Phosphorus: Pollutant and Essential Plant Food Element
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PHOSPHORUS: POLLUTANT AND ESSENTIAL PLANT FOOD ELEMENT

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Plant and animal growth occur only when ample phosphorus (P) is present. Low levels of phosphorus in soil result in retarded plant growth rates and low crop yields. Low levels in animal feed also result in slow growth and inefficient feed utilization.

Deficiencies in both plants and animals do not occur as frequently as in the past because phosphorus-containing fertilizers are now used on almost all farms. Well balanced animal diets have reduced the magnitude of the phosphorus deficiency problem in the livestock industry.

The use of excessively high rates of fertilizer phosphorus does not usually create a toxicity problem in plants. Most frequently, high rates of phosphorus fertilizer reduce the uptake of zinc (Zn) and iron (Fe). These two elements then become deficient, causing decreased yields. This condition is frequently classed as a nutrient imbalance and not a phosphorus toxicity.

Phosphorus as a Pollutant

Concern for phosphorus as a pollutant occurs primarily when it stimulates the growth of undersirable organisms. In water, elevated phosphorus levels stimulate excessive growth of aquatic plants, especially during the summer months when water temperatures are relatively high. This situation results in reduced water quality as related to several uses, but especially for recreational uses such as fishing, swimming and boating. Thus there is widespread interest in reducing phosphorus levels in water where levels are relatively high and in maintaining levels where these are low.

A Phosphorus Cycle

Most essential plant food elements move through a series of cycles from soil to plant to animal etc. One of the phosphorus cycles is shown in Figure 1. The soil phosphorus represents a complex mixture of both organic and mineral materials that vary greatly in solubility. Plant roots absorb phosphorus from the soil only if the phosphorus is present in the soil solution as an *ion*[2]—$H_2PO_4^-$ or HPO_4^{--}. Plants can use both of these ions, but where the soil pH level is above 6.3, the availability of the HPO_4^{--} ion is likely to be reduced. Soluble mineral phosphorus may be precipitated as calcium, iron or aluminum phosphates. Some phosphorus is adsorbed on the surfaces of carbonates, hydroxides, oxides and clay particles. Such materials are relatively insoluble and move primarily in the erosion process.

After phosphorus moves into the plant (crop) it may be lost from this cycle when the crop is harvested. Loss from the cycle may also occur when manure, municipal wastes and animal products are not returned to the soil and when accelerated soil erosion occurs. Phosphorus from manure, fertilizer and decaying crop residues represent nonpoint source pollutants when wind and water erosion occur.

Phosphorus may be added to the cycle through the use of fertilizers, animal wastes, crop residues and municipal or industrial wastes.

Soil Phosphorus (P)

Phosphorus reserves in the world are limited. Most phosphorus occurs as a diluted material located mainly in the topsoil. The plow layers of many agricultural soils often contain 1,000 to 2,000 lb phosphorus/acre, or 500 to 1000 ppm (parts per million). This is total phosphorus of which only a small part is soluble. In some instances, ¾ of the phosphorus in the plow layer is present as organic compounds.

Research has shown that the concentration of phosphorus in the soil solution is frequently less than 0.1 ppm. Such a dilute solution is the basis for the widespread use of fertilizer phosphorus and the great increase in crop yields associated with the use of fertilizer phosphorus on deficient soil.

Soil tests measure "plant-available phosphorus" which includes more phosphorus than is soluble in water alone. "Average" plant-available phosphorus levels in surface soil have increased gradually, as research has demonstrated since 1959. Also, ranges in test levels have been wide. In one 1974 research project involving phosphorus tests on soil that was producing corn, tests ranged from 3 to 315 lb/acre of plant-available phosphorus. The number 3 represents a very deficient condition, while the 315 is an exceptionally high test.

The average test levels reported in Table 1 are from this same study. The values are less than those in more recent reports, which invariably include test results from highly fertilized crops such as sugar beets, potatoes and vegetables. The data clearly show that plant-available phosphorus levels in the profiles of 135 soils used for corn production decrease with both depth and sand content of the soil.

The data in Table 1 also suggest that a slight movement of phosphorus downward in the profile has taken place. Tests in the B horizon (subsoil) are equal to or higher than in the C horizon (parent material). Because the plant-available phosphorus is concentrated in the surface soil, intense efforts should be made to prevent soil erosion and phosphorus movement.

[1]*The authors are members of the Department of Crop and Soil Sciences. They gratefully express appreciation to Drs. C.M. Harrison, B.G. Ellis and D. Warncke for suggestions made during the preparation of this bulletin.*

[2]*Ion—an electrically charged form of an element.*

Table 1. **Average "plant-available" phosphorus levels in the profiles of several Michigan soils.[1]**

Dominant profile texture	A	*Horizon[2]* B	C
		ppm P_2O_5	
Clay and clay loam	57	9	9
Loams and sandy loams	69	21	11
Loamy sands and sands	71	37	16

[1]*From MSU Research Report 281, "Test Levels in Soil Profiles of Michigan Corn Fields."*

[2]*A = Surface soil, B = Subsoil, C = Parent material*

Table 2. **The fixation of fertilizer phosphorus during 22 weeks by a Conover loam soil.[1]**

Fertilizer treatment	*Original test level*	*Soil phosphorus plus fertilizer phosphorus*	*Final soil test*	*Pounds fertilizer fixed*	*P_2O_5 fixed*
		lb P_2O_5/acre			%
0	48	48	48	0	0
46	48	94	55	39	85
92	48	140	64	76	83
148	48	232	110	122	82
364	48	416	175	241	66
736	48	784	350	434	59
1472	48	1520	833	687	47
2944	48	2992	1757	1235	42
5888	48	5936	3933	2003	34

[1]*Soil test levels are usually expressed as pounds of phosphorus per acre. In this table, phosphorus has been converted to P_2O_5 to expedite discussion.*

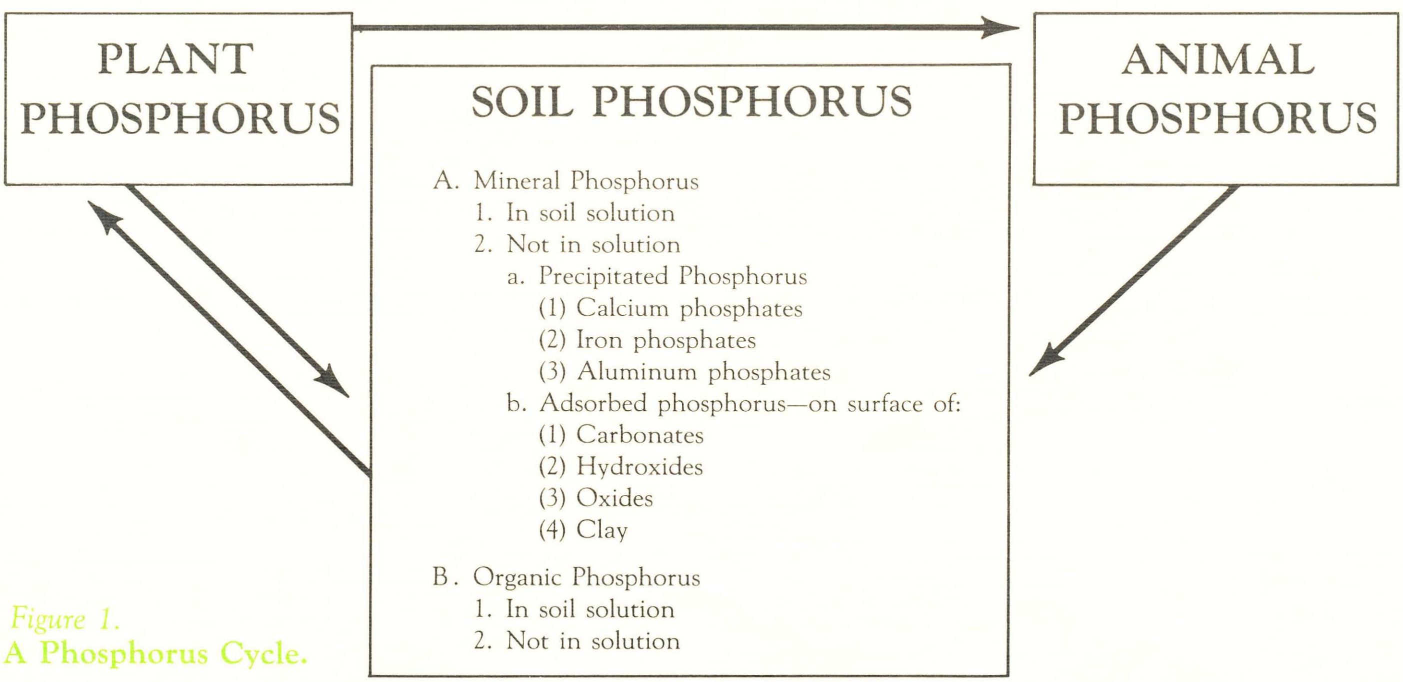

Figure 1.
A Phosphorus Cycle.

Other studies have shown that the continued use of fertilizer phosphorus on very high testing sandy soil may lead to increased phosphorus levels in both percolation and runoff water. Regular and systematic soil testing should serve as a basis for preventing the excessive accumulation of phosphorus in the soil profile.

Some of the fertilizer phosphorus used in crop production is "fixed" by the soil. Fixation is a chemical conversion process that occurs in the soil when soluble phosphorus fertilizer materials are changed to less plant-available forms. Most of the fixed phosphorus remains in the part of the soil where fixation occurs.

The data in Table 2 illustrate the amount of fixation that occurred in one Conover loam soil. These data imply that even though the percent phosphorus fixed was reduced with an increase in rates, the use of up to almost 3 tons per acre of P_2O_5 did not satisfy the total fixing power of this soil.

The data in Table 2 also indicate that soil test levels for plant-available phosphorus can be increased with the use of fertilizer phosphorus. This suggests that phosphorus losses associated with accelerated erosion can be significant on well-fertilized soil with high soil test levels unless high levels of soil conservation management are used.

Phosphorus in Water

There has been much publicity about elevated phosphorus levels and low water quality. This is as it should be because increased phosphorus levels are usually associated with a degradation of water quality. The relationship, however, is not as simple and direct as many believe.

To understand the relationship between phosphorus and water quality, one should realize that the phosphorus content of water represents the sum of that in solution and that in suspension. Solution levels in lakes and streams are usually very low.

The average total phosphorus content of Michigan's rivers, almost without exception, is less than 1 ppm. In 1981, according to the Michigan Department of Natural Resources, average total phosphorus levels ranged from 0.02 ppm in the Thunder Bay River at Alpena to 0.15 ppm in the Grand River at Grand Haven. Levels as high as 0.76 ppm have been reported in Ingham County's Sloan Creek.

The total phosphorus content of tile drainage water in Michigan varies greatly, but always is in the "low" range. Levels as high as 0.30 ppm and as low as 0.06 ppm have been reported in water from tile drained mineral soils. Levels in water from tile drained organic soil were less than 0.05 ppm.

Phosphorus levels in surface runoff water vary greatly, depending on circumstances. Levels are likely to be relatively high where runoff occurs immediately after fertilizer or manure application. Levels may be very high where accelerated soil erosion occurs.

Surface runoff and the associated soil erosion undoubtedly accounts for the greatest phosphorus loss from agricultural soils. Suspended materials in water flowing across cultivated land may have a phosphorus content as high as 1 lb per ton of transported material. This is a tolerable level where soil erosion rates are low—in the range of 1 to 3 tons/acre. It is totally unacceptable where soil losses are in excess of 10 tons per acre.

There is one other important consideration: not all phosphorus-containing sediment ends up in ditches, streams, rivers, lakes or ponds. Fortunately, much of such material moves only a relatively short distance. Many times it does not even move out of the field where it originated. It simply moves from one part of a field to another. Thus, the problems of sediment and phosphorus in water are not as great as they appear to be.

Summary and Conclusion

Phosphorus is an essential plant food element and one of the world's most limited resources. Despite this, excessive levels of phosphorus in water stimulate aquatic plant growth, which in turn limits the use of water for many purposes.

Most of the phosphorus in the world occurs as a dilute material located primarily in the topsoil as relatively insoluble compounds, both organic and inorganic in nature.

Phosphorus levels in soil are usually relatively low, especially that classed as "plant-available phosphorus." As a result, significant and consistent increases in crop yields have been obtained from the use of phosphorus fertilizer on deficient soils.

Some have attempted to directly relate fertilizer use to the water problem. In most instances, this is not logical because soluble fertilizer phosphorus is easily fixed by soil and less soluble compounds are formed. Many farmers today are concerned about phosphorus fixation and try to use fertilizer so that fixation is reduced to a minimum. Despite this, some phosphorus fertilizer is misused. Excessive rates are sometimes used and water pollution occurs.

Much of the total phosphorus in water involves that phosphorus which is a part of sediment. Therefore, protecting soil against accelerated erosion is a prime consideration in the control of phosphorus levels in water. Maintaining low levels of phosphorus in water involves a four-part strategy:

1. The wise and careful use of fertilizer, manure and municipal and industrial wastes.
2. The promotion of rapid plant growth and the production of high grain and residue yields.
3. The use of conservation tillage methods; the use of conservation cropping systems adapted to specific sites.
4. Under special conditions, the use of mechanical devices to decrease sediment deposit rates where other means of control are not effective.

Refer to other publications in the series on water quality as well as those pertaining directly to tillage, soil erosion, water drainage and irrigation.

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