The Science and Engineering of Composting
Getting the Right Mix

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Getting the Right Mix

Calculations for Thermophilic Composting

Tom L. Richard and Nancy M. Trautmann

One of the first tasks in developing a successful composting program is getting the right combination of ingredients. Two parameters are particularly important in this regard: moisture content and the carbon to nitrogen (C/N) ratio.

Moisture is essential to all living organisms, and most microorganisms, lacking mechanisms for moisture retention (like our skin), are particularly sensitive in this regard. Below a moisture content of 35 to 40%, decomposition rates are greatly reduced; below 30% they virtually stop. Too much moisture, however, is one of the most common factors leading to anaerobic conditions and resulting odor complaints. The upper limit of moisture varies with different materials and is a function of their particle sizes and structural characteristics, both of which affect their porosity. For most compost mixtures, 55 to 60% is the recommended upper limit for moisture content. Because composting is usually a drying process (through evaporation due to microbially generated heat), starting moisture contents are usually in this upper range.

Of the many elements required for microbial decomposition, carbon and nitrogen are both the most important and the most commonly limiting (occasionally phosphorous can also be limiting). Carbon is both an energy source (note the root in our word for high energy food: carbohydrate), and the basic building block making up about 50 percent of the mass of microbial cells.

Nitrogen is a crucial component of proteins, and bacteria, whose biomass is over 50% protein, need plenty of nitrogen for rapid growth. When there is too little nitrogen, the microbial population will not grow to its optimum size, and composting will slow down. In contrast, too much nitrogen allows rapid microbial growth and accelerates decomposition, but this can create serious odor problems as oxygen is used up and anaerobic conditions occur. In addition, some of this excess nitrogen will be given off as ammonia gas that generates odors while allowing valuable nitrogen to escape. Therefore, materials with a high nitrogen content, such as fresh grass clippings, require more careful management to insure adequate oxygen transport, as well as thorough blending with a high carbon waste. For most materials, a C/N ratio of about 30 to 1 (by weight) will keep these elements in approximate balance, although several other factors can also come into play.

So, if you have several materials you want to compost, how do you figure out the appropriate mix to achieve moisture and C/N goals? The theory behind calculating mix ratios is relatively simple - high school algebra is the only prerequisite. To help you understand these equations, and calculate the right mix for your situation, we developed a set of informative pages, on-line calculations, and spreadsheets you can download and operate anytime with software on your own computer.

Moisture Content

by Nancy Trautmann and Tom Richard

When deciding what proportions of various materials to mix together in making compost, the moisture of the resulting mixture is one of the critical factors to consider. The following steps outline how to design your intital mix so that it will have a suitable moisture level for optimal composting. **In the composting industry, the convention is to report moisture content on a wet (or total weight) basis, as the formulas below indicate.**

1. Calculate the % moisture for each of the materials you plan to compost. a) Weigh a small container. b) Weigh 10 g of the material into the container. c) Dry the sample for 24 hours in a 105-110 degree C oven. d) Reweigh the sample, subtract the weight of the container, and determine the moisture content using the following equation: $M_n = ((W_w - W_d)/W_w) \times 100$ in which: M_n = moisture content (%) of material n W_w = wet weight of the sample, and W_d = weight of the sample after drying. Suppose, for example, that you weigh 10 g of grass clippings (W_w) into a 4 g container and that after drying the container plus clippings weighs 6.3 g. Subtracting out the 4-g. container weight leaves 2.3 g as the dry weight (W_d) of your sample. Percent moisture would be: $M_n = ((W_w - W_d)/W_w) \times 100$ = ((10 - 2.3) / 10) x 100 = 77% for the grass clippings
2. Choose a moisture goal for your compost mixture. Most literature recommends a moisture content of 50%-60% by weight for optimal composting conditions.
3. The next step is to calculate the relative amounts of materials you should combine to achieve your moisture goal. The general formula for percent moisture is:

$$G = \frac{(Q_1 \times M_1) + (Q_2 \times M_2) + (Q_3 \times M_3) + \ldots}{Q_1 + Q_2 + Q_3 + \ldots}$$

in which: Q_n = mass of material n ("as is", or "wet weight") G = moisture goal (%) M_n = moisture content (%) of material n You can use this formula directly to calculate the moisture content of a mixture of materials, and try different combinations until you get results in a reasonable range. Using trial and error to determine what proportions to use for a mixture will work, but there is a faster way. For two materials, the general equation can be simplified and solved for the mass of a second material (Q_2) required to balance a given mass of the first material (Q_1). Note that the moisture goal must be **between** the moisture contents of the two materials being mixed.

$$Q_2 = \frac{(Q_1 \times G) - (Q_1 \times M_1)}{M_2 - G}$$

For example, suppose you wish to compost 10 kg grass clippings (moisture content = 77%). To achieve your moisture goal of 60% for the compost mix, you calculate the mass of leaves needed (moisture content = 35%):

$$Q_2 = \frac{(Q_1 \times G) - (Q_1 \times M_1)}{M_2 - G}$$

Q_2= ((10 kg)(60) - (10 kg)(77)) / (35 - 60) = 6.8 kg leaves Mixtures of 3 or more materials can also be solved in a similar way (although the algebra is more complicated), but for an exact solution the amounts of all but one material must be specified. To find the mass of the third material (Q_3) given the masses of the first two (Q_1 and Q_2) plus all three moisture contents (M_1, M_2, and M_3) and a goal (G), solve:

$$Q_3 = \frac{(G \times Q_1) + (G \times Q_2) - (M_1 \times Q_1) - (M_2 \times Q_2)}{M_3 - G}$$

C/N Ratio

Tom Richard and Nancy Trautmann

Once you have calculated the moisture content of your compost mixture, the other important calculation is the carbon-to-nitrogen ratio (C/N). Grass clippings and other green vegetation tend to have a higher proportion of nitrogen (and therefore a lower C/N ratio) than brown vegetation such as dried leaves or wood chips. If your compost mix is too low in nitrogen, it will not heat up. If the nitrogen proportion is too high, the compost may become too hot, killing the compost microorganisms, or it may go anaerobic, resulting in a foul-smelling mess. The usual recommended range for C/N ratios at the start of the composting process is about 30/1, but this ideal may vary depending on the bioavailability of the carbon and nitrogen. As carbon gets converted to CO_2 (and assuming minimal nitrogen losses) the C/N ratio decreases during the composting process, with the ratio of finished compost typically close to 10/1.

Typical C/N ratios and nitrogen values for many kinds of compostable substances can be looked up in published tables such as Appendix A, On-Farm Composting Handbook. Some additional nitrogen and ash data is in the table of Lignin and Other Constituents of Selected Organic Materials (see below). To calculate the carbon content given C/N and percent nitrogen, solve:

%C = %N x C/N

You may be able to measure the carbon and nitrogen content of your own materials and then calculate the ratio directly. Soil nutrient analysis laboratories or environmental testing laboratories can do the nitrogen test, and maybe carbon as well. Your local Cooperative Extension office can give you the names of soils laboratories in your area. The Cornell Nutrient Analysis Lab has information about their procedures for total carbon, organic carbon, and total nitrogen analysis. You can also estimate the carbon content from ash or volatile solids data if either is available. Once you have the C/N ratios for the materials you plan to compost, you can use the following formula to figure out the ratio for the mixture as a whole:

$$R = \frac{Q_1(C_1 \times (100 - M_1) + Q_2(C_2 \times (100 - M_2) + Q_3(C_3 \times (100 - M_3) + \ldots}{Q_1(N_1 \times (100 - M_1) + Q_2(N_2 \times (100 - M_2) + Q_3(N_3 \times (100 - M_3) + \ldots}$$

in which: R = C/N ratio of compost mixture Qn = mass of material n ("as is", or "wet weight") Cn = carbon (%) of material n Nn = nitrogen (%) of material n Mn = moisture content (%) of material n

This equation can also be solved exactly for a mixture of two materials, knowing their carbon, nitrogen, and moisture contents, the C/N ratio goal, and specifying the mass of one ingredient. By simplifying and rearranging the general equation, the mass of the second material required would be:

$$Q_2 = \frac{Q_1 \times N_1 \times \left(R - \frac{C_1}{N_1}\right) \times \left(100 - M_1\right)}{N_2 \times \left(\frac{C_2}{N_2} - R\right) \times \left(100 - M_2\right)}$$

Returning to the previous example of grass and leaves, let's assume the nitrogen content of the grass is 2.4% while that of the leaves is 0.75%, and the carbon contents are 45% and 50% respectively. Simple division shows us that the C/N ratio of the grass is 18.75 and the C/N content of the leaves is 66.67% For the same 10 kg of grass we had before, if our goal is a C/N ratio of 30:1, the solution is:

$$Q_2 = \frac{10 \times 2.4 \times (30 - 18.75) \times (100 - 77)}{0.75 \times (66.67 - 30) \times (100 - 35)}$$

$$= 3.5 \text{ kg}$$

Note that we need only 3.5 kg leaves to balance the C/N ratio, compared with 6.8 kg leaves needed to achieve the 60% moisture goal according to our previous moisture calculation. If the leaves were wetter or had a higher C/N ratio, the difference would be even greater. So how many leaves should you add?

If we solve the general form of the C/N equation for the 10 kg of grass and the 6.8 kg of leaves (determined from the moisture calculation), and use the same values for percent moisture, C, and N, the resulting C/N ratio is a little less than 37:1. In contrast, if we solve the general form of the moisture equation for 10 kg of grass and only 3.5 kg of leaves, we get a moisture content over 66%. (To gain familiarity with using the equations, you can check these results on your own).

In this example, as is often the case, moisture is the more critical variable. This is especially true toward the wet end of the optimum (>60%), where anaerobic conditions are likely to result. So it is usually best to err on the side of a high C/N ratio, which may slow down the compost a bit but is more likely to be trouble free. If, on the other hand, your mixture is dry, then you should optimize the C/N ratio and add water as required.

As with moisture calculations, mixtures of 3 or more materials can be solved for the mass of the third material if the first two are specified (one equation & one unknown). Given the carbon, nitrogen and moisture contents of each ingredient, the masses of the first two, and the C/N ratio goal, the solution for the mass of the third material is:

$$Q_3 = \frac{RQ_1N_1(100 - M_1) + RQ_2N_2(100 - M_2) - Q_1C_1(100 - M_1) - Q_2C_2(100 - M_2)}{C_3(100 - M_3) - RN_3(100 - M_3)}$$

If we also want to consider moisture content, we can solve both equations simultaneously (moisture and C/N) for any two unknowns.

Bioavailability of Carbon and Nitrogen

Tom Richard

Carbon-to-nitrogen ratios may need to be adjusted depending on the bioavailability of these elements. This is commonly an issue with high carbon materials, which are often derived from wood and other lignified plant materials, as increased lignin content reduces biodegradability. Particle size is also an important factor, with smaller particles degrading more quickly than large particles of the same material. Bioavailability can also be a factor with nitrogen sources, especially fertilizer nitrogen, where nearly instant availability can exceed the assimilative capacity of the microbial community and be lost as ammonia odors and nitrate in leachate.

Use of Fertilizer Nitrogen to balance C/N Ratios

Tom Richard

When composting high carbon materials such as leaves, additional nitrogen may be required to reduce the C/N ratio to the optimal range. If considering using fertilizer as an N source, one needs to proceed cautiously. While the theoretical number should be the same as calculated using the C/N ratio formulas, the nitrogen in fertilizers is released much more rapidly than that in organic nitrogen (from which the rules of thumb are derived).

Organic nitrogen sources provide a natural "time release" that makes them available at a rate comparable to the growth rate of microorganisms in the compost, so they are utilized efficiently. The rapid availability of nitrogen fertilizers is especially a concern in the fall and winter, when low temperatures slow down the growth rate of microorganisms, and nitrogen uptake will be correspondingly slow. To mimic a natural time release with synthetic fertilizers, they should be applied sparingly and in a series of applications. While there is not a research base on which to estimate what the right rate would be, sniffing for ammonia volatilization may indicate if too much was applied too soon. In addition, because none of the fertilizer nitrogen is locked into compounds that are difficult to degrade (as is the case with organic sources), the total applied should be significantly less than the calculations indicate - perhaps half to two thirds.

The Effect of Lignin on Biodegradability

Tom Richard

Plant cell wall material is composed of three important constituents: cellulose, lignin, and hemicellulose. Lignin is particularly difficult to biodegrade and reduces the bioavailability of the other cell wall constituents. A bit of knowledge about each of these constituents is helpful in understanding the vastly different rates that different plant materials decompose. This discussion also presents the mathematical models developed to compensate for the effect of lignin on biodegradability in anaerobic systems and suggests some constraints on applying these models to aerobic composting systems.

Cell Wall Constituents

Cellulose is a long chain of glucose molecules, linked to one another primarily with beta 1-4 glycosidic bonds. The simplicity of the cellulosic structure, using repeated identical bonds, means that only a small number of enzymes are required to degrade this material. Although people do not produce the enzymes required for cellulose degradation (and thus do not get much energy from eating paper, straw, or other cellulosic material), some microorganisms do. Cows and other ruminants create an environment in their rumen which encourages this microbial degradation, converting cellulose to volatile fatty acids and microbial biomass which the ruminant can then digest and use.

Hemicelluloses are branched polymers of xylose, arabinose, galactose, mannose, and glucose. Hemicelluloses bind bundles of cellulose fibrils to form microfibrils, which enhance the stability of the cell wall. They also cross-link with lignin, creating a complex web of bonds which provide structural strength, but also challenge microbial degradation (Ladisch et al., 1983; Lynch, 1992).

Lignin is a complex polymer of phenylpropane units, which are cross-linked to each other with a variety of different chemical bonds. This complexity has thus far proven as resistant to detailed biochemical characterization as it is to microbial degradation, which greatly impedes our understanding of its effects. Nonetheless, some organisms, particularly fungi, have developed the necessary enzymes to break lignin apart. The initial reactions are mediated by extracellular lignin and manganese peroxidases, primarily produced by white-rot fungi (Kirk and Farrell, 1987. Actinomycetes can also decompose lignin, but typically degrade less than 20 percent of the total lignin present (Crawford, 1986; Basaglia et al., 1992). Lignin degradation is primarily an aerobic process, and in an anaerobic environment lignin can persist for very long periods (Van Soest, 1994).

Because lignin is the most recalcitrant component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate. The effect of lignin on the bioavailability of other cell wall components is thought to be largely a physical restriction, with lignin molecules reducing the surface area available to enzymatic penetration and activity (Haug, 1993).

Modeling Lignin's Impacts on Biodegradability in Anaerobic Systems

Chandler et al. (1980) formulated a mathematical correction for bioavailability of an organic substrate based on its lignin content. Using data collected from the anaerobic degradation of a range of lignocellulosic materials (40-day retention time), they developed a linear relationship to describe this effect:

$$\text{Biodegradable fraction} = 0.83 - \left(0.028 \times \text{lignin}_{\%\,VS}\right)$$

where

$$\text{lignin}_{\%\,VS} = \frac{\text{lignin}_{\%}}{VS_{\%}\ /100} = \text{ lignin content as a percent of volatile solids}$$

$\text{lignin}_{\%}$ = the lignin content as a percent of total solids

$VS_{\%}$ = volatile solids as a percent of total solids

Kayhanian and Tchobanoglous (1992) proposed using the above equation to adjust C/N ratios for mixture calculations in a sequenced anaerobic/aerobic process. The effect, for highly lignified materials, can be significant. For example, using their lignin data for newspaper versus office paper:

Material	**Lignin Content (% of VS)**	**Biodegradable Fraction of VS**
Newsprint	21.9	0.217
Office Paper	0.4	0.819

Thus, while about 82% of the carbon in office paper is biodegradable, only 22% of the carbon in newsprint would be available through anaerobic digestion. Put another way, it would take almost 4 tons of newsprint amendment to provide the same bioavailable carbon as 1 ton of office paper. This clearly has significant implications for mixture ratio calculations.

Further evaluation of Chandler et al.'s (1980) relationship compared the predicted biodegradability with long term (75 day) batch studies in a high-solids anaerobic digestor (Kayhanian, 1995). The predicted biodegradability of this solid waste mixture based on its lignin content (typically 4%) was 68%, which was comparable to the 70% biodegradability measured in the long-term batch study.

The linear relationship given by Chandler et al. (1980) is simple and appears to provide reasonable accuracy for materials of relatively low lignin content. While Chandler et al.'s relationship makes mechanistic sense for relatively small lignin fractions, materials with a high lignin content may be affected differently. With a large amount of lignin present, some of the lignin would be overlapping other lignin molecules rather than cellulose, so the incremental effect will be smaller (Conrad et al., 1984). Recent analysis of extensive databases on the maximum digestibility of lignocellulosic materials in the rumen suggests a log-linear relationship provides a better fit (Van Soest, 1996):

$$\text{digestable fraction of cell wall} = 100 - 5.41\left(\text{lignin}_{\%\,\text{cell wall}}\right)^{0.76}$$

where

cell wall = approximately the sum of cellulose, hemicellulose, and lignin. Plant cell wall is also called Neutral Detergent Fiber (so named for the analytical procedure used).

$\text{lignin}_{\%\,\text{cell wall}} = \left(\dfrac{\text{lignin}_{\%}}{\text{cell wall}_{\%}/100}\right)$ = lignin as a percent of plant cell wall, and

$\text{cell wall}_{\%}$ = cell wall as a percent of total solids

Applying the formula of Van Soest (1996) to the cell wall fraction, we can calculate an overall biodegradable carbon content:

$$C_{\text{biodegradable}} = C_{\text{total}}\left(\frac{\text{cell wall}_{\%}}{100}\right)\left(1 - 0.0541\left(\text{lignin}_{\%\,\text{cell wall}}\right)^{0.76}\right) + C_{\text{total}}\left(1 - \frac{\text{cell wall}_{\%}}{100}\right)$$

This biodegradable carbon content can then be used to calculate biodegradable C/N ratios using the usual formulas. If we apply this equation to newsprint, wheat straw, maple wood chips and poultry manure, using data from the Table of Lignin and Other Constituents of Selected Organic Materials (page 24) and other sources, we get the following biodegradable C/N ratios.

Material	Carbon (% Total)	C/N (Total)	Carbon (% bio-degradable)	C/N (bio-degradable)	Lignin (% dry basis)	Cell wall (% dry basis)	Nitrogen (% dry basis)
Newsprint	39.3	115.5	18.4	54.2	20.0	97.0	0.34
Wheat straw	51.1	88.7	33.6	58.4	23.0	95.0	0.58
Manure, poultry	43.3	9.6	41.8	9.3	2.0	38.0	4.51
Wood chips, maple	49.7	51.2	43.8	45.1	12.7	32.0	0.97

Note, however, that when correcting carbon/nitrogen ratio calculations for lignin content, it may also be necessary to reduce the carbon/nitrogen goal. The typical recommended C/N ratio of 30:1 must presumably already include some discount for lignin, which is a component of most common carbonaceous materials.

It is also important to remember that these formulas are all based on data from anaerobic systems. Since lignin is degradable (albeit slowly) in aerobic systems, the restriction on biodegradability will be less in aerobic composting.

Lignin degradation under aerobic conditions

There is some debate and perhaps significant variability in the rate of lignin decomposition in aerobic systems. Lynch and Wood (1985) state that "little, if any, lignin degradation occurs during composting", and Iiyama et al. (1995) assume constant lignin as the basis of their calculations of polysaccharide degradation. However, Hammouda and Adams (1989) measured lignin degradation ranging from 17% to 53% in grass, hay and straw during 100 days of composting, and Tomati et al. (1995) measured a 70% reduction in the lignin content of olive waste compost after 23 days under high moisture (65-83%) thermophilic conditions. Interestingly, after this initially high decomposition rate under thermophilic conditions, Tomati et al. found no further reductions in lignin content during the subsequent 67 days under mesophilic conditions. In contrast, in a laboratory incubation study, Horwath et al. (1995) measured 25% lignin degradation during mesophilic composting and 39% during thermophilic composting of grass straw during 45 day experiments.

Adding small quantities of nitrogen to woody materials can increase lignin degradation rates. Over a two-week incubation with a white-rot fungi at 39-40°C (the optimum temperature for growth of Phanerochaete chrysosporium, the fungi used in this experiment), adding only 0.12% nitrogen (dry weight basis), lignin degradation in alder pulp increased from 5.2% to 29.8% (Yang et al., 1980). In this same study, the increase in lignin degradation of hemlock pulp with 0.12% supplemental nitrogen was only 2.2% to 3.9%, and additional nitrogen did not provide further benefit. The differences between plant species is likely related to differences in lignin structure, with gymnosperm lignin composed of coniferyl alcohols, angiosperm lignin composed of both coniferyl and sinapyl alcohols, and grass lignin of coniferyl, sinapyl, and p - coumaryl alcohols (Ladisch et al., 1983).

While significant lignin degradation appears possible during aerobic composting, several factors are likely to affect the decomposition rate. Conditions which favor the growth of white-rot fungi, including adequate nitrogen, moisture, and temperature, all appear to be important in encouraging lignin decomposition, as does the composition of the lignocellulosic substrate itself.

The impact of lignin degradation on the biodegradability of the remaining carbon has not been extensively researched. In one of the few studies which might provide such insight, Latham (1979) measured a 5 to 11% increase in anaerobic digestibility of barley straw after 3-to-4-week aerobic incubations at 30°C with various pure cultures of white-rot fungal species. Increases in biodegradability would likely be even greater with a mixed culture under thermophilic conditions, as evidenced by the lignin degradation rates cited above.

Pretreatment to enhance biodegradability

Biodegradability can be enhanced by pretreatment of lignocellulosic materials, including acid (Grethelin, 1985) or alkali treatment (Jackson, 1977; Van Soest, 1994), ammonia and urea (Basaglia et al., 1992; Van Soest, 1994), physical grinding and milling (Ladisch et al., 1983; Fahey et al, 1992), fungal degradation and steam explosion (Sawada et al, 1995), and combined alkali and heat treatment (Gossett et al., 1976). Gharpuray et al. (1983) examined several of these pretreatment options individually and in combination and found that those treatments which enhanced specific surface area were most effective at increasing enzymatic hydrolysis.

While pretreatment may be uneconomical when considered as a separate process in compost feedstock preparation, in some cases it may be incorporated in other preprocessing operations at little additional cost. However, because many lignocellulosic ingredients in composting serve dual roles as energy sources and porosity enhancers, treatments which reduce porosity and pore size distributions may prove counterproductive to maintaining an aerobic process.

Summary and Conclusions

Researchers have developed quantitative relationships between lignin content and the biodegradability of lignocellulosic materials during anaerobic digestion. However, before applying these formulas to aerobic composting other factors should be considered. Several studies indicate significant biodegradation of lignin can occur during composting, which would increase the availability of other plant cell wall materials. Bioavailability will also be affected by particle size and other factors for which no quantitative correction presently exists. When analyzing aerobic composting systems, the mathematical relationships developed by Chandler et al. (1980) and Van Soest (1996) are best used in a comparative sense, to help understand the differences in bioavailability of different composting substrates.

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Lignin and Other Constituents of Selected Organic Materials

Substrate	Lignin	Cell Wall	Lignin/Cell wall	Crude protein	Cell soluble
Wheat straw	8.9	77.1	11.6	9.3	22.9
Corn stalks	3.9	49.6	7.8	6.6	50.4
Corn leaves	3.8	59.3	6.5	19.0	40.7
Cattails	8.5	63.5	13.4	13.6	36.5
Treated kelp	6.0	33.2	18.1	30.0	66.8
Water hyacinth	8.7	60.1	14.5	17.7	39.8
Corn meal	2.0	21.6	9.1	11.1	78.4
Newsprint	20.9	88.7	23.6	5.1	11.3
Elephant m.	10.4	77.4	13.5	7.0	22.6
Chicken m.	3.4	45.2	7.5	33.9	54.8
Pig manure	2.2	40.5	5.4	27.6	59.5
Cow manure	8.1	57.1	14.1	19.4	42.9
Cow manure	7.9	52.3	15.1	20.1	47.7
Cow manure	10.1	62.9	16.1	17.2	37.1
Pin cherry	8.98	26.2	34.3	1.77	
Yellow birch	12.0	42.5	28.2	1.42	
Sugar maple	8.49	32.5	26.1	0.97	
Beech	12.7	61.5	20.7	1.55	

The Effect of Particle Size on Bioavailability

Tom Richard

Decomposition occurs primarily on or near the surfaces of particles, where oxygen diffusion into the aqueous films covering the particle is adequate for aerobic metabolism, and the substrate itself is readily accessible to microorganisms and their extracellular enzymes. Small particles have more surface area per unit mass or volume than large particles, so if aeration is adequate small particles will degrade more quickly. Experiments have shown that the process of grinding compost materials can increase the decomposition rate by a factor of two (Gray and Sherman, 1970). Gray et al. (1971) recommend a particle size of 1.3 to 7.6 cm (0.5 to 2 inches), with the lower end of this scale suitable for forced aeration or continuously mixed systems, and the upper end for windrow and other passively aerated systems.

A theoretical calculation by Haug (1993) suggests that for particles larger than 1 mm in thickness, oxygen may not diffuse all the way into the center of the particle. Thus, the interior regions of large particles are probably anaerobic, and decomposition rates in this region are correspondingly slow. However, anaerobic conditions are more of a problem with small particles, as the resulting narrow pores readily fill with water due to capillary action. These issues are addressed more fully in the section on factors leading to anaerobic conditions.

References:

Gray, K.R., and K. Sherman, 1970. Public Cleansing 60(7):343-354. Gray, K.R., K. Sherman, and A.J. Biddlestone. *Process Biochemistry* 6(10):22-28. Haug, R.T., 1993. Practical Handbook of Compost Eng'g. Lewis Publishers, Boca Ratan, FL. p.411.

Estimating Carbon Content

Tom Richard

If you know the nitrogen content for an ingredient, but not the carbon content or the C/N ratio, you can estimate the % C based on the volatile solids content if that value is known or can be measured. Volatile Solids (VS) are the components (largely carbon, oxygen, and nitrogen) which burn off an already dry sample in a laboratory furnace at 500-600°C, leaving only the ash (largely calcium, magnesium, phosporus, potassium, and other mineral elements that do not oxidize). For most biological materials the carbon content is between 45 to 60 percent of the volatile solids fraction. Assuming 55 percent (Adams et al., 1951), the formula is:

% Carbon = (% VS) / 1.8 where % VS = 100 - % Ash

References

Adams, R. C., F. S. MacLean, J. K. Dixon, F. M. Bennett, G. I. Martin, and R. C. Lough. 1951. The utilization of organic wastes in N.Z.: Second interim report of the inter-departmental committee. New Zealand Engineering (November 15, 1951):396-424.

Solving the Moisture and Carbon-Nitrogen Equations Simultaneously

Tom Richard

In high school algebra we learn that for any number of independent equations we can usually solve for that same number of unknowns. In this case we have two equations (one for moisture and one for the carbon-nitrogen ratio), and we can solve them for any two unknowns. Normally we use this approach to develop a mix ratio of several different ingredients, knowing the moisture, carbon, and nitrogen contents of each. If we specify the quantities of all but two ingredients, and the C/N and moisture content we'd like to achieve in the mixture, we can solve for those two remaining quantities to get the mix we want.

In selecting which material quantities to specify and which to solve for as unknowns, it is important to use a little common sense. If your moisture goal is 60%, and you are trying to compost wet leaves, sawdust, grass, and food scraps, it would be smart to make sawdust one of the unknown quantities, since all the other materials are likely to have moisture contents greater than 60%. There is no way to bring the moisture content of a mix down by adding more of a wet ingredient, and, similarly, there is no way to bring the C/N ratio up by adding high nitrogen materials.

Another useful tip, particularly for dry ingredients, is to include water as one of the unknowns. Water will bring up the moisture content without altering the C/N ratio. And since water is cheap and usually readily available, it can be an easy way to develop an appropriate mix.

The solution can be obtained in several ways using linear algebra or matrices. With patience, one can use simple algebraic methods to solve the moisture equation for one of the unknown quantities, and then substitute that value in the C/N equation and solve the C/N equation for the other unknown. At that point, back-substitution into the solution of the moisture equation gives both unknowns in terms of known values.

The algebraic manipulations required for a mixture of three materials are straightforward but do take a little time, as is evident from the solution below.

The three-ingredient equation for moisture is:

$$G = \frac{M_1 \times Q_1 + M_2 \times Q_2 + M_3 \times Q_3}{Q_1 + Q_2 + Q_3}$$

in which:

Qn = mass of material n ("as is", or "wet weight")
G = moisture goal (%)
Mn = moisture content (%) of material n

and the three-ingredient equation for C/N ratio is:

$$R = \frac{Q_1(C_1 \times (100 - M_1) + Q_2(C_2 \times (100 - M_2) + Q_3(C_3 \times (100 - M_3)}{Q_1(N_1 \times (100 - M_1) + Q_2(N_2 \times (100 - M_2) + Q_3(N_3 \times (100 - M_3)}$$

in which:

R = goal (C/N ratio)
Cn = carbon (%)
Nn = nitrogen (%)
and Mn and Qn are as previously defined

The resulting solutions are:

$$Q_2 = \frac{A}{B} \quad and \quad Q_3 = \frac{C}{B}$$

where:

A = Q1 (M1 C3 (100 - M3) - M1 R N3 (100 - M3) - M3 C1 (100 - M1) + R N3 (100 - M3) G - R N1 (100 - M1) G +C1 (100 - M1) G - C3 (100 - M3) G + M3 R N1 (100 - M1))

B = R N2 (100 - M2) G - R N2 (100 - M2) M3 - R N3 (100 - M3) G + R N3 (100 - M3) M2 - C2 (100 - M2) G + C2 (100 - M2) M3 + C3 (100 - M3) G - C3 (100 - M3) M2

C = Q1 (R N1 (100 - M1) G - R N1 (100 - M1) M2 -R N2 (100 - M2) G + R N2 (100 - M2) M1 - C1 (100 -M1) G + C1 (100 – M1) M2 + C2 (100 - M2) G - C2 (100 - M2) M1)

To see how this equation works, plug in the material characteristics from our previous example with grass and leaves, and the food scrap characteristics given below. Then solve for the quantity of leaves and/or food scraps needed to optimize C/N and moisture for 10 kg of grass.

Ingredient Characteristic:

A = 10 x (77 x 42 x (100 - 80) - 77 x 30 x 5.0 x (100 - 80) - 80 x 45 x (100 - 77) + 30 x 5.0 x (100 - 80) x 60 - 30 x 2.4 x (100 - 77) x 60 +45 x (100 - 77) x 60 - 42 x (100 - 80) x 60 +80 x 30 x 2.4 x (100 - 77))

A = -243,000

B = 30 x 0.75 x (100 - 35) x 60 - 30 x 0.75 x (100 - 35) x 80 - 30 x 5.0 x (100 - 80) x 60 + 30 x 5.0 x (100 - 80) x 35 - 50 x (100 - 35) x 60 + 50 x (100 - 35) x 80 + 42 x (100 - 80) x 60 - 42 x (100 - 80) x 35

B = - 18,250

C = 10 x (30 x 2.4 x (100 - 77) x 60 - 30 x 2.4 x (100 - 77) x 35 - 30 x 0.75 x (100 - 35) x 60 + 30 x 0.75 x (100 - 35) x 77 - 45 x (100 - 77) x 60 + 45 x (100 - 77) x 35 + 50 x (100 - 35) x 60 - 50 x (100 - 35) x 77)

C = -148,625

Remembering that

$$Q_2 = \frac{A}{B} \quad and \quad Q_3 = \frac{C}{B}$$

we find that:

Q2 = 13.31 kg and Q3 = 8.14 kg

Thus, if we mix 13 kg of leaves and 8 kg of food scraps with the initial 10 kg grass clippings, the mixture will achieve our goals of 60% moisture and a 30:1 C/N ratio.

Note that this simultaneous solution for three ingredients depends entirely on having the right three ingredients to combine. With many combinations the resulting Q2 and/or Q3 will be negative, indicating that no solution is possible. In that case you can add an additional material to add to the mix, such as sawdust or wood chips if the moisture or nitrogen levels are too high. Of course, if we add more ingredients, we also need a different formula to determine the solution.

For increasing numbers of materials, this formula becomes even more complicated. The solution for a mixture of four ingredients follows.

The four-ingredient equation for moisture is:

$$G = \frac{M_1 \times Q_1 + M_2 \times Q_2 + M_3 \times Q_3 + M_4 \times Q_4}{Q_1 + Q_2 + Q_3 + Q_4}$$

and the four-ingredient equation for C/N ratio is:

$$R = \frac{Q_1(C_1 \times (100 - M_1) + Q_2(C_2 \times (100 - M_2) + Q_3(C_3 \times (100 - M_3) + Q_4(C_4 \times (100 - M_4)}{Q_1(N_1 \times (100 - M_1) + Q_2(N_2 \times (100 - M_2) + Q_3(N_3 \times (100 - M_3) + Q_4(N_4 \times (100 - M_4)}$$

where all terms are as previously defined

If we know the carbon, nitrogen, and moisture contents of each of these materials, specify goals for moisture and C/N ratio of the mixture, and quantities of Q1 and Q2, then we can solve for Q3 and Q4. The solution is:

$$Q_3 = \frac{D}{E} \text{ and } Q_4 = \frac{F}{E}$$

Where:

D= -(Q1C4(100-M4)G+Q2C4(100-M4)G-Q2C2(100-M2)G-Q1C1(100-M1)G-Q1RN4(100-M4)G-Q2RN4(100-M4)G+RQ1N1(100-M1)G+RQ2N2(100-M2)G-M4RQ1N1(100-M1)-M1Q1C4(100-M4)+M4Q1C1(100-M1)-M2Q2C4(100-M4)-M4RQ2N2(100-M2)+M1Q1RN4(100-M4)+M4Q2C2(100-M2)+M2Q2RN4(100-M4))

E= RN3(100-M3)G-RN3(100-M3)M4-C3(100-M3)G+C3(100-M3)M4-RN4(100-M4)G+RN4(100-M4)M3+C4(100-M4)G-C4(100-M4)M3

and

F = -RN3(100-M3)GQ1-RN3(100-M3)GQ2+RN3(100-M3)M1Q1+RN3(100-M3)M2Q2+C3(100-M3)GQ1+C3(100-M3)GQ2-C3(100-M3)M1Q1-C3(100-M3)M2Q2+RQ1N1(100-M1)G-RQ1N1(100-M1)M3+RQ2N2(100-M2)G-RQ2N2(100-M2)M3-Q1C1(100-M1)G+Q1C1(100-M1)M3-Q2C2(100-M2)G+Q2C2(100-M2)M3

This is where computers come in handy. These simultaneous solutions are included on spreadsheets you can download and use on your own computer.

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Compost Mixture Calculation Spreadsheet

You can download spreadsheets with built in equations to solve compost mixture calculations for up to 4 ingredients. MS Excel 2010 (updated March 2014).