

Phosphorus and Delaware Agriculture

Phosphorus (P) is one of the most important plant nutrients required by Delaware crops. It is essential for most physiological processes in plants, such as photosynthesis, energy transfer, genetic regulation of cell division and growth, and the production of seeds and fruits. If soils are deficient in P, plants may become stunted, with poorly developed root systems, and significant reductions in yield may occur.

Profitable crop production requires that plants be provided with an adequate supply of P, either from the soil or from soil amendments such as commercial fertilizers or animal manures. The amount of fertilizer or manure P needed for optimum crop yields has been documented through long-term field research with most of the soils and crop management systems found in Delaware. Research has also been conducted to determine the most effective sources of P, timing of P application, and placement methods for P fertilizers. Because of this research, successful agronomic management practices for P are now available for Delaware agriculture.

At present, the consensus of most agricultural scientists is that maximizing the return on an investment in P fertilizers begins with the use of a soil test-based P fertilizer program. Soil testing is a reliable, inexpensive way to evaluate the P fertilizer requirement of most crops. The University of Delaware Soil Testing Program uses the criteria shown in Table 1 to rate soils according to the likelihood of an economic response to P fertilization. Actual fertilizer recommendations received by farmers will vary slightly depending on factors such as crop, soil type, tillage, irrigation, and manure use.

Table 1. General P fertilizer recommendations for Delaware.

Soil P Rating	UD Fertility Index Value ²	Typical P Fertilizer Recommendation ¹ (lb P ₂ O ₅ /acre)
Low	0-25	100
Medium	26-50	50
Optimum	51-100	25
Excessive	> 100	0

¹Fertility index value = soil test P (Mehlich 3) in ppm.

²P fertilizer recommendations are for a broadcast application. If the P fertilizer is banded, recommendations are halved.

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Phosphorus and the Environment

Environmental concerns with P center around *eutrophication*, defined as "...an increase in the fertility status of natural waters that causes accelerated growth of algae or water-plants". In most fresh surface waters (lakes, ponds, rivers), and some estuaries, the growth of algae or aquatic plants is limited by inadequate levels of P. Inputs of P to surface waters from nonpoint sources by erosion, runoff, or subsurface groundwater flow, can remove this limitation and induce eutrophic conditions. Point sources of P, such as municipal wastewater systems, can also contribute to eutrophication. The most common undesirable effects of eutrophication are algal blooms, foul odors, insect problems, impeded water flow and boating due to aquatic weeds, sediment buildup in shallow lakes, low dissolved oxygen levels, and the disappearance of desirable species of fish.

The University of Delaware has always advocated an agronomically sound P management program, one that has traditionally focused on maximizing profitable crop responses to P. Today, however, the situation is more complex. As seen in Figure 1, it is apparent that most of Delaware's agricultural soils are now rated as optimum or excessive in P. Soils in these categories have little, if any, need for fertilizer or manure P. Indeed, many Delaware soils have soil P levels high enough to meet crop P needs for 10 years or more without any inputs of P. Because in some situations high P soils contribute to eutrophication of surface waters, P management strategies that maintain both agricultural profitability and environmental quality are badly needed. This fact sheet describes one such approach, the *Phosphorus Site Index*.



Figure 1. Percentages of agricultural soil samples in each soil test category in Delaware (based on ~15,000 soil samples submitted to the University of Delaware from 1992-1999).

The Phosphorus Site Index

In 1990, the USDA Soil Conservation Service (now the USDA Natural Resources Conservation Service or USDA-NRCS) formed a national work group of scientists from Universities, Cooperative Extension, and the USDA Agricultural Research Service to develop a P-indexing procedure that could identify soils, landforms, and management practices with the potential for unfavorable impacts on water bodies because of P losses from agricultural soils. The long-term goals of this national work group were:

- To develop an easily used, site-specific, field rating system (referred to as the **Phosphorus Site Index**) for USDA-NRCS technical specialists, Cooperative Extension, crop consultants, farmers and others that rates soils according to their relative potential for P loss to surface waters.
- To relate the **P Site Index** to the sensitivity of receiving waters to eutrophication.
- To develop agricultural management practices that minimize the buildup of soil P to excessive levels and the transport of P from soils to sensitive water bodies.

The **P Site Index** is designed to assess the relative risks of P loss from differing fields, not to estimate the actual quantity of P lost in runoff. This risk assessment allows us to design best management practices (BMPs) to reduce agricultural P losses to surface waters and to prioritize the locations in a watershed where BMPs will have the greatest water quality benefits.

Using the Phosphorus Site Index

The **P Site Index** evaluates 12 characteristics, which are separated into two groups: Part A (site factors affecting P transport) and Part B (P source and management factors) to obtain an overall rating of the potential for P loss at a site (Table 2). By doing this it is possible to obtain separate risk assessments for P transport from a site, based on factors such as topography, hydrology, and proximity to surface waters (Part A), and for P source and management practices (soil test P, fertilizer/manure P management - Part B).

Each of the 12 characteristics in the **P Site Index** is assigned a numerical value from an *interpretive rating scale*: VERY LOW, LOW, MEDIUM, HIGH, or VERY HIGH or from calculations using a *weighting factor* based on the relationship between the characteristic and the potential for P loss from the site. At present, the interpretive ratings and weighting factors are based on the best professional judgment of the scientists who are developing the **P Site Index**. The final **P Site Index** value for the site integrates the effects of factors from Part A and Part B (see below for the actual steps used to calculate the **P Site Index**).

Table 2. Site characteristics and management factors used to determine the **P Site Index**.

Part A - Site and Transport Characteristics

Soil Erosion
Soil Surface Runoff Class
Subsurface Drainage
Leaching Potential
Distance from Field to Surface Water
Priority of Receiving Water

Part B - Source and Management Characteristics

Soil Test P Value
P Fertilizer Application Rate
P Fertilizer Application Method
Organic P Source Application Rate¹
Organic P Source Application Method

Note that variations in P availability/solubility between different types of organic P sources are accounted for by use of a Phosphorus Availability Coefficient (PAC).

Calculation of the Phosphorus Site Index

The current version of the **P Site Index** (Table 3) is provided in this fact sheet, along with two example calculations. Use the following steps to determine the **P Site Index** for a site. The University of Delaware also provides a *Technical Guidance Manual for the Phosphorus Site Index* that has more detailed information on this process. Contact your local Cooperative Extension office to obtain this manual.

1. Calculate field values for all of the site and transport characteristics in Part A, using data obtained from a county soil survey manual, the revised universal soil loss equation (RUSLE), and necessary field measurements (i.e., distance from field to surface water).
2. Add all Part A factors together and multiply them by a *scaling factor* (0.02). The scaling factor is used to convert the overall P transport potential at the site to a scale of 0 to 1.0 (highly erodible sites may have a final Part A value > 1.0).
3. Calculate field values for the P source and management characteristics in Part B using information collected from the farmer and recent soil test results (obtain new soil test data if current results are over three years old or a significant addition of P has occurred since the last test).
4. Multiply the final site values for Part A and Part B together to obtain the overall **P Site Index** value. Compare the **P Site Index** value obtained with the interpretations in Table 4, which categorizes site vulnerability to P loss. Then determine the BMPs needed at this site to reduce the risk of P loss to waters (see Table 5 for examples of BMPs).

Table 3. The Phosphorus Site Index for Delaware.

Part A: Phosphorus loss potential due to site and transport characteristics.

Characteristics	Phosphorus Loss Rating					Value
Soil Erosion	2 x [Soil erosion value from RUSLE (tons/acre)]					
Soil Surface Runoff Class	Very Low 0	Low 2	Medium 4	High 6	Very High 8	
Subsurface Drainage	Very Low 0	Low 2	Medium 4	High 6	Very High 8	
Leaching Potential	Low 0		Medium 2	High 4		
Distance from Field to Surface Water	> 100 ft 0	< 100 ft AND > 50 ft vegetated buffer <u>OR</u> < 100 ft AND > 25 ft vegetated buffer AND > 25 ft additional no P application zone 2	< 100 ft AND > 25 ft vegetated buffer AND < 25 ft additional no P application zone 4	< 100 ft AND < 25 ft vegetated buffer AND > 25 ft additional no P application zone 6	< 100 ft AND < 25 ft vegetated buffer AND < 25 ft additional no P application zone 8	
Priority of Receiving Water	Very Low 0	Low 1	Medium 2	High 3	Very High 4	

Sum of Site and Transport Characteristics: _____

Scaling factor: x 0.02

Total Site and Transport Value for Part A: _____

Part B: Phosphorus loss potential due to P source and management practices.

Characteristics	Phosphorus Loss Rating					Value
Soil Test P Fertility Index Value (FIV)	[0.2] x [FIV from University of Delaware Soil Test]					
P Fertilizer Application Rate	[0.6] x (lbs P ₂ O ₅ applied per acre)					
P Fertilizer Application Method and Timing	None applied 0	Injected/Banded below surface at least 2" 15	Incorporated within 5 days of application 30	Surface applied March through November OR incorporated in > 5 days 45	Surface applied December through February 60	
Organic P Source Application Rate	[Phosphorus Availability Coefficient (PAC; default=0.6)] x (lbs P ₂ O ₅ applied per acre)					
Organic P Source Application Method and Timing	None applied 0	Injected/Banded below surface at least 2" 15	Incorporated within 5 days of application 30	Surface applied March through November OR incorporated in > 5 days 45	Surface applied December through February 60	

Total P Source and Management Value for Part B: _____

Table 4. Generalized interpretation of the Phosphorus Site Index.

<i>P Site Index</i>	Generalized Interpretation of <i>P Site Index</i>
< 50	LOW potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site. Nitrogen-based nutrient management planning is satisfactory for this site. Soil P levels and P loss potential may increase in the future due to N-based nutrient management.
51 - 75	MEDIUM potential for P movement from this site given current management practices and site characteristics. Practices should be implemented to reduce P losses by surface runoff, subsurface flow, and erosion. Nitrogen-based nutrient management should be implemented no more than one year out of three. Phosphorus-based nutrient management should be implemented two years out of three during which time P applications should be limited to the amount expected to be removed from the field by crop harvest or soil test P based application recommendations, whichever is greater.
76 - 100	HIGH potential for P movement from this site given current management practices and site characteristics. Phosphorus-based nutrient management should be used for this site. Phosphorus applications should be limited to the amount expected to be removed from the field by crop harvest or soil test P based application recommendations. All practical management practices for reducing P losses by surface runoff, subsurface flow, or erosion should be implemented.
> 100	VERY HIGH potential for P movement from this site given current management practices and site characteristics. No phosphorus should be applied to this site. Active remediation techniques should be implemented in an effort to reduce the P loss potential of this site.

PHOSPHORUS SITE INDEX : EXAMPLE CALCULATIONS FOR DELAWARE

Scenario #1: An agricultural field located in the upper coastal plain, in New Castle County.

Site and Hydrology: The dominant soil type is a Matapeake silt loam, a well-drained soil with moderate permeability and a depth to the seasonal high water table > 6'. The field has slopes of 5 to 7% that lead to an adjacent stream. There is a riparian buffer between the edge of the cultivated field and stream that varies in width from 8' to 12' and either a gully or steep grade leading down to the stream.

Phosphorus Source and Management: The crop rotation at this site is wheat (conventional till) – double cropped soybeans (no-till) – corn (no-till). The soil test P value is 75 FIVs (UD Fertility Index Values), which is in the “optimum” range for crop production. Starter fertilizer is used only with the corn at an application rate of 25 lbs P₂O₅/acre. No manure is used at this site.

<i>Site Information</i>	<i>Information Used to Determine P Loss Rating</i>	<i>Value for P Site Index Calculation</i>	
Part A: Site and Transport Factors			
Soil Erosion	RUSLE: 2.5 tons/acre	5	MEDIUM
Surface Runoff Class	Slope, soil permeability	4	MEDIUM
Subsurface Drainage	Drainage, water table depth	2	LOW
Leaching Potential	USDA-NRCS rating scale based on soil series	0	LOW
Distance to Water	Distance from field to surface water	8	VERY HIGH
Priority of Receiving Water	State watershed categorization scale	3	HIGH
	<i>Sum of Part A</i>	22	
	<i>Scaling factor</i>	<i>x 0.02</i>	
	<i>Part A Value</i>	<i>0.44</i>	
Part B: P Source and Management Factors			
Soil Test P	UD soil test value: 75 FIVs	15	HIGH
P Fertilizer Rate	25 lbs P ₂ O ₅ /acre	15	LOW
P Fertilizer Application Method	Banded below surface	15	LOW
Organic P Rate	None applied	0	n/a
Organic P Application Method	None applied	0	n/a
	<i>Part B Value</i>	45	
<i>P Site Index (Part A Value x Part B Value) = [0.44] x [45]</i>		20 (LOW)	

PHOSPHORUS SITE INDEX : EXAMPLE CALCULATIONS FOR DELAWARE

Scenario #2: An agricultural field located in the coastal plain region of Sussex County.

Site and Hydrology: The dominant soil type is a Pocomoke sandy loam – a very poorly drained soil with moderately slow permeability and a depth to the seasonal high water table of 0-1'. The field has slopes of 0.5% and is bordered by drainage ditches. There are no buffers between the edge of the cropped field and the ditches.

Phosphorus Source and Management: The crop rotation at this site is corn-soybeans-corn (all conventional till). The soil test P value is 400 FIVs (UD Fertility Index Values), which is in the “excessive” range for crop production. Starter fertilizer is used only with the corn at an application rate of 25 lbs P₂O₅/acre. Poultry manure is applied in March each year at a rate of 3 tons/acre.

<i>Site Information</i>	<i>Information Used to Determine P Loss Rating</i>	<i>Value for P Site Index Calculation</i>	
Part A: Site and Transport Factors			
Soil Erosion	RUSLE: 0.5 tons/acre	1	LOW
Surface Runoff Class	Slope, soil permeability	0	VERY LOW
Subsurface Drainage	Drainage, water table depth	6	HIGH
Leaching Potential	USDA-NRCS rating scale	2	MEDIUM
Distance to Water	Distance from field to surface water	8	VERY HIGH
Priority of Receiving Water	State watershed categorization scale	4	VERY HIGH
	<i>Sum of Part A Scaling factor</i>	21	
	<i>Part A Value</i>	$\frac{21 \times 0.02}{0.42}$	
Part B: P Source and Management Factors			
Soil Test P	UD soil test value: 400 FIVs	80	VERY HIGH
P Fertilizer Rate	25 lbs P ₂ O ₅ /acre	15	LOW
P Fertilizer Application Method	Banded below surface	15	LOW
Organic P Rate	180 lbs P ₂ O ₅ /acre	108	VERY HIGH
Organic P Application Method	Surface, March through November	30	HIGH
	<i>Part B Value</i>	248	
P Site Index (Part A Value x Part B Value) = [0.42] x [248] = 104		104 (VERY HIGH)	

Management Options for the Two Example Scenarios

Information on best management practices to consider after *P Site Index* evaluation is found in Table 5. Some management options that would be appropriate for the two scenarios above are:

Scenario #1:

Follow a nitrogen-based nutrient management plan. Review the need for soil conservation measures that can reduce the risk of P loss in certain areas on the farm (e.g., consider widening buffer strips in some areas near surface waters). Monitor soil test P values to prevent the buildup of soil P to excessive levels. Consider effects of any major changes in agricultural practices on P losses before implementing them on the farm.

Scenario #2:

Follow a phosphorus-based nutrient management plan. Avoid applications of P at this site from any source (fertilizers or manures). Use a starter fertilizer that only contains nitrogen (N). Review and/or update soil testing results for the entire farming operation to identify areas where P can best be applied. Apply manure to other fields that have lower *P Site Index* values. Implement soil conservation practices that will reduce the likelihood of P loss to surface or shallow ground waters. Monitor changes in soil test P with time to determine when N- and P-based management practices can be followed.

Management Options Based on the Phosphorus Site Index

Minimizing nonpoint source pollution of surface waters by P from agricultural cropland requires management practices that control both the *supply* and *transport* of soil P. The basic objective of environmentally sound P management is to maintain soil P fertility levels in a range that is optimum, but not excessive, for crop growth while reducing the loss of particulate and dissolved P by processes such as erosion, runoff, or drainage. Determination of the *P Site Index* for soils near to sensitive surface waters is the first step in this strategy because this prioritizes the efforts needed to reduce P losses. Once this has been done, management options that are appropriate for soils with different *P Site Index* ratings can be implemented. Some general recommendations are given in Table 5; however, P management is very site-specific and requires a well-planned, coordinated effort between farmers, extension agronomists, and soil conservation specialists.

Table 5. Management options to minimize nonpoint source pollution of surface waters by soil P.

<i>Phosphorus Site Index Value</i>	<i>Management Options to Minimize Nonpoint Source Pollution of Surface Waters by Soil P</i>
<p>< 50 (LOW)</p>	<p><i>Soil testing:</i> Have soils tested for P at least every three years to monitor build-up or decline in soil P.</p> <p><i>Soil conservation:</i> Follow good soil conservation practices. Consider effects of changes in tillage practices or land use on potential for increased transport of P from site.</p> <p><i>Nutrient management:</i> Consider effects of any major changes in agricultural practices on P losses <u>before</u> implementing them on the farm. Examples include increasing the number of animal units on a farm or changing to crops with a high demand for fertilizer P.</p>
<p>51 - 75 (MEDIUM)</p>	<p><i>Soil testing:</i> Have soils tested for P at least every three years to monitor build-up or decline in soil P. Conduct a more comprehensive soil testing program in areas that have been identified by the <i>P Site Index</i> as being most sensitive to P loss by erosion, runoff, or drainage.</p> <p><i>Soil conservation:</i> Implement practices to reduce P losses by erosion, runoff, or drainage in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management).</p> <p><i>Nutrient management:</i> Any changes in agricultural practices may affect P loss; carefully consider the sensitivity of fields to P loss before implementing any activity that will increase soil P. Avoid broadcast applications of P fertilizers and apply manures only to fields with lower <i>P Site Index</i> values.</p>
<p>76 - 100 (HIGH)</p>	<p><i>Soil testing:</i> A comprehensive soil testing program should be conducted on the entire farm to determine fields that are most suitable for further additions of P. For fields that are excessive in P, estimates of the time required to deplete soil P to optimum levels should be made for use in long range planning. Consider using crops with high P removal capacities in fields with high soil test P values.</p> <p><i>Soil conservation:</i> Implement practices to reduce P losses by erosion, runoff, or drainage in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management).</p> <p><i>Nutrient management:</i> In most situations fertilizer P, other than a small amount used in starter fertilizers, will not be needed. Manure may be in excess on the farm and should only be applied to fields with lower <i>P Site Index</i> values. A long-term P management plan should be considered.</p>
<p>>100 (VERY HIGH)</p>	<p><i>Soil testing:</i> For fields that are excessive in P, estimate the time required to deplete soil P to optimum levels for use in long range planning. Consider using new soil testing methods that provide more information on environmental impacts of soil P (contact UD Cooperative Extension for information on new soil P tests). Consider using crops with high P removal capacities in fields with high soil test P values.</p> <p><i>Soil conservation:</i> Implement practices to reduce P losses by erosion, runoff, or drainage in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management).</p> <p><i>Nutrient management:</i> Fertilizer and manure P should not be applied for at least three years and perhaps longer.</p>

For more information on how to use the *Phosphorus Site Index* please contact University of Delaware Cooperative Extension, the USDA Natural Resources Conservation Service, or your local conservation district.