Understanding & Applying the Carbon-to-Nitrogen Ratio in Nurseries

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You probably remember something called the carbon-to-nitrogen ratio (C:N) from your soils or ecology class in college. This relatively simple index provides a lot of practical information on the horticultural properties of organic materials and how they can be used in both bareroot and container nurseries.

What It Is

To really understand C:N, it's necessary to discuss some basics of soil microbiology. The soil contains a wide variety of microorganisms but we are only interested in the ones involved with the breakdown of organic matter. Decomposition is initiated by insects, snails, and earthworms, which physically breakdown the material into smaller pieces. Then, smaller microbes (Figure 1A) complete the process through chemical decomposition (Martin and Gershuny 1992).

Bacteria - These single-celled microbes are so small that one million bacteria could be found in a pea-sized crumb of soil. However, they are the most versatile of soil microorganisms and can produce enzymes to digest any type of organic matter.

Actinomycetes - These thread-like bacteria are morphologically more similar to fungi. Although they are not as numerous as true bacteria, actinomycetes release ammonia when decomposing organic matter into humus. Actinomycetes are responsible for the sweet, earthy smell when a biologically active soil is tilled.

Fungi - These primitive plants exist in many sizes and shapes in the soil, and perform many biological functions during the decomposition of organic matter. Most importantly, fungi are able to breakdown the more resistant hemicellulose and lignin that found the structure of woody plant tissue.

Organic materials that could be useful in nurseries have a wide range of C:N (Table 1). The C:N is one of the most important considerations when evaluating organic matierals because it is an indicator of whether nitrogen will be limiting or surplus in the soil or growing media. The higher the C:N, the greater the likelihood that nitrogen will be unavailable for plant uptake. On the other hand, when an organic source with a high C:N is incorporated into the

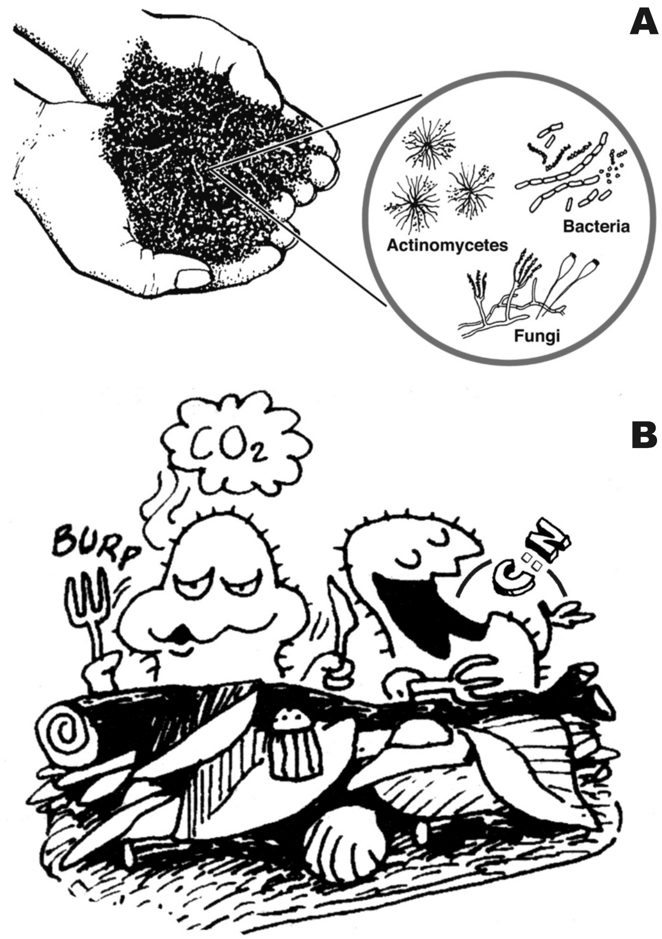

Figure 1 - Organic matter is chemically decomposed by bacteria, actinomycetes, and fungi (A); these microbes consume organic material and incorporate nitrogen (N) into their bodies and release carbon dioxide (CO_2) (A, modified from Crespo 2000; B, modified from Martin and Gershuny 1992, and Dindal 1982).

soil, carbon becomes available as an energy source for soil organisms.

Composting literature states that soils or organic matter with C:N of 20:1 to 30:1 are relatively stable (Table 1). Most common organic amendments have a C:N greater than 50:1 with sawdust and bark having the highest ratios. Sawdusts from broadleaved tree species have C:N around 400:1 and with their bark around 75:1; conifers woods and bark can be 2 to 4 times higher. Organic materials with C:N of 20:1 or lower are considered fertilizers because their decomposition results in a net release of nitrogen. Animal manures have C:N of around 10:1, which explains why they are the world's oldest fertilizers. Leguminous cover crops such as clover also have low C:N so, when they are tilled into the soil, their decomposition provides nitrogen for future crops (Table 1). One of the most comprehensive evaluations of C:N of common organic materials used in horticulture can be found in Bollen (1953).

Why Does Nitrogen Tie-up Occur?

Traditionally sawdust has been one of the most readily available and inexpensive organic amendments for forest and conservation nurseries, but many nursery managers are reluctant to use wood wastes because of growth problems with subsequent crops. Even if growers haven't experienced stunting themselves, they have surely heard horror stories from others. Although many blame "toxins" for these growth problems, the main cause is the high C:N of wood wastes and many other common organic amendments (Table 1).

Soil microbes have a C:N of approximately 30:1 so, when they are decomposing organic materials with a higher C:N, they have to obtain extra nitrogen from the surrounding soil or growing medium. Therefore, nitrogen "tie-up" occurs when inorganic nitrogen is converted to organic forms by microbes that use these nutrients to build their tissues. The stunting occurs because most of the nitrogen is temporarily immobilized in the microbial bodies, and little, if any, nitrogen is available for crop uptake. Visual symptoms of nitrogen tie-up are those of classic nitrogen deficiency: chlorosis and stunting. Symptoms often appear in a scattered "mosaic" pattern (Figure 2), because sawdust and other organic amendments are often not uniformly incorporated into the soil or growing medium. Plants in areas with too much high C:N amendment will appear chlorotic and stunted.

These conditions persist until the populations of decomposing bacteria, actinomycetes, and fungi decrease and the organic nitrogen in their tissues is mineralized to inorganic forms (nitrate and ammonium) that are readily available to plants. Therefore, addition of high C:N amendments to soil or growing media results in a temporary reduction of plant available nitrogen, but the final result is a slow release source of organic nitrogen and humus.

Compensating for Nitrogen Tie-up

Most nursery managers realize that organic amendments require supplemental nitrogen to facilitate breakdown and prevent chlorosis and reduced growth.

Material	% Nitrogen (Ovendry)	C:N
Chicken manure	5.50	7:1
Cow manure	2.60	15:1
Clover	2.20	18:1
Stable Carbon-to-Nitrogen Ratio		20:1 to 30:1
Corn stalks	1.20	33:1
Sphagnum peat moss	1.00	54:1
Tree leaves	0.70	60:1
Red alder bark	0.70	71:1
Straw of wheat & oats	0.40	100:1
Corn cobs	0.45	108:1
Rice hulls	0.30	140:1
Red alder wood	0.13	377:1
Douglas-fir bark	0.04	471:1
Douglas-fir sawdust	0.05	944:1

Table 1 - The percent nitrogen and carbon-to-nitrogen ratios of organic materials used in nurseries (modified from Allison 1965, Bollen 1969, and Handreck and Black 1994).

Figure 2 - Incorporating uncomposted sawdust in soils or growing media can result in stunting due to nitrogen tie-up (photo courtesy of Davis and others 2009).

So, the real question is: how much nitrogen, what form of nitrogen, and when is the best time to apply it? To be completely safe, the best procedure is to compost the organic matter beforehand but somehow there's never enough time or space for that.

In bareroot nurseries, the most practical solution is to "compost in place", which means to apply the organic matter as soon after harvest as possible and allow it to decompose over the fallow year. Applying nitrogen fertilizer at a rate of 15 to 20 pounds of nitrogen per ton of dry material is a good place to start (California Plant Health Association, 2002), but actual nitrogen demand will vary with type of amendment, soil type, moisture, temperature, and other factors. One of the most comprehensive studies with Douglas-fir (*Pseudotsuga menziesii*) sawdust recommends applying 25 to 50 pounds of ammonium sulfate or its fertilizer equivalent for each ton of sawdust. Half of the fertilizer should be incorporated with the sawdust, with the second half being broadcast later and irrigated into the soil (Bollen and Lu 1975). Some nurseries have sown field peas or other leguminous crops after the organic matter incorporation so that their naturally-fixed nitrogen will help compensate for the increased nitrogen demand.

In container nurseries, it's much easier to satisfy the nitrogen demand created by the increasing populations of decomposing microorganisms. When using high C:N components, some growers incorporate slow release fertilizer when mixing the growing media. For example, Robbins and Evans (2010) recommend that growers using fresh bark in their growing medium incorporate a starter charge of nitrogen at the rate of 0.25 to 1 pound N/yd^3 of medium. However, the easiest way to keep up with the projected nitrogen tie-up is to fertigate with a nitrogen solution with each irrigation. This ensures that some nitrogen will always be available for crop uptake.

As you can see, that results will vary considerably so the best procedure is to try a test in your nursery to see what works best under your conditions. Again, remember that this fertilizer is not being lost but is being converted to an organic form that will be available to your crops later in the season.

Applying the Carbon-to-Nitrogen Ratio in Nurseries

The effect of using organics with high C:N varies considerably with intended use and method of application. In nurseries, this is an issue when using organic mulches, amending bareroot soil, or creating a growing medium for containers.

Mulches - Mulches are one of the most widely used cultural practices in bareroot and container nurseries because they offer many benefits (Borland 1990). Fibrous mulches create a textural change at the soil surface that stops water from moving upward through capillarity and evaporating. All types of mulches reduce soil erosion by dissipating the energy of raindrops and wind that can dislodge soil particles and leave them vulnerable to wind and water erosion. Mulches stop soil crusting and allow irrigation and rainfall to slowly soak into the soil that improves water infiltration. Thick mulches form an insulating layer that dissipates solar energy and prevents soil temperatures from reaching damaging levels. When applied over cold or frozen soils, mulches slow soil warming which can prevent loss of dormancy or premature germination of fall-sown crops. A thick mulch can prevent soluble salts from moving upward as water is lost from the soil surface by evaporation. Because they insulate the soil surface, mulches prevent the recurring freeze and thaw cycles, which cause frost heaving. Mulches physically supress weeds and reduce light levels to the soil surface, which inhibits germination of many weed seeds (Mathers 2003).

Sawdust has been used for covering seeds in bareroot and container nurseries. Because only the mulch along the soil or growing media interface is accessible to microorganisms, nitrogen tie-up has not been a serious problem with high C:N mulches (Figure 3). To be safe, however, calculations for determining how much nitrogen fertilizer to add to various types and thicknesses of wood waste are provided in Rose and others (1995). In one bareroot nursery, seed germination under a mulch of 0.50 to 0.75 inches of fresh sawdust was actually better than the germination test (Knight 1958). Because of its lower C:N and slower decomposition rate, tree bark has even better advantages as a seed mulch.

Soil Amendments - Traditional organic soil amendments include sawdust, bark, peat moss, and manure, but innovative nursery managers have also used many other organic sources including mushroom compost, dried sewage sludge, ground cones, mint waste, and even dead fish from hatcheries. Regardless of the source, organic amendments provide many benefits (Davey 1984). As microbes consume organic material, they produce glomalin which binds soil particles into crumbs. Organic matter decomposes into humus, which acts like a sponge and retains water in the soil. Humus has a very high cation exchange capacity and prevents mineral nutrient ions from leaching. As organic matter decomposes, mineral nutrients are gradually released, especially the anions phosphorus and sulfur which are easily lost to leaching. In addition, the nitrogen which was added to speed decomposition becomes gradually available as the soil microbes die off. The high cation exchange capacity binds excess hydrogen ions. Improved soil structure helps create and maintain macropores, which are essential to water drainage and air exchange. Decomposing organic matter binds soil particles into stable crumbs instead of monolithic pans.

Unfortunately, traditional organic amendments such as sawdust and bark are becoming more expensive and less available to nurseries, so other sources such as municipal and industrial composts should be considered. Because seedlings and other nursery crops are not foodstuffs, nurseries are able to accept municipal and industrial organic wastes that cannot be used on food crops. Besides organic soil amendments, green manure crops are the only other way to maintain soil organic matter. Recently, however, cover crops and green manure crops have been discouraged due to concerns about the buildup of soil pathogenic fungi (Hildebrand and Stone 2001). So, as sawdust and other wood wastes become more unavailable, nursery managers will have to be more creative in their search for organic amendments.

Growing Media - All artificial growing media contain a high proportion of organic materials because they provide many benefits for growing plants in containers (Landis and others 1990).

Organics generate a large proportion of macropores for aeration and micropores for water-holding capacity. Organic material is less subject to compaction than inorganics. All types of organic material have high cation exchange capacities, so they can retain nutrient ions against leaching as well as provide a buffer against rapid changes in pH or salinity.

The amount of organic material used in growing media varies considerably, generally ranging from 25 to 50% (by volume). Joiner and Conover (1965) considered that 40 to 50% organic matter was ideal. For container nurseries that use commercially prepared growing media, such as mixtures of peat moss and vermiculite, the C:N is not an immediate concern. The topic needs to be considered, however, for nurseries that create their own custom growing media and espcially for those who are looking for an organic substitute for peat moss.

In Canada and Scandinavia, where peat bogs are common, forest tree nurseries use a growing media of 100% *Sphagnum* peat moss. *Sphagnum* peat moss has a C:N of around 50:1 (Table 1) and so rapid decomposition with corresponding nitrogen tie-up won't be a problem with normal fertilization. Several forest nurseries in the Pacific Northwest have tried using conifer sawdust in their growing media. Some growers experienced stunting caused by nitrogen deficiency, and therefore decided against using raw sawdust in the media (Justin 2009; Davis 2009). This mosaic stunting pattern is characteristic of nitrogen deficiency due to microbial immobilization (Figure 2). Other nurseries, however, have successfully incorporated sawdust in their

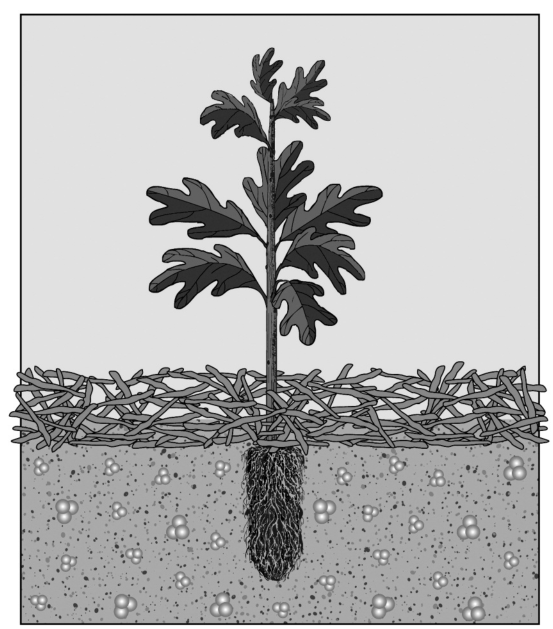

Figure 3 - Nitrogen tie-up is not a serious concern with organic mulches because of the limited contact with the soil.

media. Using a growing medium of 70% peat moss: 30% sawdust, one nursery produced crops as good as a peat-vermiculite growing medium while realizing savings of over 40% (Schaefer 2009). In a research trial comparing a 7 parts peat moss to 3 parts sawdust growing medium with a traditional 1 part peat moss to 1 part vermiculite medium, irrigation and fertilization were carefully controlled. Although seedlings growing in the sawdust mix showed some stunting early in the crop cycle, they were of similar size to the control seedlings by the end of the experiment, presumably because immobilized nitrogen became available later in the growing season. In addition, the sawdust medium required less frequent irrigation (Dumroese 2009).

Other organic materials are also being used in growing media. For example, composted rice hulls have worked out well as a peat moss substitute for another nursery (Lovelace and Kuczmarski 1992). One of the biggest problems with using composts or other organic materials in growing media is the variation from batch to batch, so the initial C:N should be checked regularly. With wood wastes, particle size is a consideration because microorganisms will only decompose the surfaces of larger particles (Handreck and Black 1994). Chipped pine logs (Wright and Browder 2005) and pine tree substrate (Jackson and others 2009), which is a product of whole tree chipping, have successfully been used in growing media for ornamental crop production.

Therefore, sawdust and other organic materials can be used as peat moss substitutes in growing media as long as the C:N of the material is known so that commensurate nitrogen fertilizer can be applied. Crop growth should also be carefully monitored so that, if needed, additional nitrogen can be immediately supplied through fertigation. For the more research-minded, a nitrogen drawdown index can be computed by treating a sample of the organic matter with a known nitrogen source, and incubating it for a few days (Handreck 1992). However, for nurseries that don't want this additional challenge or don't use fertigation, they should stick to traditional growing media.

Take-Home Message

Organic amendments have many beneficial uses in forest, conservation, and native plant nurseries and growers shouldn't shy away from using them because of past experiences. Nitrogen tie-up can be managed by knowing the C:N of the material beforehand, and by being prepared to supply additional nitrogen fertilizer in the proper amount and at the proper time. It's also important to remember that this nitrogen isn't lost but merely converted to an organic form that will serve as a slow-release fertilizer later in the season.

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