Nitrogen Mineralization from Organic Fertility Sources

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INTRODUCTION

Nitrogen is essential for plant growth and a yield-limiting nutrient in many production systems. Organic materials provide plant-available nitrogen, but there is considerable variation in how much and how quickly the nitrogen is converted to plant-available forms (mineralized). This is of particular concern in organic cropping systems, where a delay or deficiency of nitrogen can hurt crop yields or quality.

This factsheet describes the factors that affect nitrogen mineralization from organic materials, various types of organic fertility sources and how to manage these materials to meet crop requirements with minimal losses to the environment.

FACTORS INFLUENCING NITROGEN AVAILABILITY

Nitrogen that is taken up by plants is in the mineral form (ammonium (NH_4^+) or nitrate (NO_3^-)). Every organic fertilizer contains a mix of organic nitrogen compounds, of varying degradability, along with varying amounts of mineral nitrogen. These organic compounds must be broken down (mineralized) to release NH_4^+, which is then converted to NO_3^-. This entire process happens through soil microorganisms. Because biology drives mineralization, it is also affected by the physical conditions in the soil, like soil texture, structure, moisture and temperature. There is a tendency for more N mineralization in coarse-textured soils than in loams or clays, but this effect may show up more in the first few weeks after the material is added than in the total amount released (Lazicki et al., 2020). Ideal conditions for mineralization are warm, moist soils with extremes of either temperature or moisture slowing the process. In Atlantic Canada, limitations to N mineralization are often due to soils that are either too cold or too dry.

Many different organic compounds contain nitrogen, but there is a huge range in how easily they are broken down and, therefore, how quickly the nitrogen is available for plant uptake. Amino acids and nucleic acids are most quickly mineralized, where enzymes can relatively easily cleave off amine groups to release ammonium. Proteins and amino sugar compounds are more complex and require more steps to break down; some proteins like keratin (in hair or feathers) or chitin (in insect shells and fungal hyphae) have many cross-linkages that resist breakdown. Also resistant to breakdown are many cyclic organic molecules that are hydrophobic (repel water, like waxes or oils) enzymes which are dissolved in water. As a rule, simpler compounds will mineralize their nitrogen more quickly and completely than more complex compounds.

Adding complexity to this picture is the carbon included with the fertilizer material, which is food for the microorganisms that ultimately control the release of nitrogen from the fertilizer. The bacteria, actinomycetes and fungi in the soil immediately begin consuming any organic materials added to the soil, using it both to grow, multiply and respire. During their growth, they need nitrogen to build the proteins and nucleotides in their cells at a ratio of about 1 part N to 8 parts of C (also expressed as a C:N ratio of 8). During this growth phase, the microbes will multiply until they use up the nitrogen supply, potentially robbing plants of available nitrogen if carbon is too abundant. With billions of microbes in every gram of soil, plants are outcompeted by bacteria and fungi for nitrogen, materials with a C:N ratio >15 often immobilize soil N. These microbes are short-lived, so there is a rapid cycle of growth and death, which contributes back N into the soil system. More carbon means more cycles to get to this point, so materials with a high C:N ratio may never release useful amounts of N to fertilize your crop, at least not in this growing season.

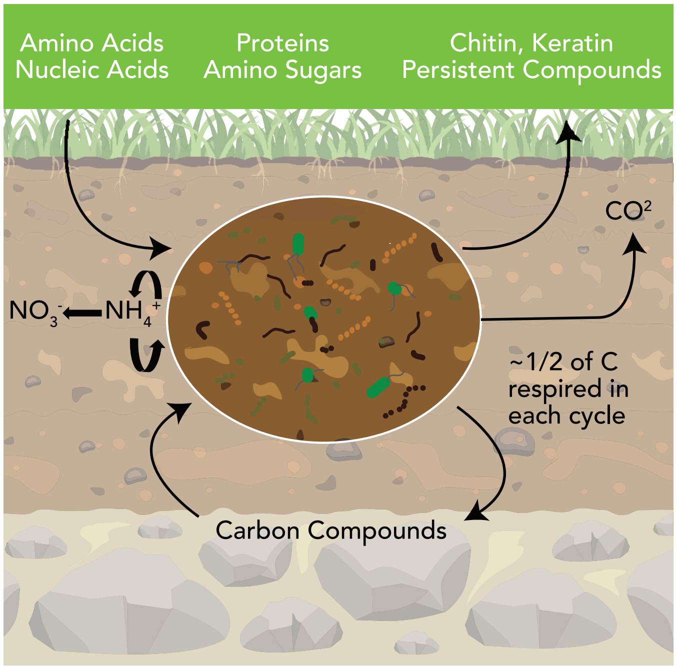

Figure 1: Cycling of N and C from organic materials during decomposition. Microbes may either tie up or release N, depending on how much carbon is available.

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CHARACTERISTICS OF ORGANIC FERTILITY SOURCES

There is a spectrum of organic amendments that are used to provide nitrogen to crops. The commercially available ones fall into three broad categories: 1. Organic fertilizers derived from livestock or plant products; 2. Composted or processed livestock manures; 3. Leaf and Yard waste compost. These classes are ranked from the fastest and greatest N release to the slowest and lowest. The characteristics of typical organic amendments are shown in Table 1.

Table 1: Nutrient concentrations in typical organic amendments used as fertility sources. Nutrient values are approximate, so fertility decisions should be based on guaranteed analysis or laboratory analysis (see factsheet Interpreting Compost Analysis Results).

Material	Fertilizer Grade (N-P_2O_5-K_2O)	Organic N as % of total N	C:N Ratio
Blood Meal	12-0-0	>99	3.3
Feather Meal	10-0-0	>99	3.1
Fish Meal	9-5-0	90	4
Soybean Meal	7-1-2	100	7
Bone Meal	4-10-0	100	4
Alfalfa Meal	2.5-0.2-2.5	100	12-15
Kelp Meal	1-0-2	100	10
Chicken Litter Pellets	4-1-2	75	10-16
Composted Broiler Litter	3-2-2	67	8-20
Composted Cattle Manure	0.9-0.3-1.1	95	15-25
Leaf and Yard Waste Compost	0.5-0.1-0.4	>99	20-30

The nitrogen in materials like blood meal or bone meal is in the form of amino acids and simple proteins, and they are rapidly mineralized when added to the soil. Feather meal is protected from breakdown by the many cross-linkages between the protein strands unless there has been sufficient heat treatment to break these linkages, as can be the case when the product is formed into a 'meal'. As the narrow C:N ratio suggests, these materials are nearly equal to mineral fertilizer in their nitrogen release into the soil solution. The plant-based organic fertilizers are composed of more complex proteins and have slightly higher C:N ratios, so while the N availability is similar to animal-based materials, the release is slightly slower. The exception to this is alfalfa meal, where the higher C:N ratio reduces the N mineralization; at least one study showed N immobilization from alfalfa meal amendment (Cassity-Duffey et al., 2020), although this most likely varies with the N content of different alfalfa meals.

Manure-based composts are highly variable, depending on the feedstocks used and the composting process, so the short-term impact can range from nitrogen mineralization to nitrogen immobilization. Muñoz et al. (2008), in a comparison of fresh and composted manures applied to corn, found that 57% of the N was released in the first year from fresh poultry manure compared to 14% from composted poultry manure. Eghball and Power (1999) showed a similar pattern with cattle manure, where N mineralization was 38% from fresh manure and 20% from composted manure. The composting process converts more of the organic N into forms that are slow to mineralize (recalcitrant).

Leaf and yard waste composts can have properties that overlap those of manure-based composts but are generally much lower in nitrogen and higher in carbon. These materials, with a high C:N ratio, will usually immobilize nitrogen from the soil rather than mineralize it and are ill-suited for application to crops with high N requirements.

Based on laboratory analyses, organic materials marketed as fertilizers will have guaranteed minimum nutrient concentrations. The N guarantee should include the proportion of organic N along with the total N concentration in the material. Most composts will be marketed as soil amendments rather than fertilizers, so it is important to get a compost analysis before applying the material.

PREDICTING NITROGEN AVAILABILITY TO CROPS

There are two key questions to consider with organic nitrogen fertilizers: 1. how much of the applied N will be mineralized for the crop to use, and 2. will the N release match the time the crop needs it? The ideal circumstances would be "just-in-time" delivery of exactly the right amount of N to feed the crop without any excess that could be lost to the environment. In some systems, organic fertilizers can behave this way, as the rate of mineralization is fastest under warm, moist conditions, which matches good conditions for plant growth, but this is not always the case. The rate of mineralization may not match the timing of N requirements for the specific crop being grown and release the N after the crop needs it. This makes the management of organic fertilizers different from mineral fertilizer, where we assume that all of what we apply is available for crop uptake very soon after application.

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Both Lazicki et al. (2020) and Cassity-Duffey et al. (2020) found strong relationships between the C:N ratios of applied materials and the proportion of N mineralized that season, with about 80% mineralization at a C:N ratio of 5, dropping to zero (or net immobilization) at C:N>15. Mineralization was fastest for the materials with lower C:N ratios, with the majority of release during the first three weeks. Manure-based composts took longer to mineralize, extending beyond the end of the incubation study at 12 weeks. Both studies were incubations done in the lab with consistently warm soils. Cool soil temperatures will reduce the rate of N mineralization, which can both delay and reduce the amount of nitrogen available to the crop. This impact is greater in materials with higher C:N ratios (Agehara & Warncke, 2005; Geisseler et al., 2021); a 10°C reduction in temperature decreased N mineralization from alfalfa pellets by 20%, while the reduction from composted poultry manure was about 10% and urea showed no change in N release. This delay in release is an advantage if materials are applied in late fall, as they will stay primarily in the organic form until the weather warms up in the spring, but it can also mean that short-season crops may not be able to fully benefit from the N in organic materials.

The organic compounds in organic fertilizers must break down (mineralize) to release nitrogen as ammonium before it is available to plants. The speed of this process will be affected by the nature of the material as well as the temperature and moisture of the soil.

Combining this information, the availability of nitrogen to crops from spring-applied organic materials can be estimated with the following steps:

1. Determine the amount of organic and mineral N in the organic fertilizer. In the case of a processed fertilizer, this will be included in the fertilizer grade of the product; the N will be listed as total N, but there should also be a number for the proportion of organic N. For composts or other non-commercial products, a lab analysis will be required. If possible, the C:N ratio of the material should be determined.

2. Determine the application rate of the material. Estimates of application rates for manure and compost are often wildly inaccurate and are generally much higher than farmers think they are applying.

3. Calculate the total N applied (TN) by multiplying the application rate by the concentration of N in the applied material.

4. Estimate the maximum N mineralization from the material under ideal conditions:

$$AN = TN * (0.8 - \left(\frac{(C:N - 3)}{10}\right))$$

   a. If the C:N ratio of the material is known, calculate the available N (AN) using the formula

      If the C:N ratio is <3, assume that 80% of the TN is available, and if it is >13, the N availability will be zero.

   b. If the C:N ratio is not available, assume the maximum availability of N from an organic fertilizer material is 80%, from a manure-based compost is 30%, and from a leaf and yard waste compost is <5%.

5. Adjust the Available N by a temperature factor to account for the delay in N mineralization in cool soils. For each degree that the average daily temperature is below 20C, reduce the AN by 0.4% times the C:N ratio minus 2.5.

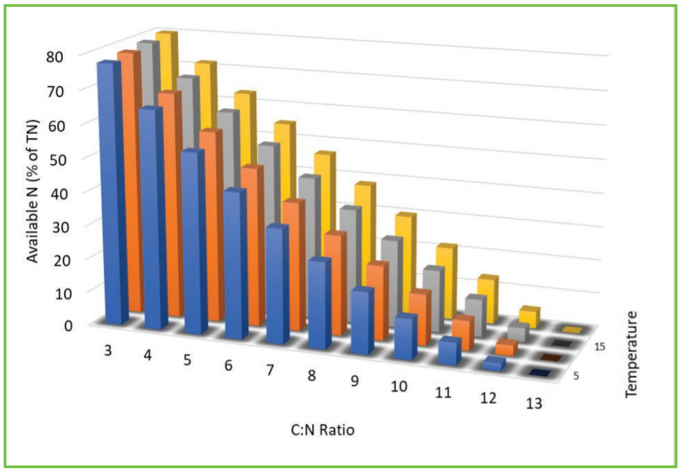

Figure 2: Predicted mineralization of N from organic fertilizers in response to the C:N ratio of the material and soil temperature following application.

Calculating the compost application rate:

1. Weigh a load of compost (lbs. or kgs.)
2. Measure the area that load covers at normal application rates (width X length)
    a. Width is measured from center to center of adjacent passes
    b. If you are estimating the distance travelled in rods, convert to feet by dividing by 16.5, or to meters by dividing by 5.
3. Area in acres = width (ft) X length (ft) /43,560
   Area in hectares = width (m) x length (m) /10,000
4. Application rate is weight of the load divided by area covered.

These calculations will provide estimates only, so it is important to monitor the performance of the crop to ensure that growth is not limited by insufficient available nitrogen. If deficiencies are evident, and warmer weather is not in the immediate forecast (in the case of delayed mineralization due to cool weather), a top-dress or side-dress of mineral N or a highly available organic N fertilizer will maintain crop productivity.

The extended release of N from organic materials will mean they fit best with crops that grow for the entire season, like grain, silage corn, or main crop potatoes. Shorter-season crops like early vegetables may not be able to utilize all the N released later in the season unless a double crop or cover crop is planted to soak up the excess. N release late in the season is at risk of loss to the environment through leaching to groundwater or denitrification that emits nitrous oxide.

Worksheet to calculate N mineralization from organic fertilizers (Imperial)

Factor	Calculation	Result
1. N concentration in organic fertilizer	Copy the values from fertilizer grade or lab report for %N and C:N ratio. Approximate C:N ratios for some materials are listed in Table 1.	%N = ________________(A) C:N = ________________(B)
2. Material application rate (AR)	For pelleted materials, use the calibrated rate for the fertilizer spreader. For bulky materials, measure the application rate (see text box)	AR (lb/ac)= ____________(C)
3. Total N application rate (TN)	Multiply the %N by the application rate	TN (lb/ac) = _________(C) * _________(A)/100 =______________(D)
4. Available N (AN)	$AN = TN * (0.8 - \left(\frac{(C:N-3)}{10}\right))$	AN (lb/ac) = ___________(D) * (0.8 - ((______B -3)/10) =______________(D)
5. Temperature Adjusted Available N (TAAN)	TAAN = AN * (1 – ((20 – temp)*(C:N – 2.5)*0.004	TAAN (lb/ac) = __________(D) * (20 – temp) * _______B-2.5 * 0.004 Where "temp" = average daily temperature in the previous week = ______________

Worksheet to calculate N mineralization from organic fertilizers (Metric)		
Factor	**Calculation**	**Result**
1. N concentration in organic fertilizer	Copy the values from fertilizer grade or lab report for %N and C:N ratio. Approximate C:N ratios for some materials are listed in Table 1.	%N = ________________(A) C:N = ________________(B)
2. Material application rate (AR)	For pelleted materials, use the calibrated rate for the fertilizer spreader. For bulky materials, measure the application rate (see text box)	AR (kg/ha)= ____________(C)
3. Total N application rate (TN)	Multiply the %N by the application rate	TN (kg/ha) = _________(C) * ________(A)/100 =_____________(D)
4. Available N (AN)	$AN = TN * (0.8 - \left(\frac{(C:N - 3)}{10}\right))$	AN (kg/ha) = ___________(D) * (0.8 - ((_______B -3)/10) =______________(D)
5. Temperature Adjusted Available N (TAAN)	TAAN = AN * (1 – ((20 – temp)*(C:N – 2.5)*0.004	TAAN (kg/ha) = __________(D) * (20 – temp) * _______B-2.5 * 0.004 Where "temp" = average daily temperature in the previous week = ______________

SUMMARY

Organic materials can be excellent sources of nitrogen for field and horticultural crops, but effective use of their nutrients requires an understanding of the nature of different materials and how they behave when applied to the soil. Careful planning can reduce much of the guesswork about the amount of N mineralization to expect, improving the profitability of crop production and reducing potential environmental impacts.

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