Compost Production and Use

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Producing and using compost is a great place to start and to continue learning about soil fertility and plant health management. *Compost is a key building block of organic farming.* Producing high quality compost is not difficult, but it does require a certain degree of commitment and preparation. Composting plant residuals, animal manure and bedding, or hay harvested specifically for making compost can provide a stable, weed and pathogen free source of organic matter and nutrients. In addition to being a source of available and stable nutrients, compost is a source of bacterial and fungal diversity that is often lacking in soils that have been used for conventional, chemical agriculture. Compost can be used as a potting media component for container grown transplants. We are also learning more about how to use water extracts or teas of compost to manage foliar and soil born fungal plant pathogens.

Microbes

It helps to start with a mental picture of how composting works. A simple comparison with a system we can see makes it all obvious. When a horse or any other farm animal eats hay, part of the hay is incorporated into the animal's body. A large part of the carbon fraction of the hay is lost to the atmosphere as carbon dioxide in the animal's breath. The remaining solid and liquid manure fraction contains a concentrated and available form of nutrients and less available organic matter.

We can also think about what we feed a farm animal and how that influences the manure. We can feed grain, which is high in protein and therefore nitrogen. We can feed alfalfa or legume hay that will also have protein and nitrogen, but not as much as grain. Or we can feed grass hay, which will have less protein and nitrogen than grain or alfalfa. Feeding an animal more protein might increase the growth, but it will definitely increase the nitrogen in the manure.

Making compost is managing a microbe farm. All it takes is food, air, and water, just like for any other farm animal. The food does require a certain degree of a balanced diet as for any other living creature. We start with balancing the carbon and nitrogen. The microbes will use the plant material or animal manure as a food source. Carbon will be lost as carbon dioxide and the volume of the pile will decrease. Some carbon and nitrogen will be incorporated into the microbes. And there will be "manure" that will vary based on what the microbes are fed.

Certain microbes, particularly bacteria, use more nitrogen. Or, if there is more nitrogen in the feed, there will be more bacteria. If there is less nitrogen, other microbes, particularly fungi, will take over feeding on the organic matter. In either case, eventually there is a veritable graveyard of dead microbes and microbe manure. When the microbes die, the nutrients become available for other microbes or for plants. When all the food is consumed, the microbe manure improves or becomes more stable with aging, just as with any other manure source.

Materials

When selecting materials for composting, we have several primary goals:

- Provide the desired ratio of carbon (C) and nitrogen (N)
- Provide a balanced diet of all the other essential nutrients
- Provide the greatest possible biological diversity to inoculate the pile
- Provide a mix of particle sizes that favors aeration in the pile
- Provide materials that favor adequate but not excessive moisture retention

Examples of materials available for composting include legume and or grass hay, leaves, farm or garden plant residues; vegetable or fruit processing residue, chopped corn (silage), soybean stems, animal manure: sheep, llama, horse, poultry, beef, dairy, swine, straw or wood shaving bedding and liquid or tankage materials.

A safe rule of thumb for starters is to use three times the amount of carbon materials than nitrogen materials (based on weight), and adjust the mix based on whether the pile heats up or not. Tables or book values of carbon and nitrogen content are available and a small sample of values are presented in Table 1 based on values from Rynk (1992). If there is excess nitrogen at the start, there is a high probability it will be lost in leaching water or as gaseous nitrogen – ammonia (NH_3) f the pH is high or nitrogen gas (N_2) if oxygen is low. Mature compost or soil may be added as an additional microbe source.

In each case we can "fix" or adjust the recipe if one of the basics in missing. There can be too much nitrogen, in which case a high carbon material such as leaves, straw, or sawdust, can be added. If there is not adequate nitrogen, an organic nitrogen fertilizer source can be added to the pile to provide more nitrogen. Alfalfa hay is a good source of nitrogen that also brings a balanced addition of other essential nutrients. Animal manure or food wastes are also higher in nitrogen.

One of our better batches of compost to date at MSU was a mixture of 20% by volume swine manure and wood shavings, 20% dairy manure and horse (hay) bedding mixture, 20% peat, 10% aged leaves, 10% chopped corn silage, 10% alfalfa hay and 10% grass hay. While I don't have data or evidence, my first composting teacher was very big on materials and microbial diversity. He really liked variety in the pile.

Water and air should also be considered as essential materials. Without adequate moisture, the microbial activity will be limited. Without oxygen, microbial activity will continue, but the type of microbes and the end products are generally not considered desirable. A general recommendation is to avoid materials that have been piled and rotted without adequate oxygen. These materials will usually have a foul odor or stench of decay. The bacteria that form when materials decay without adequate oxygen usually creates products in the compost that are not desirable.

Potential harmful contaminants must be avoided. One example would be herbicide residues. Most herbicides are broken down or degraded in the composting process. Recently two herbicides that are used to control broad-leaved weeds have been shown to be present in finished compost and at concentrations that will damage or kill crops. These herbicides are being found in cattle manure when pasture was treated and in lawn and grass clippings from residential use of the herbicide.

*H*ow much organic material is to be composted will ultimately determine the amount of space needed, and helps in evaluating what method(s) to use. For composting recipes, the relative amounts of materials to add to achieve a proper balance of C:N ratio are computed based on the mass or weight of the materials. Usually one starts with an estimated volume and calculates the mass based on bulk density of the material. For example, the bulk density given by Rynk (1992) for vegetable "wastes" is 1,585 pounds per cubic yard. If a pile is 3 feet wide, 3 feet high and 12 feet long, there is approximately 4 cubic yards (3x3x12=108 cu ft divide by 27 cu ft per cu yd = 4 cu yds, times 1,585 pounds per cu yd = 6,340 pounds.

A recipe can be based on mixing volumes of feedstocks, such as the number of bucket loads of a front-end loader, or the number of manure spreader loads. If a farmer has access to a weighing scale, then the mix can be done on a weight basis, which would provide for the most accuracy. But scales are not typically available, hence using book values, and with time, experience, should be sufficient for developing quality mixes based on volume and number of loads.

A farmer needs to determine the amount of material being generated to estimate the area required for composting. This can be done by simply keeping track the number of bucket loads or manure spreader loads collected either daily, weekly, or monthly. There are always some fluctuations in how much material is generated, especially with plant matter. Fluctuations with manure depend on the type of handling facilities used. There are daily haul systems where manure would be available for composting everyday. There are other systems such as packed bedding where the materials are available every 6-8 weeks. **Always design a compost operation based on peak generation.**

The farmer needs to know some basic characteristics of the materials, primarily the amount of carbon and nitrogen (C:N ratio), moisture content, and physical structure, in order to come up with a good compost mix. Table 1 lists the C:N ratio, %N, %C, estimated moisture content, and bulk density of a variety of farm-generated organic materials. The first six materials listed are typically below the desired optimal C:N ratio and are considered *nitrogen* feedstocks. The remaining five materials are well above the desired C:N Ratio and are considered *carbon* feedstocks. Materials like "vegetable produce" itself will have a wide range of variability in terms of the type of vegetables, but vegetable matter in general should be treated as a *nitrogen* feedstock. The properties of feedstocks can vary for a number of reasons. One important factor is how the material is handled prior to composting. High nitrogen feedstocks, especially wet manure and vegetable matter, should immediately be incorporated into a compost mix. If these materials are stockpiled for several days, microbial activity could deplete the available oxygen and create anaerobic conditions. This would create a host of problems including odor, diminished quality to the compost, and attract vectors (flies, rodents).

Here are a few tips if you plan to calculate the C:N ratio of a mixture. First, you need more than just the C:N ratio of the starting materials. You cannot calculate the %N or %C from just the C:N ratio. If you have 100 lbs of material with a C:N ratio of 30, you do not know how much C or N is present. There could be 30% C and 1% N, or 60% C and 2% N, or 15% C and 0.5% N. Some tables will give the %N also and this is essential. You will likely have to calculate the %C but it is in some tables. There are three basic formulas to keep in mind. The C:N ratio = the %C / %N. The %N = the %C / C:N. The %C = C:N / %N.

Second, it is easier to make a mixture from common sense and then calculate the C:N ratio then to set out to get a specific C:N from several components. If you have 2 components and you know the moisture content, %N, and %C, one option is to start with asking what would the C:N ratio be if I started with 100 lbs of each? The %C and %N are based on what is present in dry material. So the first step is to estimate the weight of the dry material. The next step is to multiply the dry material time the %N and %C to get the pounds of N and C.

Leaves: 100 lbs x 35% moisture = 65 lbs Dry
1% N = 65 x 0.01 = 0.65 lbs N
54%C = 65 x 0.54 = 35.1 lbs C

Hay: 100 lbs x 10% moisture = 90 lbs Dry
2.5% N = 90 x 0.025 = 2.3 lbs N
45% C = 90 x 0.45 = 40.6 lbs C

lbs C = 35.1 + 40.6 = 75.7
lbs N = 0.65 + 2.3 = 2.95

75.7 lbs C / 2.95 lbs N = C:N 26.0

If I double the amount of leaves, to 200lbs, the C:N ratio increases to 31.2 and if I triple the leaves to 300lbs the C:N ratio goes to 34.7. All of these values are acceptable, and the last one with about 3 “browns” (leaves) to 1 “green” (hay) would probably be the best starting point to conserve nitrogen.

Third, based on playing with an Excel Spreadsheet designed to help calculate C:N ratios of mixtures, in many cases it appears that there is a lot of room for change in the recipe before the C:N ratio changes very dramatically. You just have to get close.

The calculator at the Cornell Compost web site can be used to make some original estimates. Once you have the basic idea and some idea of how different components alter the C:N ratio, it becomes relatively easy to come up with a reasonable mix that will heat and compost well.

Finding the right compost recipe does take knowledge of C:N ratio and moisture content, but it also involves some playing around with the materials. There are circumstances where the organic material is almost at an ideal C:N ratio and moisture content for composting. With packed bedding, some farmers have adjusted how much straw bedding is continually added to stalls so that when it is removed from the stalls, typically every 6-8 weeks, it is ready for composting without the need for additional amendments. The packed bedding cleaned from stalls at the Michigan State University Dairy Teaching and Research Center is typically above the optimal C:N ratio. Manure collected from the tie and free stall dairy units is added to bring the nitrogen levels up.

It is better to be higher than the optimal C:N ratio than lower. The higher the carbon levels in the compost mix, the more nitrogen conserved and the less likelihood for the process to go anaerobic thus preventing the occurrence of offensive odors. The drawback in increasing carbon also increases the amount of time to produce finished compost, and this in turn increases the space required.

Do not exceed the optimal moisture content! Excessive moisture will lead to anaerobic conditions and the production of foul odors. Sometimes the mix will be a compromise between C:N ratio and moisture content, but often moisture content will be the deciding factor. **Carbon feedstocks such as straw, wood shavings, and leaves, are typically dry unless stored uncovered.** Therefore, if a nitrogen feedstock is very wet, the mix will likely have a C:N ratio above optimal thus prolonging the time it takes to compost. One method composters will use in such cases is to incrementally add the wet nitrogen feedstock to an active compost pile. A hot compost pile losses moisture quite rapidly. **Increasing turning frequency will also help liberate water vapor and thus reduce moisture content**

Different *carbon* feedstocks decay at different rates. Wood shavings and woodchips in particular are very slow to decompose due in part to the presence of lignin. Leaves are very quick to decompose when mixed with *nitrogen* feedstocks, but there are differences mainly in C:N ratio between freshly raked leaves, and leaves that were stored for several months or years.

The following are ratios of mixes that have been tested at Michigan State University and are representative mixes:

1 skidloader bucket load of dairy manure from tie and free stall (C:N ratio = 18:1, MC = 75-80%) and 1 skidloader bucket load of sawdust horse bedding (C:N ratio = 80:1, MC = 45%). Resulting C:N ratio of 28:1 to 32:1 and a moisture content of 60-65%.

1 skidloader bucket load of dairy manure from tie and free stall and 2 skidloader bucket loads of 1 year old leaves (C:N ratio = 55:1, MC = 56%). Resulting C:N ratio of 25:1 to 30:1 and a moisture content of around 60-65%.

1 skidloader bucket load of poultry manure (C:N ratio = 5:1, MC = 65%) and 4 skidloader bucket loads of 1 year old leaves. Resulting C:N ratio of 25:1 to 30:1 and a moisture content of around 55-60%.

Many yard clippings compost operations will set up piles or windrows of leaves in the fall, and then incrementally add grass during the spring. Early in the spring the C:N ratio of the mix is very high but decreases as more grass clippings are added. This same type of approach can be followed with any carbon and nitrogen feedstocks used in farm compost mixtures.

There are also cases where for instance poultry manure is partially composted without any carbon feedstocks and sold as a fertilizer. Poultry manure is considered a very hot nitrogen feedstock in that it heats up very rapidly, and the heat drives off moisture to the point that it dries the manure out before it has fully composted. While a significant portion of nitrogen is lost as ammonia, the resulting product is still high in nitrogen.

Livestock farmers are often faced with not having enough farm-generated carbon feedstocks to mix with the manure in terms of achieving proper C:N ratios. In such cases the farmer will import carbon sources such as leaves from neighboring communities. Many farmers have found such practices actually serves to connect the farm to the community. However, in some states there are regulatory issues involved if a farm receives and composts materials not generated on the farm. Farmers intending to include off-farm materials in compost mixes should investigate the local and state regulations pertaining to farm compost operations.

Methods

The newly released federal standards contain specific methods and criteria that must be met for “composting”. The letter of the law initially required a specified number of turns (5), with specified temperatures (131-170F), in a specified period of time (3 days in a static aerated pile or 15 days in a windrow). The spirit of the law is concerned about assuring that human pathogenic bacteria are not present in the compost. To assure this is not the case, standards developed for the composting of sewage sludge were applied to on farm composting. Recent changes to the rule have removed the requirement for five turns and replaced it with a requirement for turning to assure that the entire pile heats to the necessary temperature.

The organic standard also provides rules for when animal manure is applied directly to cropland without composting. There must be a 90 day period for above ground crops or 120 period for crops in contact with the ground from between the time manure is applied and crops are harvested. It seems logical that as long as these same time criteria are met from the starting point of addition of animal manure to the compost pile until the compost is used, the spirit of the law is met.

All of this is relevant because ***high quality compost can be made quickly with frequent turning or slowly with less frequent turning***. The more frequently piles are turned and mixed, in general, the greater the availability of food, air and water, and the faster the rate of microbe growth. Microbe growth and composting will occur with less turning, but it will take more time. A minimum pile size (usually 3' x 3' x 3') is necessary to obtain adequate heating. In very large piles, pipes or tubes like 4" plastic drainage pipe available for about $20/100 feet may need to be added to provide adequate aeration. Placing them on an angle so that warm air rises and creates a draw helps pull more air through the pile.

The methods used are also dependent on the quantity of compost desired. It is possible to make quantities needed for container media and compost tea by hand turning with pitchforks. It is much easier with the use of a front-end loader. To make farm size quantities, a loader or other turning equipment is necessary.

*Siting and Space Requirements.*The area should be easily accessible, well drained, and as close as possible to the source of material generation. A water source is highly desirable. Irrigating a compost pile or windrow is difficult. Compost can hold a tremendous amount of water, and simply spraying a pile or windrow will only wet the edges. Some municipal compost facilities will not turn windrows that have dried up but rather wait for a rain and turn during a rain if pad conditions permit. This way the wetted outer edge material is incorporated along with the water, and the drier inner material is then exposed to the rain.

Never put a compost pile or windrow in the lowest part of a field. The ideal situation is to have a dedicated area where the surface has been graded to a minimum of 2% slope and topped with packed clay or concrete. Packed clay works well but can limit access during very wet weather. Compost windrows should be set up along the grade, not across it. If no covers are used or the area is unsheltered, provisions should be made to collect the surface runoff and either store it using a retention pond, then either apply it to land, add it to the compost piles/windrows, or apply it to grass infiltration areas.

Some farmers have set up windrows in fallow fields. This is an acceptable practice as long as the field has a minimum of 2% slope, and the windrows should be covered (e.g. fleece blankets) during periods of heavy precipitation to avoid leaching of nutrients into the groundwater.

When time and space is not critical, a farmer has significantly greater flexibility in how they use their compost. A batch of compost set up in the spring, even if not fully cured, can be applied to fields in the fall. However, batches set up in the summer and fall may not be mature enough for spring application, hence experienced farmers often wait a full year before using a batch to ensure the compost is fully cured and mature, especially when used on high-valued crops or in transplant medium.

The amount of space needed for a composting area depends on the amount of material to be processed, the type of method used, and the amount of time available to store and cure the compost. Piles can be setup one next to the other in order to maximize the space occupied. Windrows turned with a dedicated turner require less area than windrows turned with a front-end loader. Even with a dedicated turner, there should be space between windrows to maneuver a front-end loader.

A windrow is just a long pile. There are two main limitations to how big to make a windrow:

aeration, and method of turning. Mechanical turning with a front-end loader is a good option because farmers often already have that equipment on hand. The main drawback with front-end loaders is if the farmer intends to sell the compost. Front-end loaders do not break up and mix the materials as thoroughly as a dedicated turner, which will result in some clumps and a product that does not have the "look" consumers have grown accustomed to with compost.

Plant material typically has better structure than manure, which is critical in providing porosity and hence, aeration. For manure compost, bulky materials like straw or woodchips are often used to provide and maintain structure and porosity. They also are a suitable carbon source. These materials, or bulking agents, will allow for manure compost to be piled higher, but the drawback, especially in the case of wood chips, is they decompose much slower than other types of carbon feedstocks. Leaves provide structure early in the compost process, but tend to loose their structure later in the process.

The **volume reduction of bulky mixes** can be over 50%. The **volume reduction of denser mixes** tends to be no greater than 40%. Because of the volume reduction, piles and windrows can be combined at some point during the process, which frees up space. It is also a good idea to not let piles or windrows get too small or else they may not be able to retain the heat generated, and they may dry out very quickly.

The physical structure of the pile affects overall porosity and determines how well or how poorly a compost mix aerates during composting. **Poorly aerated compost requires the most management in order to prevent potential build-up and release of offensive odors and a decrease in compost quality.** Referring again to the dairy cow packed bedding, the straw provides very good structure to the compost mix for aeration, in fact a little too good. **Well-aerated compost will reduce the amount of turning and improve compost quality, but can also lead to rapid drying of the compost before it has fully decomposed.**

In the case of heavier, denser, and less porous mixtures such as wet manure and sawdust, aeration can be enhanced by building the piles/windrows on a base of porous material like woodchips at the base, and further enhanced by placing perforated pipes in the base. In this type of system, known as passively aerated composting, the compost is not turned. This requires very thorough initial mixing of the materials. This can be accomplished by passing the mixture through a manure spreader. Some farmers use a feed mixing wagon to mix compost. If the mixture contains manure, either power wash the mixer wagon before using it to mix feed, or dedicate the wagon for just mixing compost. After the mixture has been piled, cover the entire pile/windrow with a layer of finished compost, peat, mulch, or woodchips. This layer acts as insulation, which is needed to ensure uniform heating and decomposition throughout the whole pile/windrow. Using finished compost or peat as a cover is preferable because it can be incorporated with the compost pile/windrow without diminishing quality. Mulch and woodchips are not fully decomposed and would either need to be screened out or, if left in the mixture, the compost would need to be cured for a longer period of time.

Turning is probably the most demanding part of composting in terms of time and energy. If the mix has good structure in terms of porosity, then the pile or windrow will only need to be turned 2-3 times during the entire process. The main reason to turn is to incorporate the material that are on the edges of the pile or windrow into the inner regions where composting happens at a much more accelerated rate.

Denser compost mixes need to be turned more frequently to allow for better airflow, but the mix tends to settle within 2-3 days of turning, so it's a short lived benefit. It was commonly believed that turning introduces air into the pile, but several researchers have found that the microbes consume the air introduced into a compost mix from turning in a matter of hours.

If anaerobic conditions develop even slightly in compost, turning will release the odors that built up in the inner regions of the compost. One may think, "If I don't turn the compost, I won't release the odors." Not turning the compost may actually be worse than turning more frequently because the longer a pile sits unturned the more odors build up, and these odors can eventually escape even if the compost is not turned. Quality is also significantly diminished in compost that has been subjected to prolonged anaerobic conditions. Frequent turning to minimize odors then simply becomes the dilution solution for controlling odors, and it is strongly recommended to take preventative measures such as adjusting the mix by adding bulkier carbon feedstocks.

There are several ways to approach when to turn and how frequently. As stated earlier, temperature is the main way to monitor the progress of a compost mix. A compost mixture that exceeds 160 °F should be turned to release heat. At such temperatures the beneficial microbes needed for decomposition begin to be killed off. For compost mixtures that have a moisture content in excess of 75%, turning can help release water vapor. Turing too often can result in too much moisture being released.

When mixing and turning piles/windrows with a front-end loader, dig into the bottom of the pile, lift the bucket, and drop the material. As discussed previously, front-end loaders do not break up the material and mix as thoroughly as a dedicated compost turner. But if the compost is to go onto agricultural fields or vegetable beds, "clumpy" compost is acceptable. Passing the compost through a spreader can break up these clumps. Any compost producer considering marketing the compost will likely need to screen the compost, so the clumps could be removed and added to new compost piles/windrows.

If a pile is not heating (see next section), the food supply (carbon and nitrogen), moisture level, and aeration needs to be considered. If the pile is mixed and heating occurs, then either aeration (oxygen) was limiting, or the layers and sources needed to be mixed. If no heating occurs and water may be limiting, add water. If both air and water are present and the pile has been mixed, either composting is finished or more nitrogen or carbon needs to be added.

We created three piles at MSU with the same recipe but different management methods. Ingredients for the first pile were put in a manure spreader and mixed as the windrow was formed. Two additional piles/windrows (5'x50' base) were formed by layering the materials mentioned above. The first and second piles were turned about every two weeks with a compost turner. The third pile was rolled or turned about every three weeks with a front-end loader. The pile mixed with a manure spreader and turned with a turner was done cooking in about 8 weeks. Nitrogen tested at 2.5%, the pH was 6.5, and the C:N ratio was 12:1. The batch that was layered first and then turned with a turner took about 2 to 3 weeks longer to finish heating. The final pile took much longer, about 16 weeks, and still had some hay that was not decomposed. Eventually the quality of the compost was similar, but the equipment and effort were much different.

Factors That Can be Managed During Composting

1) **C:N Ratio**
2) **Moisture Content**
3) **Aeration (particle size, pile size, turning)**
4) **Temperature (pile size, turning, etc)**
5) **pH**
6) **Organisms Present**
7) **Time for Composting**

These factors can be used a number of ways including making a compost with more bacterial or fungal activity.

Monitoring

Monitoring is usually a combination of intuition, observation, and experience along with actual empirical data measured with equipment. Equipment will often substitute for experience if measurements are made and interpreted properly.

Temperature will be the easiest indicator to monitor. Compost thermometers with over 12" probes are available for under $20. When a human hand can be placed into the pile and not burned, the temperature is below 130F. When a hand cannot be held in the pile for longer than a few seconds, the temperature is above the 130F mark. Temperature above 160F is not desired because certain beneficial bacteria are lost. The location in the pile will influence the temperature. Normally it is recommended to test the internal temperature, about 2/3rd down and 1/3rd in from the side. The hottest spot in a windrow will be the top of the pile where convection currents exit the pile. This is the place to check for excessive heating. Figure 1 on the last page provides some ideas of how temperature patterns are influenced by the C:N ratio.

The ***moisture*** content of compost during active composting should be at a point that some water can be squeezed out by hand. There is not an easy or affordable way to accurately measure water content other than using a scale. For example, if a sample of compost weighs 10 pounds moist and 6 pounds after oven drying, then the moisture content is (10-6) divided by 10 or 40%. Moisture content in the 50 to 75% range would be recommended. A bucket and a spring scale may be the easy way to measure a larger sample. The weight of five gallons of compost can be multiplied by 40 to provide an estimate of the weight per cubic yard. A bucket of compost spread out in a thin layer can dry in 2 to 3 days in a bright sunny location. This will be air dry and not oven dried which is preferred – but air dry under warm sunny conditions will provide a reasonable estimate. If the compost is being dried for nutrient analysis, do not dry on an absorbent material that will remove water and nutrients.

Aeration can be measured with oxygen probes but the cost is prohibitive for most small farms and the equipment is not likely necessary. Oxygen levels above 5% are desired. Levels of 2% or less usually indicate turning is necessary. The appearance of the pile and the odors produced will be an indicator of low oxygen. A sour or foul smell will develop if oxygen is limiting.

Many farms may have equipment or access to equipment to measure ***pH(acidity).*** Either a meter or litmus test strips can be used. At high pH (>7.6), the probability of nitrogen loss to the atmosphere is increased. Overall pile pH of < 7.5 is desirable but not necessarily essential. Dairy and swine manure compost has had a higher pH than plant based compost in our studies. Over time it is expected that the pH of the pile will begin to decline, which is an indicator of maturity. In our research, we have added peat at 10 to 20% by volume to lower pH. We have added sulfur at 2 to 4 pounds per cubic yard for a heavily manure (30 to 40% by volume) compost.

For container plant production, the availability of fertilizer in soilless media is monitored using an ***electrical conductivity*** meter ***(EC***). Pure water does not conduct electricity and has a conductance of zero (0). The more salt (positive cations and negative anions) in the water, the greater the conductance (mhos or millisiemens). High conductance readings indicate a high level of soluble salts. The salts can be beneficial such as nitrate, ammonium, potassium, calcium, magnesium, or the salts can be undesired such as sodium and chloride.

While more detailed testing is necessary to determine what salts are present, measuring EC is a quick way to monitor both progress of the process and potential problems. Usually a volume of soil or compost is diluted with two parts (volumes) of distilled or RO water. A reading of 0 to 2 mmhos or millisiemen would be low, between 2 and 4 would be moderate, and greater than 4 would indicate a high level of soluble salts that might be a concern. Ideally ***nitrate-nitrogen*** could also be measured by ion selective electrode or color indicator strips. For monitoring equipment contact Spectrum at (800-248-8873, www.specmeters.com) More complete testing of soluble or total nutrients can be performed by many private or university soil testing labs. The carbon content can also be analyzed to the provide C:N ratio. Interpretation guidelines for nutrients are available.

Maturity

As mentioned above, a decline in temperature does not necessarily assure the compost is completely finished. Compost is finished when no adjustment of water, aeration or C:N results in additional heating. Additional steps occur after heating that result in increasing stability and what is usually identified as a mature state. Bacterial, fungal, and microbial populations stabilize during this period. Nitrogen in the biological or complex form as dead microbes is mineralized first to ammonium and then to nitrate forms. This process is partially responsible for a decline in pH and an increase in nitrogen availability.

Compost maturity is usually measured by the rate of carbon dioxide evolution. Test kits are available to measure a maturity index and one example is sold by Woods End Institute (http://www.woodsend.org). Immature compost may also be loosing nitrogen in the form of ammonia, which can also be measured colorimetrically. It is usually recommended that at least two months pass between the end of heating and use of the compost. Four to six months would likely improve the quality of the compost assuming it is maintained moist but protected from leaching rains.

Another way to test the maturity of compost is to germinate seeds in the compost or compost mixed with a soilless root medium. Seedling bioassays provide a reasonably fast and very inexpensive measure on nutrient availability. A seedling bioassay can also indicate the presence of any phytotoxic chemicals or compounds in the compost. Recommended species include tomato, peas, corn, sunflower, and beans. This provides a range of plant types with known sensitivities to herbicides (tomato) and other compounds (peas). Corn and sunflower are very responsive to the amount of nitrogen present. A comparison to plants grown with added water soluble fertilizer like fish emulsion will give an indication if nitrogen is limiting. Snap beans also respond to nitrogen, but seem to be more sensitive to soluble salts. If adding fertilizer does not increase growth, see if leaching the compost with water to wash out salts will help.

Mathematics (Application and Use)

Compost contributes many beneficial effects to the soil. Microorganisms contribute to the *biological* diversity of the soil. The carbon and humus contribute to soil *physical* structure, water absorption and retention, and microbial activity. Compost is also an important source of nitrogen, potassium, phosphorus, and other elements that contribute to soil chemical properties.

The rate and frequency of application will determine the benefits attained. Low rates of 2 to 10 ton/acre will primary help with biological activity through both innoculum and providing a carbon source. Increasing rates (10 to 20 ton /acre) will contribute to soil physical properties and water absorption and retention. Higher rates will have a more rapid effect on physical and chemical properties and provide essential nutrients.

How do you calculate nutrient additions for compost? You need some information first. You need to know what the nitrogen content is (%N) and the density (weight per unit volume). For this example, we will assume that the nitrogen content is 1% (range 1 to 1.5 common, could be up to3%). We will assume that the dry weight of the compost is 20 lbs/cu ft or 540 lbs/ cu yd. An application of 10 ton per acre at 1% nitrogen equals

10 ton/acre times 2000 lbs/ton = 20,000 lbs

20,000 lbs times 0.01 (1%) = 200 lbs of N/acre

But we have to ask how much of that nitrogen is available the first year? The answer is it will vary depending on the compost and the soil microbial activity. Research is being done to get a better handle on what this number is, but I have been taught to assume 10% is available.

What would 10 ton/acre look like? We need to put things in a perspective of volume (cu yd), depth (inches), and dollars ($). We need some assumptions and facts. First, let's assume that compost at around 40% moisture would weigh 900 lbs/cu yd (range might be 800 to 1200). This weight would give us the 540 lb/cu yd dry weight. We also need to know that there are 43,560 sq ft per acre, and 27 cu ft per cu yd. So,
-10 ton x 2000 lbs/ton = 20,000 pounds
-20,000 lbs divide by 900 lbs/ cu yd = 22.2 cu yd
-22.2 cu yd x 27 cu ft/ cu yd = 600 cu ft
-600 cu ft / 43,560 sq ft/ acre = 0.01377 ft depth
-0.01377 ft x 12 in/ft = 0.165 inch or 1/6 inch
-At $30 per ton ($13.50 per yard) the cost is
$300 per acre.

These calculations can be done in reverse also. Let's say you applied 1 inch of compost and you want to know how much nitrogen you applied. You could start this way:
-1 inch / 12 inch per foot = 0.0833 feet
-0.0833 feet x 43,560 sq ft/acre = 3630 cu ft
-3630 cu ft / 27 cu ft/cu yd = 134 cu yd

-134 cu yd x 900 lbs /cu yd = 121,000 lbs
-121,000 lbs / 2000 lbs per ton = 60 ton per acre
-121,000 x 1.5 % N = 1,815 lbs of N total
-1,185 lbs x 10% available = 181 lbs N available

½ inch would be 30 ton (67 yard) (91 lbs N)
¼ inch would be 15 ton (33 yard) (45 lbs N)

Normally recommended rates are 5 to 10 ton per acre per year for several years while building the soil. It takes time to build up nutrient levels and microbial activity. Vegetable crops and heavily cropped soils would be on the high end. In a hoop house, the higher rates shown in the calculation examples are not detrimental with a good quality compost. Watch for excessive P application.

There are reports of yield responses and other beneficial effects at rates as low as one ton per acre (about 2 cubic yards). At lower rates and applications each year, compost can be applied to large acreage and for field crops. Lime or fertilizer application equipment is used for the low rates.

More

Two additional important uses of compost are as a component for potting medium to grow transplants or container-grown plants, and compost as a source of nutrients and biological diversity to be applied as a foliar spray or soil drench.

Transplants. Not just any compost is suitable for use in container media. Compost in this case is the end result of a well-developed recipe. The percent compost in a transplant medium can be as high as 100% and as low as 10% by volume. The soluble salts and pH need to be measured and hopefully kept in the low range. Blending with peat, coconut coir, or other components is done to attain the desired soluble salt reading (0.5 to 1.5 mS on a 1:2 media to water dilution) and pH (6.0 to 7.0). The volume of compost will typically range from 10% to 50%, although it can be higher. For higher rates, the compost would need to be very mature and stable.

Here is an example of a reproducible compost recipe: (suitable for potting medium or compost tea): 1 bale straw, 1 bale grass hay or grass alfalfa mix, 1 bale wood shavings for bedding, 1 bale (3.8 cu ft) peatmoss, 6 cubic feet (wheel barrow) of soil, 6 cubic feet (wheel barrow) of grass clippings (If green plants are not available, use alfalfa hay), 6 to 12 cubic feet (wheel barrow) of green plants like comfrey.

Higher nutrient levels can be obtained by incorporating fertilizer such as rock phosphate, greensand, or alfalfa meal during the composting process. The assumption here is that the compost can be protected from leaching rains with either a roof or a fleece blanket. If sphagnum peat will be incorporated into the medium eventually, it also may make sense to add the peat to the compost processing.

Water Extracts (Tea). The biological diversity and nutrients in compost can also be extracted with water and used as a nutrient source or disease prevention tool. These water extracts or "teas" as they are referred to are particularly important in the early stages of transitioning to organic production methods when soil quality or natural biological diversity are limited in the production environment. There is an increasing body of evidence that compost water extracts can be used to reduce the impact of plant pathogenic diseases on roots and leaves. Management of damaging insects may also be possible. Our research leads us to suggest that brewers and lots of aeration are not necessary. Take a mature compost with proper moisture in a five gallon bucket, feed it some alfalfa meal or Bradfield Alfalfa fertilizer if you want bacteria, or some cooked rice if you want fungi, wait 2 or 3 days, make a water extract (10:1 water to compost and stir) and you have biologically active "extract" or tea if you please. The organisms you want grow better in the solid phase then in a liquid phase, with less worry about bad guys. It's simple.

Summary

Making high quality compost requires some practice, experience and experimentation. There is not agreement on one best way to make compost and many different methods will work. Start with a "resource" approach rather than a "waste" approach. Work to increase the diversity of stock materials. Ask the hard questions about how to make a quality product that will demand a higher price and return a fair return for time invested.

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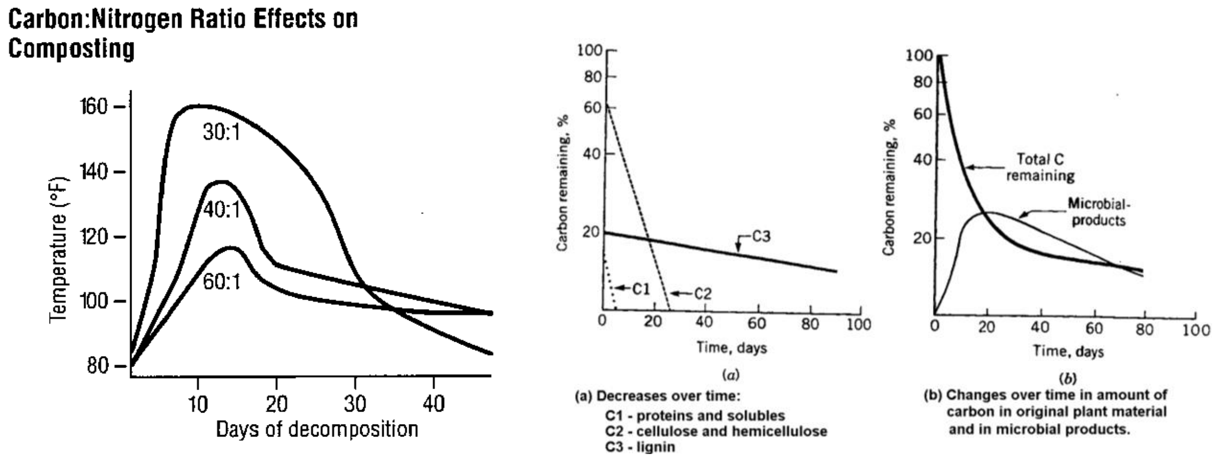

Figure 1. http://whatcom.wsu.edu/ag/compost/fundamentals/carbonnitrogen.htm

When using temperature as an indicator of the compost pile progress, consider at least these five criteria:

1. Rate of heating: (assuming air and feedstock temperature of 60F or greater), 120F in 3 to 4 days (good mix); should continue to 140 next day and 150 following day

2. Maximum temperature: 130 to 160F, Maximum at 130 or less, either nitrogen, water or air are limiting.
Looking for a peak around 140 to 150. Greater then 160, break down the pile.

3. Length of heating: (Also an indicator of available carbon.) How long does the temperature stay up? Could be 1 or 2 days, a week, a month, or more.

4. Rate of Cooling: How fast does the temperature come down? More nitrogen will be slower.

5. Temperature of reheat : If there is nitrogen and carbon available, the pile will reheat with mixing and water addition. Addition of a soluble nitrogen source like alfalfa meal in part of the pile can also give an indication if nitrogen is limiting if that part of the pile heats up.

Table 1. C:N Ratio, Nitrogen Content, Moisture Content, and Bulk Density of Some Common Organic Materials Generated On Farm (Rynk, 1992)

Material	C:N Ratio	% Carbon	%Nitrogen	Moisture Content % (wet weight)	Bulk Density (lbs/cu yd)
Vegetable "wastes"	12-19	40-50	2.5-4	87	1,585
Hay - general	15-32	40-50	0.7-3.6	8-10	225 (MSU)
Grass clippings	9-25	40-50	2.0-6.0	82	300-800
Dairy cattle manure	11-30	30-40	1.4-4.2	67-87	1,323-1,674
Laying hens manure	3-10	30-40	4-10	62-75	1,377-1,620
Turkey litter	16	40-45	2.6	26	783
Apple pomace	48	45-55	1.1	88	1,559
Corn stalks, mature	60-73	40-55	0.6-0.8	12	32
Straw - general	48-150	45-55	0.3-1.1	4-27	58-378
Sawdust	200-750	45-60	0.06-0.8	19-65	350-450
Leaves	40-80	40-55	0.5-1.3	38 (average)	300-800

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