Important Factors Affecting Crop Response to Phosphorus

Phosphorus responses are expected in crops growing on soils testing medium or lower in soil test P. Plant roots of annual crops typically explore less than one percent of the soil volume. This helps explain why many factors other than soil test level should be considered in P application decisions. Some are manageable, others are not. They include soil characteristics, crop grown, climate, tillage systems, interactions with other nutrients, crop management, and fertilizer management.

> Although soil test level is a major consideration, numerous other factors also affect crop response to phosphorus (P).

Soil Physical Factors

- **Soil texture.** Responses to fertilizer P at a certain P soil test level tend to be greater on sandy soils than on those containing more silt and clay. Diffusion, which occurs mainly through soil water films, is an important process in P movement toward roots and is slower in coarse-textured soils. Higher P soil tests or higher rates of fertilizer P are needed on such soils. Some soil components react readily with fertilizer P to lower its availability (P fixation). Fixation increases as soil clay content increases. This means that larger amounts of P must be applied to those soils in order to increase soil test values and P availability to plants. Highly weathered soils are likely to have this characteristic.
- **Soil aeration and compaction.** Phosphorus uptake by plant roots requires energy from carbohydrates. Generating that energy requires oxygen for normal root metabolism. If soils are compacted, pore space is diminished, oxygen is limited, and P absorption suffers. Compaction also limits P use by decreasing the thickness of water films on soil particles through which P moves to root surfaces. Increasing concentrations of soil P by adequate fertilization can help offset this effect.
- **Soil temperature.** Low soil temperatures depress P availability and plant uptake. Lower temperatures reduce the rate of mineralization of soil organic P because of lowered microbial activity. Low soil temperatures also reduce root growth rates and the rate of diffusion of P, causing a decrease in the amount of P accessed by roots. The metabolic release of energy, which drives P absorption mechanisms, is also slowed by low soil temperatures.

  Cold soils are often associated with large P responses, even at high test levels. Lower soil temperatures are associated with reduced tillage systems because of surface shading by residues. Studies have shown that reduced tillage corn and other crops frequently respond to starter P at high soil test levels, even when responses in other tillage systems are unlikely.
- **Soil moisture.** Moisture stress also reduces P availability and uptake. Greater crop response to P at a given level of soil P may be expected under moisture stress conditions. Low soil moisture has been found to decrease P availability to wheat more than added P fertilizer increased availability. The percentage of P in the crop from fertilizer has been reported highest when moisture availability was lowest. Field studies indicate larger corn and soybean incremental responses to P on a medium P testing soil under low rainfall conditions.

Soil Chemical Factors

- **Soil mineralogy.** Forms of mineral P in the soil are a result of the soil's parent material, weathering, and, to a lesser degree, P fertilization. Types of clay, amounts of iron (Fe) and aluminum (Al) oxides, and amounts and forms of calcium (Ca) affect a soil's ability to fix fertilizer P.
- **Soil organic matter.** Generally, higher soil organic matter levels are related to greater P availability. Studies have emphasized the importance of organic P in plant nutrition. Apparently a fairly constant portion of organic P is converted into inorganic forms which are taken up by plants. Gradual release of organic P provides a steady supply of P under conditions which would otherwise result in P fixation.
- **Soil pH.** Soil pH has an important role in P availability and affects the efficiency of applied P. Phosphorus fixation by Fe and Al oxides is greatest in acid soils, but declines as soils are limed. Availability in most soils is at a maximum in the pH range 6 to 7. As soil pH increases above 7, Ca and magnesium (Mg) react with P, and the availability again declines. Trying to lower the pH of calcareous soils to improve P availability is not practical. Placement of P near the seed or seedlings is much more feasible.
- **Interactions with other nutrients.** Crop responses to P are affected by the availability of other nutrients. Interactions of P with micronutrients, particularly zinc (Zn), usually involve lowered micronutrient availability and uptake when P availability is high. Deficiencies of other nutrients can limit crop response to P.

  Phosphorus fertilizer absorption and use efficiency by crops is improved by the presence of ammonium-nitrogen (NH_4-N) in the soil with the P. Ammonium-N absorption by roots lowers the pH in the vicinity of the root surface improving P uptake. High concentration of NH_4-N can also change the soil chemistry of P and delay normal fixation reactions.

Soil Biological Factors

Soil biological processes, in addition to mineralization of organic P, can influence availability and responses to applied P.

- **Effects of crop residues.** Incorporation of crop residues increases microbiological action and can result in immobilization of available P into microbial cells. The same process affects the availability of N, sulfur (S), and other nutrients. Immobilized P is gradually released for plant use as residues decompose. Soil aeration, temperature, soil moisture, pH, and supplies of other nutrients such as N have a direct effect on biological action, immobilization, and release of P.
- **Effects of plant roots.** Roots affect the biology of the soil by providing energy sources for microbes and influencing soil properties such as tilth, structure, and nutrient availability.
- **Effects of mycorrhizae.** Mycorrhizae (meaning "fungus-root") are a close association of plant roots and a fungus where both partners benefit. Plants grow better when colonized by the beneficial fungi, which act as extended root surfaces. Improved nutrient absorption, especially P, results from the plant-fungus association. Increasing the soil P concentration to the levels needed for high yielding crops may essentially eliminate mycorrhizae as a factor in overall plant growth. However, even with high P testing soils, mycorrhizae may be important in early season plant growth. Mycorrhizal infection may be severely reduced by fallow periods in crop production, which increases the importance of starter P fertilization for crops grown in a fallow rotation. Prolonged wetness and flooding can decrease the mycorrhizal inoculum levels to the point that increased P fertilization may be needed.

Crop Factors

Crop species, varieties, and hybrids vary in their abilities to absorb and respond to fertilizer P. Several factors are associated with those differences.

- **Root development and distribution.** Most available P is present in the surface soil and helps concentrate roots in that zone. However, if surface moisture is limiting, soil P becomes less useable and P use-efficiency declines. High levels of applied P can increase P movement into the subsoil and help overcome this problem, by allowing better root development in the subsoil and increasing the ability to extract water.

  Outstanding corn yields are often associated with deep distribution of nutrients, including P.

  Root length and density affect response to P since length is the major determinant of absorbing surface area.
- **Crop varieties and hybrids.** Crop varieties and hybrids differ in their requirements for P. Corn hybrid responses to P have differed by over 100 percent in dry matter production and by over 200 percent in terms of P uptake in some studies. Sizeable yield increases have been documented, even at high soil test P levels, with N- and P-containing starter fertilizers (**Figure 1**). In the future, specific recommendations for P fertilization of individual hybrids and varieties may be a part of intensive crop management.
- **Crop yield levels.** Some corn and soybean studies have indicated that the amount of P taken up by plants per bushel or per ton of grain yield does not vary substantially. Yield effects on P requirements are often estimated as essentially a straight line function. Increased yields with increased P fertilization can result in a higher grain P content and a greater P removal than what may be predicted with simple linear relationships from lower-yielding studies. Alfalfa, for example, tends to remove more P per ton of production as yields increase due to P fertilization.

Fertilizer Factors

Chemical and physical characteristics of P fertilizers may influence crop response and management decisions on P sources.

- **Water solubility.** Water solubility of P fertilizers is considered important in some countries, but there is little agreement on what percent of the total P should be water soluble. Available P is that soluble in ammonium citrate and includes the water-soluble fraction. Research in North America has shown that water solubility is important, but it is difficult to find data that indicate superiority of one P fertilizer source over another based on water solubility, provided water solubility is 60 percent or higher.
- **Chemical forms of phosphorus.** Studies of P fertilizer materials indicate that ammonium phosphates, superphosphates, and nitric phosphates are largely equal as P sources for plants. These classes of compounds have a high percentage of P availability. Although research has shown some advantages to the presence of NH_4-N with P in terms of plant P absorption, modern crop production practices frequently involve high concentrations of N in the soil which diminish differences among these classes of compounds.

Comparisons of monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium polyphosphate (APP), and urea-

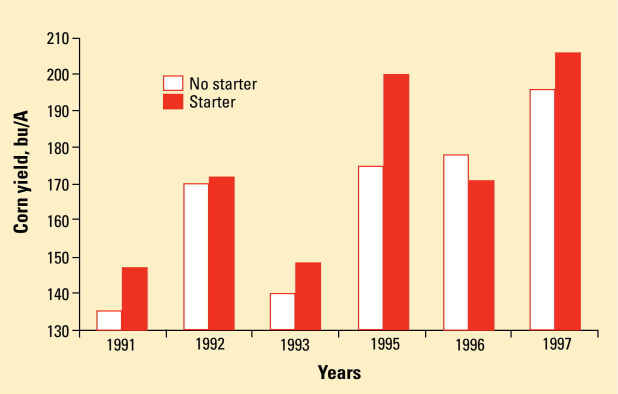

Figure 1. Corn response to in-furrow starter P fertilizer on a high P soil. (Mascagni and Boquet. Louisiana, 1998)

ammonium phosphate (UAP) show few consistent differences. At high rates, DAP can cause germination damage when placed in direct seed contact on alkaline soils, due to the release of some free ammonia. Limited rates of application control the problem. Formulations of UAP have an even greater probability of germination damage in direct seed contact due to ammonia release from urea hydrolysis. Application rates of UAP in seed contact should be lower than DAP. While APP provides some superior physical characteristics in liquid fertilizers, agronomic capabilities of MAP, DAP, APP, and UAP are essentially equal.

- **Physical form of phosphorus fertilizers.** Solid and fluid forms of P involve the same compounds mentioned earlier. Agronomic capabilities of solid and fluid P sources are essentially equal. Handling differences, adaptability to methods of application, and abilities to co-apply micronutrients as well as pesticides are valid management considerations when evaluating P fertilizers.
- **Phosphorus placement.** Placement can have tremendous effects on crop responses to applied P. For more information on placement, see the article beginning on page 34. BC

Crop Maturity... *(continued from page 15)*

TABLE 4. Balanced P and K increase proportion of cotton in first picking (Tennessee).

P_2O_5, lb/A	K_2O, lb/A 0	30	60
	% cotton in first picking		
0	65	71	74
40	77	77	77
80	78	78	78
120	78	81	79

P hastened first bloom in tomatoes by as much as 10 days or more. Broadcast treatments were less effective in promoting early bloom, **Figure 3**. BC

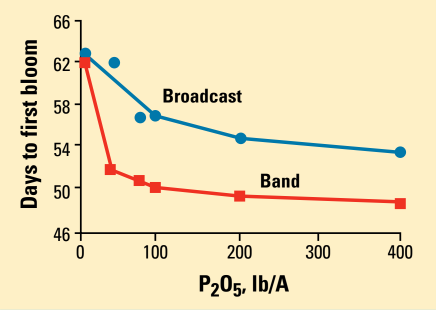

Figure 3. Influence of P rate and placement on time to first bloom of tomato plants.

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