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Soil Phosphorus: Management and Recommendations

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Phosphorus – Necessary for Plant and Animal Growth

Phosphorus (P) is a naturally occurring element that can be found in all living organisms, as well as in water and soils. It is an essential component of many physiological processes related to proper energy utilization in both plants and animals. Phosphorus can be added to the environment by man's activities as point source discharges or as non-point source runoff. Typical sources include industrial and municipal wastewater point source discharge or runoff from agricultural and urban areas. This publication addresses management issues and recommendations arising from application of P, mainly as manures to agricultural lands.

Plants derive P from soil; livestock, in turn, derive part of their P needs from plant materials. However, much of the naturally occurring P in grains is in a form that is indigestible to the animal. Therefore, inorganic P sources are added to animal diets to ensure adequate nutrition and sound bone development and reproduction. As a result, much of the dietary P passes through the animal (70 percent) and is excreted in animal manure. Applying animal manure as a fertilizer to crop and grazing land can utilize this excreted P.

Plants, like animals, need a certain amount of P for healthy growth.

Plants uptake P from soil as dissolved orthophosphate. However, native soil P levels are often low enough to limit crop production. Both inorganic P fertilizers (treated rock phosphates) and organic P sources (animal manures) are equally adept at supplying the orthophosphate ion and correcting P deficiencies in soil. Although it varies, typically 30 to 50 percent of the P in animal manure is in an organic form, which must be converted to plant-available inorganic forms via soil biological activity, a process known as mineralization. The net effect of this mineralization is that P derived from animal manure can act more like a slow-release fertilizer than commercial inorganic fertilizers, in which the P is formulated to be more soluble and readily available to plants.

Not all the P applied to soil is taken up by plants – some is fixed; and not all the P fed to animals is absorbed – some is excreted.

Understanding Soil Test Numbers

The University of Arkansas' P fertilizer recommendations for pastures and crops are based on soil testing where samples are analyzed to determine the current levels of P available to the plant. Research-based recommendations are then made on the amount of additional P needed to achieve yield goals.

When discussing P, it is important to make the distinction between

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elemental P and phosphate (P_2O_5). Soil test results are usually reported as elemental P, while commercial fertilizers are reported as P_2O_5, where 2.29 pounds of P_2O_5 is the equivalent of 1 pound of P. For example, 100 lbs of P_2O_5 is equivalent to 44 lbs P.

Soil test phosphorus (STP) is an indicator of how much P is expected to be available for plant use. If STP values are to be compared, the laboratory test method for extracting P and how the number is reported (parts per million – ppm or lbs/acre) must be known. Different testing laboratories can use different methods for extracting P, producing different test results that are difficult to compare even for the same sample. The University of Arkansas Soil Testing Laboratory uses the Mehlich-3 extraction method, with results reported in ppm and lbs/acre. The lbs/acre units on the soil test report assumes a 6-inch sample depth representing 2,000,000 lbs of soil, which results in lbs/acre values being two times greater than ppm. Finally, Mehlich-3 is one of the most common STP methods used on acidic soils (i.e., noncalcareous soils) in the U.S.

Soil test P estimates how much P is available in a soil for plant use.

To convert an STP value reported as ppm to lbs/acre, the depth of soil sample taken is needed. The conversion from ppm to lbs/acre, as used in the Arkansas P Index, assumes that a 4-inch deep layer of soil (furrow slice) covering 1 acre weighs 1,300,000 lbs. A 4-inch soil sample depth is recommended for pastures in Arkansas. To convert soil test results from ppm to lbs/acre for a 4-inch soil sample, multiply the value in ppm by 1.3. For example, an STP value of 100 ppm is the same as 130 lbs/acre.

Applying manure can increase soil fertility and productivity by adding nutrients and organic matter, which increase ground cover and reduce surface runoff.

The Phosphorus Concern

Commercial fertilizers are commonly applied to pastures and croplands in a mixture of nitrogen (N), P and potassium (K) that is balanced to meet the nutrient needs of the desired crop. However, nutrients in livestock manure are not balanced with respect to crop requirements.

Table 1 reveals that there is about two to four times more N than elemental P for various manures. However, Table 2 indicates that typical forage crops require about six to ten times as much N as P. As indicated by these two tables, using animal manures to supply a crop's N requirement tends to result in applying more P than the plant needs.

Growers with confined livestock and poultry operations import feed onto the farm. This feed contains P at nationally recommended dietary levels for healthy animals to maintain bone structure strength, reproduction, etc. However, as only about 30 percent of that P is absorbed by the animal, most of the dietary P passes through the animal and is excreted in manure. In turn, the manure is spread on fields to take advantage of its nutrient value and organic matter. This practice has increased the overall fertility and productivity of soils by providing needed nutrients and organic matter which can increase ground cover and improve water infiltration and holding capacity. In turn, this decreases runoff and erosion.

EXAMPLE SCENARIO
Comparing N- vs. P-Based Litter Applications

This example is for a broiler farm, consisting of four houses, that places 20,000 four-pound birds per house and averages five flocks per year. The litter produced will be applied to produce 4 tons of fescue per acre.

Assumptions

- Litter is produced at a rate of 1 ton per 1,000 birds per flock.
- The litter contains 60 lbs N/ton and 55 lbs P_2O_5/ton.
- The fescue produced will contain 36 lbs N/ton and 15 lbs P_2O_5/ton.
- 25% of the N is lost during litter application to volatilization.
- No other mineralization, denitrification or leaching losses for N or P are considered.

Litter Nutrient Information

- 400 tons litter/year
- 18,000 lbs N available/year
- 22,000 lbs P_2O_5 available/year

Fescue Nutrient Information

- 4 tons fescue/acre
- 144 lbs N required/acre
- 60 lbs P_2O_5 required/acre

Application Comparisons

N Based	P Based
• 125 acres required	• 393 acres required
• 3.2 tons litter/acre	• 1 ton litter/acre
• 144 lbs N applied/acre	• 46 lbs N applied/acre
• 176 lbs P_2O_5applied/acre	• 55 lbs P_2O_5 applied/acre
• N needs met	• 98 lbs N deficit/acre
• 116 lbs P_2O_5 surplus/acre	• P needs met

Comment

For the N-based application, a P_2O_5 surplus of 116 lbs/acre does not imply that the STP will increase by 116 lbs/acre. Due to soil chemical reactions, significant amounts of the surplus P will become bound in soil in forms unavailable for plant use, which are not estimated by soil test procedures. For this reason, a 116 lbs/acre surplus of P_2O_5 will increase the STP level by less than 14 lbs P/acre; from about 6 to 13 lbs P/acre depending on soil properties.

TABLE 1. Typical Nutrient Values for Manure Samples Collected by Arkansas Producers

Type	N	P_2O_5 (P)†	K_2O (K)†	N/P
Broiler litter (n = 522)‡				
Mean	61.60	65.5 (28.6)	59.8 (49.4)	2.2
Minimum	20.60	24.7 (10.8)	25.4 (21.0)	
Maximum	88.20	116.8 (51.0)	89.8 (74.2)	
Dairy manure (= 142)¶				
Mean	11.57	6.8 (3.0)	10.4 (8.6)	3.9
Minimum	1.01	0.2 (0.1)	0.4 (0.4)	
Maximum	41.67	34.3 (15.0)	53.1 (43.9)	
Swine slurry (n = 535)¶				
Mean	9.99	9.8 (4.3)	8.0 (6.6)	2.3
Minimum	0.17	0.01 (0.006)	0.1 (0.1)	
Maximum	97.33	256.0 (111.8)	79.5 (65.7)	

† To convert from P_2O_5 to elemental P, divide by 2.29, and from K_2O to elemental K, divide by 1.21.

‡ These values (lb/ton) are derived from poultry litter samples submitted from the Eucha-Spavinaw Watershed to the University of Arkansas Agricultural Diagnostics Laboratory between 2005 and 2009.

¶ These values (lb/1,000 gal) are derived from manure samples collected by producers and sent to the University of Arkansas Agricultural Diagnostics Laboratory between 2007 and 2009.

TABLE 2. Nutrients Removed Per Ton of Forage Dry Matter for Samples Submitted to the Fayetteville Agricultural Diagnostic Laboratory (University of Arkansas, Division of Agriculture) and Identified as Hay

Forage Type	No. of Observations	N	P_2O_5 (P)†	K_2O (K)‡	N/P
	- - - - - - - - - - lbs removed / ton forage - - - - - - - - - -				
Alfalfa	378	62.6	14.0 (6.1)	51.4 (42.5)	10.3
Bahiagrass	369	31.4	9.8 (4.3)	31.9 (26.4)	7.3
Bermudagrass	6,676	42.0	13.7 (6.0)	48.0 (39.7)	7.0
Clover	31	45.4	11.9 (5.2)	45.4 (37.5)	8.7
Fescue	1,532	36.2	14.7 (6.4)	49.0 (40.5)	5.7
Legume/grass	268	40.6	13.7 (6.0)	46.8 (38.7)	6.8
Ryegrass	366	37.2	13.7 (6.0)	46.6 (38.5)	6.2
Sudangrass	773	36.4	13.7 (6.0)	47.2 (39.0)	6.1
Wheat	127	36.2	18.5 (8.1)	55.2 (45.6)	4.5

† To convert from P_2O_5 to elemental P, divide by 2.29.

‡ To convert from K_2O to elemental K, divide by 1.21.

¶ N from N fixation not N fertilizer.

Data from the UACES “Feed Analysis Program” database as determined on Jan. 5, 2010.
Available at http://feedanalysis.uaex.edu/.

Litter and manure were historically applied to meet the N requirements of forages or crops and to offset the use of costly mineral N fertilizers. However, this approach applied two to four times more P than was needed by the plant (Tables 1 and 2). Repeated application of manure based on plant N needs results in the accumulation of P in the soil, primarily in surface layers. In some cases, years of repeated applications have increased STP above optimum levels for production [36 to 50 ppm P (47 to 65 lbs P/acre)], particularly for pastures not cut for hay.

Soil is not an infinite sink for P.

In the past, this STP buildup has not been perceived as significant cause for concern. For instance, even at high levels, P is usually not detrimental to plant growth. Furthermore, it was understood by the national scientific community that P was tightly bound to soil in relatively stable forms. It was further thought that significant movement of this P off fields only occurred if soil moved by erosion. Finally, N management had been a priority to address concerns about elevated nitrate concentrations in groundwater.

The repeated application of manure at rates meeting plant N needs will increase soil test P levels.

A large amount of research between 1985 and 2000, showed that as STP increased, especially in the top 2 to 4 inches of soil, so did the concentration of soluble P in runoff (Figure 1). While conservation programs and improved pasture management and productivity were decreasing total P losses, research found that more of the P that was moving was in a soluble form, which was immediately available for algal uptake. This exacerbated the frequency and occurrence of nuisance algae blooms in freshwater lakes and reservoirs. In most cases, biological productivity (or eutrophication) is accelerated by P inputs because N and carbon can freely exchange between air and water and some blue-green algae can fix atmospheric N.

Research shows as soil test P increases, so does the concentration of P in runoff.

How Much Soil Test Phosphorus Is Needed?

Arkansas scientists agree that there is no agronomic reason or need for STP levels to be greater than about 50 ppm P (Mehlich-3 extraction; or 65 lbs P/acre for a 4-inch soil sample). Typical forage crops will annually remove from 4 to 8 pounds of elemental P per ton of production. As an example, bermudagrass removes about 14 P_2O_5 lbs/ton or 84 lbs P_2O_5 for a 6-ton/acre crop annually.

It must also be emphasized that P contained in plant material is recycled to the soil unless it is removed, either by crop or forage harvesting, soil erosion or runoff. On grazing land, most P is recycled to the soil in manure, with only a small portion (<30 percent) of ingested P removed from the land with the animal.

The measurement of soil test P is an important management and educational tool. Testing every year to every other year facilitates tracking soil test P buildup/reduction trends over time.

How Much Soil Test Phosphorus Is Too Much?

With the move from agronomic to environmental concerns with P, soil P testing has been used to indicate when P enrichment of runoff may become unacceptable. A common approach has been to use agronomic soil P standards, following the rationale that soil P in excess of crop requirements is vulnerable to removal by surface runoff or leaching. As agronomic standards already exist for STP, this approach required little investment in research and development and could be readily implemented. However, care must be taken in interpreting STP values for environmental purposes (Figure 2).

Interpretations given on soil test reports (i.e., low, medium, optimum and above optimum) are based on the expected crop yield response to P and not on soil P release to surface or subsurface runoff. Some have tried to simply extend crop response levels and say that STP above the level where no crop response is expected is in excess of crop needs and, therefore, is cause for concern (Figure 2). Although research has shown agricultural soil P tests can estimate a soil's potential to enrich runoff with P, this relationship is neither direct nor quantitative. It is of critical importance to remember that soil P is only one of several sources (rate, timing and type of manure or fertilizer P applied) and transport factors (runoff, erosion and proximity of a field to a stream) that influence the potential for P transport, which are site specific. Because of this, the P Index was developed and is now widely used to assess the risk of P loss in runoff from a given site (see fact sheet *FSA9531, Arkansas Phosphorus Index*).

There are several Best Management Practices that can decrease the risk of P loss in runoff from fields.

FIGURE 1
Relationship Between Mehlich-3 Extractable Soil P and Dissolved Reactive P (DRP) in Runoff (based on STP levels in the top 1 inch of soil)

Adapted from Pote et al., 1996, and Sharpley et al., 2001

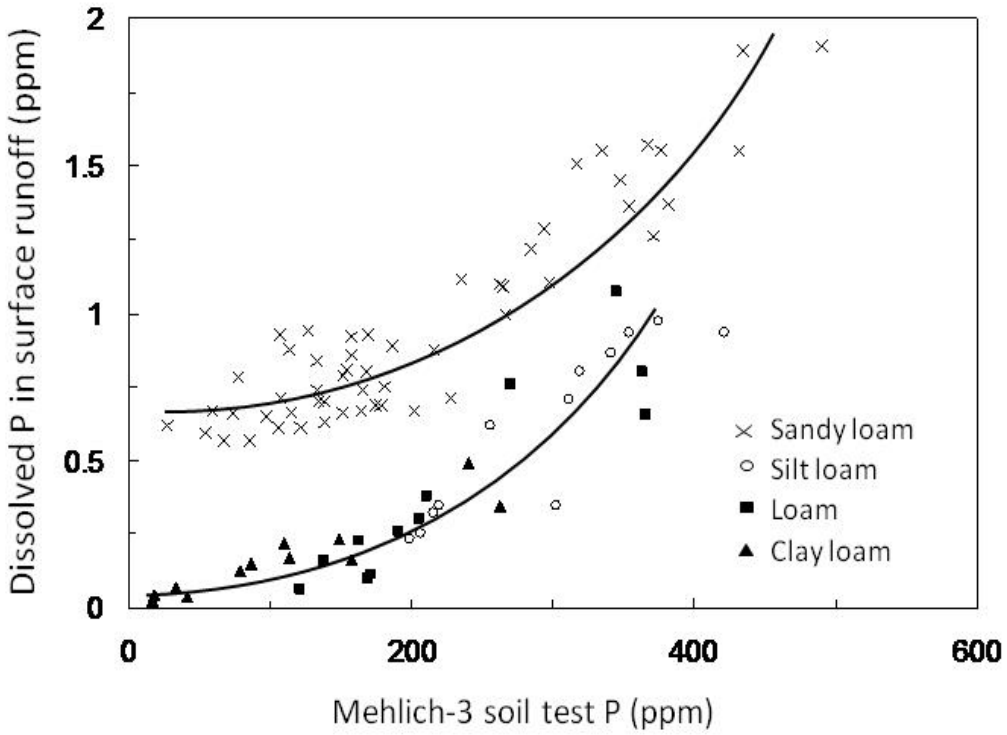
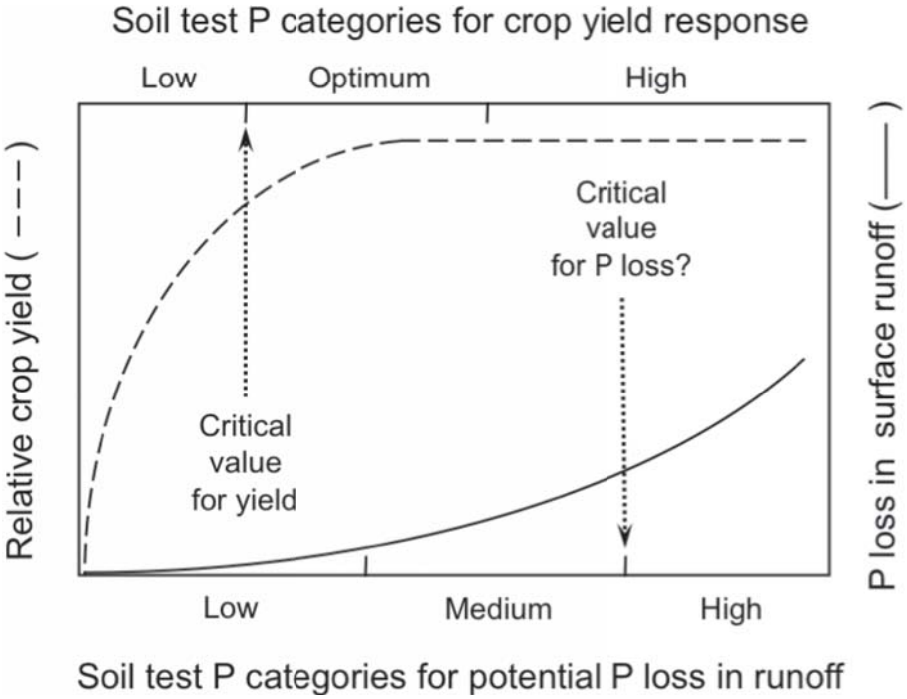


FIGURE 2
As Soil P Increases So Does Crop Yield and the Potential for P Loss in Surface Runoff



Recommendations and Concerns

- If applying animal manures to pasture or cropland, it is highly recommended to voluntarily obtain a nutrient management plan written by a state-certified plan writer or from NRCS that utilizes the P-Index approach, which determines the relative risk of P-loss and makes site-specific recommendations related to:
  - ➢ Maximum allowable manure application rate for individual fields;
  - ➢ Appropriate "Best Management Practices" that can reduce the transport potential of P from a given field;
  - ➢ Appropriate "set back" distances from critical water features.
- Current scientific evidence is limited on how much P can be tolerated for all fields in all situations. However, growers with management alternatives for litter or manure should consider reducing P applications to fields with high STP. It is known that high P fields can require as much as 15 to 20 years of continuous crop harvesting, with no added P during that time to reduce high STP levels. Therefore, it is to the landowner's advantage not to let STP build to high levels if he/she has alternatives for management.
- Litter and manure management applications should be based on the risk of P loss, of which STP is one of many factors controlling the loss. This is a requirement of managing P applications in nutrient surplus areas of Arkansas (see Fact Sheets *FSA9528, What Is Water Quality?,* and *FSA9529, Nutrient Analysis of Poultry Litter*).
- Growers should be encouraged to make commercial fertilizer applications formulated with N, K, and lime to meet the forage needs of fields where animal manure is no longer applied. Otherwise, decreased fertility can result in a loss of forage cover and increase the potential for runoff and erosion.
- Proper soil sampling techniques are critical to the accurate characterization of STP in pastureland. Samples should be collected from a minimum of 12 to 15 locations within a field in a zigzag pattern across the field. These samples should be mixed together and a composite sample taken from the mixture. This provides the most representative sample possible. Also, care should be taken to collect a sample approximately 4 inches in depth. Producers are encouraged to contact their local county extension office for sampling instructions prior to sampling.

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