Phosphorus-Based Nutrient Management Planning

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Historically, nutrient management plans were based primarily on nitrogen (N) to optimize forage production and to minimize nitrate contamination of groundwater. For example, most nutrient management plans written in Arkansas to date have been based on nitrogen since forage crops need much more nitrogen than phosphorus (P). In nitrogen-based plans, the long-term use of poultry litter as fertilizer on forages typically leads to the buildup of soil P. Due to the sensitivity of water quality to P and the excessive P applications in nitrogen-based plans, nutrient management plans are now being written where greater emphasis is given to appropriate P application rates.

This approach does not necessarily mean that application rates will be based on phosphorus instead of nitrogen. If it is determined during the planning process that minimal environmental impact from P exists, then the application rates may well be based on nitrogen. The production ramifications of P-based application rates when using manure are that more acreage will be needed to spread the same amount of manure and that nitrogen needs from the manure itself will be insufficient to meet high production goals.

Phosphorus Planning Options

When the federal agencies, Natural Resources Conservation Service (NRCS) and Environmental Protection Agency (EPA), switched to P-based planning, they listed three options for doing so:

1. Forage phosphorus needs based on soil test.
2. Environmental Soil Test P thresholds.
3. Phosphorus Index (P-Index).

Option 1 would only allow the application of P to pastures where soil test recommendations would warrant P fertilizer needs. The establishment and maintenance of most cool- and warm-season grasses grown as forage in Arkansas do not require additional P when soil test P is greater than 120 lbs/acre, as determined by the University of Arkansas Soil Test Lab (Modified Mehlich 3 extractant). This option is the most restrictive on the use of litter on most forages grown in Arkansas, especially where litter has been used previously.

Option 2 is based on research that indicates that the concentration of P in runoff increases with each increase in soil P and at some soil P threshold, the concentration in runoff becomes environmentally questionable. In Arkansas, 300 lbs per acre has been the most discussed threshold. For example, if the soil P in your pasture

is > 300 lbs per acre, then additional P applications would be halted. This option is not as restrictive as option 1, but many pastures in Arkansas already exceed this threshold. However, several states have adopted environmental soil test P thresholds.

Options 1 and 2 have the potential to cause social and economic harm for producers, who legally and without malice, have applied animal manures to pastures for years. One scientific argument against options 1 and 2 is that soil test is not the only factor that influences P movement in runoff. Other factors such as runoff potential, slope, ground cover, application timing, rainfall, etc., can influence the movement of P from pastures. Another problem with option 2 is that research has shown that at the same soil test P level, P losses can be different for different soils. This implies that a P environmental threshold may, in fact, be different for different soils so that a single threshold value would not work for all soils.

The biggest scientific fallacy of options 1 and 2 is that they only focus on soil P levels to the exclusion of other factors that may in fact have as much influence on the fate of land-applied phosphorus as soil P levels.

The P-Index Approach

Option 3, the P-Index, allows the flexibility for these other factors to be accounted for in P-based plans and application rates. It is thought that the movement of P is some function of the interaction between a P source such as soil P or soluble P in poultry litter and those factors that influence the transport of P and other considerations such as management or:

*P Loss to Edge of Field = f (source * transport * other considerations)*

Because so many variables can affect the loss of P to the edge of the field, it is extremely difficult to accurately quantify P loss without collecting a known runoff volume from a given field and analyzing the runoff water for P concentration. By multiplying the runoff volume by the P concentration, the mass of P loss can be determined. Obviously, this monitoring approach is neither economically feasible nor logistically practical for every field where nutrient management plans are to be developed.

The interaction between a P source and the factors that can influence its movement is highly complex and not well understood or quantified. Research will continue to improve our understanding. Mathematical models have been developed to predict the P movement from agricultural fields. The problems with this approach include:

- Requires many parameters, some of which have to be measured.
- Many parameters are highly variable within a field.
- Outcome accuracy can by accompanied by a high degree of uncertainty.
- Mathematical sophistication may require a high level of expertise for proper use and interpretation.

These factors limit the ability of predictive mathematical models to be a practical tool for nutrient management planners in developing appropriate P-based plans. For this reason, many scientists have taken an indexing approach to account for P. The premise behind an indexing approach is that if you can't quantify P loss from an individual, then at least you might be able to determine the relative risk of P loss by considering only a few important indicators in a weighted matrix approach. This a form of risk assessment that can be used to make better management decisions without actually quantifying P loss but rather determining the potential risk relative to a predetermined acceptable risk standard.

The original P-Index was developed by NRCS for row crop applications. It considered the following factors along with their respective weighting factor to indicate the degree of influence of the factor (Table 1).

Table 1. Influencing factors for phosphorus loss in the original P-Index along with the weighting factors

Factor	Priority Weighting
Soil erosion	1.5
Irrigation erosion	1.5
Soil erosion	1.5
Distance from watercourse	1.0
Soil runoff class	0.5
Soil test P	1.0
P fertilizer application rate	0.75
P fertilizer application method	0.5
Organic P (manure) application	1.0
Organic P application method	0.5

A weighting factor of greater than 1 means that factor is considered more important in considering risk than a weighting factor of 1. At the other extreme, a weighting factor less than 1 means that factor isn't deemed as important as a factor with a weight of 1 in considering risk. The weighting factors are used to mathematically rank the factors in potential influence.

For each category of a given factor, a P loss rating is assigned. For example, the P loss ratings for categories of soil test P in the original index are shown in Table 2.

Table 2. The soil P loss rating for given soil test P category

Soil Test P	P Loss Rating	Loss Weighting Factor
None	Negligible	0
Low	Low	1
Medium	Medium	2
Optimum	High	4
Excessive	Very High	8

To determine the influence of soil test P, simply multiply the soil test P weighting factor and P loss rating. For example, the soil test P weighting factor is 1 and the P loss weighting factor for optimum soil test is 4; therefore, the contribution from soil test is 1 x 4 = 4. This process is repeated for each of the factors and then the contribution of each factor is summed to calculate a relative risk assessment value.

The P-Index philosophy has been adopted in 47 states as the phosphorus management planning tool of choice. Because the factors that influence P loss can be different in their influence, the weighting factors in the original P-Index had to be adjusted to fit the given situation using local knowledge and research. Each state has modified the original P-Index to fit its situation and conditions. The state of Arkansas has developed P-Index approaches for given situations that are used to determine manure application rates in nutrient management plans.

The P-Index provides a better risk assessment of P loss in runoff, while providing greater management flexibility for producers. The basic premise of this approach is to determine the relative vulnerability of P loss in runoff from a given pasture. It is not meant to accurately predict P concentration in runoff, but rather assign relative risk by a detailed evaluation of those factors that affect the fate of P in the environment. Based on this vulnerability assessment, a P-Index value is determined which is used to develop pasture management options and manure application rates.

P Source Terms

Of the 47 states that utilize a P-Index, 46 include soil test P as a term to describe potential P sources available for transport. Soil test procedures are not universal and vary from state to state. In fact, at least 12 different chemical extractants are used across the country, and even those states using the same extractant may use a different method of analysis. Thus, comparing soil tests from different states and even different labs is not encouraged. Close attention should be paid to the soil test lab recommended by the given P-Index as the results from other states or labs may produce erroneous P-Index values.

The other common source term is application rate of P as P_2O_5 as either manure or fertilizer in lbs/acre/year. All but six states use this factor. For the most part, this factor estimates the total P potentially available to be lost. In actuality, only a small percentage of P applied may be lost, but this percentage is difficult to determine under natural conditions.

The method of application is considered by almost all states. The three prevalent categories include surface applied, incorporated via tillage and injection. The prevailing philosophy is that there is greater potential for P loss in surface application than in incorporation or injection. The lone exception to this would be the case when tillage for incorporation promotes excessive rates of erosion.

P Transport Factors

The movement of P can be influenced by soil erosion, surface runoff, subsurface flow, soil and site conditions and slope. These are the most common factors among the 47 states that utilize a P-Index approach. The consideration of only these factors implies determining the movement to the edge of a given field. However, many states also try to account for watershed-scale factors such as hydrological connectivity to a stream, distance to a stream and potential P retention between fields and stream. These factors are used to account for movement beyond the field of origin to streams or other P-sensitive water bodies.

Almost all states use the Revised Universal Soil Loss Equation to account for soil erosion. Almost all states account for runoff potential. However, how they account for it varies greatly from state to state. Some use the NRCS runoff curve method, others use only soil hydrologic group, while others use a combination of factors such as slope, precipitation, etc. Yet, other states use soil permeability or subsurface flow as an indicator of potential runoff.

More states than not account for watershed-scale factors to assess the risk of P moving beyond the edge of a field to a receiving stream. Distance to stream is the most prevalent factor that is considered. Some states consider other factors such connectivity to a stream, the presence of a grass buffer, flow channeling and riparian zone status.

Determining the Risk Assessment Value

As discussed earlier, individual states use different factors in their respective P-Index schemes. They also use different weighting factors based on local knowledge and experience, and different

methods in calculating the P-Index risk value. Many states use an additive approach similar to the original P-Index, while others use a multiplicative approach. Individual states also have developed their own interpretations and risk acceptance values. P-Index values from one state cannot be compared to values from other states. Sharpley et al. (2003) provides an extensive review of all 47 states' P-Index approaches. The P-Index is the superior option for developing P-based nutrient management plans. It provides greater flexibility for planners in developing nutrient management plans and provides greater flexibility for producers to effectively manage P.

Selected References

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