Chapter 8

Overview of the Balanced Soil Amendment Approach for Mixtures of Biosolids and Carbon-Rich Residuals

Biosolids provide more than just N to soils. The value of the organic matter in biosolids as a soil amendment (conditioner) is as important as, if not more important than, its value as a fertilizer. Soils that can benefit most from the conditioning properties of biosolids are soils that have been recently disrupted by either human activity or natural disturbances, soils whose original soil characteristics are poor (sandy or gravelly soils), or soils that are used to manufacture topsoil.

The organic matter in biosolids can influence most of the processes that occur in soils: (1) storage of nutrients and water, (2) immobilization of trace elements, (3) support of plants, (4) aeration of plant roots, and (5) transport of excess water. Short-term soil productivity can be improved both by nutrient addition and by changing the moisture holding capacity of the soil. Long-term soil productivity can be improved by a continual slow release of nutrients as the organic matter decomposes.

As other chapters in this manual have emphasized, the amount of N that will be available to plants must be taken into consideration when determining biosolids application rates. Too much N may transform to nitrate and leach into groundwater; too little available N will reduce plant growth. Compared with some other residuals, biosolids are lower in organic matter and higher in N. Biosolids application rates must be calculated so that inorganic N does not exceed plant N requirements. A carbon-rich residual—such as wood chips, paper fines, or straw—could be used as an alternative to biosolids to achieve the desired organic matter content of the soil. However, such residuals will generally immobilize (store) N in organic forms that are not available to the plants.

One possible solution is to mix biosolids with a carbon-rich residual in order to achieve a balanced carbon-to-nitrogen ratio (C:N). This approach—called the Balanced Soil Amendment Approach—is still in the early stages of development. The remainder of this chapter presents results of studies conducted on the C:N ratio and provides methods for calculating appropriate application rates for such a mixture.

Results of studies on carbon-to-nitrogen ratios

Mineralization and immobilization of N are governed by C:N ratios. Traditionally, it has been suggested that a C:N ratio greater than 30:1 will immobilize N, a ratio less than 20:1 will mineralize N, and a ratio between 20:1 and 30:1 will produce no net changes in N availability. These ratios have been used as a "rule of thumb" for agricultural systems where C and N sources are fairly consistent in nature and degradability. A number of studies using various residuals suggest that decomposition dynamics may be too complex to solely rely on the C:N rule of thumb (Chandler et al., 1980; Hatiori and Mukai, 1986; Henry, 1991). Release or demand for N depends not only on the C:N ratio but also on the types of organic compounds in the residual and how long breakdown of these compounds has been occurring. Different residuals have different stability in terms of organic decomposition rates and thus have different impacts on the mineralization or immobilization of N. If the carbon is in a form that is difficult to decompose or if the majority of the carbon sources are large in particle size (thus decreasing the surface-area-to-mass ratio and restricting access by the decomposing microorganisms), net mineralization may occur when the C:N ratio is considerably higher than 20:1, and, in the same sense, the average C:N ratio for net immobilization to occur may have to be much higher than 30:1.

Decomposition rates of organic compounds

Residuals consist of many different kinds of compounds (Figure 8.1a). As decomposition occurs, both the quantities and characteristics of C change to resemble those found in soil (Figure 8.1b). Organic compounds decompose at different rates, loosely defined by stages (Figure 8.2). Compounds such as sugars, starches, fats, and proteins are broken down by bacteria during the rapid decomposition period in the first few weeks. Hemicellulose and cellulose are broken down by actinomycetes and fungi over a period of months to years. Lignin and lignocellulose are fairly recalcitrant, similar to humus, and are decomposed by fungi over a period of tens to hundreds of years.

Studies support this concept of differing decomposition rates depending on the type of C compound. For example, Chandler et al. (1980) found that decomposition was strongly related to lignin content during fermentation of different plant parts and manures. As lignin content increased, decomposition decreased. Similarly, Hatiori and Mukai (1986) found that as the inorganic and lignin fractions in different biosolids increased, the amount of C in biosolids that mineralized decreased. Lerch et al. (1992) found that the mineralization of C in biosolids was strongly related to biosolids proteins.

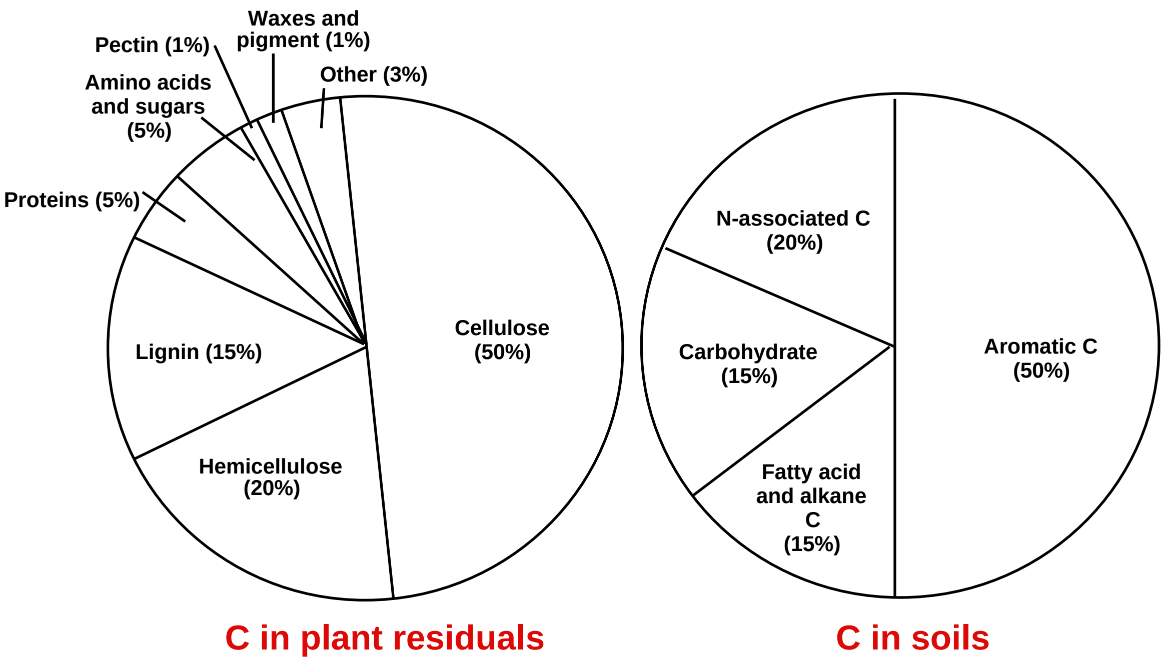

Figure 8.1. Types and general fractions of carbon compounds found in plant residues and soils (modified from Brady, 1997).

Influence of time on carbon-to-nitrogen ratios and nitrate leaching

C:N ratios change with time. Complete decomposition of organic matter produces carbon dioxide (CO_2), water, and minerals. The CO_2 releases to the atmosphere, while the N usually gets reincorporated into organic compounds. The net effect is to reduce the C:N ratio. If this ratio moves to below 15:1, excessive N will volatilize in the form of NH_3. Compost piles provide good examples of the changes that take place as residuals decompose (Table 8.1). Often mixtures of materials in compost piles start at C:N ratios greater than 30:1 and drop to below 15:1 after stability is reached.

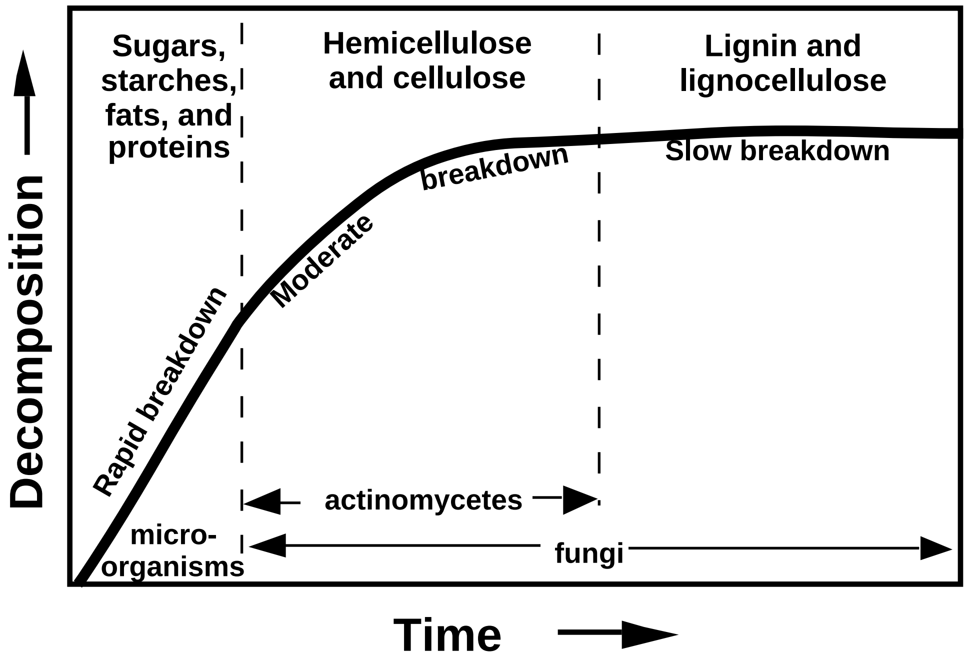

Figure 8.2. Conceptualized rate of decomposition of different organic compounds (modified from Henry, 1996).

Table 8. C:N ratios of different kinds of mature compost and their corresponding raw materials.

	C:N Ratio	
	Raw Material	Compost
Biosolids	8.7	11.2
Biosolids + sawdust	21.5	17.9
Biosolids + rice hulls	14.9	14.2
Garbage + bark	21.6	16.1
Garbage	16.0	15.8
Municipal refuse	20.7	14.9
Cow Manure	22.0	11.3
Cow manure + pig manure + straw	-	12.7
Chicken manure	5.3	8.2
Leaves	33.4	12.1

Source: Modified from Chanyasak et al., 1983a.

The complex and time-dependent relationships of C and N influence the amount of NO_3^- that leaches from the soil. A 1995 study illustrates this relationship (Van Ham and Henry, 1995). The study investigated the relationship between the C:N ratio of mixtures of biosolids and paper mill fines. Paper mill fines (C:N ratio = 82:1) are C-rich, small, particle-sized rejects from paper making. In the study, soil columns filled with soil amended with different ratios of biosolids and paper mill fines were subjected to a short-term laboratory incubation; leachings of water were taken weekly to quantify release of N.

Figure 8.3 presents the weekly accumulative NO_3^- leaching results for two of the mixtures with C:N ratios of 12:1 and 52:1 to contrast the effect of greatly differing C:N ratios. The results indicate a far greater release of NO_3^- with the 12:1 C:N ratio treatment (note that the scales are also different). Surprisingly, *NO_3^- was also released from the mixture with a 52:1 C:N ratio*, but with a far greater *delay* in the appearance of the NO_3^-.

Further interpretation of the study results shows that N loss does not correspond to decomposition; in fact, in this experiment, the opposite was true. The study showed that the higher the C:N ratio, the higher the percentage of organic matter that decomposed and the lower the percentage of N that leached (Figure 8.4). In both cases, there was a very good linear relationship. This supports the concept that as decomposition progresses in high C:N ratio materials, CO_2 releases while N gets reincorporated into the organic mass. It appears that there is a continued loss of CO_2 without corresponding loss of NO_3^- until the C:N ratio is reduced to some critical point, which results in a delay of the appearance of NO_3^- depending on the initial C:N ratio (Figure 8.5).

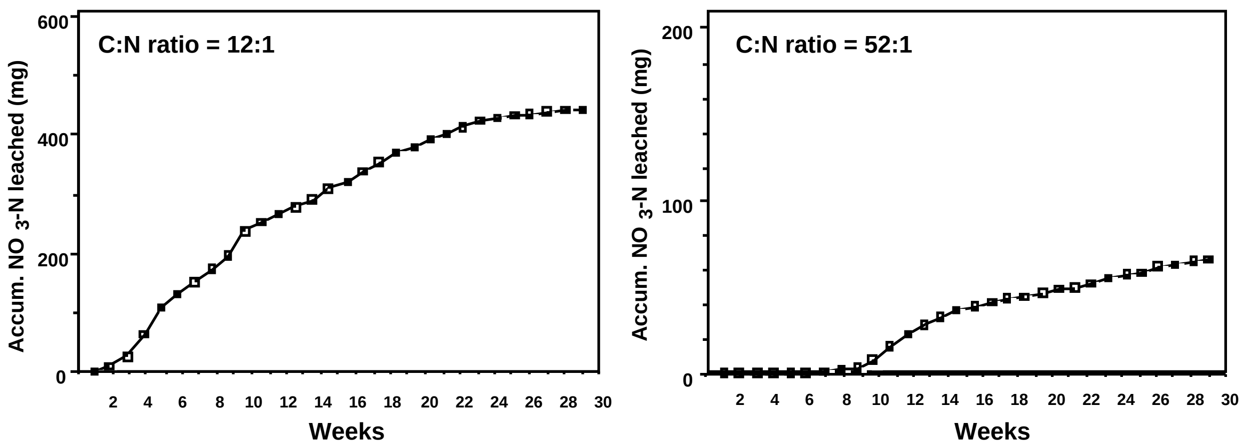

Figure 8.3. Comparison in accumulative mass of nitrate leaching between two biosolids/paper mill fine mixtures with 12:1 and 52:1 carbon-to-nitrogen ratios.

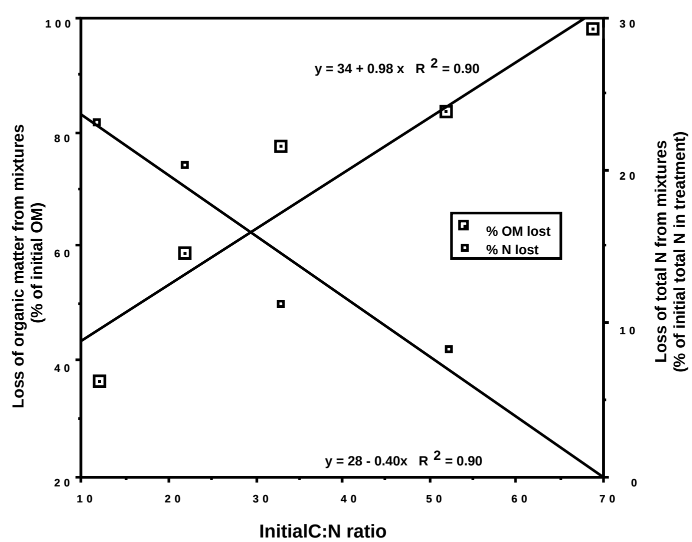

Figure 8.4. Percentage loss of organic matter in mixtures and percentage loss of total nitrogen from biosolids/paper mill fine mixtures as a function of initial carbon-to-nitrogen ratios of the mixtures.

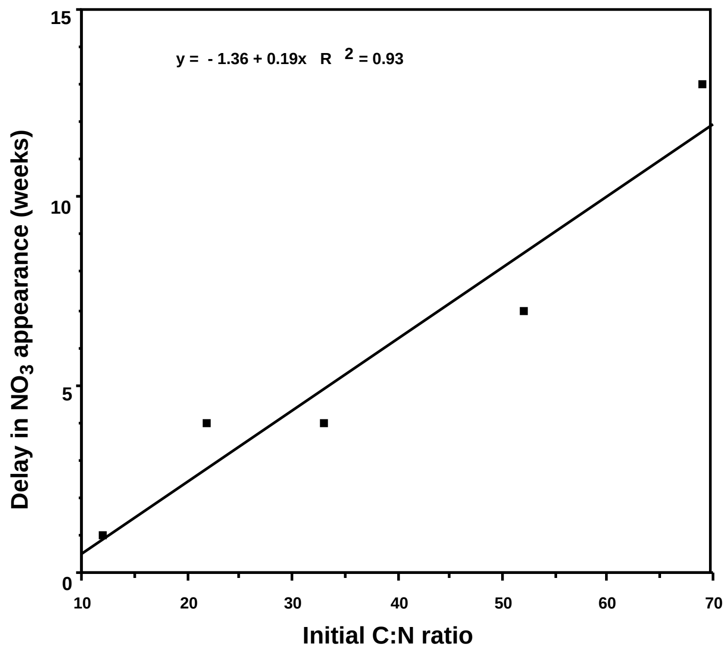

Figure 8.5. Delay in the appearance of nitrate leaching from tubes as a function of initial carbon-to-nitrogen ratios of biosolids/paper mill fine mixtures.

Choosing an initial organic matter content and C:N ratio

Figure 8.6 shows a conceptualization of the Balanced Soil Amendment Approach. The goal is to make N available so that plants have adequate nutrition throughout the course of a treatment and to achieve a balance between C and N. To achieve this goal, the appropriate initial organic matter content and C:N ratio must be selected (Figure 8.7) in order to reach a long-term stable organic matter content at a balanced C:N ratio.

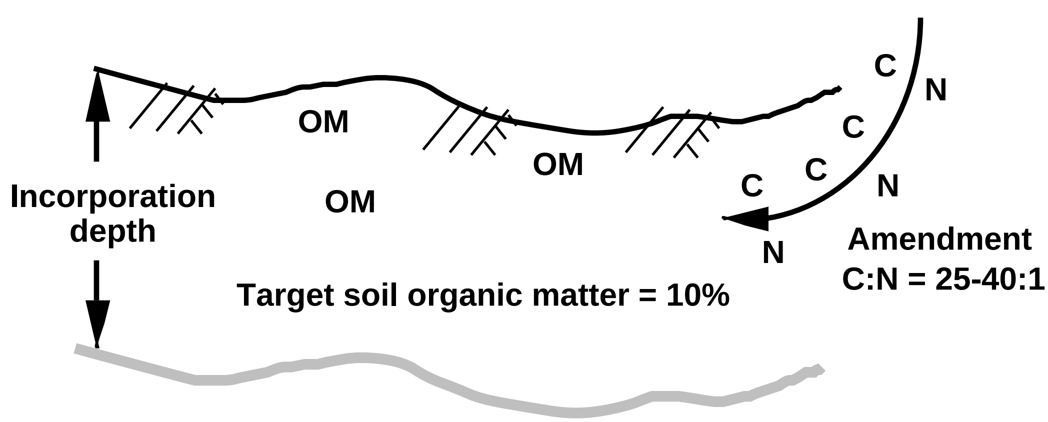

Figure 8.6. The conceptual Balanced Soil Amendment Approach.

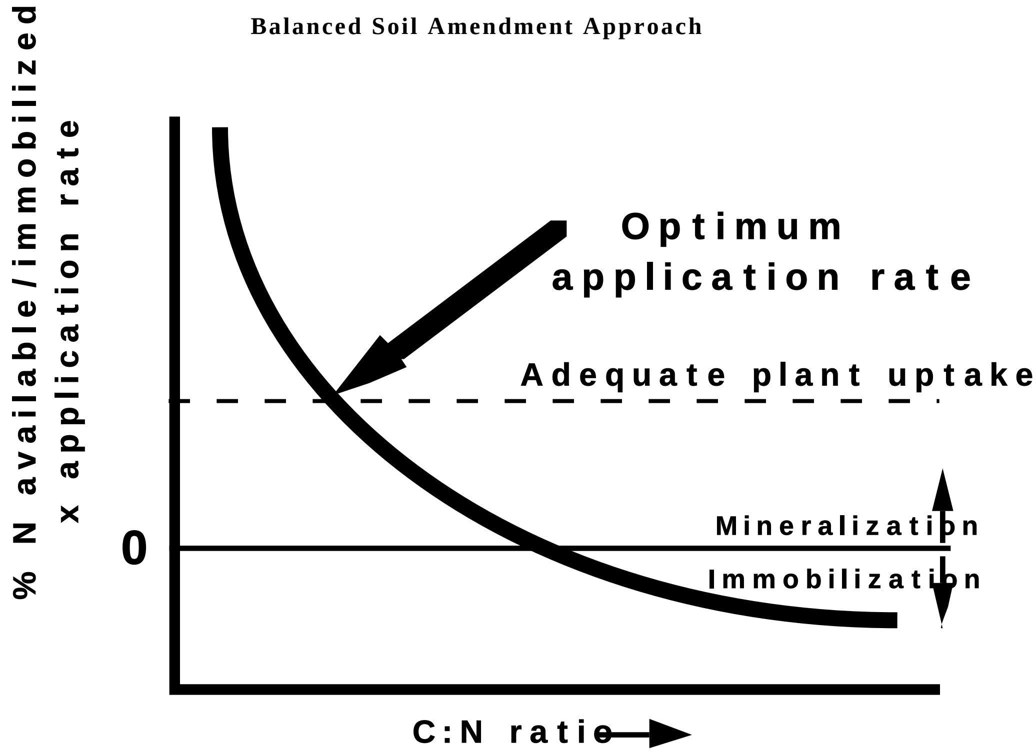

Figure 8.7. Ideal release curve for nitrogen as a function of carbon-to-nitrogen ratio.

Initial organic matter content

A topsoil that has a stable organic matter of 5 percent is usually considered productive. This amount of organic matter gives the soil desirable chemical, biological, and physical properties. In the Balanced Soil Amendment Approach the goal is to achieve a long-lasting productive topsoil by altering the organic matter and nutrient content of the top foot—the rooting zone—of the soil. Because the organic compounds in the residuals (biosolids and other organic matter) added to soil do not have the same stability as humus, a significant portion of the compounds will decompose in the soil within a few years following application. For most residuals, we can assume that about 50 percent of the organic compounds will decompose in the soil in 1 to 2 years. This assumption is only an rough approximation. Some organics such as straw will decompose much faster (and in our biosolids/paper mill fines study where far more than 50 percent loss occurred in 30 weeks), and some organics, such as wood that has a lot of lignin, will decompose much slower.

So if the long-term goal is to have 5 percent organic matter, then a 10 percent initial organic matter content would account for variable decomposition rates.

Initial carbon-to-nitrogen ratio

As discussed earlier, excess N added from biosolids can be immobilized by excess C added as C-rich residuals (such as wood chips, paper fines, and straw) that will be released later for plant use as decomposition continues. The type and stability of the C-rich residual must be taken into account when deciding on an initial C:N ratio for the amendment. If fresh carbon-rich residuals are used, a beginning C:N ratio of 30-40:1 for the mixture is appropriate. If a stable compost is used, then a beginning C:N ratio of 20-30:1 is appropriate.

Table 8.2 lists recommended C:N ratios for different C-rich residuals.

Table 8.2. Recommended initial carbon-to-nitrogen ratios for mixtures of biosolids and carbon-rich residuals for use as soil amendments.

	C:N Ratio
Faster decomposing materials	
Hardwood leaves	40:1
Yard waste	40:1
Pulp and paper sludge	40:1
Straw	40:1
Slower decomposing materials	
Stable compost	25:1
Sawdust	35:1
Wood chips[a]	45:1

[a]Wood chips have smaller surface-area-to-weight ratios than sawdust and are not as effective in immobilizing N.

Calculating application rates using the Balanced Soil Amendment Approach

Calculation of application rates using the Balanced Soil Amendment Approach consists of three steps:

Step 1. Analyze the soil, biosolids, and C-rich residual to determine the C and N concentrations and bulk density of each.

Step 2. Determine the ratio of the mass of the soil and C-rich residual to the mass of the biosolids.

Step 3. Translate the ratios into application rates, using the bulk densities.

For the sake of example, some values for depth of incorporation (1 ft.) and initial target soil organic matter content (10%) have been selected. As experience is obtained for specific sites, different depth or organic matter content may be justified.

Step 1: Analyze the soil, biosolids, and C-rich residual

The first step is to analyze the soil, biosolids, and C-rich residual. It is important to determine the C and N concentrations and bulk density of each. Some organic residuals, such as yard waste that is high in grass content, may not classify as a C-rich residual, because the C:N ratio may already be below the target C:N ratio.

Step 2: Determine the ratio of the mass of the soil and C-rich residual to the mass of the biosolids

The second step is to determine the ratio of the mass of the soil and C-rich residual to the mass of the biosolids. This ratio is determined by solving the following equations for calculating the weighted average of C:N and organic matter. These equations include two unknowns: the mass of biosolids per unit mass of soil and the mass of C-rich residual per unit mass of soil.

$$\frac{M_b C_b + M_c C_c}{M_b N_b + M_c N_c} = \text{C:N (target)}$$

and

$$\frac{M_s OM_s + M_b OM_b + M_c OM_c}{M_s + M_b + M_c} = \% \text{ OM (target)}$$

where

M_b = Unit mass of biosolids (set = 1)
M_s = Mass of soil
M_c = Mass of C-rich material
C_i = C concentration of biosolids and C-rich residual
N_i = N concentration of biosolids and C-rich residual
OM_i = Percent organic matter of soil, biosolids, and C-rich residual (about 1.73 times the % C)

Then, Equation 8.1 is used to solve for the mass of C-rich residual per mass unit biosolids:

$$M_c = \frac{C{:}N \times N_b - C_b}{C_c - C{:}N \times N_c} \tag{8.1}$$

Then, Equation 8.2 is used to solve for the mass of soil per mass unit of biosolids:

$$M_s = \frac{OM_b + M_c(OM_c - \% \text{ OM}) - \%\text{OM}}{\% \text{ OM} - OM_s} \tag{8.2}$$

The final step is to use the bulk densities to translate the ratios into application rates. Equations 8.1 and 8.2 simplify into Equation 8.3:

$$BAR = \frac{21.8 \times D}{\frac{M_s}{Bd_s} + \frac{1}{Bd_b} + \frac{M_c}{Bd_c}} \tag{8.3}$$

and

$$CR = BAR \times M_c \tag{8.4}$$

where

BAR = Biosolids application rate, t/ac
D = Incorporation depth, ft.
CR = C-rich residual application rate, t/ac
Bd_i = Bulk density of biosolids, C-rich residual, and soil, lb/ft^3
21.8 = Conversion factor (43,560 ft^2/ac/2,000 lb/t)

Table 8.3 compares biosolids-only application rates with application rates of biosolids/C-rich residual mixtures with two different C:N ratios.

Table 8.3. Application rates for biosolids/C-rich residual mixtures with initial C:N ratios of 30:1 and 40:1 and a 10 percent initial organic matter content compared with application rates for biosolids only.

	Biosolids	C-Rich Residual	Soil
Assumed N content (%)	5.2	0.8	0.1
Assumed C content (%)	43	45	1
Application rates (t/ac)			
Biosolids only, calculated with the N Balance approach	5		
Biolsolids only, calculated to provide 10 % organic matter (C:N = 9:1)	181		
Biosolids/C-rich residual mixture, C:N = 30:1	23	125	
Biosolids/C-rich residual mixture, C:N = 40:1	11	135	

Summary

This chapter presents the Balanced Soil Amendment Approach to achieving a long-lasting productive topsoil by changing the organic matter content and the nutrient status of the soil. This approach is still being developed, but early lab and field studies have yielded encouraging results. Field studies have been conducted with compost, pulp mill fines, and wood waste (Henry, 1995). As comprehensive data and experience grow, the approach promises to be a valuable tool if used correctly.

The Balanced Soil Amendment Approach provides general guidance for designing an application rate for a mixture of biosolids and a C-rich organic material. A number of C-rich materials can be used. Each of these materials has different characteristics of nutrient content and decomposition, and each must be studied before embarking on a major application program using this approach. In addition, small-scale studies should be conducted to determine the right mixture of biosolids and C-rich residual. The goal is to reach a long-term stable organic matter content of 5 percent at a balanced C:N ratio of between 20-30:1. This amount of organic matter at this C:N ratio normally gives the soil desirable chemical, biological, and physical properties. Because of the changes that take place with decomposition once the mixture is incorporated into the soil, both the initial organic matter and C:N ratio targets are higher than the long-term goal.

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