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.

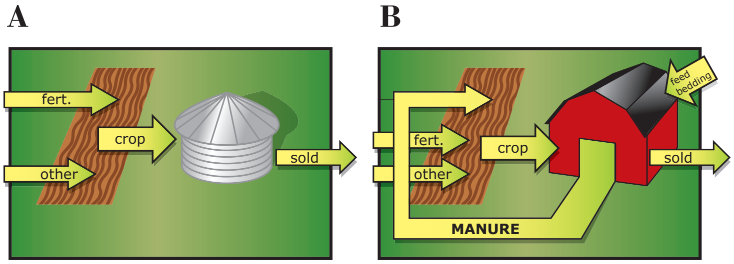

Figure 1. Nutrient inputs are required to maintain soil fertility on farms where crops are harvested and sold (A). On farms where crops and animals are both grown (B), nutrient management is more complex, but replacing harvested nutrients is still essential.

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.

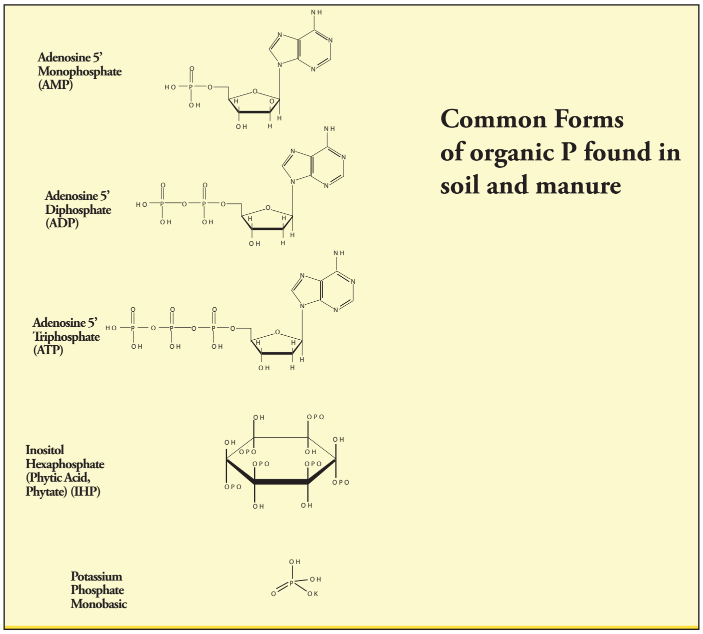

Figure 2. Common forms of organic compounds found in soil and manure compared with inorganic phosphate.

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

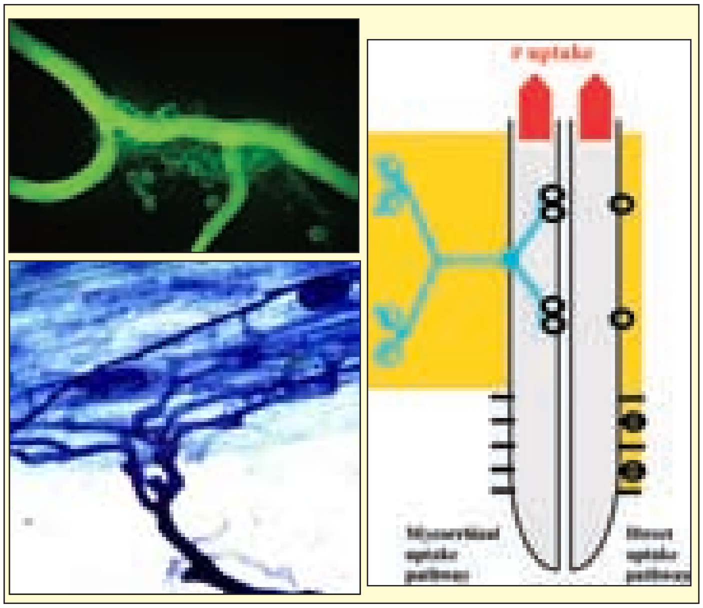

Figure 3. Mycorrhizal fungi play an important role in providing P for 80% of global plant species. Hyphal strands of fungi extend from 1 to 15 cm into the soil, scavenging the soil for immobile nutrients such as P.

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.

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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