting.

6) Why consider the Carbon-to-Nitrogen ratio of the various compost materials? What is considered the ideal C:N range for composting and why?

7) What factors can influence the C:N ratio of a material?

8) What may happen if too much water is added to a compost pile? What may happen if the materials are too dry?

9) Why is aeration important in a compost pile?

10) What are some advantages and disadvantages to turning a compost pile? When and how often should compost piles be turned? (Please explain.)

11) Describe five qualitative indicators of compost maturity. What are some quantitative ways of assessing compost maturity and stability?

12) Imagine that you have an unlimited amount of each of the following materials for composting: Straw, chicken manure, horse manure, food scraps, greenish-brownish crop residues and weeds, and sawdust. How would you make a pile using these materials? Draw a diagram of the pile you would create. Discuss your layering, including thickness of each layer, order, water added or not. Add a short description of your suggested management plan (turning, monitoring).

Assessment Questions Key

1) List four benefits of aerobic, high temperature composting.
   - *Stabilizes volatile nitrogen. Composted organic matter contains nitrogen in a more stable form that is more usable by plants.*
   - *Kills most pathogens and weed seeds (if piles are above 131˚F for 15 days)*
   - *Introduces a wider population of microbes than found in the raw ingredients*
   - *Reduces volume of wastes (by approximately 50%)*
   - *Allows for use of raw materials that shouldn't be put directly in soil (e.g., sawdust, raw manure)*
   - *Degrades contaminants since most pesticides are petroleum- (carbon-) based and thus digestible. Organic matter also has a high capacity to bind heavy metals.*
   - *Guarantees that most of the end product will be humus and slowly-decomposing material that will become humus in the soil*
   - *Recycles organic matter on the farm and reduces off-farm inputs*
2) List four improvements to soil quality that would result from regular incorporation of compost into the soil.
   - *Improves soil structure and soil aggregate stability resulting in better drainage, aeration/gas exchange, erosion resistance, workability (tilth). Microbes secrete glue-like compounds that help bind soil particles together.*
   - *Increases moisture retention(100 lbs. of humus can hold 195 lbs. of water)*
   - *Slow release of nutrients and increased availability of others. Cation Exchange Capacity (CEC) is increased thus increasing availability of Ca, Mg, and K. (Also humic acids help dissolve minerals in the soil, making more minerals available to plants.)*
   - *Increases the population and diversity of microbes in soil that continually make nutrients available to plants. Provides food for microbes.*
   - *Helps buffer soil pH (compost pH is optimally 6.5–8)*
   - *Promotes disease suppression (different microbes suppress Fusarium, Pythium, Phytopthora, Rhizoctonia)*
   - *Plays key role in soil fertility management in organic systems. Along with soil organic matter and cover crops, compost is a major source of plant available N, P, and K.*
3) Name the key decomposer organisms and describe their role at the various composting stages/temperatures.
   - *Bacteria: Aerobic bacteria are the primary decomposers in the first stages of decomposition, feeding first on the most readily-available food sources like plant sugars. Their role is to do most of the primary consumption of simple carbon compounds, resulting in the liberation of heat and the warming of the compost pile and creating the environmental conditions for the subsequent colonization of microorganisms (below).*
   - *Fungi: Fungi decompose complex carbon compounds like chitin and cellulose*
   - *Actinomycetes: Actinomycetes decompose complex carbon, like chitin and cellulose*
   - *Macroorganisms: Earthworms and other later immigrants such as nematodes, mold mites, springtails, wolf spiders, centipedes, sow bugs, earthworms, ground beetles continue to break down organic matter after the pile has cooled*
4) What temperature range is considered best for composting and why? What is too hot?
   - *Between 131°–150°F for a minimum of 15–21 days. This should kill potential pathogenic organisms and weed seeds and prevent the volatilization of nitrogen containing compounds (e.g., ammonia) at higher temperatures.*
   - *Maximum temperatures of the compost pile should not exceed 150°F*

5) List the key conditions necessary for aerobic, high temperature composting.

- *Proper carbon to nitrogen ratio of materials: 25:1–40:1*
- *Moisture: 50%–60% by weight or "moist as a wrung-out sponge"*
- *Aeration: Periodic re-aeration through turning*
- *Surface area of compost materials: Small particle size will result in more rapid decomposition*
- *Volume of compost pile: A minimum of 5x 5x 5 is recommended*
- *Turning and troubleshooting: Compost piles should be turned when temperatures exceed 150°F and when the temperature of the pile has began to decline. National organic standards require 5 turnings within a 15-day period with a sustained temperature of 131°–170°F.*

6) Why consider the Carbon-to-Nitrogen ratio of the various compost materials? What is considered the ideal C:N range for composting and why?

- *C:N ratio affects the rate of decomposition. A low C:N ratio (below 25:1) may result in too rapid decomposition and the loss of nitrogen in the form of ammonia. A C:N ratio that is too high may result in a too long a decomposition process and a low quality end product.*
- *Ideal C:N ratio range is 25:1–40:1*

7) What factors can influence the C:N ratio of a material?

- *C:N ratio of a material can change due to many factors: plant growth, storage, how fertilized, and what an animal was fed*

8) What may happen when a pile is too wet or too dry?

- *If a compost pile is too wet it may not heat up, turn anaerobic, forming compounds that may be offensive smelling and detrimental to plant growth if not aerated prior to application*
- *If a compost pile is too dry it may not heat up or not sustain heat long enough to degrade the organic materials into a finished and useable product. Will often require reassembling the materials and moistening.*

9) Why is aeration important in a pile?

- *To assure adequate amounts of oxygen for aerobic decomposition*

10) What are some advantages and disadvantages to turning a compost pile? When and how often should piles be turned? (Please explain)

- *Compost piles should be turned when temperatures exceed 150°F or when the temperature of the pile has peaked, plateaued, and begun to decline. National organic standards require 5 turnings within a 15-day period with a sustained temperature of 131°–170°F. The greater the number of turnings, the faster the material will break down.*

11) Describe five qualitative indicators of compost maturity.

- *"Parent material" should be largely indistinguishable*
- *Texture should be crumbly*
- *Very small particle size*
- *Temperature has cooled down to ambient temperature*
- *Signs of macro life (e.g., redworms, sowbugs, springtails)*
- *Dark brown to blackish-brown in color*
- *Earthy smell (no ammonium or anaerobic odor)*
- *Feels "greasy" or slick when squeezed between fingers*

What are some quantitative ways of assessing compost maturity and stability?

- *Compost maturity and stability may also be determined through measurements of carbon dioxide and ammonium levels. This is commonly done in large-scale and commercial composting operations.*

Resources

PRINT RESOURCES

BOOKS

Brady, Nyle C. and Ray R. Weil. 2008. *The Nature and Properties of Soil, 14th Edition.* Upper Saddle River, NJ: Prentice Hall.

Comprehensive (965 pages) textbook on soils—great for those who want to "go deeper" into the origins, classifications, and workings of soil.

Cantisano, Amigo. 2012. *Know Your Soil: A Handbook for Understanding and Utilizing a Soil Analysis for Organic Growing, 3rd edition.* N. San Juan, CA: Organic Ag Advisors.

This 27-page booklet includes information on making and applying compost, and tips on what to look for when purchasing commercially made compost.

Dougherty, Mark (ed.). 1999. *Field Guide to On-Farm Composting.* NRAES-114. Natural Resource, Agriculture, and Engineering. Ithaca, NY: Cornell University Cooperative Extension.

A handy reference guide that helps on-farm composters find practical information about composting quickly and easily. Includes sections on equipment, compost recipes, site considerations, environmental control, and compost use.

Gershuny, Grace. 2011. *Compost, Vermicompost, and Compost Tea: Feeding the Soil on the Organic Farm.* White River Junction, VT: Chelsea Green Publishing Co.

Covers the principles and biology of composting, including methods, materials, and costs. Includes information on compost tea and vermicomposting, along with a section on legal issues related to composting and the National Organic Program. Appendices include recipe calculator, potting mix recipes that use compost, and sample compost production budget sheets.

Gershuny, Grace. 1993. *Start with the Soil.* Emmaus, PA: Rodale Press.

Includes an introduction to the tools and techniques of home- and garden-scale composting.

Howard, Sir Albert. 1943. *An Agricultural Testament,* Oxford, UK: Oxford University Press, archived from the original on 2 July 2010, pdf per Special Rodale Press Edition, 1976.

Jeavons, John. 2012. *How To Grow More Vegetables, Fruits, Nuts, Berries, Grains, and Other Crops Than You Ever Thought Possible on Less Land Than You Can Imagine, 8th Edition.* Berkeley, CA: Ten Speed Press.

Includes a section on the tools and techniques of home- and garden-scale composting.

Magdoff, Fred, and Harold van Es. 2009. *Building Soils for Better Crops: Sustainable Soil Management, 3rd Edition.* Sustainable Ag Network Series Handbook #10. Sustainable Agriculture Research and Education Program (SARE) and the US Department of Agriculture. *www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition*

This 294-page book covers all aspects of building healthy soil, including a section on making and using compost.

Martin, Deborah, and Grace Gershuny, eds. 1992. *The Rodale Book of Composting: Easy Methods for Every Gardener.* Emmaus, PA: Rodale Press.

A comprehensive introduction to home- and garden-scale composting, including a chapter on large-scale composting.

Smillie, Joe, and Grace Gershuny. 1999. *The Soul of Soil: A Soil-Building Guide for Master Gardeners and Farmers, 4th Edition.* White River Junction, VT: Chelsea Green Publishing.

Contains a brief section on farm-scale composting.

Stell, Elizabeth P. 1998. *Secrets to Great Soil.* North Adams, MA: Storey Publications.

Contains an introduction to the tools and techniques of home- and garden-scale composting.

Van Horn, Mark. 1995. *Compost Production and Utilization: A Growers Guide*. Publication 21514. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Includes sample calculations for achieving optimal C:N ratios, suggestions on compost management, nutrient profiles, and nutrient release patterns of composts.

PERIODICALS

BioCycle. The JG Press, Inc. *www.biocycle.net*

Offers business-oriented information on composting, anaerobic digestion, and biofuels processing.

WEB-BASED RESOURCES

Biocycle Magazine

www.biocycle.net/magazine/

BioCycle magazine online.

CalRecycle (California)

www.calrecycles.ca.gov/organics/

Includes extensive information on compost use in agriculture, including case studies, commercial compost sources, and state regulations.

California Integrated Waste Management Board

www.ciwmb.ca.gov

Provides health and safety information for composting.

Cornell University: Cornell Composting

compost.css.cornell.edu/index.html

Provides access to a variety of composting educational materials and programs developed at Cornell University.

EPM, Inc.

www.wormwigwam.com

Procedures for composting using earthworms, and a worm-composting system offered for sale.

Klickit County, Washington Solid Waste

www.klickitatcounty.org/solidwaste/fileshtml/organics/compostCalcAbout.htm

Resources for calculating the C:N ratio of compost piles.

National Organic Program

www.ams.usa.gov/nop

Provides regulations and standards for meeting composting requirements for organic certification. See Title 7, Agriculture; Part 205-National Organic Program; Subpart C-Organic Production and Handling Requirements, for rules relating to compost production.

Washington State University: Center for Sustaining Agriculture and Natural Resources

csanr.wsu.edu/compost/

WSU's compost research and education program provides useful information on large- and small-scale com-posting, use of composts, and regulations.

University of California Vegetable Research and Information Center

vric.ucdavis.edu/pdf/compost_rapidcompost.pdf

Information from University of California plant pathology professor Robert Raabe on a technique to rapidly produce compost, featuring frequent pile turning. 2 pages.

Worm Digest

www.wormdigest.org

Information, networking, and resources on all aspects of vermicomposting.

VIDEOS

The Compost Video Series. University of California Cooperative Extension Master Gardeners of Orange County, California. Available at *uccemg.com/Soils-Fertilizers-Compost/Composting-Video-Series-386/*

Nine short videos address a variety of home composting topics, including how to start, turn, and troubleshoot a compost pile.

Do the Rot Thing: The Simple Art of Home Composting. 1998. Alameda, CA: Alameda County Waste Management Authority and Recycling Board (22 minutes). Available on YouTube (search by title).

Covers the basics of home-scale composting.

SUPPLEMENT 1

Making Quality Compost on a Garden Scale

Compost, the process and the product, is an example of harnessing biology to assist in promoting healthy soil that in turn grows quality crops. Composting is about the decomposition and transformation of heterogeneous organic wastes (anything that was once alive) into a homogeneous, stable end product—organic matter/humus, that is, compost. Quality compost is a uniform product black in color, crumbly in texture, sweet smelling, slightly greasy to the touch, and a powerful reservoir of plant nutrients that are released slowly over time via further biological activity.

Benefits

Among the attributes of compost are –

- Immobilizes nutrients in the bodies of microorganisms. This keeps nutrients, especially nitrogen, from leaching out of the pile. When the finished compost is applied to the soil, nutrients are released slowly and in forms available to plants.
- Increases soil organic matter and cation exchange capacity.
- Provides a feedstock of nutrients as well as the "habitat" for beneficial soil microbes.
- Kills (some, not all) plant pathogens and weed seeds during the composting process.
- Inoculates the soil with beneficial microbes (bacteria, fungi, actinomycetes, etc.).
- Improves soil structure by promoting soil aggregation (binding soil particles together), which in turns promotes aeration, moisture retention, permeability, and consistency, thus improving the "workability" of a soil.
- Usually panacea-like in solving whatever problem your soil has.

Process and Participants

In constructing a compost pile you are setting the stage for the biological, chemical, and physical decomposition of bulky organic wastes and recycling of nutrients, taking the large, the rigid, the dry (think corn stalks), as well as the particulate, the wet and the slimy (think matted grass clippings or soggy kitchen scraps) and then transforming them.

This is a highly aerobic process, as oxygen fuels the metabolism of the microbes principal in the decomposition process. In fact, you could refer to a compost pile as a "microbial layer cake." The decomposition is carried out by succeeding waves (populations) of micro- and macro-organisms. You play the role of facilitating this process. In a sense, composting is a form of animal husbandry or "microbe farming."

As with any successful husbandry effort, habitat, diet, and water are the key building blocks of a successful compost pile. A compost pile is simply "pasture" for microbes. Via its ingredients, the pile provides a feedstock for the initial microbial populations and eventually the "finishers" or "shredders and chewers," macro-organisms such as earthworms, mites, sow bugs, centipedes, millipedes, etc. Microbial populations tend to be ubiquitous, thus there is no need for inoculants, as small populations exist on much of the substrate used in composting.

The composting process has three distinct phases:

1: Mesophilic (50º–113ºF) – Moderate temperatures, usually lasting under a week

2: Thermophilic* (113º–150ºF) – High temperatures, usually lasting 3–4 weeks

3: Curing – Ambient temperatures, lasting >3 months

**small piles, made incrementally, will not get very hot*

During the first phase, waves of bacteria and fungi multiply rapidly and feed on the succulent plants in the pile. When the pile is properly constructed, the first 24–48 hours feature an explosive, literally exponential growth of these organisms (bacteria can double their populations every 20–60 minutes). Often, there is no recognizable plant material in the pile after even a few days thanks to the chemical decomposition taking place. Remember, bacteria and fungi do not have mouthparts, and thus do not chew; rather, they secrete enzymes and acids that break down plant materials, and absorb the sugars and simple proteins for nutrition.

The next phase of decomposition features thermophilic, or heat-loving, organisms—still some bacteria, but increasingly, fungi. Fungi decompose (again, chemically) more complex carbon compounds such as chitin, cellulose, and lignin.

As the pile cools and begins its curing process, a third microbial population comes to the fore—a type of actinobacteria often referred to as actinomycetes. These have the simple cell structure of bacteria, but grow multicellular, hyphae-like filaments resembling fungi. Their enzymatic role is to degrade tough, resistant-to-rot woody stems and bark. Their gray-white filaments look "cobwebby" and have a pleasant, earthy smell. They can rot a redwood stake in the ground in 9–15 months.

When a pile has cooled and cured for 1–3 months, macroorganisms move in to finish the job. These organisms—mites, springtails, centipedes, millipedes, sowbugs, ants, nematodes, earthworms, etc.—are physical (as compared to chemical) decomposers. They use their mouthparts to chew, shred, and further break apart resistant materials, as well as feed on dead bacteria and fungi. In doing so, they also create a softer, more "open" substrate that can be re-colonized by bacteria and fungi, which break the materials down further.

Five Criteria for Success

What are the criteria for successful husbandry of a compost pile?

1. Pile Size and Dimensions

Conventional wisdom now states a minimum size of 5' x 5' x 5' is required for successful composting. But those working in small spaces shouldn't despair— ideal dimensions are about (maximum) volume to (minimum) surface area ratios. That is, a big pile has more internal mass and thus a more hospitable decomposition environment for the microbes involved. The bigger pile also features less surface area, as the ambient environment largely degrades the pile's surface.

Some tips on pile dimensions:

- Oxygen does not move passively more than 3–4' into a pile, so width should not exceed 6–8'.
- It is impractical (i.e., too much heavy lifting) to build a pile more than 4'–5' in height.
- Length is simply a function of the volume of material on hand.
- A cube-shaped pile is better than a pyramid or tapered haystack

2. Particle Size of Ingredients

The principle is the smaller the particle size (via chopping and shredding) the greater the surface area, the more the microbes can "occupy space" and thus the faster the rate of decomposition. Chopping plant material also breaks apart the rigid, often waxy outer cuticle of plants, making the succulent "innards" more accessible to the enzymatic and acidic secretions of bacteria and fungi, thus speeding and contributing to more thorough decomposition.

3. Aeration

As oxygen fuels the metabolism of the decomposers in a pile, the pile construction should feature adequate pore/air space. This is readily achieved by layering together an admixture of course materials and fine-chopped materials.

Once the process is underway (1–3 weeks) a pile will settle, losing 30–50% of its volume as the materials are physically broken down. At that juncture there is usually a sharp drop in temperature. As the pile settles, reducing pore/air space, and as microbial populations exhaust the oxygen supply, oxygen becomes a limiting factor. This is an opportune time to turn and re-aerate a pile. There is often a spike in temperature associated with turning: as oxygen is resupplied, microbial populations boom—the heat generated is a byproduct of their metabolism as they continue to break down materials in the pile.

4. Moisture

Compost pile ingredients should be about 40–60% moisture by weight. This equates to the consistency of a wrung-out sponge. It is best to apply water (sprinkle-spray, not drench) incrementally to each layer as you construct a pile. The moisture is for the microbes, but it also softens the pile ingredients. A note: as water will trickle down from top to bottom, apply less water to the lower layers of the pile. Also, as plants are merely supported columns of water (60–90% by weight), more water will be released into the pile as decomposition progresses. Thus, be conservative with the initial water application.

5. Carbon to Nitrogen Ration (C:N)

The ideal C:N ratio at the outset is suggested as 30–40:1. This means the pile has 30–40 times more carbon-rich than nitrogen-rich material by weight. While all materials contain some carbon, carbonaceous materials (think "browns": straw, leaves, wood chips, etc.) contain primarily carbon, and similarly, nitrogenous materials (think "greens": fresh, lush plant material and animal manures) feature a high nitrogen content relative to carbon.

What is important vis a vis C:N ratio is that this is the ideal proportion to fuel the diet of the pile's microbial decomposers. In essence, they use carbon to nitrogen in a 30–40:1 ratio.

Microbes use the carbon-rich ingredients as building blocks for cellulose and, as we do, for carbohydrates that fuel their work. They use the nitrogen to build proteins, amino acids, and enzymes that are necessary for cell growth, function, and reproduction. Enzymes are also key to the decomposition process; they act as biological catalysts, accelerating biochemical reactions and hastening the breakdown of organic matter. It is interesting to note that the enzymes produced by bacteria and fungi persist and function long after the producing organisms have died. In fact these same enzymes contribute to the breakdown of the "microbial corpses" that produced them.

You can achieve the desired 30–40:1 C:N ration by combining comparative volumes of carbon-rich (brown) and nitrogen-rich (green) ingredients in layers. A wide range of comparative volumes will work, from 50% carbon-based materials combined with 50% nitrogen-based materials, to as much as 80% nitrogen-based materials and 20% carbon-based materials. The pile higher in nitrogen will heat up more quickly, get hotter (130–150ºF), stay hot longer, break down faster, and kill more weed seeds and plant pathogens.

In creating the "microbial layer cake," thin, repeated layers work best. For example:

- C: 2" straw/leaves/wood chips, etc. (straw is a good absorptive material to use at the base of the pile)
- N: 2" kitchen scraps
- C: 2" straw/leaves/wood chips, etc.
- N: 6" fresh horse manure
- C: 2" straw/leaves/wood chips, etc.
- N: 4" greens
- C: 2" straw

Repeat to height of 4'–5'

The pile would then feature 40% carbon-based materials and 60% nitrogen-based materials by approximate volumes and predictably, do quite well. Note that vegan, or non-manure piles, work fine. The value of animal manures is that they are both rich in nitrogen and microbes—a sourdough starter of sorts to jumpstart a pile.

Compost and soil organisms metabolize carbonaceous materials to get carbon for building essential organic compounds and to obtain energy. However, no organism can grow, function and reproduce on carbon alone. They also need a sufficient amount of nitrogen to make nitrogen-containing cellular compounds such as—

Amino acids and enzymes, used to decompose organic matter—especially carbonaceous materials

DNA

Structural proteins; e.g., bacteria's structural proteins make flagella, used for locomotion

Soil microbes need to incorporate into their cells (on average) about 10 parts of carbon for every 1 part of nitrogen. Because only about 1/3 of the carbon ingested is actually incorporated into cells (the remaining 2/3 is respired and lost as CO^2), microbes need 30 parts carbon to 1 part nitrogen in their "feedstock," or a 30:1 C:N ratio. Note that although various texts give differing "ideal" C:N rations, from 20–40:1, we have found a 30:1 ratio most effective in hand-built compost piles.

Thus, a compost pile made with ingredients at a 30:1 C:N ratio provides microbes with a balanced diet that in turn enables them to thrive and reproduce and to decompose and digest the coarse material of a compost pile efficiently at the outset, and transform it into the fine, granular, soil-like product we call finished compost.

For more information on C:N ration see: ***compost.css.cornell.edu/calc/cn_ratio.html***

Finishing

Your finished compost can be used both to fertilize plants and to improve soil structure. Before you work the soil (digging or forking), spread compost on the surface of your bed. Then as you dig it will be worked in uniformly to the depth you are working the soil. Typical intensive garden application rates are ½–2 pounds/square foot. This range is dependent on your present soil development and fertility.

SUPPLEMENT 2

Field-scale Compost Production at Phil Foster Ranches: A Case Study

Phil and Katherine Foster farm 295 acres of vegetables and fruits on two certified organic ranches in San Juan Bautista and Hollister (San Benito County, California). At peak season, they work with a crew of 55 employees to produce more than 60 different crops, which are direct marketed through ten regional farmers' markets and a popular roadside stand. Phil also sells to numerous retail stores, where the Pinnacle Organic brand is a familiar sight to shoppers from Carmel to the San Francisco Bay Area.

Phil Foster is regarded as one of the region's most successful and progressive organic growers, in large part because of the craftsman-like approach he takes to building and maintaining healthy soil. He's the first to say that the compost he uses in his operation, produced on his Hollister ranch, is one of the keys to the exceptional quality and abundance of Pinnacle Organic's produce (*www.pinnacleorganic.com*). Phil generously offered to share the story of his compost operation during a visit to the ranch in spring 2014.

Background

After working in the conventional produce industry in California's Central Valley, Phil started farming organically in 1988 (both his ranches are certified organic by the California Certified Organic Farmers, CCOF). He initially spread manure on his fields in the fall to replenish organic matter following the cropping season and ahead of the winter rains, then switched to buying in commercially made compost from New Era. After attending a seminar on the Luebke compost production method[1] (also referred to as controlled microbial composting) at the nearby Herbert Family Organic Farm, Phil started making his own compost at the Hollister ranch in 1995. The compost yard now covers 4 acres, where his compost crew produces 2,000 tons of finished compost annually, enough for all of both ranches' needs.

Labor, Machinery and Compost Yard Set Up

Originally, the operation used an 8' self-propelled compost turner and a Zeton spreader from Farmers Equipment. Phil has since switched to a used 10' Sandberger pull-behind machine upgraded by HCL Machine Works (*www.compostturners.com*) in Dos Palos, California, which he purchased for $7,000 (new units run approximately $20,000). He had the machine rebuilt with common drum bearings to make it easier to fix in-house.

Other equipment used in the operation includes:

- Tractor with creeper gear or hydrostatic transmission for pulling the compost turner. Phil's crew runs it with an 80HP orchard tractor or a 90HP JD6410. You need roughly 10HP per foot of compost (10' to 80-90 HP).
- Wheel loader for moving feedstock, building windrows, and loading finished compost (he purchased his used for $10,000).
- Instruments to measure temperature, CO_2 production, microbial life levels (approximate cost $500).

Other compost yard considerations:

- Access to a water source to wet down compost during turning. Pinnacle's operation uses a dedicated tank with a trickle-fill system at 5 gallons/minute, so as not to disrupt the irrigation system.
- Adequate space to accept deliveries of large loads of feedstock and to store finished compost
- Proper grading to shed water and prevent pooling.

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1 Read more about controlled microbial composting at *www.herbertfamilyorganicfarm.com/Compost.html*

Key to the operation is Pinnacle employees Manuel Estrada, who works with other staff to meet the feedstock deliveries, build the piles, run the compost turning equipment, and measure and record temperature, CO_2 production, and other factors as the piles mature. Employees who work in the compost yard also have other roles on the ranch, but Phil notes that the expertise Estrada has developed over the years is vital to the compost operation's success.

Feedstocks

The composting operation uses a variety of feedstocks to create the proper balance of carbon and nitrogen in the windrows:

- Wheat straw is often laid down as a "footing" for each windrow, using 65 bales per row (though it has not been used the past two years). With a 70:1 C:N ratio, it quickly decomposes. Phil notes that bales that have been rained on can be purchased at a discount.
- Greenwaste includes "fines," or tub-ground vegetation from Vision Recycling in Santa Cruz County, which he cites as producing a high-quality product that offers an ideal 30–40:1 C:N ratio.
- A tree company provides a regular source of chipped wood and branches, another good carbon source.
- Cow manure is brought in from a dairy operation in Los Banos (a closer dairy that once delivered regularly recently shut down).
- Horse manure is delivered from local horse ranches.
- The farming operation generates a year-round source of "greens" for the piles in the form of culls, which make up 10–15% of each windrow by weight.

Timing

Pinnacle's compost operation kicks off in May, and during May and June the crew fills the yard with compost that will be finished August through September. They build more piles in October and November, before it typically becomes too wet to easily produce compost.

Once built, each 10'-wide x 400'-long windrow is turned every 2–7 days and requires about 16 weeks from building to finished material, during which time the volume shrinks by about half.

During the season the crew generates about 2,000 tons of finished compost for the two ranches (a trucking company trucks finished compost to the San Juan Bautista ranch); any piles left in the yard during winter are covered with breathable synthetic material to prevent leaching.

Temperature, Finishing, and Safety Considerations

The thermophyllic (high temperature) stage is critical to the production of a safe, high-quality product. A properly built pile should heat to 130º–150ºF for a minimum of 15 days, which requires turning the pile to reheat it by reintroducing air and water when it cools (note that National Organic Program regulations require the pile to be turned at least 5 times in a 15-day period). Turning reduces the temperature from above 150ºF. In addition, if the temperature gets too high, clay soil can be added as a buffer. When finished, temperature in the pile drops to 80ºF, CO_2 level decreases, and pH drops below 8.

To prevent cross-contamination, the compost turner, front end loader, and other equipment are thoroughly cleaned between turnings and between windrows, going from unfinished to finished piles. A hedgerow planted around the yard protects adjacent crops from windblown material and absorbs runoff from the site, and Phil avoids planting leafy greens around the yard to minimize any potential contamination issues.

In addition, each finished windrow is tested for *E. coli* and Salmonella. Phil also does a nutrient screening from 2–3 rows of finished compost each year to check N:P:K levels, as well as a microbial analysis to assess diversity and activity. In addition to meeting CCOF record-keeping requirements, the operation has also been inspected by the county health inspector annually.

Application Rate, Cover Crops, and Soil Organic Matter Levels

The ranches use about 10 tons/acre of finished compost mixed with gypsum in a 4:1 ratio (8 tons compost plus 2 tons gypsum). After bedding up, compost is spread using a manure spreader that matches the bed configurations (40" and 80") and worked in with a rolling cultivator prior to pre-irrigation.

In the orchards, compost is applied to every other row on top of a mowed cover crop using a smaller manure spreader, then worked in with a spader.

In addition to compost applications, every field is planted with cover crops in spring, late summer, or fall at least every other year, although for the last two years cover crop planting has been significantly reduced at the Santa Ana Ranch due to the drought. The combination of regular compost applications and cover crops has raised the soil organic matter levels on the ranches from 2–3.5% when Phil started farming in the 1980s to the current levels of 5–6%—remarkably high by Central California soil standards.

Costs, Pros and Cons

Phil says it costs about $35–$38/ton to produce compost on site, including labor, feedstock, fuel, and equipment repairs, which is comparable to the cost of purchasing finished compost from a commercial source.

Even with the relatively equivalent costs, he sees a number of advantages in making your own compost versus "buying in," including:

- The ability to control both the quality of inputs and the production process; that quality will show in improved soil health.
- Generating compost when you need it.
- Reducing farm waste products by using up culls; this also helps reduce levels of diseases and pests (e.g., maggots in culled onions).
- Spreading out costs over a longer time period.
- Having a known testing system in place in an ever-changing food safety regulatory environment.

Phil also acknowledges the drawbacks in running your own composting operation. These include:

- The up-front costs of buying the necessary equipment and ongoing labor, feedstock, fuel, water, and feedstock expenses.
- The learning curve involved—Phil says it took him 4–5 years to become fairly proficient at producing good quality compost—and the ongoing time commitment required for production and testing.
- Dedicating a portion of land to a compost yard.
- Issues with feedstock quality and availability.

If you decide to purchase compost from a commercial source, Phil recommends visiting the operation to assess the quality of the material and the practices used. Make sure the producer is approved by the Organic Materials Review Institute (OMRI, *www.omri.org*). Ask for records of inputs and practices, and get a nutrient analysis done.

SUPPLEMENT 3

Built on Compost—The Good Food Revolution at Growing Power

In 2008, the distribution of the world's population shifted for the first time from a rural to an urban majority.[1] That nearly 87% of the world's population was rural only 113 years ago puts the recent change into perspective. Interestingly, the U.S. population made the same transition much earlier, around 1920.

Rapid urbanization, compounded by globalization, has had lasting effects on the agricultural sector and on both urban and rural communities: As urban populations increase, they place more demands on a shrinking group of rurally-based food suppliers. And as the movement for locally-based food systems grows to address this and other food system problems, urban agriculture has become a focal point for discussion, creativity, and progress. Indeed, the production of food in and around densely populated cities bears much promise as part of any solution to food supply and access issues for urban populations.

What is Sharecropping?

Sharecropping was a Southern U.S. land-leasing system that replaced labor formerly done by slaves. After the Civil War, former slaves sought jobs, and former plantation owners sought labor. Without land of their own, many black laborers farmed land owned by whites for a share of the profit from the crops. Throughout the season, equipment and seeds were distributed on credit that was settled at the end of the harvest. High interest rates, unpredictable harvests, restrictive laws, and unscrupulous landowners and merchants kept black farmers in a cycle of debt that had to be paid the next season, tying them to the land in much the same way as slavery.

Growing Power, Inc. (*www.growingpower.org*), a Milwaukee-based organization, exemplifies the way that urban agriculture can address some of the needs of rapidly growing urban communities, particularly those with poor, minority populations. Will Allen, Growing Power's founder—born to former sharecroppers in 1949—was drawn back to agriculture after a career in professional basketball. Aside from his love for growing food, he saw that the mostly poor, black community near his roadside stand in North Milwaukee had limited access to fresh vegetables or to vegetables they preferred. Confirming his observation, a 2006 study found that more diverse food options exist in wealthy and white neighborhoods than in poor and minority neighborhoods.[2]

Allen decided that he would serve this unmet demand by growing fresh food in the neighborhood where his customers lived and involve the community in the process. In 1993, long before urban agriculture bloomed into the movement it is today, Growing Power began.

The importance of equal access to fresh food cannot be overestimated. While ever more exotic fruits and vegetables from around the world stock health and natural foods stores in wealthy and predominantly white neighborhoods, poor and

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1 United Nations Department of Economic and Social Affairs. 2008. UN expert group meeting on population distribution, urbanization, internal migration and development. New York, 21–23 January, 2008. *www.un.org/esa/population/meetings/EGM_PopDist/EGM_PopDist_Report.pdf*

2 Moore, Latetia V., and Ana V. Diez Roux. 2006. Associations of neighborhood characteristics with the location and type of food stores. *American Journal of Public Health,* 96:2: 325-331. *www.ncbi.nlm.nih.gov/pmc/articles/PMC1470485/pdf/0960325.pdf*

minority communities face fewer and less healthy food choices in the form of convenience stores, fast food restaurants, and disappearing supermarkets. This lack of access can lead to higher rates of diet-related illnesses (see Lecture 2 in Unit 3.2, Social Issues in Current U.S. Agriculture).

Growing Power has been working to create an alternative food system based on intensive fruit and vegetable production, fish raising, and composting, in order to make healthy food available and affordable to the surrounding community, and to provide community members with some control over their food choices. But as anyone who has initiated an urban agricultural project knows, fertile, uncontaminated land is often difficult to find in a city. Even if land with soil is available, most empty lots are in former industrial areas where toxic contamination often renders land unusable (see Supplement in Unit 1.11, Reading and Interpreting Soil Test Reports).

In Milwaukee, Growing Power sat on a lot with no soil and five abandoned greenhouses. Compost became the foundation for all of Growing Power's activities. The raw materials needed to produce it were in abundant and cheap supply in the city—food waste, brewery grains, coffee grounds, newspaper waste, grass clippings, and leafmold are all by-products of urban life destined, in most places, for the landfill. Businesses will often donate these materials to urban agriculture projects, saving the cost of garbage hauling services. Compost, and vermicompost in particular, also provides a renewable source of fertilizer that doesn't rely on fossil-fuel inputs and can itself be used as a growing media. With a healthy compost-based system, Growing Power discovered a low-cost, renewable, and easy-to-duplicate solution to one of the biggest hurdles people face when growing food in cities.

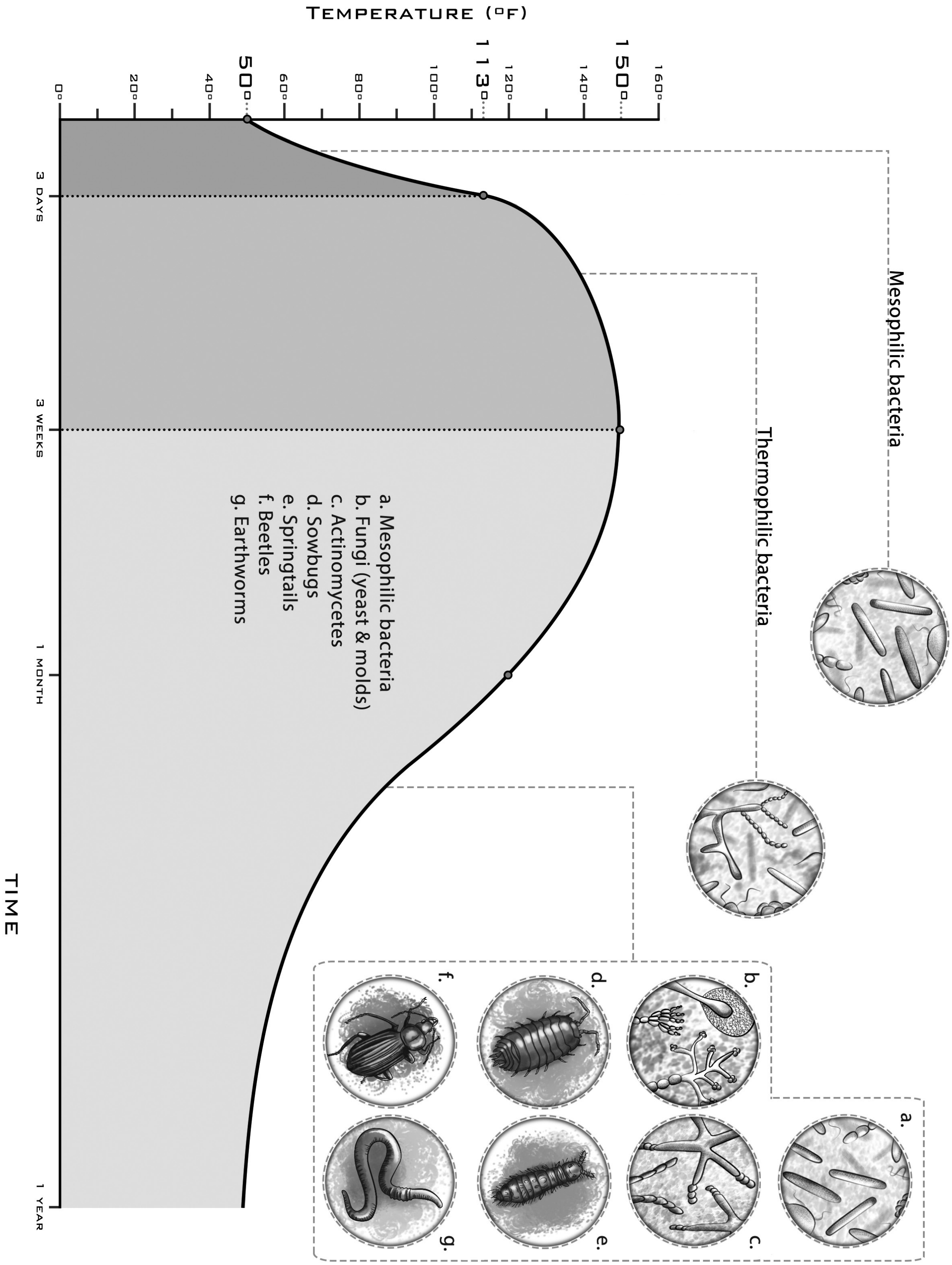
Since 1993, Growing Power has grown in size and scope, starting gardens in Chicago as well as Milwaukee, and training centers in 15 cities, and including youth training, outreach and education, and policy initiatives in its mission. Interest in urban agriculture has also blossomed into a movement that includes commercial urban farms, scores of community farms and gardens, and educational gardens and training programs growing food and flowers and raising chickens, bees, goats, and other livestock for local consumption.

Urban agriculture has grown so rapidly in the last two decades that in 2012, the USDA granted $453,000 to Penn State University and New York University for a nationwide survey of the "State of Urban Agriculture"[3] with an eye toward providing technical assistance, evaluating risk management, and removing barriers for urban farmers. The federal government's interest in urban agriculture comes on the heels of state and local initiatives to encourage urban agriculture in numerous cities, including Milwaukee, Chicago, New York and San Francisco.

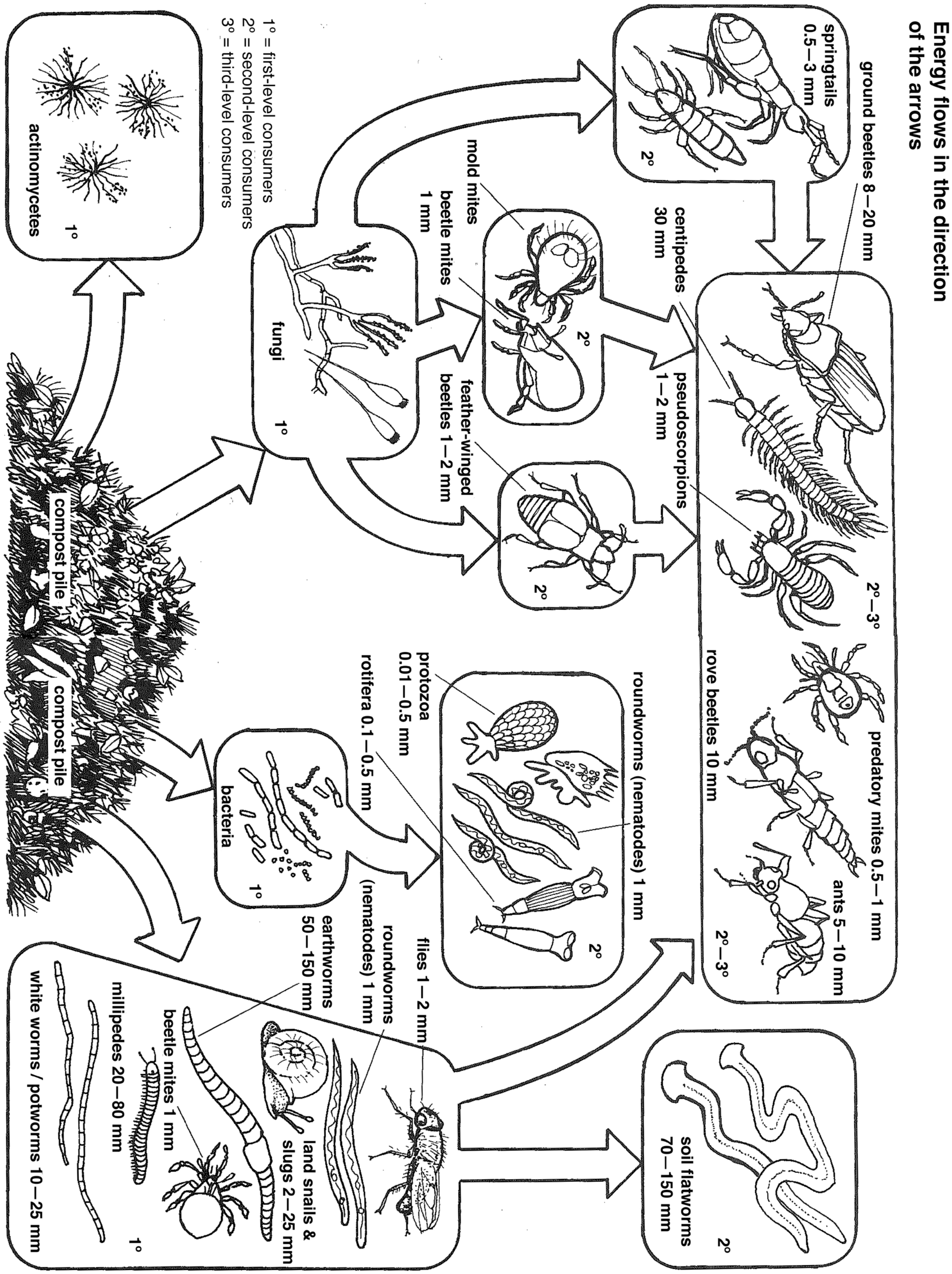
The driving force behind these initiatives and the urban agriculture movement as a whole has always been groups of committed individuals in urban communities in search of food, community, opportunity, security, and access. What makes the Growing Power model work is not just its innovative techniques and creative use of urban spaces, but the partnership with its neighbors who not only receive the program's services, but contribute significantly to its success.

3 Penn State News. Study to examine trends in urban agriculture. August 17, 2012. *news.psu.edu/story/147385/2012/08/17/study-examine-trends-urban-agriculture*

Appendix 1: Compost Time/Temperature Curve



Appendix 2: Compost Food Web



From the *Rodale Book of Composting*. Used by permission.

Appendix 3: C:N Ratio of Common Compost Materials

MATERIAL	C:N RATIO	
Fresh chicken manure (laying)	6:1	
Tomato processing waste	11:1	
Vegetable waste	12:1	
Alfalfa hay	13:1	
Fresh chicken manure (broiler)	14:1	
Sheep manure	16:1	
Fresh turkey manure	16:1	
Grass clippings	17:1	
Seaweed	19:1	
Fresh cattle manure	19:1	Optimum C:N range
Rotted manure	20:1	Optimum C:N range
Apple pomace	21:1	Optimum C:N range
Fresh horse manure	22:1	Optimum C:N range
Grape pomace	28:1	Optimum C:N range
Legume shells	30:1	Optimum C:N range
Cereal hay	32:1	Optimum C:N range
Dry leaves	40–80:1	
Corn stalks	50:1	
Oat straw	74:1	
Grain chaff and hulls (e.g., rice hulls)	80–120:1	
Straw	80:1	
Timothy hay	80:1	
Paper	170:1	
Newsprint, cardboard	400:1	
Sawdust	400:1	
Wood chips, shavings	500+:1	

From *Start with the Soil*, by Grace Gershuny. Used by permission of Chelsea Green Publishing Co.

Appendix 4: Calculating C:N Ratios for Compost —A Rough Guide

You have 5 pounds of grass clippings (C:N ratio = 20:1).

You have 5 pounds of leaves (C:N ratio = 40:1).

You have a total of 10 lbs. of material:

1/2 (50%) are grass, 1/2 (50%) are leaves.

Multiply the % of grass by the C:N ratio of grass, add the multiplication of the % of leaves by the C:N ratio of leaves:

(50% X 20/1) + (50% X 40/1) =

10 + 20 = 30 —> which in fraction notation is 30/1 or 30:1.

The C:N ratio is 30:1. (*Optimal C:N Ratio is 25–30:1)

Adapted from "Calculation of Carbon-to-Nitrogen Ratio (C:N)" by Master Composter, available online at *www.mastercomposter.com*. See also: *compost.css.cornell/edu/calc/cn_ratio.html*

Appendix 5: Compost Materials & Temperature Chart

NAME OF PILE: ______________________ BUILT BY: ______________________

DATE: ______________________

RAW MATERIALS (NAME AND DESCRIPTION)

CONSTRUCTION (SEQUENCE AND THICKNESS OF LAYERS)

DRAW YOUR PILE HERE:

APPROXIMATE FINISHED SIZE:

RECORD

DATE	TEMP °F	OBSERVATIONS + ACTIONS

Appendix 5 (cont'd): Compost Materials & Temperature Chart