Phosphorus Indices to Predict Risk for Phosphorus Losses

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Purpose of this publication: Phosphorus-Indices (P-Indices) have been developed by scientists to help producers and nutrient management planners evaluate and rank potential risk for P loss from agricultural fields. However, the general public and many of our policy makers may not have a complete understanding of the concept or the potential use of the P-Index as a tool in phosphorus management. Therefore, this reader friendly "**position paper**" was developed on the concept and science behind P-Indices, as well as the benefits and limitations of their use.

Introduction

Phosphorus (P) losses to surface waters (rivers, streams and lakes) are a serious concern in some regions, as elevated P concentrations can cause water quality problems in P-sensitive water bodies. Point sources of pollution such as municipal sewage treatment outlet pipes are relatively easy to identify. However, "non-point" or "diffuse" sources such as agricultural fields that may generate P runoff are much more difficult to identify, as their contribution to environmental pollution can vary greatly with time and can enter surface waters over a wide area. The US Department of Agriculture-Natural Resources Conservation Service (NRCS) has proposed three strategies for improving P management and controlling P losses from agricultural fields. These three strategies for P application management, contained in the NRCS conservation practice standard for nutrient management (590), are: either an agronomic or an environmental soil test P threshold above which no more fertilizer or manure P may be applied, or third a P-Index based assessment. Soil testing for P is commonly used to predict the likelihood of a crop response to additions of fertilizer or manure P. Soil testing alone cannot predict environmental P losses, as many other factors (such as rainfall, erosion, drainage, etc.) will influence the concentration of P in runoff and leaching waters. Field management strategies such as crop rotations, tillage, and establishment of conservation buffers, can also impact P losses. Much research has been conducted over the last decades on how P moves from soils to surface waters, with most of this research concentrating on understanding individual P release and transport processes or pathways. In the P-Index, best available knowledge about the individual processes is put together to create one numerical P-Index score. The process takes into account the source and transport for P in order to conduct a comprehensive assessment of the risk of P runoff loss from a site. Once the assessment has been made, if a "High" risk of P loss is calculated, it is then necessary to alter the management of the site to reduce the risk of P losses. Many states (49 states to date) have developed P-Indices by modifying the basic components to make it suitable for local conditions (Sharpley et al., 2003). Such widespread adoption of this indexing concept shows the consensus among scientists, the fertilizer industry and policymakers with regards to the validity of the P-Index approach (Sharpley et al., 2003; Snyder et al., 1999).

Common Structure of Phosphorus-Indices

Most P-Indices require similar input data such as soil test P, P fertilization (inorganic and organic P) rates, method and timing of application, soil erosion, and distance to streams. If a source of P exists at a particular field (such as high soil test P, or recent fertilizer or manure applications), but there is no significant transport pathway for this P to leave the field and enter a stream, then the site does not represent a high risk for environmental P loss. Similarly, if there is a high risk of transport from a site (such as moderate runoff and/or erosion), but there is no large source of P at the site (i.e. low soil test P, or only small or no applications of fertilizer and/or manure), this site also will not represent a high risk for P loss. This is the basic concept of all P Indices, they identify two important categories that can generally be defined as ‘source’ and ‘transport’ factors for P loss, which together identify *critical source areas* (Sharpley et al., 1993).

Phosphorus-Indices rank fields according to risk of P loss in unit-less categories such as “Low”, “Medium”, “High”, and “Very High”. These categories describe whether or not improved management of P is required, and how stringent the P management needs to be, although recommendations vary by state. For example, “Low” and “Medium” indexed sites may continue nitrogen-based manure applications. This most often leads to more P being applied than the soil test recommends or a crop can remove, therefore most states suggest that some P management remediation efforts take place at “Medium” sites. For the “High” sites, the recommendation is generally to limit P applications to no more than what can be removed by the crop, while for “Very High” sites, no additional P may be added in an attempt to lower the P-Index scores (and soil test P) over time (Leytem et al., 2003; Sharpley et al., 2003). Most states also suggest the implementation of best management practices (BMPs) that can reduce the risk for P loss from “Very High” ranked fields (Weld et al., 2001; SERA17, 2005). Such BMPs will vary depending on site specific criteria, but can include options such as reduced fertilizer and manure P applications, changes in the timing and method of application, soil conservation (erosion reduction through reduced tillage and/or cover crop use), installation of conservation buffers, etc.

Science Underpinning the Phosphorus-Indices

All P-Indices were developed and modified using the best available professional knowledge and documented in a wide range of scientific literature. For example, the North Carolina version of the P-Index lists approximately 150 publications in its supporting scientific literature (NC PLAT Committee, 2005). The scientific literature generally reports on individual research studies that investigate and quantify relationships between source and/or site characteristics and P losses in runoff and/or leaching. Phosphorus-Indices consolidate these individual studies into a comprehensive tool that links major transport and source characteristics to rank the risk of P loss. Some validation of P-Indices has occurred showing that higher P-Index rankings correspond to greater P losses, but more validation work is desirable (Veith et al., 2005).

The P-Index was not originally developed to quantify actual (lbs/acre) P losses from fields (Lemunyon and Gilbert, 1993). However, with the increasing number of studies being reported in the scientific literature and with additional P-Index validation studies, some of the currently implemented P-Indices may in the future be modified to allow for quantification of P loss at the field scale. An extension of the risk assessment and indexing procedure will lead to a P model that uses site-specific data and processes to quantify actual P losses.

Benefits of Phosphorus-Indices

The use of P-Indices in the field to assess P loss risk requires a number of site-specific characteristics. The field data have to be readily assessable in order for the field technician or producer to do the index. Some of the data can come directly from the producer (e.g., timing, rate, and method of P application). Other site characteristics may be found in soil surveys and soil test results, while others may require some preliminary planning, like making erosion predictions using RUSLE2 for water or the wind erosion equation.

Many studies have demonstrated good relationships between soil test P values and particulate and soluble P losses in runoff when all other conditions are equal (e.g. Pote et al., 1996). However, soil test P alone does not take site management into consideration. Lemunyon and Gilbert (1993) reported that in general, cultivated fields lost most P in the particulate form while forest and grassland lost most P in the soluble form. Torbert et al. (2005) observed dissolved P losses increased with increasing rate of manure application, but that incorporation of manure decreased P losses. Phosphorus-Indices incorporate soil test P as one variable, but a comprehensive P-Index considers individual site and management characteristics instead of soil test P value alone and is far superior for determining potential runoff risk. Phosphorus-Indices can show that some fields with high soil test P have little risk of P losses due to minimal risk of transport from the field, and therefore do not strictly limit P additions to these fields. Limiting P applications on soil test P alone is therefore generally more restrictive than implementing a P-Index. In situations where livestock producers have to dispose of excess manure, a P-Index would be less restrictive than application of manure P based on a soil test P threshold. This may be a benefit to the producer in the short term, but may lead to problems in the long run as soil test P may increase further in these fields until it causes the site to be ranked “High” by the P-Index.

Phosphorus-Indices generally identify only relatively small numbers of fields within watersheds as needing improved management of P, allowing producers to continue with their normal practices outside of these critical source areas (Leytem et al., 2003). Flexibility in management is a key asset to implementation of P-Indices. With the soil test P threshold approach, P application would be restricted once soil test P values reach the threshold. However, P-Indices allow producers or other land users to select from many strategies that will reduce the risk for P loss, including changing the method and/or timing of fertilizer or manure application, changing crop rotations and tillage practices to reduce erosion, or installing vegetated buffers or application setbacks to increase flow distances. This flexibility will help the producers search for the best methods to maintain profitability while protecting the environment.

Computer models, such as the Soil and Water Assessment Tool (SWAT), can give detailed output on P losses at the watershed scale. However, such models require large quantities of detailed input data as well as knowledge on how to run the computer software and interpret results, and do not necessarily represent P loss processes any better than P-Indices (Veith et al., 2005). Producers, regulators and other stakeholders normally require a more user-friendly and simple tool to evaluate the risk of P loss. Phosphorus-Indices are much easier to use and obtain input data, yet are good planning alternatives to the use of complex computer models.

Limitations of Phosphorus-Indices

As already discussed, soil test P is not as good at predicting P losses in runoff as P-Indices. However, soil test P is often routinely measured on agricultural fields. Regulating P applications above a certain level of soil test P does have the advantage of being a cheap and easy way to limit P applications (since it can be done as part of agronomic fertility soil sampling and testing guidelines anyway). As P-Indices require field input information such as slope steepness and length, a site visit is needed for the first year of an assessment of the P-Index. Therefore, P-Indices are more costly to initially determine and implement than a soil test P threshold. Advances in spatial analyses technology and database management may greatly reduce P-Index costs in the future. In the interim, due to the cost of implementation of a P-Index approach, some states have implemented a screening tool to quickly identify sites that are likely to have a high risk of P loss, and only on these sites are the full P-Index evaluations run (Sharpley et al., 2003).

Where inorganic fertilizers are used as the main P source, P-Indices will be effective at reducing P losses as reductions in P fertilizer rates in combination with better site management are relatively simple. However, for most animal feeding operations land application of manure is the only economic path for use / disposal and in some situations the amount of manure generated contains more P than local crops require. In these situations P-Indices will serve to move manure applications away from sites with a high risk for P loss to those with a lower risk, or to change management to reduce risk of P loss. This improved management of manure-P will reduce P losses in the short term. In the long term, the shift in manure application to lower risk fields will cause soil test P levels to increase. This is acceptable if soil fertility levels need to be built up, yet can be unsustainable over the long-term when soil test P reaches unacceptable levels across the farm. There may be no other options for manure application other than export from the farm. Therefore, in areas of intensive animal production, the long term goal must be to match manure P production with local crop P requirements, or to find alternative uses for the manures outside the farm boundary.

Position of SERA17 on Phosphorus-Indices

Predicting P loss from the landscape based on soil test P alone is not feasible. Phosphorus-Indices represent the “state of the science”, incorporating P source and transport components, and are valuable tools to rank fields based on their relative risk of P loss. These Indices are excellent decision support tools that offer the farm planner and producer a method to identify site characteristic and management techniques that impact the potential for P loss. These identified site conditions can be modified or altered with BMPs and management practices.

It is the position of SERA17 that P-Indices are preferable to soil test P threshold values or any other current risk assessment techniques, in situations where P loss assessment must be carried out by a variety of personnel and stakeholders. However, it should be understood that the implementation of P-Index based management only addresses short-term P loss issues. For long-term sustainability, applications of P must approach a balance with crop removal.

References

Lemunyon, J.L., and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6:483-486.

Leytem, A.B., J.T. Sims, and F.J. Coale. 2003. On-farm evaluation of a phosphorus site index for Delaware. Journal of Soil and Water Conservation 58:89-97.

NC PLAT Committee. 2005. North Carolina Phosphorus Loss Assessment: I. Model Description and II. Scientific Basis and Supporting Literature, North Carolina Agricultural Research Service Technical Bulletin 323, North Carolina Sate University, Raleigh, NC.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60:855-859.

SERA17 (Southern Extension and Research Activity 17). 2005. BMP Workgroup Publications. www.sera17.ext.vt.edu/SERA_17_Publications.htm

Sharpley, A.N., T.C. Daniel, and D.R. Edwards. 1993. Phosphorus movement in the landscape. Journal of Production Agriculture 6:492-500.

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore, and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation 58:137-152.

Snyder, C.S., T.W. Bruulsema, A.N. Sharpley, and D.B. Beegle. 1999. Site-specific use of the environmental Phosphorus-Index concept. Site Specific Management Guidelines. SSMG-1. Potash and Phosphate Institute. Norcross, GA. www.ppi-far.org.

Torbert, H. A., R. D. Harmel, and M. Dozier. 2005. Evaluation of some phosphorus index criteria in cultivated agriculture in clay soils. Journal of Soil and Water Conservation 60:21-29.

Veith, T.L., A.N. Sharpley, J.L. Weld, and W.J. Gburek. 2005. Comparison of measured and simulated phosphorus losses with indexed site vulnerability. Transactions of the American Society of Agricultural Engineers 48:557-565.

Weld, J.L., A.N. Sharpley, D.B. Beegle, and W.J. Gburek. 2001. Identifying critical sources of phosphorus export from agricultural watersheds. Nutrient Cycling in Agroecosystems 59:29-38.