Compost Quick Course

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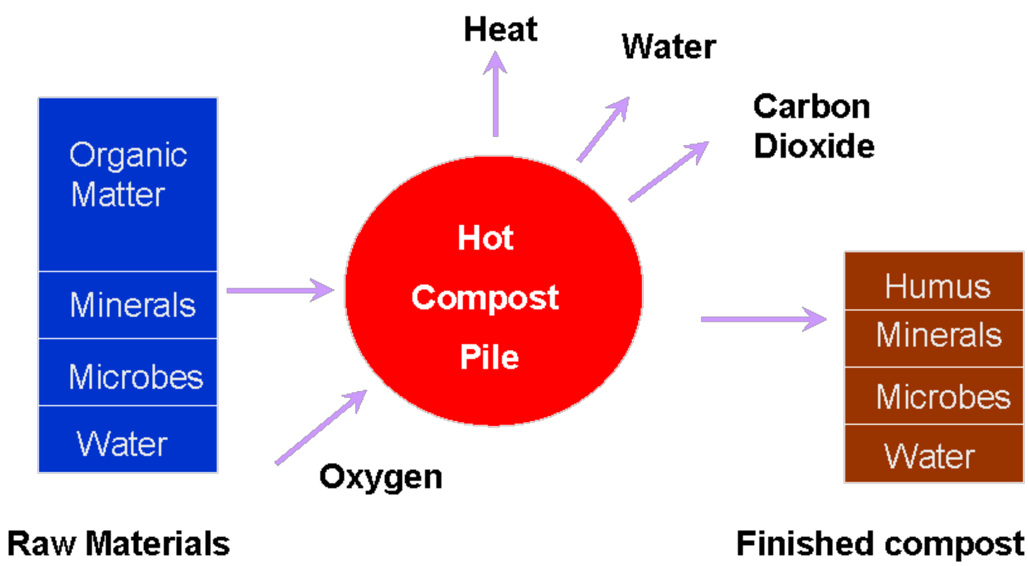
Composting is the transformation of plant material, animal manure or bedding, and other organic matter or nutrient sources to a stable and concentrated source of organic matter (humus), plant nutrients, and biological diversity called compost. Compost can be used to improve soil water absorption and retention and to provide nutrients and the organic matter necessary to maintain the microbes in the soil that provide nutrients for plant growth.

It's Alive! The compost pile is alive and can be compared to farm animals like horses and cows – billions of microorganisms are breathing in oxygen and releasing carbon dioxide. There are several factors that can be managed during composting.



- **Food:** the balance of carbon (browns/dead) and nitrogen (greens/recently alive). Usually the pile is mixed with two or three times more browns than greens. The goal is for the mixture to have a C:N of between 25:1 (1 brown to 1 green) and 45:1 (3 browns to 1 green) for hot composting.
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  Here is a general compost recipe that can be adjusted and made just about anywhere:
  - 1 or 2 bale(s) straw (carbon/brown)
  - 1 or 2 bale(s) softwood shavings (carbon/brown)
  - 1 or 2 equivalent bale(s) of moist, decayed tree leaves (carbon/brown)
  - 1 bale grass hay (first cutting) or comfrey (nitrogen/green)
  - 1 bale alfalfa hay (second cutting) (nitrogen/green)
  - 1 equivalent bale of green: garden/kitchen residues, animal manure, comfrey;
  - 1 bale of peatmoss (Neither brown or green so neutral; holds water and nutrients)
  - 1 equivalent bale of soil (not brown or green; provides microbes, minerals, water)

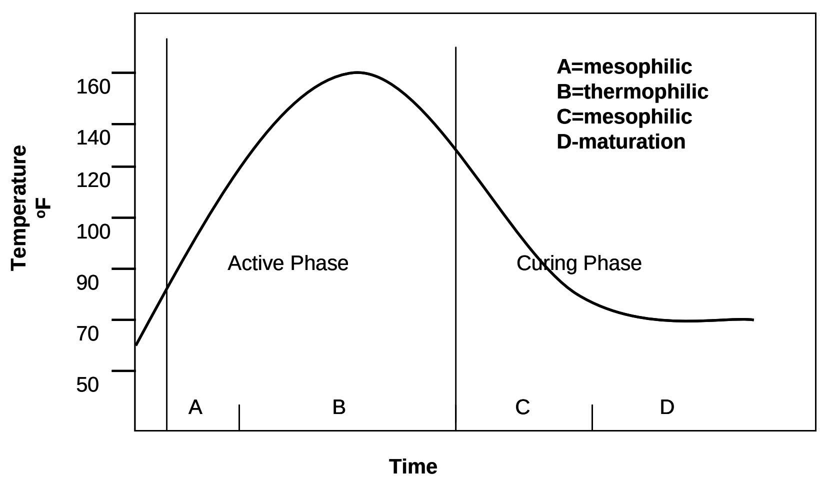
- **Air:** is influenced by particle size, pile size, and turning.
  Aeration is managed by not allowing the pile to be too wet or too large. The size of the pieces of materials in the pile also influences aeration and the rate of composting. Very small pieces increase the rate of breakdown and slow the movement of oxygen into the pile. Larger pieces are slower to break down and can provide channels for air to enter the pile.

- **Water:** lack of water is often the factor limiting the development of heat in a compost pile. Excess water is the most common cause of bad odors that might develop.
  A quick and simple method of determining moisture content is called the squeeze test.
  - Grab a handful of feedstock or compost and make a fist around it. If it releases a stream of water or you can squeeze out several drops of water, the moisture is greater than 65 percent.
  - If the squeezed handful of compost leaves the skin wet but does not release more than a drop or two of water, then the moisture content is in the desired 50 to 60 percent moisture range.
  - If the squeezed handful of compost falls apart when you open your hand, the moisture is probably below 45 percent which is too low.

- **Temperature:** is influenced by the food mixture, the air, water, pile size, turning, etc. A pile needs to be at least 4 feet around and 3 to 4 feet tall to become hot. Why does a pile get hot? Because of the rapid increase in the number of organisms present, particularly a type of bacteria that survives and thrives at high temperatures (thermophilic bacteria). Heat can reduce the presence of viable weed seeds and organisms that feed on living plants. The goal is to get the pile to temperatures of 120 to 140 Fahrenheit. If you dig your hand into the pile and the temperature is too hot to keep your hand there for more than 10 seconds, the temperature is probably more than 130 F. A compost thermometer is a good investment. A meat thermometer will work.

- **Microbes:** the necessary organisms / microbes will be present and purchased additives are not needed. Management can influence the relative amount of bacteria or fungi that are present

- **Time:** The composting process goes through stages that include the first active or hot stages that require more air and water followed by a lower temperature curing stages. The organisms present change during the stages. Composting can happen quickly at high temperature (3-4 weeks) or slowly at lower temperatures (3 to 4 months). Nutrients will increase over time and enough time must be allowed for the organic materials to become stable (2 to 4 months) if it will be used for starting seeds. The final C:N is usually between 10:1 and 20:1.



Using Compost

Compost nutrient levels can be tested like soil nutrients are tested. Growing some seeds in the compost like corn or beans or sunflowers can provide an indication of the amount of available nutrients. Finished compost is applied to the soil at rates from 5 to 50 ton per acre or 1 to 10 five-gallon buckets (about 20-25 lbs/bucket) per 100 square feet. This would range from less than one-quarter inch to one inch deep. More than that is not needed and not recommended. The compost can be worked into the soil surface or incorporated deeply. Compost can also be mixed with sphagnum peat moss at ratios of between 1:1 and 1:2 and used as a seed germination media.

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Compost for Small and Mid-Sized Farms

John Biernbaum, Michigan State University

In an organic farming system, the soil is alive, and this life needs to be nurtured and fed. Compost provides a perfect source of food for your living soil, but whether you purchase compost or make your own, it also comes with a lot of questions. The purpose of this presentation is not to cover the basics of compost but to share some relevant concepts and address farmer's concerns about how to increase the availability and use of compost. My education and professional background is conventional greenhouse production with an emphasis on fertility and root zone management of peat-based media. I wanted to grow certified organic transplants and learned that compost was the best way. I wanted to grow hoophouse vegetables and learned that compost was the most efficient way of maintaining the soil health. In both cases I needed compost that was not readily available so I learned to make compost. I now teach a course on compost production and use.

Short introductory summary:

- The composting process simplified is:
  Organic matter + oxygen + water + microorganisms → heat + water + CO_2 + humus
- The feedstock mixture and management practices have an important impact on the conservation of carbon, nitrogen and nutrients.
- The goal for organic farming (conservation) is different than the goal for refuse or residual reduction and recycling.
- Following the hot composting phase, if moisture is available, compost is dynamic and will continue to mature, loose carbon, become stable, and increase in soluble nutrient availability.
- Quality compost increases soil organic matter, provides nutrients, and improves soil biology.

Compost Contributions to a field ecosystem:

Physical properties: water absorption, water retention, reduced erosion, reduced crusting
Chemical properties: Cation exchange capacity (CEC), pH adjustment, nutrient availability
Biological properties: increased biological diversity, reduction in plant pathogens, increased worm activity, directly supports nutrient cycling (soil food web)

1. The importance of managed soil organic matter fractions and type of compost.

- Why make compost instead of incorporating the feedstocks into the soil as with green manures and cover crops? Because in addition to concerns about seeds and possible pathogens, the rapid reaction with incorporation could produce undesired end products. Compost can be something different than a green manure or a cover crop. Too much incorporated fresh organic matter in the soil is not beneficial.
- Why not just use the feedstocks as mulch? A question that John Jeavons and others have asked some time ago is whether it is worth taking crop residue off the field and composting it rather than mulching or incorporating the organic matter. Mulching clearly has benefits for maintaining soil biology and conserving soil moisture. The proposition is that the net benefit to long term soil organic matter, if that is the goal, is likely favored by composting the organic matter first.
- Do we have need for different types of composts for different purposes? Narrow starting C:N can finish faster and be allowed to mature to provide a nutrient source or be used for shorter term vegetable crops with higher nutrient requirements. Wider starting C:N ratios may not get as hot or mature as fast but can be used for field application for longer term crops where increasing soil

biology or providing carbon for soil biology is a primary objective. The goal is to use our knowledge of soil biology and composting to achieve multiple purposes.

2. The value of compost application.

What rate is applied for field production? 1 ton/acre? 10 ton/acre? 20 ton/acre? There is a large range in quantity that is discussed for a variety of purposes. What makes sense? Recommendations for the field depend on the intended purpose, the crop, soil type and other variables.

Soil Organic Matter. How much organic matter is present in soil? Common range of 1 to 5%? How many lbs or tons is that per acre? If an acre furrow slice is estimated at 2 million pounds, and 1% of that is organic matter, than there is 20,000 lbs or 10 tons of organic matter. An application of 1 ton/acre would then increase the SOM by 10%. What effect would that have? An application of 10 ton/acre would then double the organic matter? We need to keep in mind that compost is often 30-50 percent moisture (40% is a good target) so 10 ton may only be 6 ton of organic matter. But that is still a significant amount compared to the amount present. As the SOM goes up to 4 or 5%, the same application is having a smaller, but still significant effect. Recommendations from the Rodale Institute also emphasize the contribution of soil carbon to water holding capacity with the estimate that one pound of soil carbon can hold up to 40 lbs of water. Building soil organic matter increases water absorption and water holding capacity significantly.

Nutrient Additions. Assumptions about compost contribution to nitrogen availability are usually based on the concentration of total nitrogen which might range from 0.5 to 3.5% with an average closer to 1 to 1.5%. It is often assumed that 10% of the total would be available each year. So, for a 10 ton/acre application, the nitrogen contribution might be around 15 lbs per acre per year. With applications each year, the organic matter contribution will increase. Similar assumptions can be made for phosphorous (range 0.1 to 4% avg ~1% for dairy compost) and potassium (range 0.3 to 2.5%, avg ~1.0% for dairy compost).

Soil Biology. For lower rates of application like 1-2 ton/acre, since the organic matter and nutrient additions are relatively small for a first time application, it is generally assumed that the contribution of additional microorganisms and contributions to the soil food web that can increase root health are at least partially responsible for increased soil and plant health and yield that are observed.

What does it cost to purchase and apply compost? There is the cost of the material, cost of the transportation, and cost of the application. Some assumptions are needed – a cubic yard of compost at 30-50% moisture is assumed to weigh between 700-1400 lbs or about 1000 lbs on average. (Manure or dairy based compost and more aged compost will have higher bulk density.) Therefore two cubic yards are about one ton. At $30 dollars per cubic yard or $50 per ton, the range in cost per acre can be from $50 to $500 for 1 to 10 ton/acre. What would be the return per acre? This depends on the harvested value of the crop which could start at a low of $200 per acre. At the MSU Student Organic Farm we are averaging over $20,000 per acre of produce sales through a 48 week CSA and an on campus farm stand. For our hoophouses we apply one cubic foot of compost per 20 square feet which is equivalent to about 40 ton per acre. The productivity there is at least $5 per sq foot or $200,000 per acre of growing area. The soil also remains unfrozen and in production year-round so biological activity is higher than for field production.

Other factors to consider include the transportation cost and the application cost. Transportation cost per yard likely goes down as the size of the load goes up to a point. Morgan Composting in Michigan can deliver up to 90 yards at around $5 per loaded mile. For a 100 mile trip that is about $500 or about $5/yd additional to compost that starts at round $30/cuyd. The Dairy Doo compost is about 1200 to 1400 lbs per cubic yard and is about 1% each N, P, and K. Morgan Composting can preblend minerals or high N or high Ca materials like poultry litter that increases the quality of the "compost" and the value of the application. Higher rates that may be appropriate for hoophouse production with no leaching are likely not appropriate to cost effective for field production. Excess rates of application likely result in more rapid loss of the added carbon and nutrients.

Compost Availability

While the methods mentioned above can likely meet the needs of smaller scale producers (< 5-10 acres), one of the concerns seems to be whether there is adequate compost suitable for organic certification and application to larger acreage operations. In Michigan, there is one producer who works hard to find compost for organic farmers at a variety of locations around the state. Transportation cost can be a major issue so working on availability close to the farms is important. He has worked with other producers to insure that the necessary quality and the records needed for organic certification are provided. (www.dairydoo.com)

It seems like an opportunity when organic transplant root medium is being shipped from Vermont to organic farmers in the Midwest. The equipment and methods to make compost based root media are not complicated if the compost is available. In greenhouse states like Michigan and others in the Midwest, increasing availability of compost based transplant media seems like a high priority. The compost production, as noted below depends on the availability of feedstock.

Compost Production Considerations and Costs

What does it cost to make a high quality compost for use in hightunnels and for transplant media? Following is a recipe used at the MSU SOF in an effort to make 40 cubic yards of finished compost. A common assumption is that there is a reduction in volume by 40 to 50% on average. In this case the peat, leaf mold, veggie compost and soil were not expected to reduce much in volume.

Material	Quantity	Unit Cost	Total Cost	Estimated cu yd
straw	40 bales	$3.00	$120	15
wood shavings	20 bales	$5.00	$100	6
sphagnum peat	10 bales (3.8)	$12.00	$120	2
alfalfa hay	20 bales	$4.00	$80	7
grass hay	20 bales	$3.00	$60	7
leaf mold	8 cu yd	15	$120	8
veg/weed "compost"	8 cu yd	10	$80	8
field soil	8 cu yd	5	$40	8
Total			$720	60

A cost of $720 for 30 cu yd finished then would equal about $24 per cubic yard without labor or feedstock deliver charge. In reality the last three items did not have any purchase cost and some of the straw and haw were old bales obtained at no purchase cost (just transportation cost) so actual out of pocket material costs were more like $400 or $10/yd finished compost. While we currently buy baled wood shavings, we are planning to plant hedge rows of trees for coppicing that would allow annual harvest of the necessary wood. At home we took down two 30' tall Colorado blue spruce and together with branches and trimmings from the property the pile of chips was two or three times what I bought for $100. The cost was a 4hr rental of a wood chipper for $50 and several hours of labor to do the job. The labor maybe makes it a break even proposition, but almost all the resources are moved to on farm.

These components or feedstocks made a pile approximately 12'(3 yd) wide and 45' (15 yd) long at the base and 5-7' (2 yd) tall at the triangular peak and was estimated to be about 60 cu yd. The bales were loosened and added by hand while the leaf mold, vegetable compost and soil were added with a loader. A probably key step to minimize turning and to favor rapid heating is wetting down or adding water to the bales of straw, hay, shavings and peat about 12-18 hours before building the pile. (If wet too long, the feed stocks start to mold.) Multiple small applications of water over time are probably more efficient than one large application. It is not practical to add enough water during construction of the pile. Drip irrigation tape was also placed on top of the pile to add water as needed. The pile was "rolled" once from the side after about two weeks and water was added with a hose continuously during the turning with a front end loader (30-45 minutes). After four additional weeks, the pile was "rolled" back to the original location with the front end loader and water added. After four more weeks the pile was restacked and covered with polyethylene and was at least 40 cu yd.

Here is a similar recipe for completion in a pallet size pile that produces at least a cubic yard of very mature finished compost for about $33 dollars per yard. The range in the two examples then is between $20 and $33 dollars if all materials are assigned a cost. I am not sure how to account for the difference. The example below has been done at least six times with similar outcomes while the example above has only been done once and with a large bucket loader so the actual numbers are more of an estimate. Materials Key: G – Green plant material, B – Brown materials, N – Neutral. C:N = ~34 or less with N from peat & soil.

Material	Lbs/cu ft (dry)	Cu ft compact/loose	Lbs	% N	Lbs N	% C	Lbs C	Cost ($)
1 Grass hay (G) (22.5)	9	5.5 / 8	50	2.0	1	45	19	1 @ $3
1 Alfalfa hay (G) (15)	9	5.5 / 8	50	3.0	1.5	45	19	1 @ $4
2 Straw (B) (71)	6	10 / 14	80	0.7	0.5	50	34	2 @ $3
2 Shavings (B) (300)	7	7.5 / 16	60	0.18	0.11	55	29	2 @ $5
2 Aged Leaves (B)(40)	9	7.5 / 8	66	1.0	0.7	40	26	$0
Spaghnum Peat (N)	8	3.8 / 6	(40)					$10
Soil/vegi compost (N)	80	3.8 / 3.8	(300)					$0
Total		44 / 64	636		3.8		128	$33/yd

What does potting soil or transplant media cost? The range can easily be from $50 to $150 per cubic yard with an average in the $80 to $100. Professional grade sphagnum peat can easily cost over $50 per cubic yard and perlite and vermiculite would typically be twice that in smaller quantities. A root medium approved for certified organic production can increase the cost more. Compost at $30/ cuyd sounds like a pretty good deal and investing up to $50 / cuyd is likely justified. Putting compost in transplant media is a good way to get seedlings in direct contact with compost from the onset of germination and benefits including beneficial microorganisms and nutrients into the field where it can do the most.

Compost made in advance to grow transplants in will continue to decompose and increase in available nutrients over time if the compost is moist (>30% moisture content) and warm (>50F). Compost that is in a desired state needs to be either dried or held under cool conditions until use.

A key in both these examples is that the true cost including labor, feedstock acquisition cost, equipment and storage is not represented. The limitation on the small to mid scale farm is often the time to take care of compost and to make it right. Storage and protection from rain or blowing weed seeds once it is finished is also an important issue to consider.

This cost estimate also assumes no cost to get the feedstocks to the farm. The cost to move feedstocks to the farm, even a short distance of a few miles, can add a few dollars per cubic yard to the cost. So advice that I was given is that if there are materials on the farm, by all means compost them and use them. If feedstocks are to be transported to the farm and then composted, it likely makes sense to consider the cost of purchasing finished compost, particularly if high quality compost is available. The definition of high quality, in this case, is compost made specifically for the purpose of organic farming by a knowledgeable person who specializes in composting as opposed to some residual material that needs to be recycled.

Transplant Fertility Applications – Keep them Green!

Compost can also be used as an important source of nutrients during transplant production as an alternative to fish emulsion or other liquid sources of nutrients. There is a significant timing advantage of placing a green, growing transplant in the field vs a nitrogen deficient one that takes a week or two to get growing again. A transplant with adequate fertility is also more likely to grow through flea beetle or striped cucumber beetle damage. The issue for many small scale producers is how to quickly add nutrients late in production or during the hardening period so the transplants are still growing when they go to the field.

The compost can either be extracted with water for liquid application, or low moisture, screened material can be applied as a topdressing to flats at a rate of between 0.5 and 2.0 cups per flat – avg ~1 cup per flat and watered in for a rapid greening response. To apply the nutrients and biological organisms in a water solution the dilution ratio can be adjusted based on the electrical conductivity (EC) of the compost or the extract. For the non-manure compost above, a dilution of 1:5 might be appropriate. For our water that starts at 0.6 mS EC due to minerals in the water, a 1:5 dilution of compost would have an EC of 1.4 to 1.6 mS. One cup of compost plus 5 cups of water would yield about 40 fluid ounces which is what a standard flat (50 to 100 cell) can hold with one heavy watering.

If the compost to be used is low nitrogen to begin with (<1%), nitrogen can be increased by adding alfalfa, soy or corn meal at 10 to 20 lbs per cubic yard (2 to 4% by volume) and allowing several weeks of new composting at 60-70F and 40-60% moisture. If worms are added to the compost, vermicompost or worm castings can be collected and used for topdressing of flats. Vermicomposting can go a long way to increasing the uniformity and quality of on farm compost. If you let the worms do the work there is little additional labor except putting some fresh organic matter next to the finished pile so the worms vacate the finished product and take up residence next door.

Compost Feedstocks and C:N ratio

While teaching students how to calculate C:N ratios, I learned something useful that I have not noticed in any of the composting books I have read. What I learned also supports my observation that there is a pretty wide range of acceptable ratios of "browns" to "greens" that will provide for hot composting. As long as moisture is maintained. While the recommendation for browns to greens is typically 3 to 1, as the ratio changes from 3:1 to 2:1 to 1:1, the calculated C:N ratio changes in the range of 40:1 to 25:1, all of which are in the acceptable range for starting C:N for organic certification. For the examples I used mixtures of straw (brown) and hay (green) where the C:N of the brown was assumed to be around 80:1. The same would not be true if I used sawdust or woodshavings at a C:N of 300 to 400:1 for the "brown".

The other question that comes up when considering whether the 3:1 ratio of brown to green is based on volume or weight. Rarely is this point clarified or clearly indicated. Calculations are clearly based on weight. There is little difference between 3 parts brown to 1 part green by volume or weight for feedstocks of similar moisture and bulk density. But for very wet or dense manure, or when combining dry and wet materials, the C:N by 3:1 volume verses 3:1 weight can be quite different.

Factors That Can be Managed During Composting

When teaching about making compost I emphasize the same possible management points that we have used in our own research. While the list of all possible options is longer than the seven factors presented here, these are the seven that seem to be most important, most easily managed, and noted by other authors writing about compost production.

1) Starting C:N Ratio (Range from 45:1 to 25:1)
2) Moisture Content (Range from 80% (wet) to 40% (dry) with 60% as a good starting point)
3) Aeration (particle size, pile size, turning) (Limited Oxygen is not as bad as too much water.)
4) Temperature (pile size, turning, etc) Pile design and turning – range from 130F to 160F
5) pH - 5 to 8 is not uncommon; influences bacteria (decrease at low pH) and fungi
6) Organisms Present – Inherently bacteria and fungi are on the feedstocks and plant materials
7) Time for Composting – varies depending on use (ie field application vs transplants)

Making quality compost doe not require frequent turning. Extra turning beyond what is required to expost the entire pile to heated conditions can speed up the process and increase product uniformity. But excellent compost can be made with minimal turning if the pile is constructed properly.

Unanswered Questions

What about aerobic vs anaerobic? Modern composting in the United States seems to make it essential for aerobic composting. Sir Albert Howard and the Indore method was not so clear on this point since at least part of the process occurred in pits in the ground. In a class demonstration in 2008 we produced compost using the same recipes noted above, moistened to an appropriate level (~60% moisture) and wrapped in old greenhouse plastic film. As long as the mixture is not too wet, it appeared that composting continued fine without foul odors. The key is avoiding the saturated wet condition. The plastic wrap prevented the compost from drying out. In the lab we have also worked with a biodigester operated with full gas flow with either 20% oxygen or 3% oxygen and obtained reasonable decomposition ("composting") of an alfalfa based amendment within the normal range of composting EC, pH. We have not yet grown plants in the compost or amended compost or done any analysis.

What about the addition of lime or ashes? In the older literature by Howard and Rodale, the addition of lime or ashes is often mentioned as an ok step. It is often noted that academics warn that this is not correct, presumably for the same reason I have, that at high pH, nitrogen will be more likely to be in the ammonia form (NH_3) then the ammonium form (NH_4^+) and the former is more easily lost as a gas. I think the experience and the assumptions need to be tested and reviewed.

Summary

The opportunities for improvement in compost production and use as a tool to build soil organic matter, soil and plant health, and for transplant production are significant. Both existing organic farmers and new farmers transitioning to organic methods can benefit from clear information about the justifications for and the economics of compost application. I am not an economist but I can help clarify the value of compost and issues related to compost quality.

For an 11 page article covering basics of compost production and use go to www.msuorganicfarm.org under the resources tab and click on organic farming principles and practices.

Making and Using Worm Compost
Is it the "Black Gold" of Small Scale and Urban Agriculture?

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I have many (6+) years experience with the worms in our horse manure piles at home and with worms in bins and now well over a year of experience with food waste vermicomposting in an unheated hoophouse at the MSU Student Organic Farm. I have read many publications and websites about vermicomposting and looked at a lot of on-line videos. I am sorting through all that experience and information and thinking about what is most important to share in a one to two hour class. This document is supported by a slide presentation of our work over the past year with food waste composting at MSU.

Why Worm Compost?
Worm compost can be used several ways in rural, urban and backyard agriculture.
- A growing medium component for container grown transplants or plants.
- A source of well balanced available nutrients/minerals which can be applied as a dry surface application or extracted with water and applied as a fertigation (nutrients+water).
- A crop protectant that may help mitigate insect infestations and disease infections.

Why Worm Composting in addition to or rather than Hot Composting?
- Can be done in small or large space.
- Can be done with limited equipment; worms can do much of the work of turning.
- Can retain more of the nitrogen that is often lost in hot composting.
- Can have a higher concentration of soluble / available minerals.
- Can be fast (6 to 8 weeks) if worm population is high.
- Finished product can be easy to handle and odor free from materials that start out with unpleasant smells.

Worm Taxonomy (type), Anatomy (appearance) and Biology (life cycle)
Not just any worm will do. Manure Worm, Red Worm, Red Wigglers or *Eisenia fetida* are names for the same type of worm. These are not burrowing worms that go deep into the soil but a smaller worm that lives in the litter or organic matter near the surface. This type of worm reproduces quickly when food is available. Red worms have both male and female organs but must exchange the sperm with a partner to reproduce. The sperm is stored and used to fertilize eggs over an extended period of time. Multiple eggs are encased in a cocoon until the eggs hatch and the young worm survives. The eggs in cocoons can survive for years when conditions are not suitable. The presence of cocoons and newly emerged and young worms is an indication that the culture is healthy and reproducing. The presence of a band or clitella indicates the ability to reproduce. Variety of stages of life cycle is an indication of a favorable environment. The size of the worm will vary (small to large) depending on the food available. Worms breathe through the skin so moisture is important. A bedding moisture content of 60 to 90% is recommended. They are sensitive to light and need to be protected from bright sunlight.

Life Cycle
Reported time for cocoon to go from formation to hatching in favorable conditions: 4 to 6 weeks
Reported time that cocoon can protect young worms in unfavorable conditions: months to years
Reported time for worm to develop from emergence to maturity (producing young): 6 to 8 weeks
Reported time a worm will live, feed and reproduce in a favorable environment: ?? month/year

Important Factors to be Managed

- *Bedding* – favorable conditions for the worms, available carbon for decomposition and structure to provide aeration. Horse manure works very well; ground or shredded leaves from a lawn mower work well; coconut coir or peat moss also work well if available.
- *Bedding pH:* seem to tolerate pH 5 (acidic) to pH 8 (basic) but target range is 6 to 7. Can be lowered by adding peat or sulfur. Can be raised by adding lime.
- *Feed* – possibilities include: vegetable and fruit scraps; from restaurants or grocery stores, brewery waste, coffee grounds, animal manure, spoiled grain, hay or animal feed. A an important factor is not adding too much food and not adding it in a way that will cause heating that can kill the worms. Heating is more of a concern in small containers or small piles where the worms cannot move away from the heat.
- *Moisture* – on the moist to wet side as long as well aerated. Bedding can be 70 to 80% moisture (60 to 90%?). Worms breathe through the skin which must be kept moist. They can be submerged in water for a short time if there is enough oxygen in the water.
- *Oxygen* – often regulated by depth of the bed and the amount of moisture and feed. Too deep (>15-18"), too wet (>90% moisture), or too much food in a closed space can lead to low oxygen.
- *Temperature:* Tolerate 40 to 90^{o}F; favorable at 60 to 70^{o}F; low activity at 40 to 50^{o}F: heat stressed at 80 to 90^{o}F.

Estimating Quantities, Volumes, Feeding Rates and Process Time

- A common estimate is that a pound of worms in a healthy and properly managed system or worm bed can consume approximately 0.5 lb of food residue per day.
- The bed surface area necessary for this to happen is about 1 to 2 square foot.
- The bed volume necessary for this to happen is about 1cubic foot (2 feet of surface, 6 inches deep) to 2 cubic feet (2 feet of surface, 12 inches deep).
- Worms can survive in large piles (3 to 4 feet tall or deep) of relative stable or mature organic matter or compost. But if there is actively decaying food, manure or organic matter present, the pile or bed needs to be shallow (6 to 18 inches deep) to prevent overheating (temperature over 90^{o}F), and to insure adequate aeration and feeding throughout the bed.
- For example, a five gallon bucket of fruit and vegetable waste might weigh from 10 to 15 lbs. If fed to worms weekly, the amount per day would equal 1.25 to 2 lbs per day requiring 2 to 3 lbs of worms and 3 to 6 sq ft of surface area.

Worm composting can be done on scales suitable for gardening, market gardens and small, medium and large scale farming. Once an appropriate size population of worms is established in the culture bed, the primary maintenance is watering and feeding the bed with occasional turning. Minimal equipment is necessary for managing beds less than 100 square feet (4' x 25'). Very large vermicomposting operations have large equipment investment.

A well managed 4' x 4' pallet bed can produce 0.5 to 1 cubic yard of worm compost per year.
A well managed 4' x 25' bed can produce 2 to 3 cubic yards of worm compost per year.

Useable compost can be ready in as little as 2 to 3 months (60 to 90 cays) under favorable conditions but 4 to 6 is a better estimate with minimal management of the worm beds.

Here are two examples of how much vermicompost might be needed for transplant production.
For 900 flats for a year-round 5 acre vegetable farm with high tunnels, total transplant medium would be approximately 6 cubic yards. Worm compost at 20% volume would be 1.3 cu yds.
To treat 1000 flats with 1 cup vermicompost top dressing requires: 8.33 cu ft or 0.33 cu yd.

For organic certification, vermicomposting requirements (as opposed to hot composting) are:

- allowed feedstocks
- applied in shallow layers
- aerobic conditions
- high moisture (70-90%)
- duration: 12 months for outdoor windrows, 4 months for indoor container systems or angled wedge systems, or 2 months for Continuous Flow Reactors

Vermicomposting Systems

- Batch – bins, boxes, barrels, pallets
- Windrows and angled wedge systems
- Flow Through

Batch: Small plastic bins or wood boxes. In a worm bin for single-family or residence vermicomposting, the population can double about every 2 months and will stabilize at 3 to 4 pounds maximum of worms in an average sized healthy bin (18 gallons or 12 inches wide by 24 inches long by 20 inches deep). The bedding is maintained at only 6 to 12 inches deep. Because the worms are surface dwellers and aeration is important the many potential edible bedding materials include newspaper, compost, plant material, animal manure, etc. The moisture content is maintained at 60 to 80 percent. The worms will move away from light and are most active at temperatures of 65 to 75^{o} F. Activity is low at less than 50^{o} F. The worms also need protection from excessive temperature (>85^{o} F). A pH range of 5 to 7.5 is tolerated.

Newspaper is commonly recommended for bedding in home bins because it is readily available and needs to be recycled. Common feedstocks are kitchen scraps, mostly vegetables and fruits, no meats or fatty items. Melon rinds, peels, cores and banana skins are a few favorites. Recommendations are to limit citrus rinds and onion skins.

One pound of worms will eat approximately 0.5 pound of garbage – organic waste - per day (about half of the worm mass per day). The surface area is important. An 18-gallon container about 24 inches long, 12 inches wide (2 sq ft surface area) and 20 inches deep with a minimum of a pound of worms could handle up to about 4 pounds of organic waste per week (0.5lbs/day or 0.25 lbs/sq ft surface per day). For such a container, start with a pound of worms (800 to 1000 worms) and 6 to 10 pounds of bedding. Between 1 and 3 times the weight of the bedding in water (1 gal = 8.3 lbs) will need to be added to dry bedding, to increase the moisture content to 60 to 75 percent. The plastic bins need aeration holes and, potentially, drainage holes. If a bin is indoors, something must be used beneath the container to catch the drainage. Worms will try to escape if conditions are too wet or aeration is low. Commercially shipped worms will need to rehydrate, so higher initial bedding moisture is helpful.

My experience with a bin in the house has not been good over the long term. Like pets, honeybees and farm animals, worms need regular care and feeding. My estimate is that few people have the dedication to keep a bin indoors. For a larger number of people an outdoor pile is a viable option for part of the year, but an in-ground insulated bed/corral is needed for the winter in northern U.S. climates. A fruit bulk bin, approximately the size of a pallet has worked well at the MSU Student Organic Farm. The bin can be moved with a fork lift, loader or pallet jack so can be outside for part of the year and inside for the winter. A greenhouse or hoophouse provides a winter living quarters as long as regular feed is provided.

For a small farm or market garden, a worm composting area can be developed using straw or hay bales to provide an insulated wall or border. Over time the decomposing bales can be mixed into the worm bed and fresh bales placed on the perimeter. Bales placed over the top may provide adequate winter insulation. A rain shelter over the bed will prevent leaching of nutrients.

Farm-scale Windrows or Angled Wedge Systems. Animal manure or food residuals are common foods for large-scale, commercial vermiculture. Dairy or horse manure is a good substrate. Horse manure piles at Pear Tree Farm have resident populations that make the composting simple. The worms naturally move from one pile to the next with good management.

Food residuals can be very wet and may need to be diluted with bedding or another carbon source such as straw. Coffee grounds and brewery residuals have been successfully collected from coffee shops and breweries and used for vermicomposting. With an efficient system - for example - if vegetables were delivered and coffee, brewery or cafeteria residuals backhauled, the value of vermicompost may justify the effort.

Large windrows of manure or food waste outside are maintained under breathable covers that provide aeration but limit moisture and prevent leaching from rainfall. Worm farms in temperature-controlled insulated buildings produce millions of worms for sale as bait and also large quantities of vermicompost, which may be available to farmers.

For long windrows managed with the angle wedge system, fresh material is added to one side of the sloped/angled piles and worm populations move laterally. Over time the finished material is removed from one side and new material continues to be added to the opposite side. When the edge of the available composting surface/floor area is reached, finished material can be collected from the older/aged side and the direction of the pile reversed so the "composted" side becomes the "fresh" side.

Large scale Pass Through Systems. For larger, indoor commercial operations the beds are maintained in metal frames held off the ground. Fresh material is added to the top of the beds and finished material is removed from the bottom of the beds by mechanically moving a scraper bar across the open mesh or screened bottom of the bed so that finished material drops to the floor and is then collected.

Separation of worms from finished compost or castings. A key management process is separating the worms from the castings. There are at least four options:

- Option1 – Place fresh bedding and food adjacent to well worked vermicompost and worms will move.
- Option 2 – Use either light or drying to move the worms to the bottom of the pile and remove the top.
- Option 3 – Keep worms moving up through fresh material and collect vermicompost from the bottom through a screen or by using stacking layers with large screen bottoms (variation of option 1).
- Option 4 – For commercial production of worms for fishing bait, the bedding can be passed though a rotating, pitched screen that will sieve out the castings and collect the worms at the end of the screen.

Preventing migration. If conditions are unfavorable, worms will move out of the bedding and seek new lodging. If there are greener pastures nearby, you lose your worms. If there is nothing suitable nearby, mass migration means mass murder. Either way you lose as a worm farmer.

Web Sites

Vermicomposting at Wikipedia - http://en.wikipedia.org/wiki/Vermicomposting
Worms for urban farming - http://www.cityfarmer.org/wormcomp61.html#wormcompost
MSU Power point http://www.michiganorganic.msu.edu/uploads/files/31/biernbaum%202.pdf
Flower Field Enterprise: www.wormwoman.com
Adventures of Squirmin Herman the Worm: http://urbanext.illinois.edu/worms/
Largest commercial worm composter in United States http://www.wormpower.net/