Soil Test Phosphorus Threshold Levels

Task Force Members: S.E. Feagley[1] and John Lory[2]
[1]Texas A&M University, College Station, TX. [2]University of Missouri, Columbia, MO.

Purpose of This Publication

The Natural Resources Conservation Service (NRCS) and the US Environmental Protection Agency (USEPA) suggested three methods for assessing phosphorus (P) loss potential from agricultural fields to water resources: agronomic soil test P; threshold soil test P; and the P index. This paper reviews how the P threshold is currently being used in the US, considers the efficacy of a P threshold to protect water quality, considers the differences between threshold P limits and the agronomic soil test P limit, and recommends a systematic strategy for developing and using a P threshold in states where it is required.

Introduction

Phosphorus is the primary limiting nutrient in most surface freshwater bodies (Sharpley et al., 1994). Water quality issues from algal blooms have been related to excess nitrate-nitrogen (N) and P transported into surface water bodies. Reducing P inputs from non-point sources such as agricultural fields is considered essential for remediation of many nutrient impaired rivers, streams and lakes.

The NRCS Code 590, Nutrient Management Practice Standard, and the revised USEPA regulations for concentrated animal feeding operations (CAFOs) require some farms to assess potential for P loss from all fields receiving manure (USDA-NRCS, 1999; USEPA, 2000). The objective of the assessment is to identify fields with a high probability of high P loss. Interpretation of the specific assessment categories varies among states, but generally fields with a low or medium rating allow N-based manure application, high fields must use P-based application strategies and manure applications should be avoided on fields with an assessment rating of very high.

Three methods of assessment were approved at the national level. The *agronomic soil test P* approach is based on standard soil testing and interpretation procedures already in place in most states. The objective of these systems is to identify fields with a high probability of increased yield with additions of P fertilizer. A main assumption of the agronomic approach is that P applications that meet the agronomic need of a crop are justified from a water quality assessment perspective. The agronomic soil test P approach typically results in the most restrictive limits on manure application.

Threshold P is similar to the agronomic approach in that it is based on a single parameter, soil test P. The assumption of this method is that there is a soil test break point, different than the agronomic limit for crop response, where higher soil test levels lead to increased degradation of water resources. Typically, threshold P values, where they have been developed, are set substantially higher than agronomic limits.

The *P Index* approach integrates multiple characteristics of a field accounting for factors such as soil erosion, soil test P, manure and fertilizer P rate, and distance from the nearest water body. Specifics of the P index vary from state-to-state but in all cases inputs are integrated into a loss assessment rating for the field. The P index approach is considered in detail in another SERA-17 position paper.

National standards do not require states to offer all three approaches as options and many states have chosen not to implement all three. The P index has been the most universally adopted and P indices are now available in 49 states. The threshold method has been much less universally adopted. Table 1 summarizes how the P threshold has been implemented in six states that have adopted the P threshold approach.

The threshold approach has been the most controversial and least supported of the three assessment approaches. There has been consensus among most experts that P loss assessments focused solely on soil test P, such as with the threshold approach, are not the most effective method to identify fields with high potential for P loss. SERA-17, the organization of researchers that sponsored this position paper, submitted public comments recommending against the use of the P threshold to both NRCS and USEPA when those organizations were developing their nutrient management standards. We will discuss in detail the limits of the P threshold approach in a later section.

Structure of Phosphorus Thresholds

The threshold method has been implemented in a number of different ways in the US. In some states it can be used as a stand-alone tool to assess P loss from fields (examples include Indiana and Oklahoma (Table 1)). Another approach is to use the P threshold as a screening tool to identify the fields where the more time and data intensive P index approach must be used (examples include Pennsylvania and Texas). A third approach is to define a lower threshold where the P index must be used and a higher threshold above which no application of manure is allowed (examples include Virginia). Most states are very specific on the sampling depth and the soil test P method that are used in the P threshold methods (Table 1).

States vary in the threshold values used for assessment (Table 1) and the approach used to establish the soil test P threshold. In some cases the P threshold has been established without establishing a connection to water quality criteria. For example, in Texas, the high soil test P rating was based upon the Texas A&M extract (a modified Morgan extract). In the early 1990's, a group of Experiment Station and Extension soil scientist were asked by Texas Commission on Environmental Quality personnel what soil test P concentration would insure no response to added P across the whole state. Based upon the Texas A&M extract, that P concentration was 200 mg kg^{-1}. In January 2004, Texas A&M implemented the Mehlich 3 extract. The threshold P concentration has remained the same because it is in Texas regulation. (Table 1).

In contrast, McDowell and Sharpley (2001) and Sharpley et al. (2001) used a split-line model that describes two linear relationships whose slopes are significantly different to estimate threshold P concentrations for five soil series in Pennsylvania. Equations 1 and 2 describe the line below and the line above the P threshold, respectively:

$$\text{Dissolved P} = m_1(\text{Mehlich-3 P}) + c \quad (1)$$

$$\text{Dissolved P} = m_1(\text{Mehlich-3 P}) + m_2(\text{Mehlich-3 P} - \text{Mehlich-3 P threshold}) + c \quad (2)$$

where c is the intercept, m_1 is the slope of the linear relationship for values of Mehlich 3 extractable soil P less than the threshold, and m_2 is the difference in slopes after the threshold compared with m_1. The point at which the two linear relationships crossed was determined to be the P threshold. Using soil samples from 72 sites from four soils in the FD-36 watershed in Pennsylvania, Sharpley et al. (2001) found that the P threshold varied from 185 to 190 mg kg^{-1}. They used this data to establish the P threshold at 200 mg kg^{-1} for Pennsylvania.

When the P threshold is used as a screening tool for the P index another approach can be used to establish P thresholds. If there are soil test levels where it is highly likely the P index will recommend no P limits, there is no benefit to forcing planners to use the more complicated and time consuming P index approach. The appropriate P threshold can be established through trial and error, entering “worst-case scenarios” into the P index and establishing the maximum soil test level where the P index is unlikely to recommend P limits. This “lower” threshold would then be used to define the soil test level above which the P index must be used. Most of the newer P indices now include erosion and P application rates as continuous variables, making establishment of this type of threshold dependent on a judgment of the highest rates of erosion and manure application to be expected.

Another criterion for a P threshold is a soil test level above which the state P index is guaranteed to recommend no manure applications to the field. The appropriate “upper” P threshold can be established by entering “best-case scenarios” into the P index and establishing when high soil test levels in these ideal conditions still result in a very high P index rating and a recommendation of no manure applications. A best-case scenario to establish this upper soil test P threshold should assume erosion is below T (e.g. 85% of T), there have been no P applications, and other P index factors are minimized. At this point we are not aware of any states using a P threshold in this manner.

Benefits and Weaknesses of the Phosphorus Threshold

The primary strength of the P threshold is that it is a simple, easy to implement criterion for regulation. It is based on a single soil attribute, soil test P, that can be determined quickly and be cost effective. Frequently farmers already have the needed soil test completed.

There are numerous weaknesses in the P threshold approach. Foremost, it considers only soil test P and does not consider P transport factors known to be important in predicting P loss. This hampers its ability to accurately identify management practices leading to high P transport as surface runoff and/or leaching. Extensive controlled small plot research has demonstrated P concentrations in runoff will increase with increasing soil test P values. But other factors can overwhelm this effect. For example, surface-applied manures can cause very high P losses irrespective of soil test P (Withers et al., 2001; Daverede et al., 2004). Soil test P thresholds ignore these losses and do not encourage implementation of best management practices to control these losses. That is why soil test P was often poorly correlated with P loss in research including other factors involved in P loss from agricultural fields (e.g. Sharpley et al., 2001; DeLaune et al., 2004).

Another assumption of the P threshold approach is that moving P applications from high testing soils to lower testing soils will result in reduced transport of P to water bodies. In some cases this is true when there is a soil test P break point above which higher P losses have been measured (e.g. Sharpley et al., 2001). In many cases the relationship between soil test P and P concentrations in runoff has been found to be linear (e.g. Sharpley et al., 1976; Pote et al., 1999). In these situations manure applications to similar soils will result in a similar increase in P loading of surface waters on both high and low testing soils. Under these conditions there is no benefit to moving excess P applications to lower testing soils and the setting of the P threshold becomes quite arbitrary. Allowing farmers to raise soil test P to arbitrary values above agronomic P requirements does not qualify as a best management practice for water quality protection.

There are also challenges in using soil testing as a basis for a regulatory standard. Soils are heterogeneous and the application of manures, litters, biosolids, and other organic sources of nutrients are not as consistent across the field as commercial fertilizer. Fig. 1 illustrates the variability of P in a commercially fertilized field. The variability in soil sampling results for P can be greater than 50% within a field, especially for organic sources of nutrients. For example, if we assume the average Mehlich 3 soil test P level is 200 mg kg^{-1} and the variability is 50%, then the range in soil test P would be 100 to 300 mg kg^{-1}. There are numerous reasons for variability in soil test P values including variability in manure application methods and inconsistent distribution of P and other nutrients in the manure. Most soil test P extractions do not extract most of the organic forms of P, but are good extractants of inorganic forms of P. Thus, as mineralization occurs over time, soil test P will change as the organic P is converted to inorganic P forms measured by the soil test extractant. Research in Texas on small plots where manure has been applied by producers and through grazing animals indicates up to 60% variability between representative samples from four small plots (15 subsamples per 1.5 x 2 m plots) within a 20 m area (Jacoby, 2005). Soil test P is a poor criterion for regulatory compliance when the distribution of soil P is this variable. Sampling methods should be developed to reduce this uncertainty. Additional information about methods of soil sampling can be found on the SERA-17 website in a position paper discussing soil sampling.

Position of SERA-17 on the Phosphorus Threshold

We recommend that the threshold P approach not be used as the sole regulatory criterion for compliance because it provides no guidance in key factors controlling P loss. The most appropriate role for soil test P in P loss assessment is as a component of a P index or other P transport model.

A P threshold could be justified when water resource sensitivity or other factors support a threshold P limit *below* the agronomic optimum. Phosphorus thresholds can also be justified when research has documented that a soil test P break point exists where exceeding that break point leads to more rapid P losses. However, incorporating this concept into a P index is more effective than basing P loss assessment solely on this characteristic of the soil.

In some cases there may be an opportunity to use a soil test P threshold to screen soils where the added complexity of the P index is not needed to demonstrate high or low P loss potential. In this use of the P threshold, a lower threshold is set at the lowest soil test P level where the P index will require P-based manure applications under worst-case conditions. An upper threshold is set where the P index is likely to recommend no manure applications even when other P loss factors are favorable. Use of the P threshold in this way will become more difficult to implement as P indices get more complex and better address factors such as timing of P applications and soil type.

We do not support threshold P limits set at an arbitrary level above agronomic optimum levels. These thresholds are essentially a license to farmers who over-apply P to continue to potentially degrade water quality with no incentive to mitigate their impact on water quality or use the manure as a nutrient resource. Such thresholds prolong unacceptable and unsustainable farming practices.

When a federal or state regulatory agency or NRCS makes the decision to establish and use a P threshold independent of a P index, it is recommended that the procedure of Sharpley et al. (2001) be followed. This approach connects the P threshold directly to a known risk factor for higher P loss from a field. Threshold P values based on multiplying the high STP rating by two, three or four must be validated with research that demonstrates the relevance of the P threshold to the risk to water quality impairment. Because the Sharpley et al. (2001) and validation methodologies require an extensive amount of research, it is highly recommended that the research be funded by the regulatory agencies and/or NRCS and that the research be done by State Extension and/or Experiment Station personnel responsible for soil testing, soil fertility, and nutrient management related to CAFOs.

We recommended that if the P threshold is to be used that it be a two tiered system providing an upper and lower threshold value. Fields below the lower value may continue to use N-based management. Fields above the upper value should be rated very high and no manure applications should be allowed. Fields with soil test levels between the upper and lower thresholds should be required to use a P index to assess P loss from a field.

Whenever soil test P is included in a regulatory process, the challenges of obtaining a representative sample must be acknowledged in the recommended sampling procedure and the interpretation of soil test value. Furthermore the depth of sampling and the acceptable soil extraction procedure(s) must be clearly stated. Where soil test P is used as the sole criterion for P loss assessment, farmers must be trained in the optimum timing of P applications and controlling soil erosion.

Our criticism of threshold P does not extend to agronomic P limits. These applications can be justified based on agronomic goals in all but the most extreme circumstances.

References

DeLaune, P.B., B.E. Haggard, T.C. Daniel. I. Chaubey, and M.J. Cochran. 2006. The Eucha/Spavinaw phosphorus index for litter management. J. Soil Water Consv. 61:1-10.

DeLaune, P.B., P.A. Moore Jr., D.K. Carmen, A.N. Sharpley, B.E. Haggard and T.C. Daniel. 2004. Evaluation of the phosphorus source component in the phosphorus index for pastures. J. Environ. Qual. 33:2192-2200.

Daverede, I.C., A.N. Kravchenko, R.G. Hoeft, E.D. Nafziger, D.G. Bullock, J.J. Warren, and L.C. Gonzini. 2004. Phosphorus runoff from incorporated and surface-applied liquid swine manure and phosphorus fertilizer. J. Environ. Qual. 33:1535-1544.

Jacoby, F.J. 2005. Extractable soil phosphorus, correlations with P forms in soil runoff, and relationships with the Texas P Index as a nutrient management tool for CAFOs. Texas A&M University Dissertation. 156p.

McDowell, R.W., and A.N. Sharpley. 2001. Approximating phosphorus release from soils to surface runoff and subsurface drainage. J. Environ. Qual. 30:508-520.

Pote, D.H., T.C. Daniel, D.J. Nichols, A.N. Sharpley, P.A. Moore, Jr., D.M. Miller and D.R. Edwards. 1999. Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. J. of Env. Qual. 28:164-169.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel and K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. J. Environ. Qual. 23:437-451.

Sharpley, A.N. T.C. Daniel, J.T. Sims, and D.H. Pote. 1996. Determining environmentally sound soil phosphorus levels. J. of Soil and Water Consv. 51:160-166.

Sharpley, A.N., R.W. McDowell, J.L. Weld, and P.J.A. Kleinman. 2001. Assessing site vulnerability to phosphorus loss in an agricultural watershed. J. Environ. Qual. 30:2026-2036.

USDA/NRCS. 1999. Policy for nutrient management. General Manual. 190-ECS, Issue-9 (Part 402-Nutrient Management). 402:1-9.

USEPA. 2000. Proposed regulations to address water pollution from concentrated animal feeding operations. EPA 833-F-00-016.

Weld, J, D. Beegle, R. Bryant, W. Gburek, P. Klienman and A. Sharpley. 2007. The Pennsylvania Phosphorus Index, Version 2. The Pennsylvania State University College of Agricultural Sciences, Agricultural Research and Extension Publication, code # UC180.

Withers, P.J.A., Clay, S.D., Breeze, V.G., 2001. Phosphorus transfer in runoff following application of fertilizer, manure, and sewage sludge. J. Environ. Qual. 30, 180-188.

Table 1. Development and use of the phosphorus threshold.

	P assessment methods used						
State[1]	**P index**	**Agronomic P**	**Threshold P**	**Soil Test P Method**	**Sampling depth (inches)**	**Threshold Soil Test P**	**P Threshold Implementation**
Arkansas - Eucha Spavinaw	Yes	No	Yes	Mehlich 3	0 to 4	300 mg/kg	No P application
Indiana	Yes	Yes	Yes	Bray P1 or Mehlich 3	0 to 8	0-50 mg/kg 51-100 mg/kg 101-200 mg/kg >200 mg/kg	N–based 1.5X P removal 1.0X P removal No P application
Kentucky	Yes	No	Yes	Mehlich 3	0 to 6	0-400 lb/A 400-800 lb/A 800-1066 lb/A >1066 lb/A	N-based application P removal applications ½ P removal No manure application
Oklahoma	Yes	No	Yes	Mehlich 3	0 to 6	300 lbs/A 400 lbs/A	Nutrient impaired water body segment, No application Rest of state, P crop removal
Pennsylvania	Yes	No	Yes	Mehlich 3	0 to 6	200 mg/kg	A screening tool, above this value the P index must be used. Other criteria can also trigger the P index usage below this threshold.
Texas	Yes	No	Yes	Mehlich 3	0 to 2 and 2 to 6 (pasture) or 0 to 6 (incorporated)	200 or 350 mg/kg 200 mg/kg 500 mg/kg	If CAFO, must manage according to PI and NMP (200 mg/kg East Texas, 350 mg/kg West Texas) Bosque River, P crop removal Bosque River, P soil test reduction component

(continued on next page)

Table 1. (continued)

	P assessment methods used						
State[1]	P index	Agronomic P	Threshold P	Soil Test P Method	Sampling depth (inches)	Threshold Soil Test P	P Threshold Implementation
Virginia[2]	Yes	Yes	Yes	Mehlich 3	0 to 6	375 mg/kg 458 mg/kg 525 mg/kg	No application above the threshold Upper Costal Plain and Piedmont Lower Costal Plain Ridge and Valley

[1]References: AR, Andrew Sharpley, personal communication; IN, Brad Joern, personal communication; KY, NRCS 590 standard (5/21/01); OK, Hailin Zhang, personal communication; PA, Weld et al., 2007; TX, Sam Feagley, personal communication, VA, Rory MacGuire, personal communication.

[2] Virginia also uses a lower threshold below which N-based management is allowed and above the threshold you must run the P index.

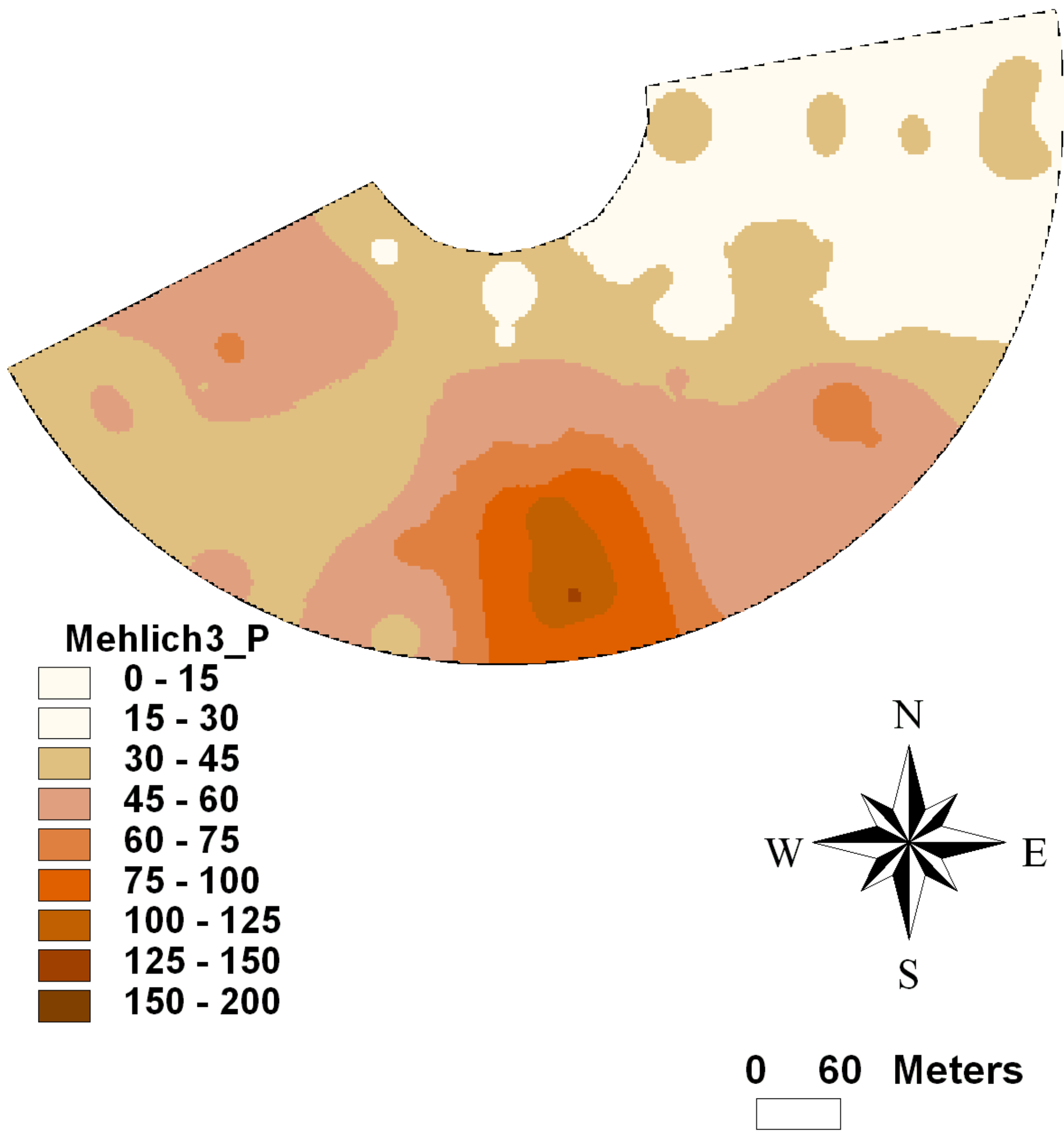

Figure 1. Phosphorus distribution in a commercially fertilized field in West Texas. Data from Kevin Bronson, Texas Agricultural Experiment Station, Lubbock, TX.