

ON-FARM IMPLEMENTATION OF THE PHOSPHORUS INDEX OBSERVED RISK RATINGS AND IMPACTS ON FERTILIZER AND MANURE PHOSPHORUS MANAGEMENT

Antonio P. Mallarino
Professor

Department of Agronomy, Iowa State University

David J. Wittry
Assistant Scientist

Department of Agronomy, Iowa State University

Why is the Phosphorus Index Useful and Needed?

The Iowa phosphorus (P) index is an assessment tool that was developed to assess the risk of P loss from fields to water resources. It provides a risk rating that also can be used to prioritize fields or field zones for manure or fertilizer P application and for implementing improved soil conservation practices. Scientists have been proposing such a tool since the early 1990s, and it has evolved from a simple subjective tool to a more complete objective tool without becoming a complex model of P flow. The need for a P index has its origin in two main issues. One is that P accumulation in many soils in excess of amounts needed by crops has increased P losses from fields and has resulted in poor water quality in many streams and lakes. Water quality is impaired through a process known as eutrophication, which occurs when nutrient levels in water (mainly P) are high and stimulate excessive algae growth. Excessive algae growth reduces water oxygen levels and creates ecological imbalances that result in reduced populations of desirable fish species as well as reduced drinking and recreational value of lakes and streams. The second issue is that P loss from fields cannot be appropriately assessed or predicted only from knowledge of soil-test P, manure or fertilizer P applied, and method of P application used. Although these P source factors are important, how P can move off fields through various transport mechanisms is as important. Therefore, a new tool that integrates P source and transport factors was needed to estimate risk of P loss from fields. The P index also provides information useful to decide among several soil conservation and manure or fertilizer P management practices that can maintain a low risk of P loss or can reduce it.

Most scientists with expertise in nutrient management and soil conservation practices had no doubt in recommending the P index when in 1999 the United States Department of Agriculture Natural Resources Conservation Service (NRCS) issued a national policy to include an environmental P assessment tool in nutrient management guidelines. The national guidelines gave the States flexibility to choose between soil-test P categories used for crop production, environmental soil-test P threshold limits, or the P index. The State of Iowa Technical Committee chose the P index approach based on advice from a task force that included scientists from Iowa State University and the USDA/ARS Soil Tilth Laboratory, technical personnel from Iowa NRCS and the Iowa Department of Natural Resources (IDNR), and representatives of various interest and commodity groups. All NRCS staff and technical service providers use the P index for guidance when providing financial or technical assistance to producers. The Iowa legislature mandated IDNR to use the P Index for manure management plans for confined animal

feeding operations, and specific rules became effective in October 2004.

Phosphorus Source and Transport Factors Impacting Phosphorus Loss

The soil-test P level and the P application rate are the most frequently mentioned factors in relation to potential P loss to surface water. Numerous completed and ongoing research projects in Iowa and other states demonstrate that the risk of P loss increases with soil-test P values and when P application rates increase. Results indicate that usually the P loss increases linearly with increasing soil-test P and P application rates. In some instances, however, increasing manure or fertilizer P rates result in exponential increases in P loss, meaning that P loss increases faster at high rates. Additional source factors needed to estimate or predict P loss from fields include the method of P application and the tillage system. Injecting, deep banding, or incorporating P reduces the concentration of P near the soil surface and, therefore, reduces the risk of P loss with erosion or surface runoff. However, P applied to no-till fields or pasture accumulates near the surface while tillage tends to reduce P stratification in the soil. Iowa research shows that heavy rainfall immediately after applying manure or P fertilizer to the soil surface results in large P losses although the loss decreases much when rainfall is delayed. The loss of dissolved P in water is higher in fields managed with no-till or pasture and the loss of P bound to soil particles is higher in tilled soils.

The previous comments demonstrate the importance of soil erosion and water runoff for estimating or predicting P loss from fields. Furthermore, the distance between the field and a stream or lake and any other factor affecting the transport of P bound to soil or dissolved in water off a field also are important. Because P does not move through soil water or with soil water nearly as easily as nitrate, for example, soil erosion or surface runoff are required to produce large loss of P from fields. Iowa research has shown that dissolved P can move through the soil profile and subsurface drainage tiles, but amounts lost are many times smaller than amounts lost through erosion or surface runoff. Because of the relationship with erosion and surface runoff, the tillage system and timing of P application become important when estimating risk of P loss. Tillage increases soil erosion and loss of P bound to soil particles in sloping ground. In no-till or pasture fields, loss of particulate P is much reduced. Large loss of dissolved P can occur when P is applied without incorporation to wet, snow-covered, or frozen fields because runoff from rainfall or snow melt is likely. The probability of P loss also is larger when P is applied in spring without being injected or incorporated compared with application in summer or fall because the probability of heavy rainfall and surface runoff is much higher in spring.

Why is it that scientists and regulatory agencies emphasize manure P sources over fertilizer P sources when considering P loss from fields? Excessive use of either fertilizer or manure P results in a similar risk of P loss from fields. In practice, however, higher soil-test P and P application rates and application during high-risk periods are more frequent for fields where manure is applied. Excess P application is more likely for manure for various reasons. Due to its N-P content and likely N loss during storage and application, manure rates that supply the N required by crops or N removed with grain harvest usually results in a soil P buildup. Also, manure is applied to snow-covered or frozen ground with high risk of surface runoff more frequently than fertilizer because of manure storage limitations and a desire to avoid soil

compaction during application.

What is in the Iowa P Index?

The Iowa P index (NRCS Field Office Technical Note 25) in its printed or worksheet calculator versions and support articles are available at the Iowa NRCS web page and other sources, so only a summary of its major components are provided here. The index includes P source and transport factors to estimate P that can reach surface water resources and to establish five risk classes. The P source factors are arranged within three components corresponding to three P transport mechanisms: Erosion Component (P bound to eroded soil), Runoff Component (dissolved P in surface runoff), and Subsurface Drainage Component (dissolved P in water flowing through tiles and/or coarse subsoil). The partial values for each component are totaled to provide an overall estimate of P loss (lb. P element/acre/year). The possible resulting numbers are placed into five risk classes ranging from very low to very high. The index values, risk rating classes, and meaning for water quality are summarized in Table 1.

The P index accounts for potential loss of both dissolved P in water and P bound to sediment. The dissolved P is readily available for algae growth, whereas a large proportion of the bound P will be released to the water over a variable period of time depending on many factors such as soil and water chemistry, water depth, water input and output patterns, and water body usage among others. The index uses common tools and models used by NRCS and Iowa State University to estimate the impact of landscape forms, soil types, and management practices on soil erosion, surface runoff, and water loss from fields. Therefore, it uses existing databases for soil classification, landscape forms, and major soil physical properties; the revised universal soil loss equation (RUSLE 2) to estimate sediment loss through sheet and rill erosion; sediment delivery ratios or sediment traps (terraces, ponds, filter strips) to estimate sediment delivery off fields; runoff curve fractions to estimate water runoff; and historical precipitation averages for each Iowa county. This approach utilizes already available information and simplifies the implementation of the P index as much as possible.

The P index accounts for soil-test P as well as manure or fertilizer application rate, method, and timing. A recent soil-test P value based on tests and soil sampling methods recommended for Iowa is needed for the index. These include four tests (Bray-1, Mehlich-3, Mehlich-3-ICP, or Olsen), a 6 inch sampling depth, and soil sampling strategies recommended by Iowa State University. The soil-test P value is used to estimate dissolved P losses through runoff and subsurface drainage as well as to estimate total soil P that can potentially be lost with eroded soil particles. Iowa research results from commonly used field practices and laboratory soil testing procedures have been used to obtain equations relating total or dissolved P loss and soil-test P. The index recognizes that injecting or incorporating manure or fertilizer into the soil with tillage as soon as possible after application reduces the risk of P loss, as long as the operation does not result in excessive soil erosion. The index also recognizes that surface application of any P source to frozen, snow covered, or water-saturated ground will sharply increase the risk of P loss with surface runoff.

The computer spreadsheet (Microsoft Excel) and printed versions of the P index were designed to require as few inputs as possible from the producer or nutrient management planner. By knowing the location of the field and soil and crop management practices, the user can obtain

erosion estimates from the local NRCS office. Nutrient managers with sufficient background knowledge can calculate erosion estimates directly using RUSLE 2. This information together with soil-test P, distance to the nearest stream, and other information provided in the printed or computer index versions allow for calculating risk values and ratings. The P index can be calculated for an entire field or, even better, for within-field conservation management units or zones. These zones are field portions with different soil types, soil-test P values, or landscape that justify different land use and nutrient management plans.

The P index does not directly provide recommendations for soil conservation or P management practices. The index rating indicates if there is a problem and its severity. However, study of partial index values for the three components provide clues about causes of high risk of P loss and changes needed to reduce P loss. Observation of partial index values for the erosion, runoff, and subsurface drainage components reveals the transport mechanism responsible for the highest risk of P loss.

Implementation of the P Index to Improve P Management Practices

We developed a three-year project in cooperation with Iowa NRCS and IDNR to implement the index on farmers' fields. The objectives of the project were to learn about the index application to real field conditions, demonstrate its use, see what ratings are obtained for a variety of conditions, and to study its application to entire fields and to field zones. We collected field information and calculated P index ratings from 33 fields grouped in six clusters across the state having different soils and management practices. In most fields new information was collected for a second year and new index ratings were calculated. The clusters were in Adams (southwest), Buchanan (northeast), Crawford (west), Plymouth (northwest), Cerro Gordo and Hancock (north), and Des Moines, Jefferson, and Washington (east-southeast) counties. The production systems at the farms involved only row crops or both livestock (cattle, poultry, or poultry) and rows crops. Twenty fields were managed with corn-soybean rotations, two with continuous corn, and nine with hay or pasture in the rotation. Table 2 provides summarized information about soil-test P levels, slopes, and estimates of erosion across the fields. These values indicate that the fields under study encompassed a wide variety of conditions commonly found in Iowa.

As expected due to the variety of fields, crops, and soil-test P values the P fertilization rates that would be needed varied widely across fields, and this information cannot be summarized here. Furthermore, the amount of manure needed to supply N and P needs of crops varied widely and varied depending on the criteria used to decided the N and P application rates. For example, current Iowa State University recommendations provide nutrient application rates needed to produce or maintain economically optimum crop yields. However, IDNR guidelines for manure management plans include nutrient application rates based on nutrient removal with harvest. Data in Table 3 provides a summary of the average P and liquid swine manure rates that would be applied according to different criteria. The very low average P rate that would be applied if P recommendations for crop production were used reflects generally high-testing soils across the fields. This result also reflects generally optimum or higher than optimum soil-test values in Iowa. The average amount of manure that would be applied (assuming average N and P concentrations) differs greatly between N-based and P-based recommendations to supply N and

P needs of crops but also between recommendations for crop production and those based on nutrient removal. Recommendations to supply P needs of crops would result in very little or no manure applied to most fields. Recommendations based on N removal with harvest would use the highest amount of manure.

A wide range of P index ratings were observed across the 33 fields. Field-average P index values ranged from 0.5 (very low class) to 8.8 (high class) across fields. Eighteen fields were classified in the very low or low index classes, eleven in the medium class, and four in the high class. This result indicates that on average approximately 50% of the fields had low risk of P loss and that 50% had higher risk and careful consideration should be given to management practices to maintain or reduce the risk of P loss. Another important result was related to the contribution of each index component to the overall index value for a field. Results summarized in Table 4 indicated that partial index values for erosion and runoff components were much larger than for the subsurface drainage component in most fields. This is the result of much larger total P loss through erosion (P bound to soil particles) and surface runoff (P dissolved in water) compared with loss through subsurface drainage (dissolved P). Results indicate that emphasis should be given to control soil erosion and surface runoff to reduce P loss from fields. Controlling soil erosion through conservation structures (terraces, ponds, vegetative filter strips, etc.), better tillage and crop residue management practices, and avoiding extremely high soil-test P levels will result in a significant reduction of sediment-bound P losses. Avoiding high soil-test P levels, using tillage and residue covers that minimize surface water flow, and eliminating application of fertilizer or manure to frozen, snow-covered, or water-saturated ground will result in a significant reduction of dissolved P in surface runoff.

Another significant and very useful result of this implementation project was that calculation of P index ratings for different zones within a field resulted in a much wider range of risk ratings and in contrasting ratings within several fields. The index ratings for some soil map units were as high as 20 (very high index class). The consequences of zoning on resulting P index ratings varied greatly across fields depending on variation in field characteristics because of location in the state, landscape forms, and history of management practices. In 18% of the fields either the field was uniform (reasons to establish zones were not obvious) or the zones had approximately similar ratings. In 61% of the fields one zone had a significantly higher or lower ratings than other zones in the field. In 21% of the fields one zone had a clearly higher rating and one zone had a clearly lower rating while other zones had intermediate ratings.

The results for field zones provided one of the most valuable results of this study because they demonstrate the benefit of zoning for P index calculation. Large variation in P index ratings within field zones in many fields should be expected because of large variation in the source or transport factors that determine risk of P loss. In a few fields zoning may not be relevant because either the field is uniform or the index rating for different zones may fall into the same risk rating class, but results could still be useful because similar overall ratings may arise from different partial index values for the three components. Therefore, in most instances field zoning for index calculation should provide useful information to make decisions about soil conservation or P management practices to be implemented.

What were the reasons for so large and frequent variation in P index ratings between zones

within a field in this study? The reasons were different depending on the field and location in the state. However, large changes in index ratings within field zones most often were explained by large change in erosion rates or the presence of terraces or grass filter strips in some field areas. Other frequent reasons for large differences in index ratings were differences in the distance from the center of the zone to the nearest perennial or intermittent stream or differences in soil-test P. Criteria to delineate zones are many and cannot be discussed here. Presence of terraces, contour cropping, tiles, flood plains, and other structures or management practices relevant to soil or water loss should be used. Information available in Iowa soil survey maps includes soil series names as well as erosion and slope phases. This information can be combined with other field information and soil-test P information and used to delineate zones for P index calculation. This information can also be used to decide not to apply manure or to apply a lower rate to the more critical areas (areas with high soil P levels, near waterways, steep slopes, high flood risk, etc.) when soil-test P is above optimum for crop production.

Because soil survey maps sometimes do not include sufficient detail due to the scale used for their preparation, information collected using precision agriculture technologies can be used to improve the information provided by the soil survey maps. A previous presentation in this conference discussed the value of using this type of information to delineate management zones within a field for soil sampling and fertilization purposes. Yield maps, high-precision elevation maps, electrical conductivity maps, and aerial or satellite images of bare soil or crop canopy can complement information from soil survey maps. However, even considering only the information in soil survey maps is useful to complement site-specific soil-test P information when deciding P fertilizer or manure application rates over a field. A previous presentation in this conference showed how variable-rate liquid manure or fertilizer P application can be used to apply P across a field according to soil-test P or P index ratings.

Summary and Conclusions

Producers can use Iowa P index ratings and knowledge of factors that influence P loss to identify causes of high P loss in their fields and to choose among alternative soil conservation and P management practices that minimize P loss. Study of factors determining high partial index values will reveal the soil or nutrient management practices that cause a high risk of P loss for a specific field or field zone. Such a study will also suggest on a field-specific basis the most economically effective management practices for reducing the risk of P loss. Results for many Iowa fields show that loss of sediment-bound P through erosion is the most common mechanism explaining high P loss and that the second most important factor is the loss of dissolved P through surface runoff. Therefore, controlling soil erosion and surface runoff and avoiding extremely high soil-test P levels are among the most effective ways of reducing the risk of P loss and improving water quality in Iowa. Because the P index has no built-in limits for soil-test P or P application rate and is a flexible site-specific tool producers can use it to identify agronomic management practices that minimize P loss from their fields and improve water quality in Iowa.

Table 1. Iowa P index values, rating classes, and relation to water quality.

P Index Result		
Value	Class	Risk for Water Quality and Management Needs
0-1	Very Low	If soil conservation and P management practices are maintained at current levels, P delivery impacts on water quality will be small.
1-2	Low	P delivery to surface water bodies is greater but current management practices keep water quality impairment low.
2-5	Medium	P delivery is significant and may produce some water quality impairment. Consideration should be given to soil conservation and P management practices so P loss is not increased.
5-15	High	P delivery likely is large and water quality impairment will be large. New soil and water conservation and/or P management practices are necessary to reduce P loss and water quality degradation.
15+	Very High	P delivery is very high and impacts on water quality are extreme. New soil and water conservation practices plus a P management plan, which may require discontinuing P applications, must be put in place to reduce water quality impairment.

Table 2. Summary of relevant characteristics of the fields.

Measurement	Field Average	Highest Value
Soil-test P (Bray-1)	8 - 218 ppm	230 ppm
Slope	1.1 - 14 %	25 %
Erosion (RUSLE)	0.6 - 7.4 ton/acre/year	19.2 ton/acre/year

Table 3. Average P and manure that would have been applied across all fields for various nutrient management recommendation systems.

Recommendation system	P Supplied	Manure Needed
	lb. P ₂ O ₅ /acre/year	gallons/acre/year
P recommendation for crops	2	74
P removal plan	50	1,647
N recommendation for crops	76	2,530
N removal plan	148	4,784

Table 4. Contribution of erosion, runoff, and subsurface components of the P index to the overall P index rating across 33 fields.

Component	Partial Component Contribution (%)	
	Average Across Fields	Range
Erosion	73	31 - 91
Surface runoff	24	7 - 58
Subsurface drainage	3	2 - 7

Useful References

- Mallarino, A.P., and D. Wittry. 2001. Management zones soil sampling: A better alternative to grid and soil type sampling? p. 159-164. *In* The Integrated Crop Management Conf. Proceedings. Dec. 5-6, 2001, Des Moines, IA. Iowa State Univ. Extension.
- Mallarino, A.P., D. Wittry, and J. Klatt. 2001. Using the Iowa phosphorus index and variable-rate technology for effective agronomic and environmental phosphorus management. p. 151-158. *In* The Integrated Crop Management Conf. Proceedings. Dec. 5-6, 2001, Des Moines, IA. Iowa State Univ. Extension.
- Mallarino, A.P., B.M. Stewart, J.L. Baker, J.A. Downing, and J.E. Sawyer. 2001. Background and basic concepts of the Iowa phosphorus index. Available at <http://www.ia.nrcs.usda.gov>.
- Mallarino, A.P., B.M. Stewart, J.L. Baker, J.A. Downing, and J.E. Sawyer. 2002. Phosphorus indexing for cropland: Overview and basic concepts of the Iowa phosphorus index. *J. Soil Water Conserv.* 57:440-447. [Also at <http://www.swcs.org/docs/A.P.%20Mallarino.pdf>.]
- Natural Resources Conservation Service. 2001. NRCS Iowa Technical Note No. 25. Available at <http://www.ia.nrcs.usda.gov>.
- Sawyer, J., A.P. Mallarino, and R. Killorn. 2003. Take a good soil sample to help make good decisions. Publ. Pm-287 (rev). Iowa State Univ. Extension.