A2520

Understanding Plant Nutrients

Soil and Applied Phosphorus

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Soils generally contain 500–1000 parts per million (ppm) of total phosphorus (inorganic and organic), but most of this is in a "fixed" form that is unavailable for plant use. Furthermore, soluble phosphorus in fertilizer or other nutrient sources is quickly converted to less-available forms when added to the soil. Although some Wisconsin soils may require large phosphorus additions for best yields, the past use of phosphorus fertilizer and applications of manure have led to unnecessarily high phosphorus levels in many soils. Based on Wisconsin soil test recommendations for field crops, the average soil test phosphorus (44 ppm of extractable phosphorus) for 450,000 Wisconsin soil samples analyzed between 1982 and 1985 was in the excessively high range.

PHOSPHORUS REACTIONS IN SOILS

The two main categories of phosphorus (P) in soils are organic and inorganic. The organic form is found in humus and other organic materials. The inorganic portion occurs in various combinations with iron, aluminum, calcium, and other elements, most of which are not very soluble in water. Both organic and inorganic forms of phosphorus are important sources of phosphorus for plant growth, but their availabilities are controlled by soil characteristics and environmental conditions.

Phosphorus Fixation

One of the unique characteristics of phosphorus is its immobility in soil. Practically all soluble phosphorus from fertilizer or manure is converted in the soil to water-insoluble phosphorus within a few hours after application. Phosphorus occurs in the soil solution as the negatively charged phosphate ion $H_2PO_4^-$ in acid soils or $HPO_4^=$ in alkaline soils. These ions react readily with iron, aluminum, and manganese compounds in acid soils and with calcium compounds in neutral and alkaline soils. They become strongly attached to the surfaces of these compounds or form insoluble phosphate precipitates. These reactions remove immediately available phosphate ions from the soil solution. Phosphate ions do not leach, as do nitrate ions, even in sandy soils. Studies of highly fertilized, intensively farmed land indicate that the annual loss of phosphorus in drainage water seldom exceeds 0.1 lb/a. The plow layer of the soil usually retains almost all (98–99%) of the applied phosphorus. This means that very little phosphorus moves into or through the subsoil. Acid soils fix more phosphorus than neutral soils; liming acid soils to a pH of 6.0–6.8 increases the availability of both soil and fertilizer phosphorus.

Phosphorus in Organic Matter

The relative amounts of organic and inorganic phosphorus vary considerably. In Wisconsin, organic phosphorus accounts for 30–50% of the total phosphorus in most mineral soils. Decomposition (mineralization) of organic matter converts organic forms of phosphorus to inorganic available forms. As with the mineralization of organic nitrogen, organic phosphorus is released more rapidly in warm, well-aerated soils. This explains why crops grown in cold, wet Wisconsin soils often respond to row-applied phosphorus even though the soil may be well supplied with phosphorus or broadcast phosphorus fertilizer has been added.

ENVIRONMENTAL HAZARDS

Aquatic weeds and algae respond to increasing amounts of phosphorus just as land plants do. Luxurious growth of weeds and algae often results when additional phosphorus enters a lake or stream. Of all plant nutrients, phosphorus is usually the most closely associated with accelerated production of weeds and algae. However, runoff water usually contains very low quantities of soluble phosphorus, even when phosphorus is surface-applied, because of phosphorus immobility in soil. Also, only negligible amounts of phosphorus in soil water percolate through soils. Phosphorus enters surface water mainly by erosion of phosphorus-holding soil particles and organic residues. For these reasons, excessive buildup of soil phosphorus should be avoided, especially in erodible soils. Contact your county Extension agent for further information on recommended practices to minimize phosphorus losses from agricultural land.

FERTILIZER SOURCES OF PHOSPHORUS

Rock phosphate is the original source of nearly all phosphorus fertilizer sold in the United States. Mined rock phosphate is too insoluble to be a useful source of phosphorus for crops, except when very finely ground and when soil pH is below 6.0. During the manufacture of fertilizer, insoluble rock phosphate is treated with an acid to convert it to more-available superphosphate or ammonium phosphate. This process neutralizes the acid; application of phosphate fertilizer results in very little residual acidity when it is applied to the soil. The common phosphate fertilizers, listed in Table 1, are seldom applied alone in Wisconsin. Usually they are manufactured or blended with nitrogen, potassium, or both to form a mixed fertilizer such as 6-24-24 or 9-23-30.

Orthophosphate versus Polyphosphate

Sources of phosphorus containing the $H_2PO_4^-$ or $HPO_4^=$ ions are called orthophosphates. Polyphosphates contain a mixture of orthophosphate and some long-chain phosphate ions such as pyrophosphate, $(HP_2O_7)_3^-$. Commercially produced polyphosphate contains approximately 50% orthophosphate and 50% long-chain phosphate compounds.

Claims that polyphosphates are superior to orthophosphates exaggerate their ability to partially chelate or combine with certain micronutrients and hold them in an available form. Research has not demonstrated that this difference improves yields or increases nutrient uptake in most soils. Polyphosphate ions react with soil moisture to form orthophosphates relatively rapidly (1–2 weeks). On almost all soils, orthophosphate and polyphosphate fertilizers are equally effective.

Effect of Water Solubility

The amount of water-soluble phosphorus in the different sources of available phosphorus varies considerably (Table 1). When phosphorus is broadcast and incorporated or when it is topdressed on forages, the amount of water solubility makes little or no difference. University of Wisconsin research shown in Table 2 illustrates that the differences in water solubility among concentrated superphosphate (85% soluble), ammoniated superphosphate (60% soluble), and monoammonium phosphate (92% soluble) did not influence yields. Increasing the amount of water-soluble phosphorus above 60% did not increase yields. All commonly used phosphorus fertilizers presently sold in Wisconsin (except rock phosphate) contain at least 85% water-soluble phosphorus.

Liquid versus Dry Phosphate

Compared to conventional dry fertilizers, liquid fertilizers are easier to handle, mix, and apply. Despite claims to the contrary, research has shown that liquid phosphate does not improve fertilizer phosphorus availability or recovery. It is the soil interactions that control phosphorus uptake, not the physical form of the fertilizer applied.

Rock Phosphate versus Superphosphate

Rock phosphate is sometimes recommended instead of superphosphate for building up the “reserve” level of phosphate in soil. The phosphorus in rock phosphate becomes available only when the soil is acid (below pH 5.5), and therefore its use by Wisconsin dairy farms is not recommended. The pH should be about 6.8 for high-quality alfalfa and at least 6.0–6.2 for most other agronomic crops. Research in the 1950s clearly demonstrated that rock phosphate is not an effective phosphorus source in most soils.

Table 1. Fertilizer sources of phosphorus.

NAME OF FERTILIZER	CHEMICAL FORMULA	FERTILIZER ANALYSIS EQUIVALENT N-P_2O_5-K_2O	WATER SOLUBILITY
		%	%
Ammonium polyphosphate	$NH_4H_2PO_4 + (NH_4)_3HP_2O_7$		
Liquid		10-34-0	100
Dry		15-62-0	100
Diammonium phosphate	$(NH_4)_2HPO_4$	18-46-0	>95
Monoammonium phosphate	$NH_4H_2PO_4$	11-48-0	92
Ordinary superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	0-20-0	85
Rock phosphate	$3Ca_3(P0_4)_2 \cdot CaF_2$	0-32-0	<1
Triple superphosphate	$Ca(H_2PO_4)_2$	0-46-0	87

METHOD OF APPLICATION

Plants need relatively large amounts of phosphorus early in the life cycle. Root development is limited in cool, wet soils, and very little phosphorus is released from soil organic matter. Some studies have found banded phosphorus to be nearly twice as efficient as broadcast phosphorus in cold soils. In well-drained, fertile soils that warm up early in the spring, however, row and broadcast applications are often equally effective. Since phosphorus moves very little from the point of application, place the row fertilizer 1–2 inches to the side and below the seed. Be careful not to apply excessive rates of starter fertilizer, particularly when using highly ammoniated fertilizers on high-pH soils. Optimum starter rates depend on soil test levels, the distance between fertilizer and seed, soil texture, and the salt index of the fertilizer applied.

DIAGNOSTIC TECHNIQUES

Deficiency Symptoms

The leaves of phosphorus-deficient plants most often appear dark bluish green, frequently with tints of purple or bronze. On corn, purpling occurs around the margins of the lower leaves, and the plant is short and dark green. Some corn hybrids exhibit a purple tinge on the lower stalk of young plants, a condition that can be confused with phosphorus deficiency. Reddening of corn leaves and stalks in the fall is not an indication of phosphorus deficiency, but of a process that occurs naturally as corn matures. Phosphorus-deficient alfalfa is stunted and dark bluish green, but purpling does not occur.

Soil Analysis

Many methods exist for measuring available phosphorus in soils. The Bray P_1 test, developed at the University of Illinois, is common in Wisconsin and throughout most of the Midwest. The interpretation of this test depends on the soil type and intended crop. See Extension publication A3030, *Optimum Soil Test Levels for Wisconsin*, for details. In general, soil-test phosphorus should be 10–30 ppm for field crops and somewhat higher for potato and some vegetable crops, including cabbage, carrot, melons, and tomato. Recommendations for phosphorus fertilizer vary with crop species, yield goal, and soil type. If soil phosphorus is below the optimum level, the amount of phosphate recommended will permit a gradual buildup (over 5–8 years) of the available supply. If soil phosphorus is high, the amount recommended will be less than the amount removed in the harvested portion of the crop, allowing some decrease in the soil test. For excessively high tests, elimination of part or possibly all of the phosphorus fertilizer allows the soil test to drop to the optimum range.

Table 2. Effect of various sources of row-applied phosphorus on the yield of corn (Arlington, WI).

FERTILIZER GRADE	SOURCE OF PHOSPHORUS IN COMMERCIAL 6-24-24[a]	WATER SOLUBILITY	YIELD OF CORN[b]
		%	bu/a
Control	No phosphorus applied	—	96
6-24-24	Ammoniated superphosphate	60	109
6-24-24	Concentrated superphosphate	85	112
6-24-24	Monoammonium phosphate	92	112

[a] *The 6-24-24 was applied at a rate of 167 lb/a to supply 40 lb/a of P_2O_5 (17 lb/a P).*

[b] *The differences in yield between the various sources of phosphorus are not significant.*

Plant Analysis

Analysis of plant tissue gives a good indication of the phosphorus nutrition of the plant. Because phosphorus levels in the plant change with age and plant part, it is important to indicate the stage of maturity when sampling the plants. Table 3 interprets phosphorus levels for the major Wisconsin field crops. See Extension publication A2289, *Plant Analysis: A Diagnostic Tool*, for additional information.

ADDITIONAL INFORMATION

These publications in the *Understanding Plant Nutrients* series are available from your county Extension office:

Soil and Applied Boron	(A2522)
Soil and Applied Calcium	(A2523)
Soil and Applied Chlorine	(A3556)
Soil and Applied Copper	(A2527)
Soil and Applied Iron	(A3554)
Soil and Applied Magnesium	(A2524)
Soil and Applied Manganese	(A2526)
Soil and Applied Molybdenum	(A3555)
Soil and Applied Nitrogen	(A2519)
Soil and Applied Phosphorus	(A2520)
Soil and Applied Potassium	(A2521)
Soil and Applied Sulfur	(A2525)
Soil and Applied Zinc	(A2528)

Table 3. Phosphorus plant-analysis interpretations for common Wisconsin field crops.

			INTERPRETATION				
CROP	**PLANT PART SAMPLED**	**TIME OF SAMPLING**	**DEFICIENT**	**LOW**	**SUFFICIENT**	**HIGH**	**EXCESSIVE**
			%				
Alfalfa	Top 6 inches	Bud	<0.20	0.20–0.25	0.26–0.70	0.71–1.00	>1.00
Corn	Whole plant	6–16 in	<0.20	0.20–0.39	0.40–0.60	0.61–1.20	>1.20
Corn	Earleaf	Silking	<0.16	0.16–0.24	0.25–0.50	0.51–0.80	>0.80
Oat	Top leaves	Boot stage	<0.15	0.15–0.20	0.21–0.50	0.51–0.75	>0.75
Soybean	First trifoliate	Early flower	<0.15	0.15–0.25	0.26–0.50	0.51–0.80	>0.80

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