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Soil Phosphorus Levels: Concerns and Recommendations

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Phosphorus – Necessary for Plant and Animal Growth

Phosphorus (P) is a naturally occurring element in the environment that can be found in all living organisms as well as in water and soils. It is an essential component for 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 discharges or runoff from agricultural lands or urban areas. This publication addresses the concerns arising from land application of animal manures.

Plants derive P needs 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 an indigestible form. Therefore, inorganic P sources are added to poultry and swine feeds to ensure adequate nutrition and to prevent rickets. As a result, much of the dietary P passes through livestock and poultry and is excreted in animal manure. Utilizing animal manure as a fertilizer on crop and grazing land can recycle nutrients.

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

Understanding Soil Test Numbers

The University of Arkansas' P fertilizer recommendations for crops are based on soil testing procedures. Soil samples are analyzed to determine the current levels of P available to the crop. Research-based recommendations are then made on the amount of additional P needed to achieve crop production goals.

When discussing P, it is important to make the distinction between elemental phosphorus (P) and phosphate (P_2O_5). Soil test results are usually reported as elemental P. Animal manure analysis results are usually reported as the amount of phosphate equivalent or P_2O_5, because commercial fertilizers are formulated with P_2O_5 (2.29 pounds of P_2O_5 is the equivalent of 1 pound of P).

Soil test phosphorus (STP) is not an indication of total P in the soil but how much is available for plant use. If STP numbers are to be compared, the laboratory test method for extracting P and how the number is reported (parts per million or pounds per acre) must be known. Different testing labs 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 III method, and the results are reported in pounds per acre of elemental P. Other soil testing labs may report their results in parts per million (ppm) without making the conversion to pounds per acre (lbs/A). This conversion from ppm to lbs/A involves assuming that a 6-inch deep layer of soil (furrow slice) covering one acre weighs 2,000,000 pounds. To convert soil test results from ppm to lbs/A, multiply the value in ppm by 2. For example, a soil test P value of 150 ppm is correlated to 300 lbs/A.

The Phosphorus Concern

Commercial fertilizers are commonly applied to croplands in a mixture of nitrogen, phosphate and potash (N, P_2O_5, and K_2O) 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
Average Nutrient Values for Manure Samples Collected by Arkansas Producers*

	N	P_2O_5	P	N/P_2O_5	
Broiler Litter	56	54	23.6	1.04	Lbs/ton
Dairy Manure	6	4	1.75	1.50	Lbs/1,000 gal
Swine Manure	14	13	5.68	1.08	Lbs/1,000 gal

*These values are derived from manure samples collected by producers and sent to the University of Arkansas Agricultural Diagnostics Laboratory. The nitrogen values are the total nitrogen concentration. The phosphorus values are the P_2O_5 and P concentrations as marked.

Table 1 reveals that N and P_2O_5 are found in about equal amounts in broiler litter. However, Table 2 indicates that typical forage crops require about 2½ to 4 times as much N as P_2O_5.

TABLE 2
Nutrients Removed Per Ton of Forage Dry Matter
(Average of Arkansas Forage Tests from 1984-1996)

	N	P_2O_5	P	K_2O	N/P_2O_5
	pounds removed per ton of forage production				
Alfalfa	58*	14	6	56	4.14
Bahiagrass	31	8	3	34	3.88
Bermudagrass	40	12	5	44	3.33
Clover	43*	12	5	44	3.58
Fescue	36	14	6	50	2.57
Legume/grass	39*	12	5	43	3.25
Ryegrass	39	16	7	54	2.44
Sudangrass	37	14	6	47	2.64
Wheat	36	13	6	40	2.77

*N from N fixation not N fertilizer

Growers with confined livestock and poultry operations have tons of P-enriched feed brought onto the farm. Much of that P passes through the animals and is excreted in manure. In turn, the manure is spread on fields to take advantage of the nutrient value and organic matter. Crops most readily respond to nitrogen, so growers have historically applied enough manure to meet crop nitrogen needs. This results in applying several times the needed amount of P (refer to Tables 1 and 2 concerning nutrient values and the example application scenario below).

EXAMPLE SCENARIO
Comparing N vs P_2O_5 Based Litter Applications

This example is for a broiler farm consisting of four houses that places a nominal 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 14 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_2O_5 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/A
- 144 lbs N required/A
- 56 lbs P_2O_5 required/A

Application Comparisons

N Based
- 125 A required
- 3.2 tons litter/A
- 144 lbs N applied/A
- 176 lbs P_2O_5 applied/A
- N needs met
- 120 lbs P_2O_5 surplus/A

P_2O_5 Based
- 393 A required
- 1 ton litter/A
- 46 lbs N applied/A
- 56 lbs P_2O_5 applied/A
- 98 lbs N deficit/A
- P_2O_5 needs met

Comment

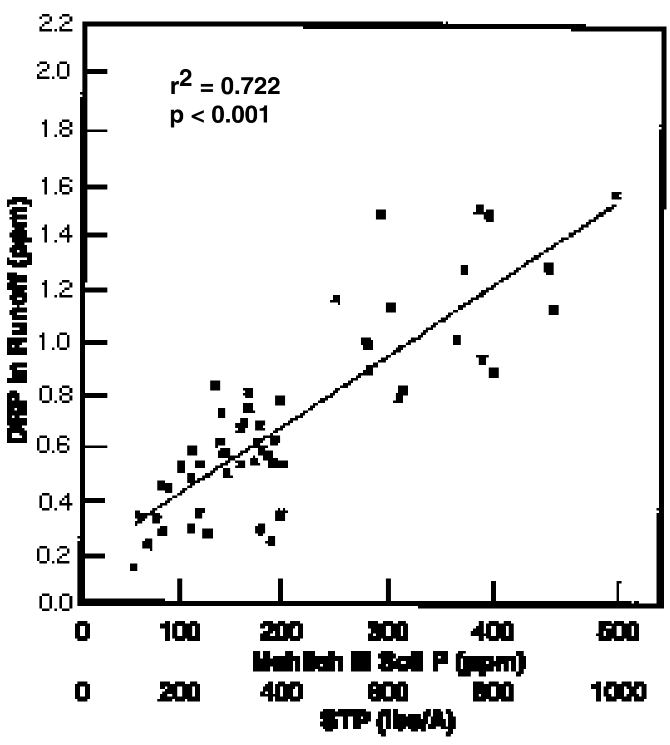
A P_2O_5 surplus of 120 lbs/A does not imply that the STP will increase by 120 lbs/A. Due to soil chemical reactions, significant amounts of the surplus P will become bound in the soil and unavailable for plant use. Because soil test procedures were developed to indicate plant-available P they will not measure bound P. For this reason, a 120 lbs/A surplus P_2O_5 will increase the STP level by significantly less than 120 lbs/A.

Repeated application of manure based on nitrogen needs causes P to accumulate in the soil. In some cases, 10 years of repeated application has caused very high STP levels, particularly on pasturelands where crops have not been removed. In the past, this build-up has not been a cause for concern. Phosphorus is a naturally occurring nutrient and, even at high levels, is not detrimental to crop production. It is also relatively stable once attached to soil particles. Phosphorus was once thought to have significant movement off fields only if soil was moved by erosion.

For land with high STP levels, it is now known that appreciable amounts of soluble P can exist in the runoff water from these areas and can significantly impact water quality in nearby streams and lakes. Looking at the top one inch of the soil profile, recent research has shown that the concentration of P in runoff increases as STP increases.

FIGURE 1

Relationship Between Mehlich III Extractable P in Captina Surface Soil and Dissolved Reactive P (DRP) in Runof (based on STP levels in the top 1 inch of soil)



Adapted from Sharpley, A.N., T. C. Daniel and D. R.Edwards, "Phosphorus Movement in the Landscape," *J. Prod.Agric.*, Vol.6, No. 4, 1993.

Phosphorus is not toxic and would not be a problem except P is the nutrient that limits biological activity in most of our clear water lakes and streams. Nitrogen and potash generally occur naturally in the environment in sufficient quantities to support algae and plant growth in water bodies. Insufficient P in most inland water bodies keeps the clear water lakes and streams from being congested with algae and aquatic vegetation. Very small increases in P can trigger unwanted algae and vegetative growth. Levels of P exceeding critical values for algae growth can lead to the acceleration of eutrophication, the natural aging process of a lake that is characterized by excessive biological activity.

Consequences of accelerated eutrophication include degradation of recreational benefits and drinking water quality, which in turn can increase treatment costs. Advanced eutrophication can also reduce aquatic wildlife populations and species diversity by lowering dissolved oxygen and increasing the biological oxygen demand (BOD). Eutrophication from excessive P has not generally been considered a public health issue like other contaminants derived from agricultural runoff, such as nitrates or pathogenic bacteria. However, there are toxic algae that can flourish with increases in available nutrients, which is causing researchers to focus more attention on the isolated events that have occurred in other states.

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 80 to 100 pounds (P by Mehlich III extraction) per acre. Typical forage crops will annually remove from 8 to 16 pounds of P_2O_5 per ton of production. As an example, bermudagrass removes about 12 pounds per ton or 72 pounds of P_2O_5 annually for a 6 ton per acre crop. (Divide P_2O_5 by 2.29 to determine elemental P; 72 lbs P_2O_5 = about 31 lbs P).

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. Only a small portion of the P uptake in the animal is retained and removed from the land with the animal.

The environmental concern of letting P accumulate to very high levels in the soil is the long period of time required to reduce STP to levels normally recommended for agronomic production. High levels of P can require as many as 15 to 20 years of continuous crop harvesting for removal, with no additional P from any source during that time.

How Much Soil Test Phosphorus Is Too Much?

A rigid, maximum STP level has not been set by soil scientists or the Natural Resources Conservation Service. However, one suggested limit that has been debated is 300 pounds P per acre (by the Mehlich III extraction testing method). This number has been suggested as an upper limit simply because it is much more than the available P needed for crop production (about three times more than needed), and it is hopefully low enough to avoid eutrophic runoff. The environmental impact of an STP level of 300 lbs/A has not been established at this time. The variables and unknowns in the movement (transport) of P once it is in runoff water make its environmental impact difficult to assess. It should also be noted that the concentration of dissolved P in runoff water changes with rainfall intensity and duration, and the research has been under very specific rainfall and runoff conditions.

Soil test phosphorus is clearly a good indicator of when an appreciable concentration of dissolved P may be in runoff water. It does not, however, offer any indication of the amount (rate) of runoff water that may be generated for a given set of conditions. The total amount of P leaving a field is a function of the runoff P concentration and the runoff volume. The real issue is not the P concentration in runoff from the edge of any one field but the total P load transported to the stream or lake from an entire watershed. The maximum amount of P that can be assimilated in a watershed without causing eutrophication depends on a number of factors including STP levels. Distance from significant streams or water bodies, slope, soil type, buffer strips and crop or forage cover are potential factors, as are the characteristics of the streams and lakes themselves. However, soil testing, if properly used, may be the most significant tool for assessing the potential for high P concentrations in runoff water.

The real issue is not the P concentration in runoff from the edge of any one field, but the total P load that is transported to the stream or lake from an entire watershed.

Some watersheds with a high percentage of cropland and pastureland receiving animal manure may require restricted P applications to avoid excess P loading of streams and lakes fed by that watershed. Maximum STP levels may be appropriate for these watersheds. Watersheds with a low population density of livestock and poultry farms may be able to tolerate higher STP levels on fields without harmful effects to water quality. However, to effectively manage P in every watershed, the factors affecting the movement of P from application sites to streams and lakes must be considered.

Recommendations and Concerns

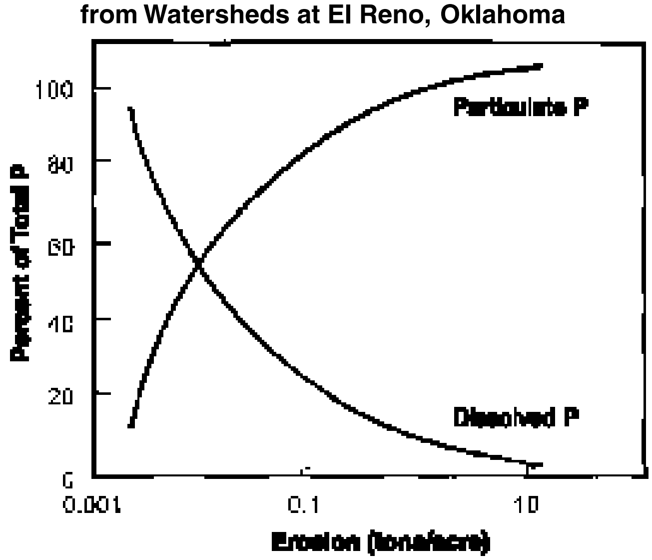
- An STP of 300 lbs/A is a good indicator that P build-up in the soil is a valid environmental concern for that particular field. Growers with management alternatives for manure or litter should reduce or totally avoid animal manure or P applications from any source on high P fields. Current scientific evidence is limited on how much P can be tolerated for all fields in all situations. However, 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 has alternatives for management.

- A STP of 300 lbs/A should not be considered an absolute maximum number for P applications at this time except in specific watersheds that have been determined to have excess P loads harmful to water quality and the environment.

- Growers should be encouraged to make commercial fertilizer applications formulated with N and K_2O to meet the forage needs of fields where animal manure is no longer applied. It must be recognized that decreased fertility will result in a loss of forage cover and increased erosion, which could create a greater P problem in runoff than continued manure applications. Research has shown that when erosion is kept to a minimum, dissolved P is predominant in runoff water, but as erosion increases the percentage of particulate P in the runoff increases.

FIGURE 2

Percentage of Total P as Dissolved and Particulate P as a Function of Erosion in Runoff from Watersheds at El Reno, Oklahoma



Adapted from Pote, D. H., T. C. Daniel, A.N. Sharpley, P. A.Moore, Jr., D. R. Edwards, and D. J. Nichols, "Relating Extractable Soil Phosphorus to Phosphorus Losses in Runoff," *Soil Sci.Soc. Am. J.* 60:855-859 (1996).

- When applying commercial fertilizer on fields with STP at 100 or more pounds per acre, do not use fertilizer with P in the formulation. It should be N (ammonium nitrate or urea) or N-0-K_2O, which is nitrogen and potash with no phosphorus.

- When making N-based early season applications with manure, late season commercial fertilizer applications should be N or N-0-K_2O with no P in the formulation.

- All livestock and poultry producers with confined animal operations should have a nutrient management plan prepared for their farm. The application rates should consider P. Low fertility fields with low P could have N-based applications for a limited time, but all fields with repeated animal manure applications will ultimately require applications that consider P.

- Proper soil sampling techniques are critical to the accurate characterization of STP in pastureland. Samples should be collected from 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 6 inches in depth. Producers are encouraged to contact their local county extension office for sampling instructions prior to sampling.

- In Arkansas dry manure or litter is not regulated, and growers have more options for handling excess nutrients on their farms. Dry manure has a higher nutrient density and can be hauled greater distances than liquid manures with fewer economic hardships. Liquid manures in Arkansas are regulated, and growers have fewer options for handling excess nutrients. The permits specify the minimum required acreage and the land application areas for each farm.

- Most livestock and poultry producers spread litter based on the best management practices at the time they started in business, only to find now that they may have inadequate land for P-based application rates. As a result, restrictive P regulations could cause financial hardship for many producers and affect Arkansas' agricultural economy unless economically feasible alternatives to land application are developed. High-quality water is also important for the economy and the people of Arkansas, so additional research is need to help producers find better ways to manage, utilize or market the valuable nutrients in excess manure.

- Carefully prepared nutrient management plans for all confined livestock and poultry operations, implementation of current technology with best management practices and limited P applications in certain critical watersheds should protect our water until new research and good science can further define more specific P recommendations.

- Additional solutions and management practices need to be developed and implemented. The areas of emphasis should include reducing the P concentrations in feeds while maintaining production, management practices to reduce the transport of P from the application areas to water bodies and the development of economical long distance transportation of manure to land areas in need of P.

References

Sharpley, A. N., T. C. Daniel and D. R. Edwards, "Phosphorus Movement in the Landscape," *J. Prod. Agric.*, Vol. 6, No. 4, 1993.

Pote, D. H., T. C. Daniel, A. N. Sharpley, P. A. Moore, Jr., D. R. Edwards and D. J. Nichols, "Relating Extractable Soil Phosphorus to Phosphorus Losses in Runoff," *Soil Sci. Soc. Am. J.* 60:855-859 (1996).

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