Understanding and Managing N-P-K for Organic Crop Production

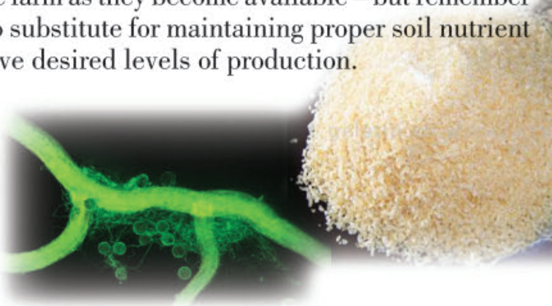
A Series of Three Articles with Practical Information

Reprinted from *Better Crops with Plant Food Magazine*
International Plant Nutrition Institute (IPNI)

There can be many reasons for a grower to select organic or unprocessed nutrient sources for crop production. Some growers use locally available resources for economic reasons. Others may be producing crops that will be certified for the organic market.

Crop nutritional needs can be met with a variety of organic materials, but their behavior is often more difficult to predict than more commonly used fertilizers. Most organic nutrient sources depend on biological or chemical processes for breakdown and nutrient release. These processes are governed by complex interactions of environment, soil, and management practices. Many organic materials are used primarily to provide a single plant nutrient, while other materials contain a wide variety of essential nutrients. Some organic sources do not contain nutrients in the ratios required by plants, so caution should be used to avoid undesirable accumulation in the soil.

The selection of specific nutrient sources should be based on cost, availability, plant nutritional needs, and the approval of certifying agencies. Remember that the fundamental principles of plant nutrition, soil biology, and crop growth remain the same regardless of the nutrient source. There is value in testing new products on the farm as they become available – but remember that there is no substitute for maintaining proper soil nutrient levels to achieve desired levels of production.



The three articles included here are reprinted from recent issues of *Better Crops with Plant Food* magazine. They briefly cover the behavior of some of the commonly used sources of nitrogen, phosphorus, and potassium for organic crop production. There are comprehensive lists of scientific references available at the IPNI website with more information regarding each nutrient: >www.ipni.net/organic/references<.

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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/reference<**.

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.

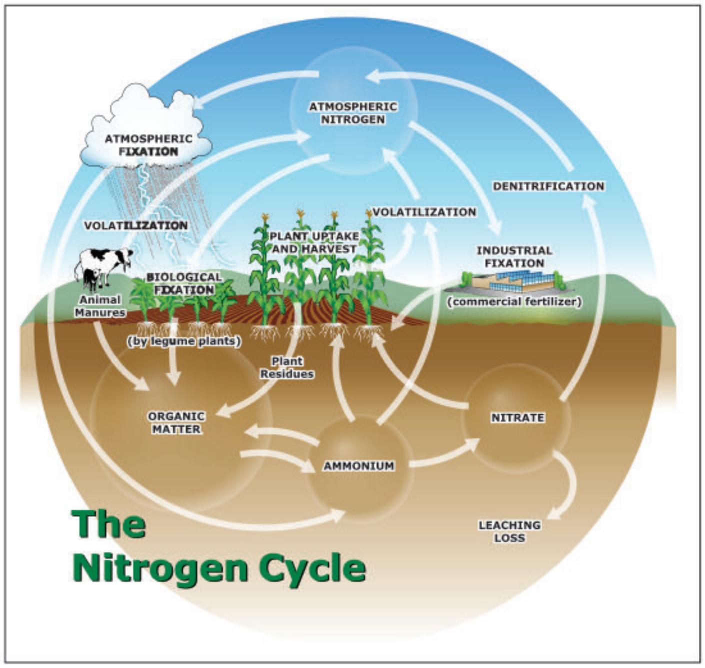

Figure 1. Where does the added N go? Organic N is converted to various inorganic N forms prior to plant uptake. Careful management reduces unwanted N loss to the environment.

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.

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**.

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

Manure type	Soil incorporated	Surface applied: Broadcast	Surface applied: 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 (C:N of 15:1 to 20:1)	0.05	0.03	
Compost (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
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.

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.

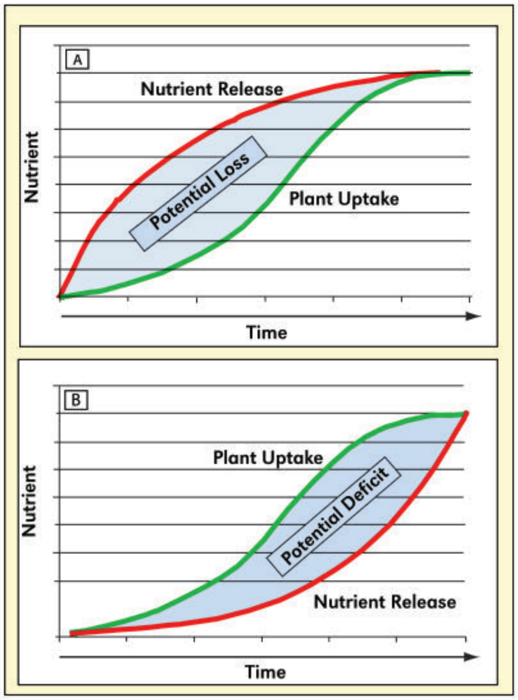

Figure 2. Synchronizing nutrient release with plant demand is a challenge with organic materials. Rapid release from organic sources with a low C:N ratio may supply nutrients more rapidly than the plant's demand (A). An organic material with a high C:N ratio may not release nutrients sufficiently rapid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

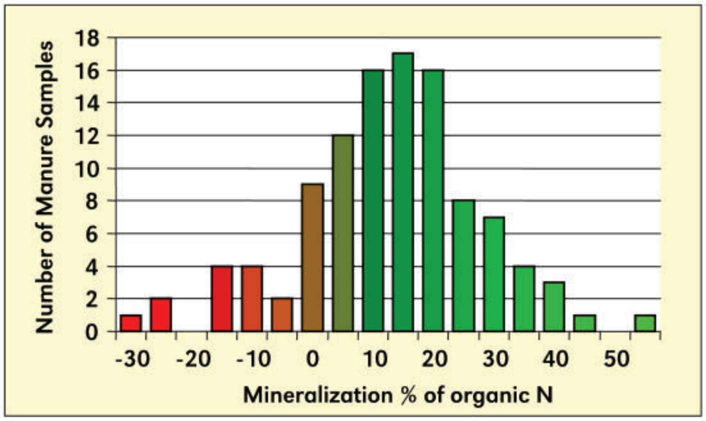

Figure 3. Nitrogen mineralization from 107 individual dairy manure samples after 8 weeks of incubation. On average, 13% of the organic N was mineralized, but 19 samples had net immobilization. Net N mineralization from the remaining 88 samples ranged from zero to 55%. (from Van Kessel and Reeves, 2002).

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 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 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-

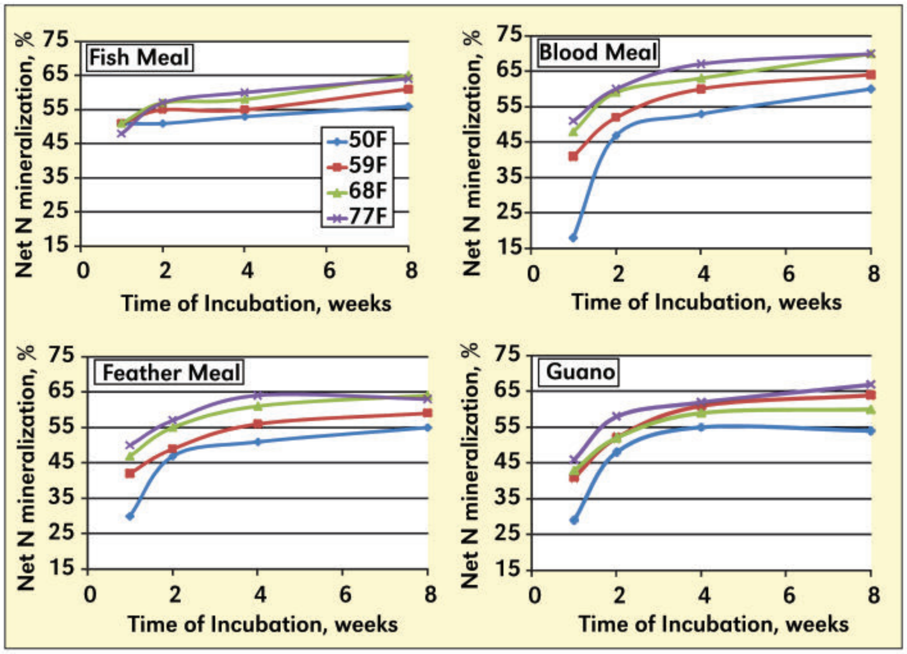

Figure 4. Nitrogen mineralization of four common organic N fertilizers at four soil temperatures. Mineralization of N expressed as percent of added organic N. Source Hartz and Johnstone, 2006.

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 ($NaNO_3$, 16% N) is mined from naturally occurring deposits in Chile and Peru, the location of the driest desert on earth where NO_3^- salts accumulate over time. Sodium nitrate is generally granulated and readily soluble when added to soil. The intended use of $NaNO_3$ 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 $NaNO_3$ is limited to no more than 20% of the crop N requirement. In some countries, the use of $NaNO_3$ 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. BC

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NORTH AMERICA

Managing Potassium for Organic Crop Production

By Robert Mikkelsen

An adequate K supply is essential for both organic and conventional crop production. Potassium is involved in many plant physiological reactions, including osmoregulation, protein synthesis, enzyme activation, and photosynthate translocation. The K balance on many farms is negative, where more K is removed in harvested crops than is returned again to the soil. An overview of commonly used K fertilizers for organic production is provided.

Potassium is an essential nutrient for plant growth, but it often receives less attention than N and P in many crop production systems. Many regions of the U.S.A. and all of the Canadian provinces remove more K during harvest than is returned to the soil in fertilizer and manure (**Figure 1**). In the U.S.A., an average of only 3 units of K is replaced as fertilizer and manure for every 4 units of K removed in crops, resulting in a depletion of nutrients from the soil and increasing occurrences of deficiency in many places.

Potassium is the soil cation required in the largest amount by plants, regardless of nutrient management philosophy. Large amounts of K are required to maintain plant health and vigor. Some specific roles of K in the plant include osmoregulation, internal cation/anion balance, enzyme activation, proper water relations, photosynthate translocation, and protein synthesis. Tolerance of external stress, such as frost, drought, heat, and high light intensity is enhanced with proper K nutrition. Stresses from disease and insect damage are also reduced with an adequate supply of K. Although there are no known harmful effects of K to the environment or to human health, the consequences of inadequate K can be severe for crop growth and efficient utilization of other nutrients, such as N and P. Maintenance of adequate K is essential for both organic and conventional crop production. More information and an extensive list of references are available at the website: **>www.ipni.net/organic/kreference<**.

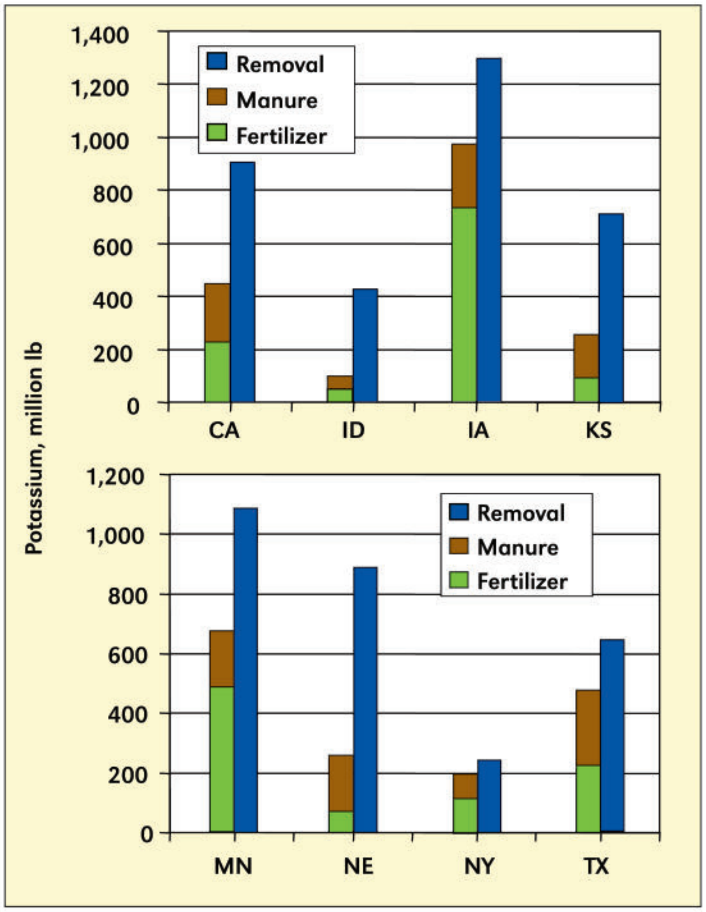

Figure 1. Annual balance of K inputs in fertilizer and recoverable manure compared with K removal in harvested crops in eight selected states: California (CA); Idaho (ID); Iowa (IA); Kansas (KS); Minnesota (MN); Nebraska (NE); New York (NY); Texas (TX).

Abbreviations and notes for this article: K = potassium; N = nitrogen; P = phosphorus; Mg = magnesium; S = sulfur.

Hay and forage crops can remove hundreds of pounds of K from the soil each year, placing a heavy demand on soil resources.

Supplemental K is sometimes called "potash", a term that comes from an early production technique where K was leached from wood ashes and concentrated by evaporating the leachate in large iron pots. Clearly this practice is no longer practical and is not environmentally sustainable. This potash collection method depended on the tree roots to acquire soil K, which was then recovered after the wood was harvested and burned. Most K fertilizer, whether used in organic or conventional agriculture, comes from ancient marine salts, deposited as inland seas evaporated. This natural geological process is still visible in places such as the Great Salt Lake and the Dead Sea.

Organic Crop Production

The basic principles of plant nutrition are the same, whatever the production system used. Both organic and conventional production systems have many common objectives and generally work with the same basic global resources. While specific nutrient management techniques and options may vary between the two systems, the fundamental processes supporting soil fertility and plant nutrition do not change.

In general, the objectives of organic plant nutrition are to (i) work within natural systems and cycles, (ii) maintain or increase long-term soil fertility, (iii) use renewable resources as much as possible, and (iv) produce food that is safe, wholesome, and nutritious.

Which Organic Standards to Follow?

The use of approved nutrient sources is governed by a variety of regional, national, and international oversight organizations. Each organization maintains somewhat different standards and allows different materials to be used in their organic production systems as they individually interpret the intent of organic agricultural principles. As a result, a grower seeking advice on permissible organic materials should first know where the agricultural produce will be sold in order to meet the requirements of that market.

In general, regulations for mined K sources specify that they must not be processed, purified, or altered from their original form. However, there is disagreement between different certifying bodies over what specific materials can be used. Unfortunately, some of these restrictions on certain nutrient materials do not have solid scientific justification and their inclusion or exclusion on various lists should not be viewed as one material being more or less “safe” than another fertilizer material.

Using On-Farm Resources

There are many variations possible for successful K management in organic production systems. The largest differences occur on farms that produce both livestock and crops compared with farms that strictly produce crops for off-farm sale. In the mixed livestock/crop systems, the nutrition of the animals generally takes first priority and the residual manure is returned to surrounding cropland. In these cases, imported K in feed and bedding frequently exceeds the output in milk and meat products, sometimes leading to an accumulation of K in the surrounding fields that receive manure. Large losses of K may occur on these farms during manure storage and composting. Since excreted K mostly goes into urine, if this fraction is not effectively recovered it will not be returned to the field with the solid portion of the manure.

Crop rotations are a central part of organic production systems. While this practice can be helpful for supplying N when legume crops are included and may also reduce K leaching losses, rotations alone do not supply any additional K to the farm. Plant roots have been shown to enhance soil mineral weathering by depleting rhizosphere K and causing a shift in the K equilibrium. This shift can speed natural processes and enhance the rate of clay transformations. Subsoil K reserves may be important for some crop rotation systems where deep-rooted plants can extract K which may be subsequently used by shallow-rooted crops. While rotational crops may influence the availability of existing soil K, the removal of any plant material from the field continually depletes the soil nutrient supply and ultimately reduces long-term productivity.

Table 1. Average K removal in the harvested portion of some common agronomic and horticultural crops (International Plant Nutrition Institute, 2007; Natural Resources Conservation Service, 2007).

Crop	Scientific name	K removal, lb K/ton
Alfalfa	*Medicago sativa*	45
Almond	*Prunus dulcis*	100
Corn grain	*Zea mays*	8
Corn silage	*Zea mays*	7
Potatoes	*Solanum tuberosum*	10
Spinach	*Spinacia oleracea*	11
Squash	*Cucurbita pepo*	10
Rice	*Oryza sativa*	8
Tomatoes	*Lycopersicon esculentum*	6
Wheat	*Triticum aestivum*	10

Moisture is based on marketing conventions.

Plant-available K is usually measured in the topsoil, but some deep-rooted plant species can take up considerable amounts of K from the subsoil. The contribution of subsoil K to the plant K requirement depends on the amount of plant-available K in the top and subsoil, potential root-limiting factors, and the root distribution pattern of the specific crop. Soil testing done near the soil surface will not account for this subsoil contribution to the K supply.

Potassium Balance

Since off-farm sales will always lead to a removal of K and additional loss of K through leaching and runoff is inevitable, the potential of a cropping management system to replenish the K reserve is important. The use of farm budgets is useful for describing the nutrient flow within a farming system and to assist with nutrient planning for long-term rotations and mixed farming systems. Depending on a variety of factors, the on-farm budgets of N, P, and K on organic farms have been shown to range from a surplus to a deficit.

The demand for K by various crops has been well established by measuring the K concentration in the harvested portion of the crop (**Table 1**). However, much less attention has been paid to the rate at which K must be supplied to

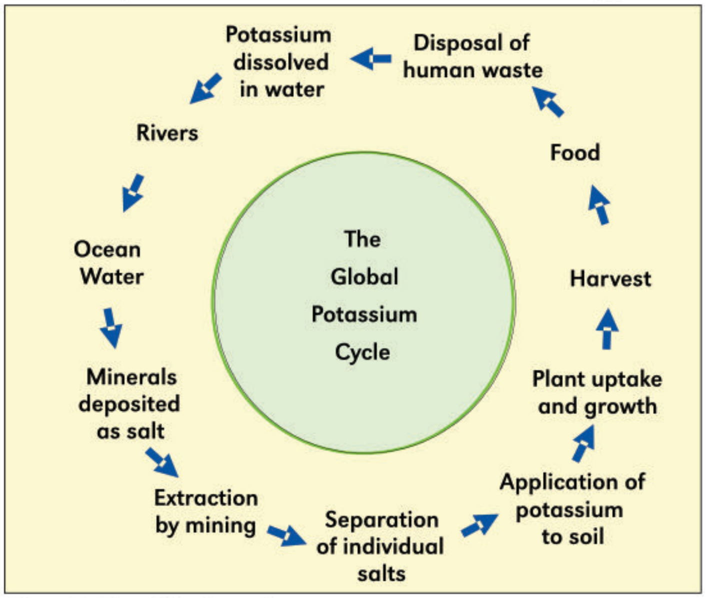

Figure 2. The global K cycle.

plants. Both the total amount required (quantity) and the rate of supply (intensity) are equally important. This concept is important for all crop growth, but requires special attention when using low-solubility nutrient sources that may provide an adequate amount of total K, but not at a rate sufficiently rapid to meet peak-demand periods of plant growth.

Potassium Release from Soil Minerals

The most common mineral sources of K in soils are feldspars and micas...soil minerals remaining from the primary parent material. Weathering of these primary minerals produces a range of secondary minerals that may also serve as a source of K in soil. These minerals include micaceous clays such as illite and vermiculite.

Crushed rocks and minerals have been evaluated as K sources in many field and greenhouse experiments. In general, plants are able to gain a very limited amount of K from minerals applied as biotite, phlogopite, muscovite, and nepheline. Feldspar K is not plant available without additional treatment or weathering.

The rate of K release from minerals is influenced by factors such as soil pH, temperature, moisture, microbial activity, the reactive surface area, and the type of vegetation. Therefore, a mineral that is somewhat effective as a K source in one condition may be ineffective in another environment.

Some soil minerals may act as a sink for removing K from solution. When K is adsorbed in the interlayer sites of illite, vermiculite and other smectite clays, the clay layers collapse and trap the K within the mineral lattice. This fixation process is relatively fast, while the release of this interlayer K is very slow. Non-exchangeable K should not be confused with mineral K, since non-exchangeable K is held between adjacent tetrahedral layers of clay, instead of being covalently bonded in mineral crystal structures.

Potassium Sources for Organic Production

Regular applications of soluble K, regardless of the source, will increase the concentration of K in the soil solution and the proportion of K on the cation exchange sites. All of the commonly used soluble K sources (including manures, composts, and green manures) contain this nutrient in the simple cationic K^+ form. Most soluble inorganic fertilizers and organic manures are virtually interchangeable as sources of K for plant nutrition. When using readily available forms of K, the overall goal of replacing the harvested K is generally more important than minor differences in the behavior of the K source. Any differences in plant performance are usually due to the accompanying anions, such as chloride (Cl^-) or sulfate (SO_4^{2-}) or the organic matter that may accompany the added K.

There is no general evidence that potassium sulfate (K_2SO_4) is more effective than potassium chloride (KCl) as a source of plant-available K, and both SO_4^{2-} and Cl^- provide essential nutrients that are required for plant health. Chloride is sometimes disparaged as being harmful to soil, but there is no evidence for this claim at typical rates of application. It has a well-documented role in improving plant health and prevention of a variety of plant diseases. Chloride-derived salinity was the same as sulfate-based salinity on its effect on common soil microbes (e.g. Li et al., 2006) and the addition of K decreased the harmful effects of salinity on soil microbial activity (Okur et al., 2002).

Organic production frequently occurs on smaller-sized farms where the use of organically approved K sources is feasible for maintaining soil fertility.

Approved and Restricted Potassium Sources

The National Organic Program in the U.S. and the Canadian General Standards Board classifies products as either allowed, restricted, or prohibited for use in organic production. Allowed products are permitted for organic production when applied as directed on the label. Restricted materials can only be applied for certain uses and under specific conditions. Prohibited products may never be used for organic production. The properties and value of these materials as sources of plant nutrients vary considerably. The following K sources are used sometimes for organic production.

Greensand has a very slow K release rate, which limits its nutritional benefit.

Greensand Greensand is the name commonly applied to a sandy rock or sediment containing a high percentage of the green mineral glauconite. Because of its K content (up to 5% K), greensand has been marketed for over 100 years as a natural fertilizer and soil conditioner. The very slow K release rate of greensand is touted to minimize the possibility of plant damage by fertilizer "burn", while the mineral's moisture retention may aid soil conditioning. However, the K release rate is too slow to provide any significant nutritional benefit to plants at realistic application rates. Soluble K is generally <0.1% of the total K present. Deposits of greensand are found in several states (including Arkansas and Texas), but the only active greensand mine in North America is located in New Jersey.

Langbeinite is available from several sources. It is allowed as an organic nutrient source if used in the raw, crushed form without further refinement.

Langbeinite (Potassium-magnesium sulfate) This material ($K_2SO_4 \cdot MgSO_4$) is allowed as a nutrient source if it is used in the raw, crushed form without any further refinement or purification. Several excellent sources of this approved product are available for use with organic crop production. Langbeinite typically contains 18% K, 11% Mg, and 22% S in forms readily available for plant uptake. The major source of langbeinite in North America is from underground deposits in New Mexico.

Manure and Compost Since these organic materials are extremely variable (based on their raw materials and their handling), they also contain highly variable K concentrations. Composted organic matter is generally allowed as a nutrient source. Raw manures have restrictions on the timing of their use, but the details depend on the certifying agency. The K in these organic materials is largely available for plant uptake, similar to approved inorganic sources. Repeated applications of large amounts of manure can result in K accumulation in the soil, which may lead to luxury consumption of K by the plant. A chemical analysis of the manure or compost composition is necessary in order to use these resources for maximum benefit. It may be helpful to consider where the compost or manure K is coming from, since neither composting nor animal digestion produces any nutrients.

Potassium Sulfate When K_2SO_4 is derived from natural sources, it is allowed for organic crop production. Much of the current production of organically approved K_2SO_4 in North America comes from the Great Salt Lake in Utah. It may not undergo further processing or purification after mining or evaporation, other than crushing and sieving. This product is not allowed in some European countries without special permission from the certifying agency. It generally contains approximately 40% K and 17% S.

Rock Powders Mined rocks, including ballast, biotite, mica, feldspars, granite and greensand are allowed without restriction. Tremendous variability exists in the K release rate from these mineral sources. Some of them are wholly unsuitable as K sources for plant nutrition due to their limited solubility and their heavy and bulky nature, while others may have value over long periods of time. In general, a smaller particle size translates to a greater surface area, reactivity, and weathering rate. Obtain information for specific rock materials before using.

Seaweed Since sea water contains an average of 0.4 g K/L, seaweed may accumulate up to several percent K. When harvested, seaweed biomass can be used directly as a K source or the soluble K may be extracted. These K sources are readily soluble and typically contain less that 2% K. While seaweed-derived products are excellent K sources, their low K content and high transportation costs can make it problematic for field-scale use, especially far from the harvesting area.

Production of high quality crops is sustained with attention to proper soil nutrition.

Sylvinite (Potassium Chloride) KCl is restricted in the USDA standards unless it is from a mined source (such as sylvinite) and undergoes no further processing. It must be applied in a manner that minimizes Cl accumulation in the soil. Generally, KCl should only be used after consultation with the certifying agency. The Canadian GSB has included KCl on the "Permitted Substances List" for organic food production systems. Unprocessed sylvinite often contains approximately 17% K.

Wood Ash Ash from hardwood trees served as one of the earliest sources of K for building soil fertility. This highly variable material is composed of the elements initially present in the wood which were not volatilized when burned. Wood ash is an alkaline material, with a pH ranging from 9 to 13, and has a liming effect of between 8 and 90% of the total neutralizing value of commercial limestone. In terms of commercial fertilizer, average wood ash would have an analysis of approximately 0% N, 1% P, and 4% K. The use of ash derived from manures, biosolids, coal, and some substances is prohibited for organic production. Check with the certifying organization prior to applying ash to soil.

Conclusions

Growers using organic production practices, like all growers, have need for an adequate supply of soil K to sustain healthy and high-yielding crops. There are many excellent sources of K that are available for replacing the nutrients removed from the soil in harvested crops. Failure to maintain adequate K in the rootzone will result in poor water use efficiency, greater pest problems, decreased harvest quality, and reduced yields. Regular soil testing for K is the key for establishing the requirement for fertilization. If a need for supplemental K exists, organic producers generally should first consider locally available K resources and supplement with mineral sources. The expense of transporting and applying low nutrient content amendments must also be considered.

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For more information and a list of references, visit the website at **>www.ipni.net/organic/kreferences<.**

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Meeting the Phosphorus Requirement on Organic Farms

By Nathan Nelson and Robert Mikkelsen

Phosphorus management can be difficult in organic production since approved sources are limited and the consequences of under- or over-fertilization can be significant. Since P is an essential element for plant growth involved in many critical plant metabolic functions, sustainable agricultural production depends on an adequate P supply.

Nutrient management in organic production systems focuses on maintaining agricultural productivity with inputs of on-farm or minimally processed materials. Nutrient inputs for organic production are typically focused on carbon-based nutrient sources (e.g., crop residue, compost, manure) and nonprocessed mineral sources (e.g., rock phosphate, lime, and gypsum).

In most agricultural systems…both organic and conventional…complete nutrient cycling does not occur (**Figure 1**). The nutrient reservoir in the soil shrinks when crops are removed from the field at harvest. This nutrient export creates a P deficit, necessitating regular P additions to replace the harvested P. Several studies investigating whole-farm P budgets have found nutrient P deficits in many organic farms and illustrate the need for nutrient additions. Because P is an essential nutrient for plant growth, all sustainable systems should at a minimum seek to replace the P removed in harvested crops in order to avoid declines in yield and quality. Although organic agriculture seeks to minimize off-farm inputs, it is essential that producers replace P removed in harvested crops.

A brief review of the most commonly used P sources for organic production is presented here. More information and an extensive list of references are available at the website: **>www.ipni.net/organic/references<** .

Soil Organic Matter

Soil organic matter can be an important source of P for crops. Some studies have shown that soil organic matter increases on organically managed farms, while other long-term studies do not show such a buildup. These differences largely depend on management practices such as tillage intensity, heavy manure additions, return of crop residues, the extent of cover cropping, and climatic factors. Soil organic matter serves as a reservoir of plant nutrients, but may also improve the soil physical conditions and root environment.

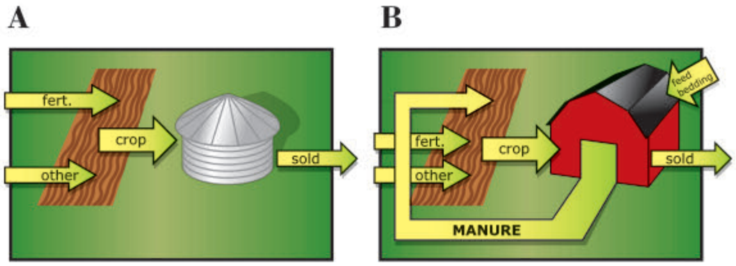

Figure 1. Nutrient inputs are required to maintain soil fertility on farms where crops are harvested and sold (A). On farms where crops and animals are both grown (B), nutrient management is more complex, but replacing harvested nutrients is still essential.

Soil organic matter contains a variety of organic P compounds, such as inositol phosphate, nucleic acid, and phospholipid (**Figure 2**). These compounds must be first converted to inorganic phosphate by soil enzymes before being used for plant growth. These phosphatase enzymes are produced by soil microorganisms, mycorrhizal fungi, or excreted by the plant root. Some organic P compounds are stable for many years in the soil, while others are converted to inorganic P within a few days or weeks.

Cover Crops

Cover crops are frequently grown in rotation with cash crops for a variety of beneficial purposes. The advantage of cover crops for P nutrition involves the accumulation of soil P by the cover crop. This P is subsequently released when the cover crop is killed. Numerous studies have shown that some cover crops can provide a P nutritional benefit for the next crop compared to crops grown without a preceding cover crop. This is attributed to the ability of some species to draw down soil P concentrations below what some cash crops can and also to their extensive root system. This P drawdown may also be the result of root exudates and the efficient P uptake by the cover crop roots. Some cover crops can be excellent hosts for mycorrhizal fungi, which may allow a greater exploitation of the soil P reserves.

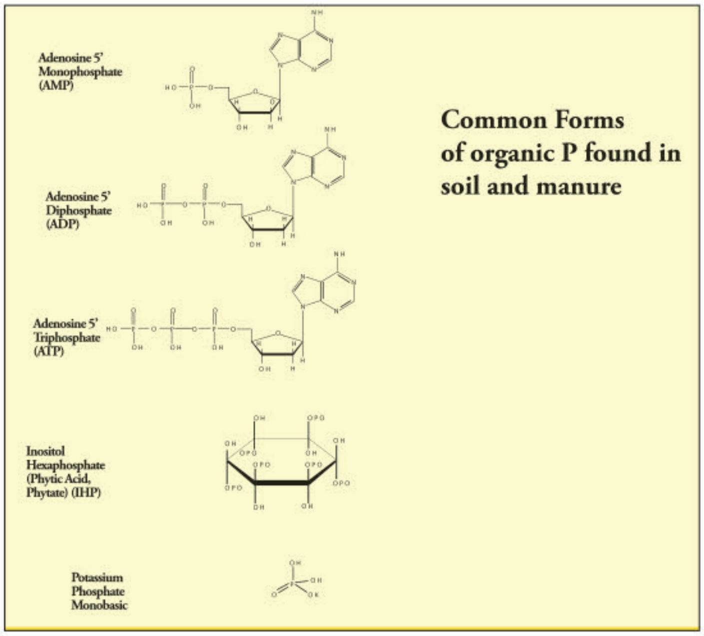

Figure 2. Common forms of organic compounds found in soil and manure compared with inorganic phosphate.

Abbreviations and notes for this article: P = phosphorus; N = nitrogen; Ca = calcium.

Cover crops can improve soil properties, reduce erosion, and increase the nutrient supply to the following crop.

There are considerable differences in the ability of various cover crops to provide additional P for the subsequent crop. Research has generally shown a greater P benefit from legume cover crops than from grass cover crops, but the effects of cover crops on P nutrition can be highly variable. In many cases, supplemental P is still required after the cover crop to eliminate P deficiency. In some circumstances, P uptake by the cash crop following the cover crop is actually reduced due to low residual soil P caused by uptake by the cover crop and poorly synchronized P release.

Cover crops offer some P nutritional benefits in some circumstances. The variable results (positive and negative responses) are due to the complicated species, microbial, and environmental interactions that are not easy to predict. However, it must be remembered that cover crops do not provide any new P to the soil, but only allow the existing soil P reserve to be used more efficiently. With removal of P from the field in harvested products, the nutrient supply must be ultimately replaced with an additional supply to maintain sustainability.

Mycorrhizal Fungi

Enhanced P uptake is frequently cited as a primary benefit of mycorrhizal fungi colonization. In this symbiotic relationship, the plant root provides the energy (carbohydrate) for the fungi in exchange for improved nutrient uptake and other plant root benefits. Almost all crop plants form this relationship with mycorrhizal fungi, which is present in the root zone of most soils. **Figure 3** shows mycorrhizal association with roots.

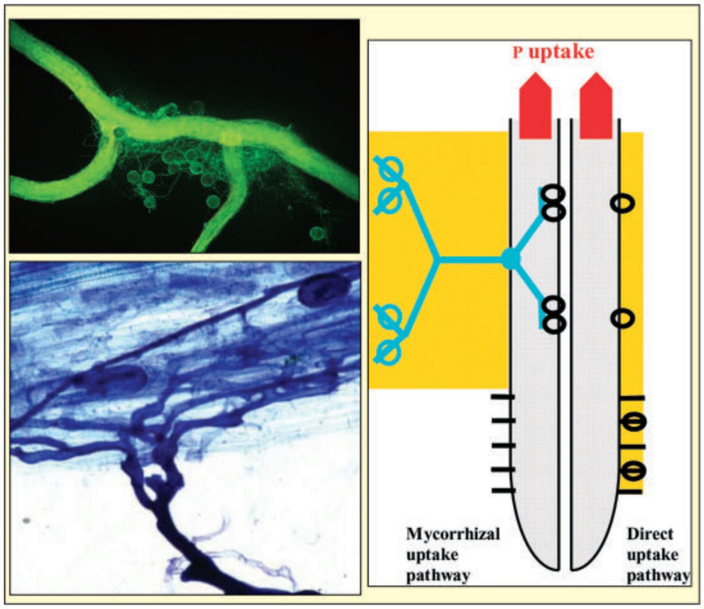

Figure 3. Mycorrhizal fungi play an important role in providing P for 80% of global plant species. Hyphal strands of fungi extend from 1 to 15 cm into the soil, scavenging the soil for immobile nutrients such as P.

Many organic growers encourage the associations of mycorrhizal fungi with crop roots through the use of cover crops and rotations. However, frequent tillage commonly used for weed control causes a disruption of the soil fungal network and may reduce its effectiveness for providing nutrients to the plant.

The value of mycorrhizal fungi for supplying P for crops is most apparent in low-P soils. In most cases, plants growing in soils with medium to high concentrations of P have less mycorrhizal association than plants in low-P conditions. Therefore, the value of mycorrhizal fungi is greatest in soils without an adequate supply of P. Similar to cover crops, mycorrhizal fungi do not provide any additional P to the soil, but can allow better utilization of the existing soil resource. Commercial sources of mycorrhizal fungi are available and may be used in specialized conditions.

Rock Phosphate

Rock phosphate.

Rock phosphate (apatite) is a general term used to describe a variety of globally distributed P-rich minerals. Of the two main types (sedimentary or igneous), sedimentary rock deposits are the source of over 80% of the total world production of phosphate rock. Depending on its geologic origin, rock phosphate has widely varying mineralogy, texture, and chemical properties. Some rock P is found in hard-rock deposits, while other rock P is found as soft colloidal (soil-like) material. This great variation in properties and the accompanying elements present in the rock (such as carbonate and fluoride) has a large effect on its value as a source of plant nutrient. This range in properties makes some rock P sources excellent nutrient sources and other sources quite unsuitable. Unfortunately, the information on P availability from a specific rock source is not generally available to the consumer.

The general reaction of rock P dissolution added to soils to a plant available form is:

Equation 1: $Ca_5(PO_4)_3F + 6H^+ \leftrightarrow 5Ca^{2+} + 3H_2PO_4^- + F^-$

Note the importance of acidity (H^+) and low Ca^{2+} in this reaction.

It is difficult to make universally applicable recommendations for rock P application because so many factors affect its dissolution and plant availability. However, the key factors to consider include:

- Soil pH is important in the dissolution of the rock P (Equation 1). Rock P is much more soluble in acidic soils (soil pH <5.5). In neutral pH to alkaline soils, rock P typically provides little benefit for plant nutrition, except under special conditions.
- Particle size influences the dissolution of rock P by controlling the surface area available for reaction. However, fine grinding a low-reactivity phosphate rock will not significantly increase P availability due to its insoluble mineralogical structure. Conversely, it may not be necessary to finely grind highly reactive rocks used for direct application to the soil. Many rock P sources are commonly ground to <100 mesh (0.15 mm) to improve reactivity, but such finely ground material may be difficult to handle and to spread uniformly.
- Low soil Ca concentrations and high soil cation exchange capacity favor rock P dissolution since Ca is one of the reaction products resulting from dissolution. Soil conditions that limit Ca availability (soil acidity, high leaching, or the presence of organic compounds that complex exchangeable Ca) also tend to favor rock P dissolution and the release of P for the plant.
- Other cultural practices that may improve P availability from rock P include broadcast applications to maximize soil dissolution reactions, and using management that promotes root colonization by mycorrhizal fungi. Application of rock P should be made several weeks or months prior to the anticipated need for plant nutrients. Although lime applications are important for reducing harmful effects associated with soil acidity, lime additions tend to reduce the value of rock P as a nutrient source.

Manure and Composts

These materials are generally excellent sources of P for plants. Even though these materials are considered as organic products, over 75% of the total P they contain is present as inorganic compounds. It is commonly recommended that the P in manure and compost be considered as 70% available for soils with low soil-test P, but 100% available for soils testing adequate or high for P.

The ratio of nutrients in composts and manures does not closely match that required by plants nor in the harvested products. When manure and compost are used as a primary N source for crops, P is typically overapplied by 3 to 5 times compared with the crop removal rate. Long-term use of manures and compost as the primary N source leads to an accumulation of P in the soil that can become an environmental concern for surface water quality.

Ground bone meal

Bone Meal

Bone meal, prepared by grinding animal bones, is one of the earliest P sources used in agriculture. Most commercially available bone meal is "steamed" to remove any raw animal tissue. The primary P mineral in bone material is "calcium-deficient hydroxyapatite" [Ca_{10}–x(HPO_4)x(PO_4)6–x $(OH)_2$–x ($0 < x < 1$)], which is more soluble than rock phosphate, but much less soluble than conventional P fertilizers. Calcium-deficient hydroxyapatite present in bone meal dissolves:

Equation 2: $Ca_{9.5}(HPO_4)_{0.5}(PO_4)_{5.5}(OH)_{1.5} + 13H^+ \leftrightarrow 9.5Ca^{2+} + 6H_2PO_4^- + 1.5H_2O$

Similar to rock P, bone meal is most effective in acidic soils and when the particle size is small. When used properly, it can be an effective P source. One of the first commercial P fertilizers was produced by reacting animal bones with sulfuric acid to enhance the solubility of P.

Concerns have been raised regarding bovine spongiform encephalopathy (BSE) in cattle and the residual effect of bone meal as a fertilizer. There are no restrictions on the use of bone meal and most commercial bone meal products have been heat treated, so the potential for prion transmission is small.

Guano

Guano is most commonly used as a source of N for plants, but some guano materials are also relatively enriched in P. Guano is mined from aged deposits of bird or bat excrement in low rainfall environments. The drying and aging process changes the chemistry of the P compared with fresh manure. Struvite (magnesium ammonium phosphate) can be a major P mineral found in guano, dissolving slowly in soil. The limited supply and high cost of guano generally restricts its use to small-scale applications.

Summary

There are several options available for meeting the P requirement for organic production. Growers are encouraged to first consider locally available materials to meet this need. Many of the allowed materials are fairly low in nutrient content, therefore transportation costs may be a concern since relatively large quantities of amendment may be needed to meet the crop demand. Regular soil and tissue testing should be conducted by all growers to avoid depletion of soil nutrients and to prevent inadvertent nutrient accumulation, regardless of production philosophy and management techniques.

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