

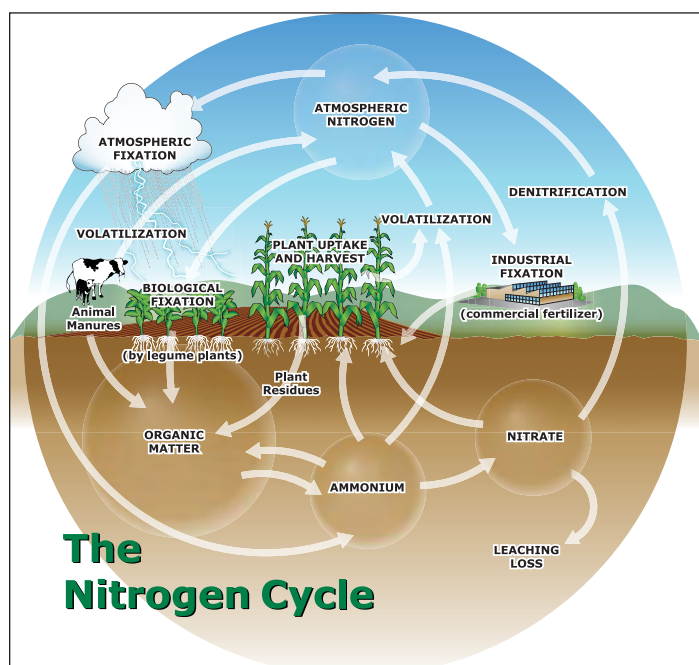
# Nitrogen Sources for Organic Crop Production

By Robert Mikkelsen and T.K. Hartz

Nitrogen is generally the most difficult nutrient to manage for organic crop production. Cover crops and composts can contribute substantial N for crops, but it is challenging to synchronize N release from these materials with the plant demand. Various commercial organic N fertilizers are available, but their costs may be prohibitive in many situations. Careful management of organic N sources is required to meet crop requirements, while avoiding undesirable N losses to the environment.

Nitrogen is the plant nutrient that is often most limiting to efficient and profitable crop production. Inadequate supply of available N frequently results in plants that have slow growth, depressed protein levels, poor yield of low quality produce, and inefficient water use. Nitrogen-stressed plants often have greater disease susceptibility compared with properly nourished plants. However, excessive N can be detrimental for crop growth and quality, in addition to causing undesirable environmental impacts. For these reasons, more research has been conducted on managing this plant nutrient than any other. This brief review does not address all the important aspects related to N management, but covers the major sources of N for organic crop production and their behavior in soil. An extensive list of references is available at this website: [www.ipni.net/organic/references](http://www.ipni.net/organic/references).

Although Earth's atmosphere contains 78% N gas ( $N_2$ ), most organisms cannot directly use this resource due to the stability of the compound. Breaking the strong chemical bond in  $N_2$  gas requires either the input of energy (to manufacture fertilizer) or specialized nitrogenase enzymes. Since the use of manufactured N fertilizer is not allowed for organic production, these materials are not specifically addressed here.



**Figure 1.** Where does the added N go? Organic N is converted to various inorganic N forms prior to plant uptake. Careful management reduces unwanted N loss to the environment.



**Composts and manures** can provide a valuable source of organic matter, but predicting the rate of N release to plants is not easy.

There are many biological and chemical processes that cause first-year recovery by plants to generally be less than 50% of the applied N. Low N efficiency can also be caused by imbalance of other essential plant nutrients. Management of N is also made difficult due to uncertainties related to weather events following fertilization. Where N recovery is low, it is important to consider where the unrecovered N may be going and the potential environmental and economic risks associated with these losses (**Figure 1**).

Almost all non-legume plants obtain N from the soil in the form of ammonium ( $NH_4^+$ ) or nitrate ( $NO_3^-$ ). Some organic N-containing compounds can be acquired by roots in small amounts, but these are not a major source of plant nutrition. Ammonium is the preferred inorganic source of N for some plants (especially grasses), but nitrification processes typically oxidize this N form to  $NO_3^-$ . Many other crops grow best with predominantly  $NO_3^-$  nutrition. In most warm, well-aerated soils, the  $NO_3^-$  concentration may be at least 10 times greater than the  $NH_4^+$  concentration.

Unlike other plant nutrients (like P and K), there is no universal or widely used soil test to predict the amount of supplemental N required to meet the crop's need. Instead, the need for N supplementation is typically based on yield expectations, field history, and measurement of residual  $NO_3^-$ . Nutrients in commercial fertilizers are generally soluble, so their availability to plants is quite predictable. However, most organic N sources require mineralization (conversion to inorganic forms) before they can be used by plants. Environmental factors such as soil temperature, pH, moisture, and management practices such as tillage intensity all impact the rate of N availability from organic sources.

A major factor for using organic N sources involves knowing both the amount of N applied and the rate of N release from the

**Abbreviations and notes for this article:** N = nitrogen; P = phosphorus; K = potassium; C = carbon.

**Table 1.** First-year N availability coefficients for different manures and application methods (plant-available N).

| Manure type                      | Soil  | Surface applied |           |
|----------------------------------|---|-----------------|-----------|
|                                  | incorporated                                  | Broadcast       | Irrigated |
|                                  | Fraction of N available during the first year |                 |           |
| Poultry litter                   | 0.6   | 0.5             | -         |
| Layer manure                     | 0.6   | 0.4             | -         |
| Scraped swine manure             | 0.6   | 0.4             | -         |
| Scraped dairy manure             | 0.6   | 0.4             | -         |
| Swine lagoon effluent            | 0.8   | 0.5             | 0.5       |
| Dairy lagoon effluent            | 0.8   | 0.5             | 0.5       |
| Compost<br>(C:N of 15:1 to 20:1) | 0.05  | 0.03            |           |
| Compost<br>(C:N >25:1)           | 0   | 0               |           |

Source: Baldwin, K.R. and J.T. Greenfield. 2006. Composting on organic farms. [http://www.cefs.ncsu.edu/PDFs/Organic Production - Composting.pdf](http://www.cefs.ncsu.edu/PDFs/Organic%20Production%20-%20Composting.pdf)  
Various authors: <http://www.soil.ncsu.edu/about/publications.php#AnimalWaste>

**Table 2.** Major processes in the N Cycle.

**Biological Fixation:** Symbiotic relationship between bacterial rhizobia and a variety of leguminous plants allows dinitrogen gas ( $N_2$ ) to be converted to plant-available forms of N. Some free-living bacteria and actinorhizal plants are also capable of biological N fixation. This is the major mechanism of supplying N in unfertilized soils.

**Industrial Fixation:** The process of combining atmospheric  $N_2$  with hydrogen to form  $NH_3$ , the precursor to most other manufactured N fertilizers.

**Ammonium Fixation:** Certain clay minerals (such as mica, illite, and vermiculite) are capable of trapping  $NH_4^+$  cations within the expanded clay layers. This phenomenon also can occur with K. The extent of this process varies considerable, from negligible to significant, depending on the clay mineralogy.

**Immobilization:** Immobilization occurs when soil microorganisms assimilate inorganic N, making it unavailable for plant uptake. The C:N ratio of added organic materials is a good, but not an absolute, predictor of whether N immobilization is likely (C:N ratio >25:1) or if mineralization is likely (C:N ratio <20:1).

**Mineralization:** The release of inorganic N from organic matter (proteins, amino sugars, and nucleic acids) following their decomposition by soil microorganisms. The rate of mineralization is influenced by numerous environmental and management factors, making it difficult to accurately predict in the field.

**Nitrification:** The 2-step bacterial oxidation of  $NH_4^+$  to nitrite and then to  $NO_3^-$ . This process requires oxygen and is most rapid under conditions favorable for crop growth.

**Denitrification:** When oxygen is in short supply in the soil, many bacteria are capable of reducing  $NO_3^-$  to gases such as  $NO_2$ ,  $N_2O$  and  $N_2$ . Denitrification results in a loss of plant available N and byproducts, such as  $N_2O$ , are potential greenhouse gases.

**Volatilization:** The loss of  $NH_3$  from soil, compost, or manures is primarily a function of the chemical environment. In an alkaline environment,  $NH_4^+$  changes to the gaseous  $NH_3$  form and can be readily lost to the atmosphere from soil or organic materials. High temperatures and drying conditions also tend to speed the volatilization reactions, especially from  $NH_3$ -containing materials on the soil surface.

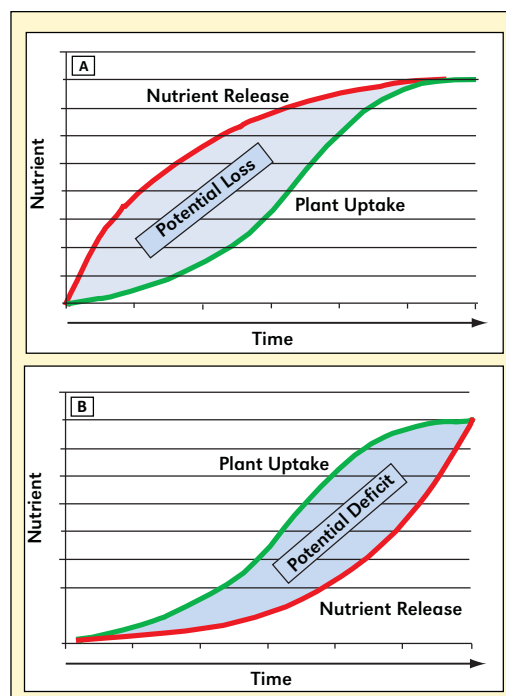
organic material. Nitrogen availability coefficients are used to estimate the fraction of total N that will be available for crop uptake during the first growing season (called *plant-available N* or PAN). The N availability coefficient can vary widely, based on the nature of the material, management practices (such as placement), and environmental factors (such as season of the year). Examples of PAN coefficients are shown in **Table 1**. Major processes of the N cycle are described in **Table 2**.

### Mineralization of Organic Matter

When the crop's N supply comes exclusively from sources such as soil organic matter, cover crops, and composts, a thorough understanding of mineralization is essential to avoid a deficiency or surplus of available N. Mineralization is not consistent through the year and crop N demand should be matched with nutrient release from mineralization. Mineralization rates are dependent on environmental factors (such as temperature and soil moisture), the properties of the organic material (such as C:N ratio, lignin content), and placement of the material. Many excellent references discuss this process in detail.

Failure to synchronize N mineralization with crop uptake can lead to plant nutrient deficiencies, excessive soil N beyond the growing season, and the potential for excessive  $NO_3^-$  leaching (**Figure 2**).

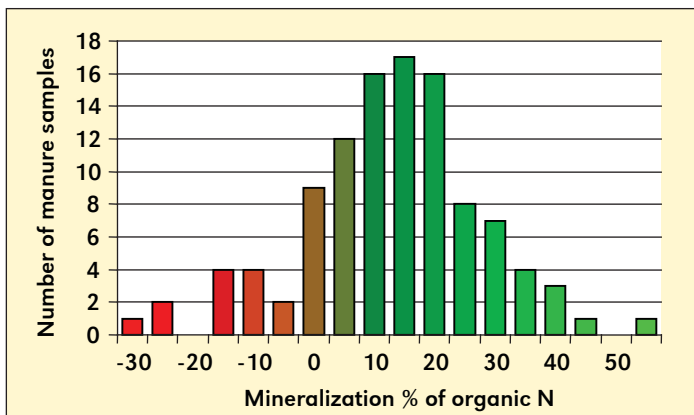
**Composts:** Generally, composts contain relatively low concentrations of N, P, and K. They typically decompose slowly and behave as a slow-release source of N over many months or years since the rapidly decomposable compounds have been previously degraded during the composting process. Composts can be made from on-farm materials, but they are also widely available from municipal and commercial sources.



**Figure 2.** Synchronizing nutrient release with plant demand is a challenge with organic materials. Rapid release from organic sources with a low C:N ratio may supply nutrients more rapidly than the plant's demand (A). An organic material with a high C:N ratio may not release nutrients sufficiently rapid to meet the need of growing plants (B).

These composts vary in quality and tend to have low immediate nutritional value, but provide valuable sources of stable organic matter. Since plastic, trash, and industrial waste may also turn up in selected municipal composts, some organic certification programs do not allow their use. Commercially composted manure is widely available from a variety of primary organic materials.

**Manure:** The chemical, physical, and biological properties of fresh manure vary tremendously due to specific animal feeding and manure management practices. The manure N is present in both organic and inorganic forms. Nitrogen is unstable in fresh manure because ammonia ( $\text{NH}_3$ ) can be readily lost through volatilization. Application of fresh manure or slurry on the soil surface can result in volatilization losses as high as 50% of the total N in some situations. The combination of wet organic matter and  $\text{NO}_3^-$  in some manure can also facilitate significant denitrification losses. The organic N-containing compounds in manure become available for plant uptake following mineralization by soil microorganisms, while the inorganic N fraction is immediately available. **Figure 3** shows the wide range in N mineralization of manure applied to soil.



**Figure 3.** Nitrogen mineralization from 107 individual dairy manure samples after 8 weeks of incubation. On average, 13% of the organic N was mineralized, but 19 samples had net immobilization. Net N mineralization from the remaining 88 samples ranged from zero to 55%. (from Van Kessel and Reeves, 2002).

Determining the correct application rate of manure and compost to supply adequate PAN during the growing season can be difficult. Begin by having manures and composts regularly analyzed for nutrient content since there is considerable variability. The PAN will always be smaller than the total N in the manure since some loss occurs through volatilization with spreading, and only a portion of the organic N will be available to the plants during the growing season following application. The remaining organic N will slowly mineralize in later years.

When manures and composts are applied at the rate to meet the N requirement of crops, the amount of P and K added is generally in excess of plant requirement. Over time, P can build up to concentrations that can pose an environmental risk since runoff from P-enriched fields can stimulate the growth of undesirable organisms in surface water. Excessive soil K can cause nutrient imbalances, especially in forages. The long-term use of P and K-enriched manures to provide the major source of N must be monitored to avoid these problems.

Manures and composts can be challenging to uniformly apply to the field due to their bulky nature and inherent variability. Application of raw manure may bring up concerns related to food safety, such as potential pathogens, hormones, and medications. The use of raw manure is restricted for some organic uses and growers should check with the certifying agency before using.

**Cover Crops:** A wide variety of plant species (most commonly grasses and legumes) are planted during the period between cash crops or in the inter-row space in orchards and vineyards. They can help reduce soil erosion, reduce soil  $\text{NO}_3^-$  leaching, and contribute organic matter and nutrients to subsequent crops after they decompose. Leguminous cover crops will also supply additional N through biological  $\text{N}_2$  fixation. The amount of N contained in a cover crop depends on the plant species, the stage of growth, soil factors, and the effectiveness of the rhizobial association. Leguminous cover crops commonly contain between 50 and 200 lb N/A in their biomass.

Cover crops require mineralization before N becomes plant available. The rate of N mineralization is determined by a variety of factors, including the composition of the crop (such as the C:N ratio and lignin content) and the environment (such as the soil temperature and moisture). As with other organic N sources, it can be a challenge to match the N mineralization from the cover crop to the nutritional requirement of the cash crop. It is sometimes necessary to add supplemental N to crops following cover crops to prevent temporary N deficiency.

## Commercial Organic Fertilizers

### Plant Products

**Alfalfa meal** (4% N), **cottonseed meal** (6% N), **corn gluten** (9% N), and **soybean meal** (7% N) are all examples of plant products that are sometimes used as N sources for organic production. These products are also used as protein-rich animal feeds. They require microbial mineralization before the N is available for crop uptake. Mineralization of these N-rich materials is generally rapid.



**Alfalfa** pellets.

### Animal Byproducts

**Blood Meal:** Derived from slaughterhouse waste (generally cattle), dried powdered blood contains approximately 12% N and rapidly mineralizes to plant-available forms. It is completely soluble and suitable for distribution through irrigation systems.

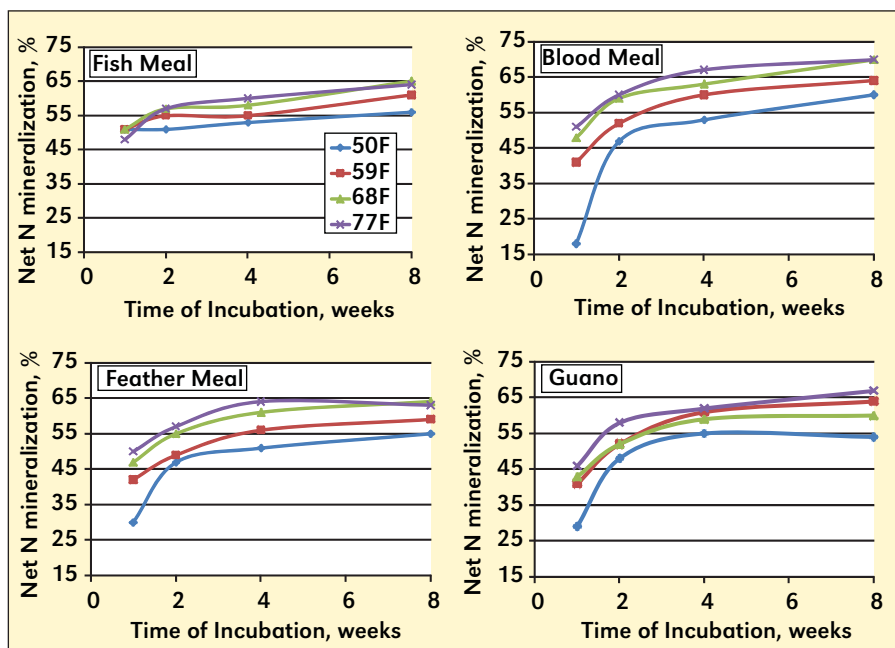
**Guano:** Seabird guano (8 to 12% N) is derived from natural deposits of excrement and remains of birds living along extremely arid sea coasts. Guano was historically a very important N source before industrial processes for making fertilizer were developed. Many of the major guano deposits are now exhausted. Guano is also harvested from caves where large bat populations roost. It can be applied directly to soil or dissolved in water to make a liquid fertilizer.



**Bat** guano.

**Feather Meal:** Feather meal (14 to 16% N), a by-





**Figure 4.** Nitrogen mineralization of four common organic N fertilizers at four soil temperatures. Mineralization of N expressed as percent of added organic N. Source Hartz and Johnstone, 2006.

product of the poultry industry, contains as much as 70 to 90% protein. It is mostly present as non-soluble keratin stabilized by highly resistant disulfide bonds. When treated with pressurized steam and animal-derived enzymes, the feather-based protein becomes a good source of available N for crop nutrition. Much of the feather N is not initially soluble, but it mineralizes relatively quickly under conditions favorable for plant growth. Pelletizing the feather meal makes handling and application more convenient. Unprocessed feathers usually have a delayed N release, but can also be an excellent N source if the difficulty in uniformly applying low density feathers to the soil can be overcome.

**Fish Meal and Fish Emulsion:** Non-edible fish (such as menhaden) are cooked and pressed to separate the solid and liquid fractions. The solids are used as fish meal (10 to 14% N) for fertilizer and animal feed. The valuable fish oil is removed from the liquid fraction and the remaining solution is thickened into fish emulsion (2 to 5% N). Additional processing is often performed to prevent premature decomposition. The odor from fish meal products may be unpleasant in a closed environment such as a greenhouse. Mineralization of fish-based products is generally rapid. Fish products that are fortified with urea to boost the N concentration are not allowed for organic production.

These high-N animal byproducts have relatively rapid N mineralization. At typical summer soil temperatures, more than half of the organic N may mineralize within 2 weeks of application (Figure 4).

### Seaweed Fertilizers

Seaweed-based products are typically derived from kelp species (*Ascophyllum*). Dried kelp contains approximately 1% N and 2% K, with small amounts of other plant nutrients. Due to their low nutritive content, kelp products are generally used in high-value cropping situations where economics

may be favorable, or for reasons other than plant nutrition.


### Sodium Nitrate

Sodium nitrate ( $\text{NaNO}_3$ , 16% N) is mined from naturally occurring deposits in Chile and Peru, the location of the driest desert on earth where  $\text{NO}_3^-$  salts accumulate over time. Sodium nitrate is generally granulated and readily soluble when added to soil. The intended use of  $\text{NaNO}_3$  in organic agriculture is typically to meet the N demand during critical plant growth stages and not to meet the entire nutritional need of the crop. In the U.S.A., the use of  $\text{NaNO}_3$  is limited to no more than 20% of the crop N requirement. In some countries, the use of  $\text{NaNO}_3$  is restricted.

### Summing Up

Choosing the “best” source of N for organic crop production is difficult since nutrient ratios, PAN, mineralization rates, local access, ease of application, and cost all need to be considered. Computer-based

tools are available to help with these choices. For example, Oregon State University has an “Organic Fertilizer Calculator” program that allows comparison of various materials to best meet the fertility needs of a soil. Similar programs are also available elsewhere.

Each organic N source has unique characteristics that require special management to gain the most benefit for plant health and economic production, while minimizing undesirable environmental losses. Commercial organic sources tend to be more costly to purchase than inorganic N sources, but many local or on-farm N sources may also be available. Some locally available N sources may contain low concentrations of N, requiring transportation and handling of large volumes of material. Cover crops are useful, but may be problematic to fit into a specific cropping system, depending on the length of growing season and rotational practices. As our understanding of soil N and organic matter improves, better N management will benefit all crop producers and the environment. 

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### Sources for Further Information

- Andrews, N. and J. Foster. 2007. Oregon State Univ. EM 8936-E. <http://smallfarms.oregonstate.edu/organic-fertilizer-calculator>
- Baldwin, K.R. and J.T. Greenfield. 2006. [http://www.cefs.ncsu.edu/PDFs/Organic Production - Composting.pdf](http://www.cefs.ncsu.edu/PDFs/Organic%20Production%20-%20Composting.pdf)
- Gaskell, M. and R. Smith. 2007. Hort Technology 17:431-441.
- Hartz, T.K. and P.R. Johnstone. 2006. Hort Technology 16:39-42.
- Sullivan, D.M. 2008. Oregon State University EM-8954E. <http://extension.oregonstate.edu/catalog/pdf/em/em8954-e.pdf>
- Van Kessel, J.S., and J.B. Reeves III. 2002. Biol. Fertil. Soils. 36:118-123.
- Various authors. <http://www.soil.ncsu.edu/about/publications.php#AnimalWaste>

For additional references, visit: [www.ipni.net/organic/references](http://www.ipni.net/organic/references).