FIELD SCALE ASSESSMENT OF PHOSPHORUS LOSS TO SURFACE WATERS FOR PLANNING AND REGULATION: P INDEXES

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ABSTRACT

Fields identified for manure application by large animal feeding operations need to be assessed for the P loss potential from the field to water bodies before March 30 2007. Many states use a phosphorus index to assess the risk of P loss. Phosphorus indices are intended to be easy to use with modest input data requirements. A P index typically considers source (site and management) and transport factors in assessing risk of P loss. A P index may be a tabular worksheet or a simple computer model. This paper discusses basic processes underlying P loss from fields, and the structure and components of P indices.

INTRODUCTION

Field-scale assessment of P loss to surface waters is typically done either using a soil test P (STP) threshold level or a P index. Many states have adopted a P index for regulation of manure application because P indices consider STP as well as numerous other factors that contribute to P loss. Phosphorus indices are tools for identification of fields with high risk of P loss to surface waters that are easy to use and have modest input data requirements. In addition, P indices are used to evaluate the effect of alternative management practices on P loss, and in education and regulation of P management practices and their effects on P loss.

Phosphorus indices typically consider two sets of factors that affect the risk of P loss to surface waters: source (site and management) factors and transport factors. Sources factors generally include: STP; P application practices including time, rate and method of application; and, for some P indices, field management practices such as tillage practices and use of cover crops. Transport factors generally include: expected volume of runoff from the field; erosion due to rainfall, snowmelt and irrigation events; and distance from P source in the field to a stream or water body, or to a channel leading directly to a water body. Some states include percolation and underground movement of P to seepage areas and sub-surface drainage.

SOURCE FACTORS

Soil test P

The potential for P loss from fields increases as STP increases. Soil P tests that measure water dissolved P or presumed bioavailable P (such as the iron oxide impregnated filter paper test) are available for environmental purposes, but most P indices call for the use of an agronomic soil test such as Bray-P_1, Olsen, or Mehlich-3. The STP results of agronomic and environmental tests are generally well correlated and predictive of P concentration in runoff, erosion and sub-surface drainage. The top 1” of soil is most exposed to runoff and contributes most of the P loss during runoff and erosion events. An agronomic soil sample of 0-6 or 0-8” may not represent the risk accurately as in Table 1 for a reduced tillage field where Bray-P1 in the surface 2” of soil is 2.5 times that for the 0-8” depth. Some P indices consider depth of sampling for reduced tillage and no-till situations. Most P indices use the results of sampling for agronomic purposes, generally to a depth of 6 or 8” inches.

Table 1. Bray-P1 and total soil P can become very stratified with manure application and reduced or no tillage. Bray-P1 in the surface 2” of soil is 2.5 times that of the 0-8” sample. Results from research in eastern Nebraska (Wortmann and Walters, 2006).

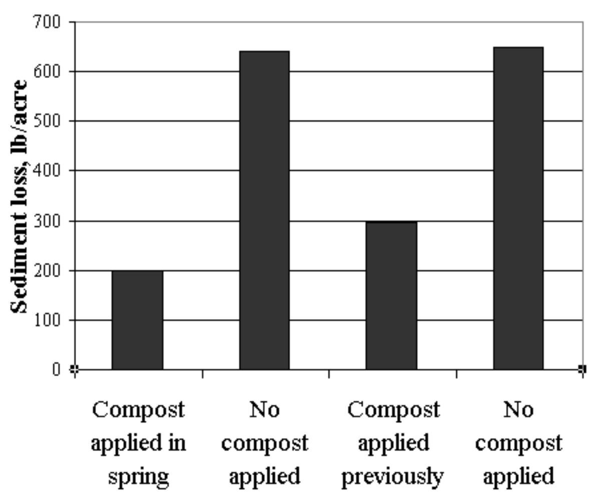
Soil depth	Bray-P1	Total P
0-2”	380	1288
2-4”	154	754
4-8”	37	506
0-8”	143	742

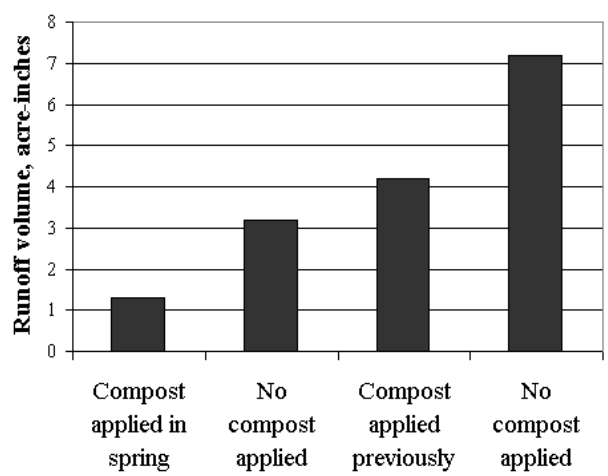
Phosphorus Application

Phosphorus application can result in increased risk of P delivery to surface waters, especially soon after application when much of the applied P is in an easily dissolved form. The greater contribution to long-term risks is the increase in STP that results with excessive P application. Source, rate, time, and method of P application can be managed to reduce P loss in runoff.

Source of applied P. Application of manure P, as compared to fertilizer P, has been found in various studies to be of greater, less, and similar P loss risk. A benefit of manure application may be improved water infiltration and soil aggregation, resulting in less runoff and erosion. These effects can persist for several years after manure applications have ceased (Fig. 1).

Figure 1. Composted manure application resulted in less loss of sediment and runoff during 3 years of annual application (compost applied in the spring) and during 4 years following application (applied previously) (adapted from Wortmann and Walters, 2006).





This amendment effect persisted for at least four years after the last application during which time runoff and sediment loss with manure applied were 60 and 45%, respectively, of the losses where no manure had been applied previously. While manure application does not always result in reduced runoff and erosion, the effect is common enough to be considered as partly offsetting the effect of increased runoff P concentration following manure application.

Rate of P application. Runoff P concentration can be expected to increase with increased rate of P application. In a runoff study conducted in eastern Nebraska, total P loss was approximately 80% more when P application rate was doubled (Wortmann and Walters, 2006).

Time of P application. The main consideration in assessing the effect of time of application on risk of P runoff is the probability of a runoff event within 2 to 8 weeks after P application. In a study conducted in western Nebraska, P loss was 5 times as great where beef feedlot manure was applied one day before as compared to one year before a runoff event (Eghball et al., 2002). Risk of P runoff can be reduced by applying P during months when runoff events are least likely to occur.

Surface application versus injection or incorporation of P. Research results on the effect of incorporation of surface applied manure and fertilizer on the loss of P have been inconsistent. Generally, however, P loss is greater with surface application if the runoff event occurs shortly after application but this effect declines with time, especially if there are a number of rainfall events following P application and before a runoff event occurs. If the field is typically tilled, injection or incorporation of applied fertilizer or manure P is often advisable. The increased risk of erosion associated with ground cover loss due to injection or incorporation of manure for no-till situations may, however, result in more P loss than if the manure was surface applied with no incorporation.

Cover Crops, Tillage, and Other Site Management Practices

Crop production practices which reduce water and soil movement from the field also reduce the risk of runoff P loss. Maintenance of good ground cover, such as with crop residues and cover crops, typically results in reduced erosion and total P loss. With no-till, however, risk of dissolved P loss may be greater than with tillage because P stratification that results in high P availability at the soil surface. In cases of excessively high P concentration at the soil surface, occasional deep plowing may protect against excessive runoff P loss when it can be accomplished without a significant increase in soil erosion.

Excessive STP can be reduced when P removal in crop harvest exceeds P application. The rate of P removal in harvest is most affected by the amount of biomass removed. Whole plant removal, as with silage harvest, needs to be balanced with the risk of increased erosion as erosion rate is often a greater determinant of runoff P loss than is surface soil STP.

TRANSPORT FACTORS

Erosion

Erosion typically has much weight in the assessment of P loss from a field. Total P loss is often closely related to the rate of erosion and can be great even when STP indicates moderate P availability to plants. Much P lost with erosion is tightly bound and not extracted with agronomic soil tests used to determine P availability. If this tightly-bound P reaches water bodies, much of it eventually becomes available to aquatic vegetation.

There are three key steps for erosion transport of P.

1) Energy of falling raindrops causes “detachment” of particulate inorganic or organic P. Ground cover by crop residues or cover crops greatly reduces detachment.

2) Flowing water transports detached particulate P. This is a function of soil particle size and sediment carrying capacity of the flowing water. Ground cover, terraces, filter strips and sedimentation areas greatly affect the amount of particulate P transported in flowing water.
3) Sedimentation and re-suspension of particulate P can occur in streams, ponds, and lakes both during and after the initial transport process. This typically is outside the scope of P indices, but important to water quality.

Runoff

Water caused soil erosion only occurs when runoff takes place, but we treat erosion and runoff as separate transport factors in the assessment of P loss risk. Erosion and runoff refer to sediment and water loss, respectively. Runoff from cropland typically carries less P than erosion, but most runoff P is immediately available to aquatic vegetation. Soil P availability within the top 1" of soil and fertilizer or manure P on the soil surface are most exposed to mixing with runoff water and eventual transport. Runoff becomes more important relative to erosion with no-tillage systems and from grasslands where erosion is well controlled but runoff is still significant.

Sub-Surface Flow and Drainage

In some situations, downward movement of water through the soil is restricted. This may be due to a rock layer, the interface of one soil parent material with another, or a high water table. With natural sub-surface flow, more transport of P to surface waters can be expected with: high STP; sandy soil which allows downward movement of P; shallow depth to restricted downward percolation; and short distance to seepage of the water to the surface. Sub-surface drainage systems that have conduits near the soil surface can remove large amounts of water from agricultural fields and the soluble P content can be high.

Distance from the Field to Concentrated Flow or to the Water Body

Potential for P delivery to a water body increases as distance from the field decreases. A large proportion, possibly 90%, of overland flow that enters water bodies occurs within 100 ft of a channel. With increased distance, there is more opportunity for sediment deposition, re-adsorption of P, and dilution.

Current US Environmental Protection Agency regulations for larger animal feeding operations prevent manure application within 100 ft of a direct conduit to surface waters if the land is cultivated; the setback is 30 ft if the setback area is in perennial vegetation. The importance of distance has not been well quantified but the rate of reduction in runoff P risk increases with distance, probably until about 300 ft, beyond which distance may not be a significant consideration.

Management Practices to Reduce P Transport

Management practices can affect P detachment from soil aggregates, the carrying capacity of flowing water, and sediment trapping. Maintenance of good ground cover affects all three of these components of P transport. Terraces, buffers, and filter strips can reduce sediment carrying capacity of flowing water and trap sediment. Grassed waterways can deliver runoff water from fields without causing gully erosion. Wetlands allow for much sedimentation of sediment-P and adsorption of dissolved P.

PHOSPHORUS INDICES

Structure

Phosphorus indices can be grouped according to structure into three categories: the additive tabular; the multiplicative tabular; and the semi-quantitative model. The earliest P indices were of the additive tabular type in which scores were given for the risk of each source and transport factor and multiplied by a factor weighting value. These products were summed and the total was used to assess the P loss risk for the field. A limitation is that tabular additive P indices did not account for interactions between source and transport factors. Therefore, a high risk rating could be determined due to source factors alone, even with negligible potential to move P from the field. The multiplicative tabular P indices addressed this weakness in that the final score is the product of the sum of the source factor values and the sum of the transport factor values. If there is either little source or transport potential for P loss, a multiplicative tabular P index does not give a high P loss risk rating.

Phosphorus indices have been developed as semi-quantitative models to improve estimates of P loss risk without increasing data input requirements. Much information is built into the model reducing the amount of information that the user needs to prepare and enter. The models use this information and integrates the various processes affecting P loss from fields. Examples of such models include the P indices of Nebraska (2005 version, www.cnmp.unl.edu), Iowa (http://www.ia.nrcs.usda.gov/technical/Phosphorus/phosphorusstandard.html, Mallarino et al., 2002), and Missouri (www.nmplanner.missouri.edu).

Factors and Components

The factors contributing to risk, and weights given to factors, differ with P indices (Benning and Wortmann, 2005). Some of differences are due to differing field conditions common in the state and others due to differences in philosophy on in the interpretation and application of available information. The components of the Nebraska P index, which is an adaptation of the Iowa P index, are discussed here.

The Nebraska P index is an Excel spreadsheet with built-in databases for soil units, landforms, runoff curves and precipitation. The user provides information on erosion rates, conservation and tillage practices, distance to a water body or to a channel leading directly to a water body, cropping system, STP, and P application. The P index has erosion and runoff components which integrate source and transport factors to give component risk values. The irrigation and manure components modify the risk values for the erosion and runoff components.

The erosion component estimates delivery of sediment P (lb P/ac/yr) which will eventually be available for use by aquatic vegetation, assuming that 70% of sediment P will eventually become bio-available to aquatic vegetation. The erosion component is a function of six factors: sheet and rill erosion (t/Ac/yr); the rates of ephemeral and classical gully erosion (t/Ac/yr); sediment delivery ratio which is estimated using a land form value and distance from the center of the field to a water body or to the point where runoff water enters a channel lying outside the field with a direct flow to a water body; the sediment trap efficiency of conservation practices; P enrichment associated with tillage practices; buffer strip effects; and STP (Bray-P1, Mehlich 3, or Olsen) which is used to estimate total soil P.

The runoff component estimates the amount of dissolved P, e.g. orthophosphate P, delivered with runoff water. It is a function of: county precipitation and runoff potential; runoff curve numbers which are calculated from soil property information, land use, and management practices; STP which is used to estimate dissolved P in runoff; and P application.

The irrigation component considers sprinkler and furrow irrigation. Sprinkler irrigation affects the runoff P risk factor due to increased likelihood of wet antecedent soil for irrigated fields when runoff events occur. Risk with furrow irrigation is primarily due to increased erosion. The furrow irrigation factor considers soil erodibility, rate of water flow, furrow slope, use of polyacrylamide (PAM), and the presence of a re-use pit for recycling of irrigation water. The furrow irrigation component modifies the erosion component of the P index. The manure component allows adjustment of the erosion and runoff components by accounting for beneficial effects of manure on soil properties.

CONCLUSION

Many fields will need to be assessed for the potential of P loss to surface waters in 2006 to comply with regulations affecting manure application by large animal feeding operations. Phosphorus indices are being used in many states for this assessment as they account for soil P test level and other field conditions, as well as the potential to transport P from the field and to deliver it to a water body.

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