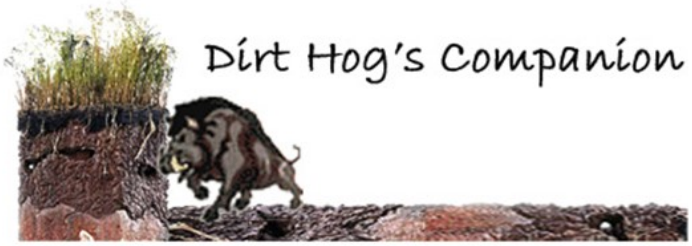

TECHNICAL NOTE 25.

COMPOSTING BASICS: C:N RATIO AND RECIPE MAKING

25.0 BACKGROUND

Aerobic decomposition of organic matter uses oxygen present in the atmosphere to break down carbohydrates, proteins, fats, and lignin derived from once-living bodies of plants and animals. Bacteria and fungi that feed on organic matter increase their cell protoplasm, or *microbial biomass,* from the nitrogen, some carbon, phosphorus and other minerals in organic matter. Organic molecules are broken down by enzymes excreted by the microbes, converting complex carbohydrates to simple water-soluble compounds.

Carbon present in water soluble form is the source of energy that fuels microbial growth and reproduction. Carbon is oxidized during cellular respiration as follows:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{heat} \qquad \text{Eq. [1]}$$

Equation [1] shows that for each molecule of glucose $C_6H_{12}O_6$ oxidized, six molecules of oxygen are consumed and the end products are carbon dioxide, water, and energy. This is the preferred metabolic pathway for organic matter decomposition when oxygen is present. Generally, microorganisms burn off about two-thirds of the carbon they consume as CO_2, while the other third is combined with nitrogen in their living protoplasm.

Nitrogen is also present in organic matter, but in smaller amounts than carbon. Most organic nitrogen is found in proteins, which are complex substances containing nitrogen, sulphur, and some phosphorus, in addition to carbon, oxygen, and hydrogen. During decomposition, proteins are first hydrolyzed to intermediate products, e.g. peptones, polypeptides, and ultimately broken down to individual amino acids via the protease enzymes of bacteria. The final stage of protein decomposition is ammonification, a process that converts organic nitrogen (nitrogenous molecules that also contain carbon) into ammonia, NH_3. The process of ammonification is very important in the global nitrogen cycle; it is constantly producing ammonia from organic matter in nearly all terrestrial ecosystems. In moist, non-alkaline ($pH<7.5$) soil gaseous ammonia is reduced to water soluble ammonium NH_4 for use by plants.

25.1 CARBON, NITROGEN, AND THE C:N RATIO CONCEPT

Carbon serves the dual purpose of energy source for cellular respiration and as an element in the cell protoplasm. Consequently, much more carbon is needed for cellular increase, compared to nitrogen. Carbon is found in cellulose, hemicellulose, sugars, and starches, collectively known as *carbohydrates* that are composed of the elements carbon, oxygen, and hydrogen. Cellulose is the most abundant carbohydrate present in plants and organic matter. Lignin is a carbon-rich polymer present in mature plant tissues, and accounts for approximately 10% to 30% of the dry matter of mature plants. Lignin imparts strength to the vascular tissue of plants and, together with cellulose and hemicellulose, accounts for 90% to 95% of the dry matter of mature plants. In short, there is a surplus of carbon in plant and animal tissue, whereas nitrogen is relatively scarce. The C:N ratio in most fresh tissue varies because of *differences in nitrogen content*, not carbon.

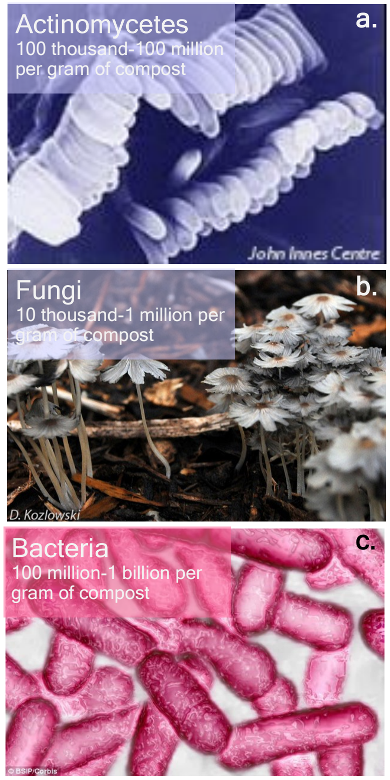

Figure 1. Every cubic centimeter of compost teems with microorganisms busily transforming organic waste. Actinomycetes (a) are filamentous bacteria that emit volatile *geosmins* during their metabolism, imparting the earthy, humic aroma of freshly turned topsoil. Telltale fruiting bodies of fungi (b) bespeak nature's irresistible yin-yang polarity. The business end of fungi are their microscopic thread-like mycelium that excrete digestive enzymes. Bacteria (c) play a key role in organic matter decomposition and nutrient cycling in the biosphere, of which compost is a microcosm. Quantities of microorganisms are from Sterritt (1988).

The bacteria and fungi that decompose organic matter need carbon and nitrogen to grow and reproduce (**Figures 1a-c**). Bacteria play a very important role in the composting process. Bacteria break down organic matter most efficiently when the source substrate has a C:N ratio of about 25:1. This means that each part of bacterial food should contain, ideally, 25 times as much carbon as nitrogen. Food sources with a low C:N ratio (less than 15:1) have an excess of nitrogen in the material that will be released as ammonia during decomposition. If C:N ratios are high (greater than 50:1) decomposition will be slow[1]. Generally, fungal biomass has a higher C:N ratio compared to bacteria (Six et al., 2006). Thus the amount of nitrogen in the food source affects fungal activity less than that of bacteria (Rousk and Baath, 2007). In the composting process microbes use the carbon substrate as their primary energy source. When the compost pile is turned, the oxygen so introduced stimulates microbial growth that, in turn, metabolizes, or "burns" off

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[1] Slow decomposition may also be a symptom of low moisture content, or low oxygen concentration, or both, in the food source.

some carbon as CO_2. Provided that nitrogen is conserved (and not lost as ammonia gas or by leaching), the C:N ratio in a moist, well-aerated compost pile decreases with time. Ultimately, a stable organic material called *humus* is formed with a C:N ratio of about 10:1, i.e. 50% carbon and 5% nitrogen. The transformation of biologically unstable raw material (aka "feedstock") to stable humus is a totally natural process that can be fine-tuned by human intervention during composting.

25.2 UNDERSTANDING C:N RATIO

The C:N ratio is given by:

$$\text{C:N ratio} = \frac{Total\ weight\ of\ C}{Total\ weight\ of\ N} \qquad \text{Eq. [2]}$$

Weight of C and N is usually reported in parts per million (ppm) or milligrams per kilogram substance (mg/kg), which are numerically equivalent. Some labs may report per cent C and N, which are convertible to parts per million by multiplying per cent x 10,000. In any case, the C:N ratio remains the same.

The weights of C and N in Eq. [2] are *dry* weights, i.e. the weight of C and N corrected for the moisture absorbed by a substance. *Total nitrogen* includes organic N, i.e. nitrogen that is chemically combined with carbon in organic matter, plus *inorganic nitrogen,* i.e. ammonium (NH_4^+) and nitrate (NO_3^-). Ammonium and nitrate are both water soluble and plant-available. The organic N content of compost is usually much greater than that of inorganic N.

Likewise, total C in Eq. [2] includes organic C and inorganic C. A problem arises when a compost feedstock contains significant amounts of inorganic C such as carbonates, which are not biodegradable. Usually this is indicated by a pH >8.5. In this case the C:N ratio may be overestimated. Most testing labs report uncorrected C:N ratios. The C:N ratio is corrected by determining the calcium carbonate equivalence (CCE) of the substance. Most agronomic labs are equipped to do this. Determining CCE and it agricultural lime equivalent (ALE) is recommended when feedstock has a high pH and the mature compost made from it is likely to have a residual liming effect when applied to the soil.

25.3 C:N RATIO AND RECIPE MAKING

The blending of raw feedstock in the correct proportion for composting is called *recipe making*. Recipe making may sound like a black art but the process is similar to making a cake. The following rules should be observed:

- Know the desired properties of feedstock for aerobic composting (**Table 1**).
- Identify the primary feedstock (e.g. poultry manure, liquid slurry, fish waste, etc.) to be managed.
- Know the material properties of the primary feedstock, minimally the approximate nutrient content and C:N ratio, dry matter, moisture content, and pH.
- Identify the secondary feedstock that will provide the proper conditions for composting when mixed with the primary feedstock.
- Create a proper mixing ratio that stimulates the natural process of aerobic decomposition.

Not all composting is done with the knowledge of material properties as shown in **Table 1**. Many composters, especially homeowners and small operators, mix raw ingredients based on their look and feel. Manure and water may be added to a pile that feels dry. Dry piles may have added ingredients like straw and wood shavings to increase porosity, and to increase structure so the pile doesn't "slump". This approach involves some judgment along with expert knowledge of material properties. With practice, it's possible to judge the moisture content of compost to within 5% according to whether the compost feels wet or dry when squeezed by hand. Technical Note 24 "Composting Basics: Bulk Density, Moisture, Porosity" gives guidance on qualitative "squeeze", and quantitative drying methods for determining compost moisture content.

When compost feedstock properties are unknown, or where optimum conditions for aerobic decomposition must be established for reasons of economics or sanitary compliance, composting under controlled conditions with recipes based on calculations is essential[2]. The calculations are based on the measured moisture content and C:N ratio of the feedstock. Moisture content usually is given priority because too much moisture leads to anaerobic conditions, toxic substances, malodors, and slow decomposition. Too little moisture inactivates microorganisms needed for decomposition. Poor C:N ratio has less damaging effects. For wet ingredients it is better to first develop a compost mixing ratio based on *moisture content*, then secondly adjust the C:N ratio without throwing moisture content out of whack. Dry ingredients can be mixed on the basis of *C:N ratio* since it's relatively easy to adjust the moisture content of the compost by adding water. But how does one calculate a compost mixing recipe?

First, we need to know the moisture content, the nitrogen content (dry weight) and either the carbon content (dry basis) or C:N ratio of the raw ingredients, also known as "feedstock" in composting lingo. Here we use "ingredient" to mean "feedstock" in keeping with our cake making analogy.

Table 1. Desired properties of raw material mixes

Property	Target range	Preferred range
Carbon to nitrogen (C:N) ratio	20:1-40:1	25:1-30:1
Moisture content	40-65%	50-60%
pH	5.5-9.0	6.5-8.5
Bulk density (kg/m^3)[a]	475-715	----
Porosity	35-50%	40-50%
Particle size	3-50 mm	12-50 mm

[a] kilograms per cubic meter *Source: adapted from Rynk et al. (1992)*

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[2] Livestock are known vectors of human pathogens, e.g. *E. coli*, *Campylobacter*, and *Salmonella*. In turn, food safety concerns over the use of manure in food production have increased. Compost must reach a temperature of 55° C for safe handling. In this technical note we describe material properties and mixing needed for aerobic composting . Information on the complete composting process including sanitary measures is included in section 25.7.

Table 2. General formulas for determining moisture content and C:N ratio

$$\text{Moisture content} = \frac{weight\ of\ water\ in\ ingredient\ a + water\ in\ b + water\ in\ c...}{total\ weight\ of\ all\ ingredients}$$

$$= \frac{(a \times m_a) + (b \times m_b) + (c \times m_c) + ...}{a + b + c + ...}$$

$$\text{C:N ratio} = \frac{weight\ of\ C\ in\ ingredient\ a + weight\ of\ C\ in\ b + weight\ of\ C\ in\ c...}{weight\ of\ N\ in\ ingredient\ a + weight\ of\ N\ in\ b + weight\ of\ N\ in\ c...}$$

$$= \frac{\left[\%C_a \times a \times (1 - m_a)\right] + \left[\%C_b \times b \times (1 - m_b)\right] + \left[\%C_c \times c \times (1 - m_c)\right] + ...}{\left[\%N_a \times a \times (1 - m_a)\right] + \left[\%N_b \times b \times (1 - m_b)\right] + \left[\%N_c \times c \times (1 - m_c)\right] + ...}$$

Symbol definitions

a = total weight of ingredient a

b = total weight of ingredient b

c = total weight of ingredient c

m_a, m_b, m_c,… = moisture content of ingredients a,b,c…

$\%C_a$, C_b, C_c,… = % carbon of ingredients a,b,c,…(% dry weight)

$\%N_a$, N_b, N_c,… = % nitrogen of ingredients a,b,c,…(% dry weight)

Source: Dougherty (1999)

Table 3. Formulas for determining individual ingredients

(a) Moisture content = % moisture content ÷ 100
(b) Weight of water = total weight × moisture content
(c) Weight of dry matter = total weight - weight of water
= total weight × (1- moisture content)
(d) Nitrogen content = dry weight × (%N ÷ 100)
(e) % carbon = %N × C:N ratio
(f) Carbon content = dry weight × (%C ÷ 100)
= N content × C:N ratio

Source: Dougherty (1999)

General formulas for a *mixture* of ingredients are given in **Table 2**, and formulas for an *individual* ingredient are shown in **Table 3**. **Table 2** looks like alphabet soup, but the procedure for calculating recipe proportions based on moisture and content and C:N ratio is not difficult. Moisture content, and the percentage N and C are determined analytically by submitting a sample of each ingredient to a testing laboratory. Many government laboratories are equipped for testing waste material for a small fee. Failing that, one is left to guess at reasonable values for moisture, carbon, and nitrogen based on published values for similar materials. In a pinch, this works but introduces more uncertainty to the process.

An example for two ingredients is given in the calculations on the next page. Note: these calculations are based on formulas given by Rynk et al. (1992) and Dougherty (1999), modified by this author using real farm data.

Problem 1. What mixing ratio is needed to produce compost with a maximum moisture content of 53%? What is the C:N ratio of this mix? (**Method 1**)

Problem 2. What mixing ratio is needed to produce compost with a C:N ratio of 25:1? What is the moisture content of this mix? (**Method 2**)

Solution: To solve both problems we need to calculate the quantity of water, dry matter, carbon, and nitrogen for an *individual* ingredient. Formulas in **Table 3** are used to calculate these amounts; qantities appear in the column to the right. Letters following each calculation correspond to the formula in **Table 3**.

1 kilogram of fresh layer manure contains

Water	1 kilogram × 0.80 = 0.80 kg (**b**)
Dry matter	1 kilogram - 0.80 = 0.20 kg (**c**)
Nitrogen (N)	0.20 × 0.015 = 0.003 kg (**d**)
Carbon (C)	0.20 × 0.11 = 0.022 kg (**f**)

1 kilogram of rice hulls contains

Water	1 kilogram × 0.31 = 0.31 kg (**b**)
Dry matter	1 kilogram - 0.31 = 0.69 kg (**c**)
Nitrogen (N)	0.69 × 0.005 = 0.0034 kg (**d**)
Carbon (C)	0.69 × 0.215 = 0.148 kg (**f**)

Method 1. Mixing ingredients to a target moisture content

To calculate the moisture content of a mixture of two ingredients, we use the general formula for moisture content given in **Table 2**:

$$\mathrm{MC}=\frac{weight\ H_2O\ in\ manure+weight\ H_2O\ in\ rice\ hulls}{total\ weight}$$

Since we want the final mixture equal to 53% moisture, the formula above is written as:

$$\mathrm{MC}\ =\ 53\%\ =\ 0.53\ =\frac{0.8+(0.31\times \boldsymbol{S})}{1+\boldsymbol{S}}$$

where $\boldsymbol{S}$ is the amount of rice hulls needed.

$$\mathrm{MC}\ =\ 0.53(1+\boldsymbol{S})=0.8+(0.31\times \boldsymbol{S})$$

$$0.22\boldsymbol{S}=0.27$$

$\boldsymbol{S}=1.23$ kilograms of rice hulls per kilogram of layer manure

Finding the value of $\boldsymbol{S}$ in the calculation above was done with a bit of algebra. Another shortcut formula that doesn't involve algebra may be used instead to find $\boldsymbol{S}$:

$$\boldsymbol{S}=\frac{m_b-MC}{MC-m_a}=\frac{0.8-0.53}{0.53-0.31}=\frac{0.27}{0.22}=1.23$$

where MC is the target moisture content and m_a and m_b are the moisture content of the manure and rice hulls, respectively (per **Table 2** definition). The shortcut formula can be used if there are only two ingredients.

Now let's check the C:N ratio:

$$\mathrm{C{:}N}=\frac{weight\ of\ \ C\ in\ manure+weight\ of\ \ C\ in\ rice\ hulls}{weight\ of\ \ N\ in\ manure+weight\ of\ \ N\ in\ rice\ hulls}$$

$$\mathrm{C{:}N}=\frac{0.022+(1.23\times 0.148)}{0.003+(1.23\times 0.0034)}=\frac{0.204}{0.0072}=28.3$$

The C:N ratio is in the preferred 25:1 to 30:1 range given in **Table 1**. For C:N ratios less than 20, increase the amount of rice hulls or decrease the amount of manure, in the proportion needed to maintain the target moisture content. In this example, the target moisture content was 53%. Since the preferred moisture content range is 50% to 60%, this leaves room for increasing the proportion of manure (=higher moisture content) to rice hulls (=lower C:N ratio).

Method 2. Mixing ingredients to a target C:N ratio

To calculate the C:N ratio of a mixture of two ingredients, we use the general formula for C:N ratio given in **Table 2**:

$$\mathrm{C{:}N}=\frac{weight\ of\ \ C\ in\ manure+weight\ of\ \ C\ in\ rice\ hulls}{weight\ of\ \ N\ in\ manure+weight\ of\ \ N\ in\ rice\ hulls}$$

The target C:N ratio is 25:1. For 1 kilogram of fresh layer manure:

$$\mathrm{C{:}N}=25=\frac{kg\ \ C\ in\ 1kg\ \ manure+kg\ \ C\ in\ 1kg\ rice\ hulls}{kg\ \ N\ in\ 1kg\ \ manure+kg\ \ N\ in\ 1kg\ rice\ hulls}$$

where $\boldsymbol{S}$ is the amount of rice hulls needed per kilogram manure.

$$25=\frac{0.022+\boldsymbol{S}(0.148)}{0.003+\boldsymbol{S}(0.00345)}$$

$$0.062\boldsymbol{S}=0.053$$

$\boldsymbol{S}=$ 0.85 kg of rice hulls per kilogram layer manure

Since there are only two ingredients, the following shortcut formula can be used to find $\boldsymbol{S}$:

$$\boldsymbol{S}=\frac{\%N_b}{\%N_a}\times\frac{(R-R_b)}{(R_a-R)}\times\frac{(1-m_b)}{(1-m_a)}$$

where R is the target C:N ratio and R_a and R_b are the C:N ratio of ingredients a (rice hulls) and b (manure), respectively.

$$\boldsymbol{S}=\frac{1.5}{0.5}\times\frac{(25-7.3)}{(43-25)}\times\frac{(1-0.8)}{(1-0.31)}$$

$\boldsymbol{S}=$ 0.85 kg of rice hulls per kilogram layer manure

Let's check the moisture content:

$$MC=\frac{0.80+(0.85\times 0.31)}{1.85}=0.573=57.5\%$$

The moisture content of this mixture is in the preferred 50-60% range. However it is not uncommon for a mixture of ingredients to be too dry or too wet when mixing is based on a target C:N ratio. If moisture content is too low, water can be added directly to the mix if an acceptable C:N ratio-moisture content cannot be obtained. Dry material (straw, wood shavings, grain hulls) can be added to a mixture that is too wet if a higher C:N ratio is acceptable.

25.4 CONVERTING WEIGHT RATIOS TO VOLUME RATIOS

In section 25.3, the calculated mixing ratios were based on the *weight* of one ingredient per unit *weight* of a second ingredient. Normally, compost ingredients are not weighed before mixing. Bucket loaders are typically used for handling and mixing ingredients and the operator must know how many buckets of each ingredient to mix (**Figure 2**). It is therefore necessary to make a weight-to-volume conversion of each ingredient. The mixing ratio is then re-expressed in terms of the *volume* of one ingredient per unit *volume* of a second ingredient, i.e. mix one bucket of ingredient a with two buckets of ingredient b. To convert the weight of a material to volume basis we need to know the material's weight per unit volume, or *bulk density*. Bulk density predicts how much volume a given weight of a material will occupy based on the amount of porosity in the material. Technical Note 24 "Composting Basics: Bulk Density, Moisture, Porosity" gives detailed instructions for measuring the bulk density of compost feedstock.

Here, we'll use measured bulk density values for the layer manure and rice hulls from section 25.3 to illustrate the point.

Problem: Convert the mixing ratio of 1 kilogram layer manure per 1.23 kilograms rice hulls to volume and express this in terms of a whole number ratio. The measured bulk density of the manure and rice hulls is 894 and 312 kilograms per cubic meter, respectively.

Solution: Since each cubic meter of manure weighs 894 kilograms, we'll calculate the ratio based on 1000 kilograms (note: the base weight is arbitrary; other weights can be used provided a total weight ratio of 1:1.23 is preserved).

$$Volume = \frac{1\ m^3\ manure}{894\ kg} \times \frac{1000\ kg}{1} = 1.12$$

$$Volume = \frac{1\ m^3\ rice\ hulls}{312\ kg} \times \frac{1230\ kg}{1} = 3.94$$

The mixing ratio is 3.94 ÷ 1.12 = 3.5 or, 1 bucket manure mixed with 3.5 buckets of rice hulls. Since a whole number ratio is desired, a decision must be made to round the ratio up to 1:4 or down to 1:3. Since the moisture content of a 1:3.5 manure:rice hull mixture is 53% according to **Method 1** in section 25.3, we can round up or down without throwing the moisture content outside the 50-60% preferred range. In this case, rice hulls represent an off-farm input. To reduce cost, a decision is made to round down to 1:3 ratio. In fact, a 1:2 ratio could also be considered while maintaining acceptable moisture content and C:N ratio (the reader may do the calculations). Here a 1:3 ratio is preferred since the farmer would like the flexibility of adding irregular quantities of cow manure, fresh weeds, etc. without hindering the process.

Figure 2. Bucket loaders mix and turn compost in volume. Bulk density is used to convert compost weight ratios to volume ratios for efficient handling.

25.5 MIXING SPREADSHEETS AND COMPOST OPTIMIZERS

Calculating a compost recipe with two ingredients is easily done by hand, as illustrated in section 25.3. The calculations increase in complexity when mixing three or more ingredients. Balancing the moisture content and C:N ratio of a multi-ingredient mixture requires expert knowledge of the feedstock and its properties. This is where computer spreadsheets come in handy. A number of these have been published on the internet and vary in quality and complexity (see section 25.6 for select URLs). It's also possible to design your own custom spreadsheet based on the formulas in this technical note. Mixing spreadsheets minimally require feedstock moisture content, carbon and nitrogen content, and bulk density as input values. Some spreadsheets include a column for per cent ash, but this isn't necessary for the calculations provided the carbon and nitrogen content is known. Advanced mixing spreadsheets may employ complex mathematical algorithms allowing the user to manipulate quantities of ingredients to optimize many parameters at once. We hope the calculations given in this technical note help the reader to better understand mixing spreadsheets "under the hood" and the rational process involved with recipe making.

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