REVISION OF THE 590 NUTRIENT MANAGEMENT STANDARD:
SERA-17 RECOMMENDATIONS

SUPPORTING DOCUMENTATION

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INTRODUCTION

Since its introduction by Lemunyon and Gilbert (1993), the P Index has morphed from an educational to an implementation, targeting, manure scheduling tool, and in some cases, a regulatory tool. A great deal of research has been conducted across the U.S. to derive, validate, and support components of the P Indexing concept, particularly those related to source factors (Table 1). The general P Indexing concept has been modified state by state to consider their particular soil, land management, physiographic, and hydrologic controls influencing the potential for P loss. As a result, there are many variations in Indices now in use as part of the NRCS 590 Nutrient Management Conservation Standard. This variation is both a strength and weakness of the Indexing concept. Variability demonstrates the robustness of the approach but has led to differences in P management recommendations under relatively similar site conditions.

The inconsistency among Phosphorus (P) Indices in terms of level of detail and scientific underpinnings among states, as well as in recommendations and interpretations based on site risk, has prompted this review of the P-Indexing approach as it is used in nutrient management planning. The need for revision has been heightened by a slower than expected decrease in P-related water quality impairment and, in some cases, an increase in soil P to levels several fold greater than agronomic optimum due to continued application of P with approval of the P Index. Recent documents related to mitigation effectiveness in the Chesapeake Bay fueled the concern that site risk assessment with the P-Indexing approach was “just not getting the job done” (Kovzelove et al., 2010; U.S. Environmental Protection Agency, 2010).

While these concerns are real, we feel that the basic scientific foundations of the P-Indexing approach are sound. For instance, soil test P (STP) or soil P saturation in and of themselves, do not represent the risk of P leaving a field and entering a water course. They do reflect the history of P management at that site; but do not address the potential for surface runoff or leaching to occur, nor the inherent differences in manure properties, application timing and method, which contribute to determining the potential for P loss.

Phosphorus is a finite natural resource that needs to be conserved. Thus, consideration needs to be given to achieving on-farm and regional P balance, with the long-term goal of meeting agronomic requirements. The unlimited over-application of P to soils is not a sustainable use of this finite resource. However, the P Index is a P loss risk assessment tool and P Indices do not address P management on a resource use basis.

The nature of concentrated animal production in the United States has led to regional P imbalances where input of P in feed, bedding, and fertilizer exceeds outputs in crop and animal produce. Such P imbalances represent a poor use of a limited natural resource; and from a resource conservation perspective, the continued application of P to fields where no further P is needed for crop production cannot be recommended. In the long-term, limiting P applications when it is not needed for production, will frequently provide water quality benefits at the field scale. However, scientific research clearly shows STP or P saturation alone, is not the only factor that determines P loss from fields. Without adequate transport pathways, P is not likely to find its way to sensitive water resources.

Well-developed P Indices are the most appropriate P loss assessment tool to be used within nutrient management planning as they integrate the multiple factors affecting P loss to water resources. This was the original justification for use of a P Index approach to define P loss risk by NRCS. Correspondingly, the most scientifically defensible approach to defining conditions for limiting P applications to protect water quality, will be based on a combination of multiple factors that influence P loss potential within the context of a state's P Index.

Many of the currently publicized failings of the P-Indexing approach derive from interpretation of the risks and associated management guidelines assigned by an Index, which have been modified with local and regional political and stakeholder involvement. This review and revision will focus on both updating the science and more clearly defining the constraints and boundaries influencing interpretation of site risk. This report discusses the concepts behind the P loss risk assessment approach, what a P loss assessment tool can and cannot do, how nutrient management planning should be integrated with such a tool, defining a relationship between STP and runoff P, and the complexities of the risk interpretation, and provides some thoughts on next generation P Indices.

BACKGROUND

NRCS's short- and long-term goals for a revised P Index or Phosphorus Risk Assessment Tool (PRAT) were:

Short-Term Goals (2010 – 2011)

1. Prevent the gradual loading of nutrients to high water quality risk levels.
2. Assist producers mitigate existing high water quality risk situations to lower sustainable levels.
3. The PRAT must have a "cutoff" to identify those conditions where no additional P shall be applied.
4. The PRAT should include the following:
   a. A tool built on a national platform with scientific underpinnings.
   b. A tool to assess the edge of field risk for P runoff and leaching.
   c. A tool based on the best available science that can be refined / improved as better technology or science becomes available.
   d. A tool that can utilize local soil, hydrology, and climate data (this data already resides in the wind and water erosion prediction tools used in the NRCS field offices) that can track erosion and sediment to concentrated flow, to a point of deposition, or edge of field.
   e. A tool that can address, where needed, irrigation induced erosion, runoff, and leaching.
   f. The tool needs the capability to be used to assess risk from manure **and/or** P fertilizer.
   g. Although the proposed PRAT would be quantitative, it is not necessary that the results be delivered numerically. A narrative or category rating (Low, Medium, High, etc.) would be satisfactory.

h. The minimum criteria for edge-of-field P runoff should be that nutrient concentrations in runoff reaching a stream or water body will not cause water quality impairment (algae, aquatic habitat, etc.). The tool will also need to identify those fields/situations where even with the best conservation, no additional P should be applied.

Long-Term Goals (2011-2014)

In the longer term (2-3 years), we would incorporate the PRAT into our integrated computing system where models are interconnected and work from common databases. This is part of our Conservation Delivery Streamlining Initiative (CDSI). This will be built using the Object Modeling System (OMS). This is currently under development with the grazing and erosion prediction tools being added in 2010. We are building databases and models that can call on other common sub-models to calculate results. For example, the hydrology model used in WEPS could also be the same model that the PRAT would use. This substantially lowers our programming and maintenance costs for software.

Our near term (2011 -2014) erosion prediction tools will be GIS/geo-referenced to calculate erosion and runoff on a cell-by-cell bases using DEM and/or LIDAR maps. This may present an opportunity to build the PRAT functions around our erosion prediction models. This would account for local climate, soils, management, and topography.

Other tools such as the Conservation Practice Physical Effects Analyzer (CPPE Analyzer) and the Nutrient Trading Tool (NTT) both being developed by NRCS utilize the APEX computer simulation model and compare a baseline field condition to a condition "with" or "with additional" conservation practices and other management changes (rate, form, timing, placement). This may be an option to build the PRAT around.

The Charge to SERA-17

Based on the above requirements the SERA-17 subgroup had the following charges (Figure 1):

1. Define criteria establishing the range of STP values where a P Index risk assessment is needed.
2. Define the upper P Index threshold that limits P application.
3. Define the minimum requirements of P Indices.
4. Define a process to evaluate P Indices.
5. Define long-term goals for development of next generation P Indices.

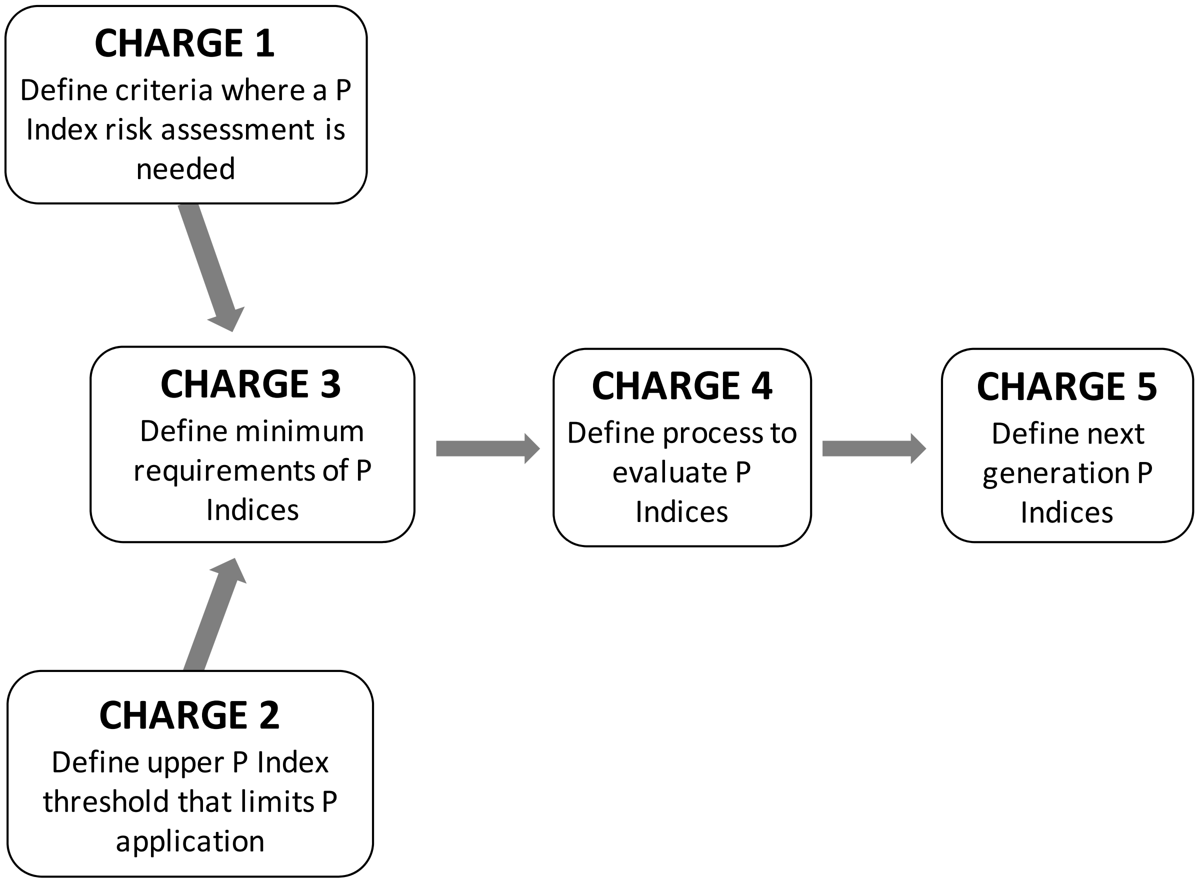

Figure 1. Organization scheme of the 590 revision charges.

Table 1. Peer-reviewed publications documenting scientific fundamentals included in components of P Indices for various states.

Title	Authors	Year	Source
Alabama			
Phosphorus accumulation and loss from Alabama soils receiving poultry litter	Mullins, G.L., and B.F. Hajek	1997	Ala. Agric. Exp. Stn. Bull. No. 631. Auburn University, AL
EPIC evaluation of the impact of poultry litter application timing on nutrient losses	Torbert, H.A., T.J. Gerik, W.L. Harman, J.R. Williams, and M. Magre	2008	Commun. Soil Sci. Plant Anal. 39:3004-3033
Broiler litter application method and runoff timing effects on nutrient and E. coli losses from tall fescue pasture	Sistani, K.R., H.A. Torbert, T. Way, C. Bolster, and J.G. Warren	2009	J. Environ. Qual. 38:1216-1223
Influences of poultry litter application methods on the longevity of nutrient and E. coli in runoff from Tall Fescue pasture	Sistani, K.R., C. Bolster, H.A. Torbert, T. Way, D.H. Pote, and D.B. Watts	2010	Water Air and Soil Pollution 206:3-12
Arkansas			
Relating extractable soil phosphorus to phosphorus losses in runoff	Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, D.R. Edwards, and D.J. Nichols	1996	Soil Sci. Soc. Am. J. 60:855-859
Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff	Pote, D. H., T.C. Daniel, D.J. Nichols, A.N. Sharpley, P.A. Moore, Jr., D.M. Miller, and D.R. Edwards	1999	J. Environ. Qual. 28:170-175
Predicting annual phosphorus losses from fields using the Phosphorus Index for pastures	DeLaune, P.B., and P.A. Moore, Jr.	2001	Better Crops 85:16-19
A portable rainfall simulator for plot-scale runoff studies	Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley	2002	Applied Engineering in Agriculture 18(2):199-204
Development of a Phosphorus Index for pastures - Factors affecting phosphorus runoff	Delaune, P.B., P.A. Moore, Jr., D.E. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel	2004	J. Environ. Qual. 33:2192-2200
Evaluation of the phosphorus source component in the Phosphorus Index for pastures	Delaune, P.B., P.A. Moore, Jr., D.E. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel.	2004	J. Environ. Qual. 33:2183-2191
Field evaluation of three phosphorus indices on new	Harmel, R.D., H.A. Torbert, P.B.	2005	J. Soil Water Conserv. 60(1):29-42

application sites in Texas	DeLaune, B.E. Haggard, and R.L. Haney		
The Eucha/Spavinaw Phosphorus Index: A court mandated index for litter management	DeLaune, P.B., B.E. Haggard, T.C. Daniel, I. Chaubey, and M.J. Cochran.	2007	J. Soil Water Conserv. 61:96-105
Colorado			
Best management practices for phosphorus fertilization	Waskom, R.W.	1994	Colo. State Univ. Ext. Bul. #XCM-175, Fort Collins, CO. http://www.ext.colostate.edu/pubs/crops/xcm175.pdf
Best management practices for manure utilization	Waskom, R.M., and J.G. Davis	1999	Colo. State Univ. Ext. Bul. 568A, Fort Collins, CO. http://cerc.colostate.edu/titles/568A.html
Irrigated mountain meadow fertilizer application timing effects on overland flow water quality	White, S.K., J.E. Brummer, W.C. Leininger, G.W. Frasier, R.M. Waskom, and T.A. Bauder	2003	J. Environ. Qual. 32:1802-1808
Predicting phosphorus runoff from calcareous soils	Schierer, R.A.	2006	M.S.Thesis, Colo. State Univ. Fort Collins, CO
Delaware			
Relationships between soil test phosphorus, soluble phosphorus and phosphorus saturation in Delaware soils	Pautler, M.C., and Sims, J.T.	2000	Soil Sci. Soc. Am. J. 64:765-773
Adapting the Phosphorus Site Index to the Delmarva Peninsula: Delaware's experience	Leytem, A. B., J. T. Sims, and F. J. Coale	2000	p. 282-301. Proc. Conf. Managing Nutrients and Pathogens from Animal Agriculture, Harrisburg, PA
Soil testing to predict phosphorus leaching	Maguire, R.O., and J.T. Sims	2002	J. Environ. Qual. 31:1601-1609
Evaluation of Mehlich 3 as an agri-environmental soil phosphorus test for the mid-Atlantic U.S.A.	Sims, J.T., R.O. Maguire, A.B. Leytem, K.L. Gartley, and M.C. Paulter	2002	Soil Sci. Soc. Am. J. 66:2016-2032
Measuring agronomic and environmental soil	Maguire, R.O., and J.T. Sims	2002	Soil Sci. Soc. Am. J. 66:2033-2039

phosphorus saturation and predicting phosphorus leaching with Mehlich 3			
On-farm evaluation of a phosphorus site index for Delaware	Leytem, A.B., J.T. Sims, and F.J. Coale	2003	J. Soil Water Conserv. 58(2):89-97
Determination of phosphorus source coefficients for organic phosphorus sources: Laboratory studies	Leytem, A.B., J.T. Sims, and F.J. Coale	2004	J. Environ. Qual. 33:380-388
Integrating phosphorus source and soil properties into risk assessments for phosphorus loss	Shober, A.L., and J.T. Sims	2006	Soil Sci. Soc. Am. J. 71:551–560
Florida			
An environmental threshold for degree of phosphorus saturation in sandy soils	Nair, V.D., K.M. Portier, D.A. Graetz, and M.L. Walker	2004	J. Environ. Qual.33:107-113
A capacity factor as an alternative to soil test phosphorus in phosphorus risk assessment	Nair, V.D., and W.G. Harris	2004	New Zealand J. Agric. Res. 47:491-497
A quick field test for evaluating phosphorus movement in sandy soils	Rhue, R.D., V.D. Nair, and W.G. Harris	2005	NZ J. Agric. Res. 48:367-375
Laboratory validation of soil phosphorus storage capacity predictions of use in risk assessment	Chrysostome, M., V.D. Nair, W.G. Harris, and R.D. Rhue	2007	Soil Sci. Soc. Amer. J. 71:1564-1569
Minimizing confounding factors in phosphorus leaching assessment for dairy and poultry manure-amended soils	Chrysostome, M., V.D. Nair, W.G. Harris, and R.D. Rhue	2007	Comm. Soil Sci. Plant Anal. 38:975-987
Introducing the phosphorus release risk factor in the Florida P-index	Nair, V. D., W. G. Harris, and D.A. Graetz	2007	Soil and Water Science Research Brief, IFAS, University of Florida, SWS-07-02
Georgia			
Phosphorus and ammonium concentrations in surface runoff from grasslands fertilized with broiler litter	Pierson, S.T., M.L. Cabrera, G.K. Evanylo, H.A. Kuykendall, C.S. Hoveland, M.A. McCann, and L.T. West	2001	J. Environ. Qual. 30:1784-1789
Phosphorus losses from grasslands fertilized with broiler litter: EPIC simulations	Pierson, S.T., M.L. Cabrera, G.K. Evanylo, P.D. Shroeder, D.E. Radcliffe, H.A. Kuykendall, V.W. Benson, J.R. Williams, C.S. Hoveland, and M.A. McCann	2001	J. Environ. Qual. 30:1790-1795

Water soluble phosphorus released by poultry litter: effect of extraction pH and time after application	Tasistro, A.S., M.L. Cabrera, and D.E. Kissel	2003	Nutrient Cycling in Agroecosystems 68:223-234
Rainfall timing and poultry litter application rate effects on phosphorus loss in surface runoff	Shroeder, P.D., D.E. Radcliffe, and M.L. Cabrera	2004	J. Environ. Qual. 33:2201-2209
Relationship between soil test phosphorus and phosphorus in runoff: Effects of soil series variability	Shroeder, P.D., D.E. Radcliffe, M.L. Cabrera, and C.D. Belew	2004	J. Environ. Qual. 33:1452-1463
Fertilizer source and soil aeration effects on runoff volume and quality in grassed plots	Franklin, D.H., M.L. Cabrera, and V.H. Calvert	2005	Soil Sci. Soc. Am. J. 70:84-89
Aerating grasslands: Effects on runoff and phosphorus losses from applied broiler litter	Franklin, D.H. M.L. Cabrera, L.T. West, V.H. Calvert, and J.A. Rema	2006	J. Environ. Qual. 36:208-215
Evaluating aeration techniques for decreasing phosphorus export from grasslands receiving manure	Butler, D.M., D.H. Franklin, M.L. Cabrera, A.S. Tasistro, K. Xia, and L.T. West	2008	J. Environ. Qual. 37:1279-1287
Testing a connectivity factor for the Georgia P Index	Bryant, J.H.	2009	Master's Thesis. University of Georgia. 85 pages
Assessment of the Georgia Phosphorus Index on farm at the field scale for grassland management	Butler, D.M., D.H. Franklin, M.L. Cabrera, L.M. Risse, D.E. Radcliffe, L.T. West, and J.W. Gaskin	2010	J. Soil Water Conserv. 65(3):200-210
Kansas			
A field-based assessment tool for phosphorus losses in runoff from Kansas	Sonmez, O., G.M. Pierzynski, L. Frees, B. Davis, D. Leikam, D.W. Sweeney, and K.A. Janssen	2009	J. Soil Water Conserv. 64(3):212-222
Kentucky			
Managing broiler litter application rate and grazing to decrease watershed runoff losses	Sistani, K.R., G.E. Brink, and J.L. Oldham	2008	J. Environ. Qual. 37:718-724
Poultry litter and tillage influence on corn production and soil nutrients in a Kentucky silt loam soil	Sistani, K.R., M. Rasnake, and F. Sikora	2008	Soil & Tillage Research 98: 130-139
Broiler Litter application method and runoff timing effect on nutrient and E. coli losses from tall fescue pasture	Sistani, K.R., H.A. Torbert, T. Way, C.H. Bolster, and J.G. Warren	2009	J. of Environ. Qual. 38:1-8
Idaho			

Phosphorus in surface runoff from calcareous arable soils of the semiarid Western United States	Turner, B.L., M.A. Kay, and D.T. Westermann	2004	J. Environ. Qual. 33:1814–1821
Idaho nutrient transport risk assessment (INTRA): A water quality risk assessment tool for conservation planning	ftp://ftp-fc.sc.egov.usda.gov/ID/technical/technotes/water_quality/waterquality_tn6.pdf	2006	USDA-NRCS, Agronomy Technical Note 6, Boise, ID
Iowa			
Using the Iowa phosphorus index and variable-rate technology for effective agronomic and environmental phosphorus management	Mallarino, A.P., D. Wittry, and J. Klatt	2001	p. 151-158. In The Integrated Crop Management Conf. Proceedings. Des Moines, IA. Iowa State Univ. Extension., Ames, IA
Background and basic concepts of the Iowa phosphorus index. A support document to the NRCS Field Office Tech. Note 25	Mallarino, A.P., B.M. Stewart, J.L. Baker, J.A. Downing, and J.E. Sawyer	2001	A support document to the NRCS Field Office Tech. Note 25. p. 63-71. In Agriculture and the Environment: State and Federal Water Initiatives. Proceedings. March 5-7, 2001. Iowa State Univ. Ames, IA
Using the Iowa phosphorus index and variable-rate technology for effective agronomic and environmental phosphorus management	Mallarino, A.P., D. Wittry, and J. Klatt	2001	p. 151-158. In The Integrated Crop Management Conf. Proceedings. Dec. 5-6, 2001, Des Moines, IA. Iowa State Univ. Extension., Ames, IA
Phosphorus indexing for cropland: Overview and basic concepts of the Iowa phosphorus index	A.P. Mallarino, B.M. Stewart, J.L. Baker, J.D. Downing, and J.E. Sawyer	2002	J. Soil Water Conserv. 57(6):440-447
Agronomic and environmental phosphorus testing for soils receiving swine manure	Atia, A.M., and A.P. Mallarino	2002	Soil Sci. Soc. Am. J. 66:1696-1705
Grazing management effects on sediment and phosphorus in surface runoff	Haan, M.M., J.R. Russell, W.J. Powers, J.L. Kovar, and J.L. Benning	2006	Rangeland Ecol Manage 59:607–615
Livestock grazing and vegetative filter strip buffer effects on runoff sediment, nitrate, and phosphorus losses	Webber, D.F., S.K. Mickelson, S.I. Ahmed, J.R. Russell, W.J. Powers, R.C. Schultz, and J.L. Kovar	2010	J. Soil Water Conserv. 65(1):34-41
Maryland			
Phosphorus solubility in biosolids-amended farm soils	Maguire, R.O., J.T. Sims, and F.J.	2000	J. Environ. Qual. 29:1225-1233

in the Mid-Atlantic region of the USA	Coale		
Accelerated Deployment of an Agricultural Nutrient Management Tool: The Maryland Phosphorus Site Index	Coale, F.J., T. Sims, and A.B. Leytem	2002	J. Environ. Qual. 31:1471-1476
Phosphorus leaching in manure-Amended Atlantic Coastal Plain soils	Butler, J.S., and F.J. Coale	2005	J. Environ. Qual. 34:370-381
Minnesota			
Evaluation of the Phosphorus Index in watersheds at the regional scale	Birr, A.S., and D.J. Mulla	2001	J. Environ. Qual. 30:2018-2025
Mississippi			
Effects of soil type on bermudagrass response to broiler litter application	Adeli A., J.J. Read, and D.E. Rowe	2006	Agron. J. 98:148-155
Effects of drying intervals and repeated rain events on runoff nutrient dynamics from soil treated with broiler litter	Adeli A., F.M. Bala, D.E. Rowe, and P.R. Owens	2006	J. Sustain. Agric. 28:91-107
Effects of broiler litter and nitrogen fertilization on uptake of major nutrients by coastal Bermudagrass	Read J.J., W.L. Kingery, K.R. Sistani, G.E. Brink, and J.L. Oldham	2006	Agron. J. 98:1065-1072
Phosphorus in Mississippi soils	Oldham, L.	2008	Information Sheet 871. Extension Service of Mississippi State University
Broiler litter fertilization and cropping system impacts on soil properties	Adeli A., H. Tewolde, K.R. Sistani, and D.E. Rowe	2009	Agron. J. 101:1304-1310
Phosphorus dynamics in two poultry-litter amended soils of Mississippi under three management systems	Beavers, B.W., Z. Liu, M.S. Cox, W.L. Kingery, G.E. Brink, P.D. Gerard, and K.C. McGregror	2010	Pedosphere 20(2):217-228
Nutrient management planning basics	Oldham, J.L.	2010	Mississippi State University Extension Service Information Sheet 1853
Montana			
Phosphorus Index assessment for Montana	Fasching, R.A.	2006	No. 80.1 Nutrient Management, Agronomy Technical Note MT-77 (Rev. 3), USDA-NRCS, MT

Nebraska			
Phosphorus risk assessment index evaluation using runoff measurements	Eghball, B., and J.E. Gilley	2001	J. Soil Water Conserv. 56(3):202-206
Nevada			
Phosphorus assessment tool for Nevada (Adapted from New Mexico Technical Note Agronomy 57)		2009	USDA-NRCS, Agronomy Technical Note Agronomy 72, Reno, NV
New Mexico			
Phosphorus assessment tool for New Mexico	Flynn, R., M. Sporcic, and L. Scheffe	2000	USDA-NRCS, Agronomy Technical Note 57, Albuquerque, NM
New York			
Phosphorus and agriculture VI: Identifying soil phosphorus thresholds for the New York Phosphorus Index	Kleinman, P.J.A., R.B. Bryant, W.S. Reid and A.N. Sharpley.	2001	What''s Cropping Up? 11: 4-5
Phosphorus in agriculture V: The New York P Index	Bryant, R., S. Reid, P.J.A. Kleinman, A.N. Sharpley, K. Czymmek, B. Bellows, L. Geohring, T. Steenhuis, F. Gaffney, S. Bossard	2001	What''s Cropping Up? 10(3): 4-5
GIS-based spatial indices for identification of potential phosphorus export at watershed scale	Giasson, E., R.B. Bryant, and S.D. DeGloria	2002	J. Soil Water Conserv. 57(6):373-380
Manure management: optimization of phosphorus index and costs of manure management on a New York dairy farm	Giasson, E., R.B. Bryant, and N.L. Bills	2003	Agron. J. 95:987-993
North Carolina			
Field-scale evaluation of phosphorus leaching in acid sandy soils receiving swine waste	Nelson, N.O., J.E. Parsons, R.L. Mikkelsen	2005	J. Environ. Qual. 34:2024-2035
Change in soluble phosphorus in soils following fertilization is dependent on initial Mehlich-3 phosphorus	Bond, C.R., R.O. Maguire, and J.L. Havlin	2006	J. Environ. Qual. 35:1818-1824
Oklahoma			

Soil characteristics and phosphorus level effects on phosphorus loss in runoff	Davis, R., H. Zhang, J.L. Schroder, J.J. Wang, and M. E. Payton	2005	J. Environ. Qual. 34:1640-1650
Rainfall sequence effects on phosphorus loss in surface runoff from pastures received poultry litter application	Demissie, T., D.E. Storm, M.S. Friend, N.T. Basta, M.E. Payton, M.D. Smolen, and H. Zhang	2010	Am. Soc. Agric. Biol. Eng. 53:1147-1158
Development of a quantitative pasture phosphorus management tool using the SWAT model	White, M.J., D.E. Storm, M.D Smolen and H. Zhang ...	2009	J. Am. Water Resources Assoc. 45:397-406
A quantitative phosphorus loss assessment tool for agricultural fields	White, M.J., D.E. Storm, P.R. Busteed, M.D. Smolen, H. Zhang, and G.A. Fox	2010	Environmental Modelling and Software 25:1121-1129
Phosphorus loss in runoff from long-term continuous wheat fertility trials	Zhang, H., J.L. Schroder, R.L. Davis, J.J. Wang, M.E. Payton, W.E. Thomason, Y. Tang, and W.R. Raun	2006	Soil Sci. Soc. Am. J. 70:163-171
A quantitative phosphorus loss assessment tool for agricultural fields	White, M. J., D. E. Storm, P.R. Busteed, M.D. Smolen, H. Zhang, G.A. Fox	2010	Environmental Modeling and Software 25: 1121-129
Oregon			
The Phosphorus Index	Oksendahl, V.	2001	USDA-NRCS, Water Quality Technical Note No. 2 (revised), Spokane, WA
Pennsylvania			
Integrating phosphorus and nitrogen management at catchment scales	Heathwaite, A.L., A.N. Sharpley, and W.J. Gburek	2000	J. Environ. Qual. 29:158-166. 2000
Source risk indicators of nutrient loss from agricultural lands	Kleinman, P.J.A.	2000	p. 237-252. In Sailus, M. (ed), Managing Nutrients and Pathogens in Animal Agriculture, Northeast Regional Agricultural Engineering Service, Ithaca, NY
Using soil phosphorus behavior to identify environmental thresholds	Kleinman, P.J.A., R.B. Bryant, W.S. Reid, A.N. Sharpley and D. Pimentel	2000	Soil Science 165: 943-950
Comparing phosphorus management strategies at the watershed scale	McDowell, R.W., A.N. Sharpley, D.B. Beegle, and J.L. Weld	2001	J. Soil Water Conserv. 56:306-315

Identifying critical sources of phosphorus export from agricultural watersheds	Weld, J.L., A.N. Sharpley, D.B. Beegle, and W.L. Gburek.	2001	Nutrient Cycling in Agroecosystems 59:29-38
Environmental management of soil phosphorus: Modeling spatial variability in small fields	Needelman, B.A., W.J. Gburek, A.N. Sharpley, and G.W. Petersen	2001	Soil Sci. Soc. Am. J. 65:1516-1522
Phosphorus transport in overland flow in response to position of manure application	McDowell, R.W., and A.N. Sharpley	2002	J. Environ. Qual. 31:217-227
Effect of mineral and manure phosphorus sources on runoff phosphorus losses	Kleinman, P.J.A., A.N., Sharpley, B.G., Moyer, and G. Elwinger	2002	J. Environ. Qual. 31:2026-2030
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WHAT A P LOSS RISK ASSESSMENT TOOL SHOULD AND SHOULD NOT BE

We know there is a diversity of goals for P loss assessment across the U.S. Regional differences in soils, climate, sensitivity of the water resource, and manure management strategies insure this. Different political and historic approaches to these issues also add state and regional differences. Potential objectives for P loss include:

- Document reductions in potential P loss from a farm.
- Facilitate reduction in P losses in impaired watersheds.
- Prioritize fields for cost-share.
- Identify fields where P loss potential is so high no manure should be applied.
- Insure agronomic use of P.
- Document a tactical commitment to reducing P loss from application of manure and other fertilizers.
- Document a strategic commitment to reducing P loss from application of manure and other fertilizers.
- Insure build up of STP does not occur on fields with a high potential for P loss as part of a strategic planning process.
- Insure that farmers minimize losses of recently applied P.
- Identify soils that have a limited or impaired capacity to fix more P.
- Minimize leaching potential of applied P.
- Attain P balance at the farm level.
- Quantify P loss from a field.

A tool to determine risk of P loss from any given field in the U.S.

We believe that the goal of a P Index is to estimate the risk of P loss and we should be able to do this on any given field. Many states have developed adequate tools to do this by describing the main factors controlling P loss in their state. However, there is variation among Indices' cutoff levels or delineation of low, medium, high, and very high risk levels. Most critically, there has to be a consistent result and interpretation regardless of the details of the tool used. Clearly, some P Indices are restrictive and limit P applications, while other P Indices that may use the same basic factors but in the final interpretation have very little impact on management.

A goal of P Indices is to avoid or remediate identified existing or potential water quality problems. To do this, there is a strong case that Index recommendations should be applied on a watershed basis rather than a state basis with an emphasis on P sensitive areas, as P risk loss is a function of the water resource of concern. To incorporate water body response or sensitivity to P inputs; however, water quality specialists within each state will need to be involved.

There should also be consideration of including some type of soil P saturation factor to minimize the potential of groundwater contamination, as well as inclusion of a depth to groundwater table factor. In the long-term, it is desirable to have a basic model structure that has the ability to include region specific modules, such as snowmelt for Wisconsin and hurricane precipitation for Florida. Another long-term goal should be to assess P management and P balance on a landscape level, rather than on a field-by-field basis.

A universal Index that can be applied across the U.S.

We believe that there are too many legitimate differences in soils, climate, cropping systems, water body sensitivities, etc., to support development and use of a single P Index that addresses all of these differences. Development of a single Index that adequately addressed these complexities would likely be a lengthy process and result in a tool that is more complex than current Indices and thus, difficult to use. However, a universal approach that could be used to develop a P loss assessment tool that addresses the P loss issues specific to a region is desirable and should be a long-term goal of SERA-17 and NRCS collaboration.

A tool that links risk and numeric nutrient criteria

Any P Index must be validated against numeric nutrient criteria. However, this is not to say that the Index itself must produce a numeric answer that can be directly linked to numeric nutrient criteria. A quantitative model is essential to developing and validating the Index; however, this committee agrees to disagree on whether a P Index should be qualitative or quantitative. The majority feel that it is not necessary or pertinent for an Index to calculate an edge-of-field P loss for the nutrient management planning process. Loss estimation is probably the only way to validate if a P Index is directionally and magnitudinally correct and site specific, and would certainly add to acceptance of management decisions made as a result of an Index application. We know that many sophisticated models do not do a good job of estimating runoff or hydrologic response, thus, there is concern that this could be a weakness of an Index that provides loss estimates. Although P loss criteria should be designed to meet water quality goals, NRCS's stated goal is to minimize runoff and leaching P losses from a field. Determining what constitutes "minimizing" is a policy decision that should be independent from assessment tool development.

A tool to identify and target appropriate P-decreasing BMPs

This is an important use of the P Index. Many states spend a lot of time in their training talking about and doing exercises on what to do after having run the Index. Most teach that this is a "keep P out of the water tool" not just a "limit manure tool." There is an iterative process of looking at increasing levels of management, for example, changing application methods (timing, method, etc.), controlling erosion and using buffers. An Index does not directly specify BMPs, but the information provided by the Index gives guidance for selecting appropriate BMPs (see Table 2).

Most P Indices already address P loss risk in the presence or absence of conservation practices, either implicitly through erosion reducing practices, or explicitly (e.g., riparian buffers). Even so, it is important to consider whether P Index determinations of conservation practice effectiveness could be made to be more consistent among states.

Because we are working at a field scale to effect change at a watershed scale, we need to understand that there are two levels of confidence associated with the effectiveness of strategies to reduce P loss.

1. Strategies that decrease P loss by addressing the fundamental processes governing P transfer from land to water and not just reducing P applications have a high probability of translating into lower P entering the water body.
2. Strategies that reduce P loss by transferring some or all of the manure applications to another location will only result in improved water quality if:
   a. the manure is transferred out of the watershed or;
   b. the P reduction from the initial field is greater than the increase in P loss from the field receiving the transferred manure.

So, for example, a strategy that reduces erosion from the field (i.e., native P losses) or reduces erosion associated with a manure application (i.e., mechanical application losses) directly translates into water quality benefits. In contrast, any strategy that results in transfer of some or all the manure to another location will only improve water quality if the P cost to water quality on the receiving field is less than the P benefit to water quality on the field being assessed.

Table 2. Best Management Practices for P loss reduction (SERA-17; http://www.sera17.ext.vt.edu/SERA_17_Publications.htm).

Best Management Practice	Description	NRCS CP Code
Barnyard/Feedlot Runoff Management		590
Composting Effects on Phosphorus Availability in Animal Manures		317
Conservation Tillage and Crop Residue Management		329, 344,346
Constructed Treatment Wetlands		656
Cover Crops		340
Dietary Phosphorus Levels for Dairy Cows		592
Dietary Phytase to Reduce Phosphorus Losses from Animal Manure		
Drainage Ditch Management		554, 607
Erosion Control Systems		330, 585
Filter Strips		393, 601
Grassed Waterways		412
Grazing Management		512, 548
Lake and Pond Treatment by Nutrient Inactivation		
Management of Spray Fields		
Manure Spreader Calibration		
Manure Testing		
Milkhouse Filters		
Phosphorus Balance		590
Phosphorus Sources, Application Timing, and Methods		590
Physical Manure Treatment (Solids Separation)		632
Phosphorus Loss with Surface Irrigation		449
Reducing Urban Phosphorus Runoff from Lawns		
Riparian Zones		391
Septic Field Drain Design and Maintenance		
Soil Testing		590
Streambank and Shoreline Protection		580
Strip Cropping		585
Terraces		600
Treating Poultry Litter with Aluminum Sulfate (Alum)		
Treating Swine Manure with Aluminum Chloride		
Tailwater Recovery		447
Vegetative Mining		

THE NUTRIENT MANAGEMENT CONTEXT OF P LOSS ASSESSMENT

Time context of nutrient management planning

Key point: *Nutrient management planning and P loss assessment are part of a multi-step process requiring strategic and tactical planning followed by implementation activities.*

Key point: *Phosphorus loss assessment tools used as part of strategic and tactical planning that occurs days, weeks, months and years before manure is applied to a field should rely on historic data sets describing climate. Implementation activities account for recent and predicted weather events.*

The ideal nutrient management planning process goes through three distinct stages:

1. Strategic planning to determine long-term goals and mapping out a strategy to attain those goals.
2. Tactical planning to address the systematic scheduling of short-term activities needed to attain the goal of a strategic plan.
3. Implementation planning to guide what those people implementing the tactical plan in the field, need to consider to ensure the goals of the strategic and tactical plan are met.

Each phase of the planning process is critical to successful implementation of a nutrient management plan (NMP). Each planning phase can have unique skill requirements for development and implementation.

The strategic planning process develops a one- to five-year plan, typically four to six months before the period of time covered by the planning process. In this process, historic estimates of manure volume and manure test results are used in combination with the most recent soil test results to develop a plan for manure application.

The resulting plan should be viewed as a feasibility plan. The strategic plan answers the question "Does the operation have sufficient land and export opportunities to handle all the manure handled by the operation?" The strategic plan is an opportune time to identify fields where P limits on manure application are needed. Most importantly, the strategic plan defines how decisions will be made in the tactical decision making phase of planning.

The level of complexity in the strategic planning process and strategic planning tools can be beyond the technical capabilities of some farmers and the people who are running the manure application equipment. Strategic planning is frequently done by consultants specializing in nutrient management planning. The high technical requirements for developing such a plan is offset to some degree by the infrequent need for such a plan (every one to five years) and the flexibility to complete such a plan during a down time of the year.

The actual rates of manure application used by the farmer in a field are anticipated to be different than those listed in the strategic plan. Planned rates typically will need to be adjusted for new manure test results and new soil test results obtained as part of the NMP process. These changes could also include changes in crop selection driven by economic- or weather-based considerations.

The second component to the planning process is the tactical scheduling. This is the approach the farmer takes to make adjustments to the strategic plan based on more current information then was available during the strategic planning process. Tactical planning answers the question "Does my plan on this field for this year account for the most up-to-date information on how I am managing this field?"

The purpose of the tactical planning process is to ensure that the actual rate of manure applied to the field accounts for the most current information about the field. Typically, the tactical planning process adjusts the strategic application rate for any changes in crop selection, STP and manure test results. Regulated operations are required to sample manure storages at least annually, so at a minimum the tactical planning process must adapt rates of manure calculated in the strategic plan to the annually updated estimates of manure nutrient concentration.

Tactical planning can occur days, weeks or months before the actual manure is applied to the field. It typically is focused on developing a tactical plan for a field or fields for the current crop year. In that sense, tactical planning is similar to strategic planning in that it can occur far enough in advance that it does not address current short-term conditions in the field, such as saturated soils or forecast rainfall.

There is a lot of demand from farmers for tactical planning tools that can be handled by farmers and/or people who apply manure in the field. The complexity of tactical planning depends heavily on how dramatically the tactical plan deviates from the strategic plan. Adjusting manure application rates for new manure test results can be relatively simple with the appropriate decision support tool. Accommodating wholesale changes in crop selection and tillage can require the degree of sophistication and training similar to strategic planning. To be most effective, tactical planning tools will likely need to be routinely usable by farmers but provide warnings when the farmer may want to visit with a consultant, because the proposed changes have implications beyond the current year and/or may have violated the assumptions of the strategic plan.

The implementation plan provides a farmer or tractor operator feedback immediately before initiating a manure application event. This form of tactical decision making addresses the question "Should I apply manure on this field on this day?" This process can focus on recent weather impacts on soil conditions and forecasted weather in the coming days to determine if conditions are appropriate for land application of manure. By definition, this planning process must be accessible to people who apply manure in the field; we cannot have a system that assumes a nutrient management specialist is needed to approve turning on a manure applicator. The implementation plan also will include record keeping requirements for manure application.

Both strategic and tactical planning looks forward into a future where actual soil conditions and the imminence of specific storm events cannot be known. The implication of this is that the P assessment tools we are attempting to build should rely on climate data. The term climate is used purposefully here reflecting the definition of climate as the regular variations weather over a period of years. In contrast, implementation planning tools must account for current conditions in the field and recent and anticipated weather events.

Is your state going to set a unilateral limit on soil test P level in soil?

Key point: *At some point any further increase in STP on a field is a waste disposal application.*

Key point: *One core decisions in developing P limits on soils is to determine if any factor other than water quality will be used to establish STP limits. Are waste disposal applications justified even if they can be demonstrated to not negatively affect water quality? Can water quality concerns supersede agronomic recommendations where P is recommended?*

Is there a STP level where P applications will be restricted based on STP alone? At the other end of the spectrum, is there a STP level, below which there is no need to run P loss assessment tools? These two limits, if implemented, define the STP range where additional P loss assessment tools are required for application of P.

Background information

Soil test P can be classified into three regions:

1. Agronomic response phase where the fertilizer recommendations based on STP recommend building or maintaining STP to maximize agronomic production. For low testing soils, the recommended rate may exceed crop need to build STP to a recommended level. At the top of this range, the recommended rate may be a maintenance application rate to insure STP do not decline. The boundaries and phases of this region are clearly defined by land-grant university nutrient recommendations.
2. Insurance phase is where many farmers will chose to build STP (applications in excess of crop removal) when given access to a cheap source of P as a hedge on future cost of P fertilizers. The bottom of this range is at the top of the agronomic phase; the top of the range is difficult to define but should not exceed a point where the current farmer has any expectation for deriving benefit from applied P.
3. Waste disposal phase is where a farmer chooses to build STP (applications in excess of crop removal) when there is no possible agronomic justification for the increase in STP. Applications transition from insurance to waste disposal at some hard to define point above the agronomic phase.

From a farmer's perspective P application decisions are largely driven by perceived economic considerations. All farmers make decisions balancing the cost of fertilizer versus potential benefits to yield and crop quality in the agronomic range. Fertilizer prices usually preclude buildup in the insurance phase but the low cost of P in some manure sources allows farmers to consider further buildup of STP to be in their economic interests. From an economic perspective, P fertilizer prices are expected to increase. Many farmers are attracted to the concept of increasing STP to the point where they will not need to buy P fertilizer for 10 or 20 years. In the third phase, farmers are deciding it is cheaper to dispose of P in their soil then make the effort to transport it to more distant fields. This may be driven in part by the value of other components of the manure to the field; the farmer may want the nitrogen (N) in manure. Exporting the manure to other fields incurs both cost and time, plus there is the additional burden of paying for N fertilizer on fields that no longer get manure.

Are waste disposal P applications allowed?

A core decision that any entity setting P policy must address, is the issue of a unilateral limit on STP. The question in its starkest form is "Is there a maximum STP that precludes additional increase in STP even if a more comprehensive analysis with a P loss assessment tool indicates the potential for loss to the watershed is within current standards?" In short, are there STP levels where there is no need to run P loss assessment tools because criteria based on STP alone has limited P applications.

One justification for such a limit is a resource conservation argument; it is not appropriate to use agricultural land as a place to warehouse excess P. The question asked here is <u>not</u> a water quality question. Instead this is It is a "values" question on the appropriateness of using soil as repository for excess P.

A second argument for unilateral STP limit is a future risk argument; current conditions demonstrating current practices limit P loss is no guarantee of future field conditions. This line of reasoning puts a limit on STP as a hedge on possible changes in field conditions that could lead to increased P loss. The rationale behind this approach is that such a limit is needed, because there is no way to insure that conservation practices that limit P loss and allow building STP will continue into the future.

There is a third mechanism that can lead to a STP limit on a field. In some states it is possible to identify a STP level that will guarantee P application restrictions with the state's P loss assessment tool.

Is agronomic need alone enough to recommend P application?

This question seeks to clarify if there is a STP range where manure can be applied with no additional P loss assessment because it is needed based on agronomic criteria. Or alternatively, should water quality restrictions supersede an agronomic recommendation for P? In many states there is no need to run additional P loss assessment tools if land-grant university nutrient recommendations based on a current STP call for P fertilizer for the field.

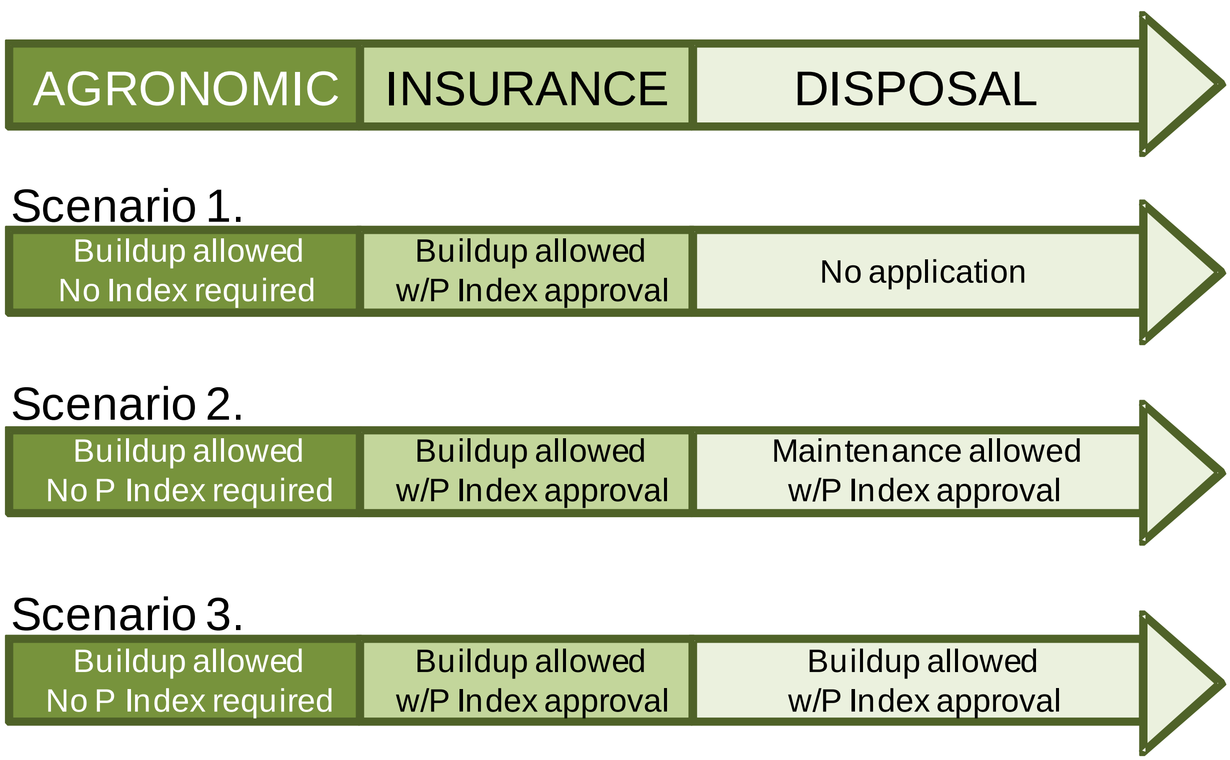
In a regulatory world, requiring P loss assessment on fields that have a recommended P need poses a fairness issue. On regulated fields, a water quality driven restriction on a field with an agronomic P need would only apply to manure as a fertilizer source; farmers applying other sources of P would not be affected by the water quality restriction. Such a restriction creates a challenge from a fairness perspective where farmers with manure feel unfairly singled out.

Language of limits

Frequently, discussion of a limit on STP in soil focuses on a specific value (e.g., no application if STP exceeds 250 mg kg^{-1} Mehlich-3 P). Such terminology will not work in a multi-state conversation and poses challenges in some states with an in-state discussion. Soil test P extractants do not directly quantify a pool of P in the soil. Instead, they extract a portion of the plant available pool of soil P and the test result is indexed against crop response through a calibration process. Consequently, the specific concentration in STP associated with a benchmark, such as optimum level for crop production is dependent on the extract used and soil sampling depth. A specific STP only makes sense if the cited value also defines these parameters (e.g., 250 mg kg^{-1} using Mehlich-3 extract on a sample of the top 15 cm of soil). To facilitate a discussion of STP limits across extract types and state-specific requirements, we should instead focus on multiples of agronomic optimum. Such a limit could be set for example at two times the agronomic optimum. The resulting limit could be interpreted correctly independent of the extraction procedure. States using a specific extraction procedure could later translate the guidance into specific extract concentrations for their state.

Moving toward a recommendation

The figure below defines three possible scenarios. In all scenarios I have allowed buildup applications in the agronomic range with no requirement for the P index. All scenarios require using P loss assessment for any applications outside the agronomic range. The scenarios differ in the restrictions applied to the disposal range. The third scenario represents many states current system allowing buildup in the disposal range if it is approved by P loss assessment. The first scenario would represent the most restrictive approach with a hard "no application" requirement for soils in the disposal range. The second scenario is a middle road "do no harm" approach that insures no further buildup on soils in the disposal range.



Integrating user capabilities and needs into the P loss assessment process

Key Point: *The degree of complexity of a tool largely determines who can use the tool and by extension the degree of voluntary adoption.*

Key Point: *There are farms that have access to highly trained personnel capable of implementing the most complex P loss assessment tools and can benefit from the flexibility in management that such tools can provide. There are also farms that put a premium on self-sufficiency and would accept less flexible tools that require less specialized knowledge.*

The complexity of a nutrient management decision support tool can largely define who is able to use the tool effectively. This in turn can define in large part which farmers have the resources and capacity to use such a tool on their farm.

Phosphorus loss assessment can be a component of all three phases of nutrient management planning. Therefore the complexity of P loss assessment tools can have implications in all aspects of the planning process.

Table 3 defines potential participants in some aspect of the NMP process, lists the expected level of training of each group, and their expected educational background and nutrient management-related skill set. All farms likely have easy access to personnel able to complete the mechanics of manure application, such as sampling soil and manure and running manure application equipment. Decision support tools typically require some level of computer literacy plus a level of technical understanding that cannot be assumed of all farm personnel.

The expectation that a highly trained nutrient management planner is available for all phases of implementing P loss assessment and nutrient management, can be imposed through cost share and regulatory requirements on some operations. But such expectations preclude the majority of producers voluntarily adopting nutrient planning activities. The success of P loss assessment and related nutrient management will largely be defined by adoption rate. Considering the expected skill set of the potential user of a decision support tool is critical to the success of that tool.

Strategic planning typically takes place months and years before implementation. This can facilitate working with a specialized off-site consultant to write the strategic plan. With proper planning the logistics, hiring, and working with a planner should pose no barrier to getting a strategic plan. A significant cohort of farmers will resist spending money to hire a strategic planner.

Tactical decisions sometimes are needed within days of application. Implementation activities by definition occur within hours of application. Requiring the use of highly complex tools in order to approve a specific manure application can create challenges for many farmers. If the farmer relies on an expert contract planner to help with such decisions, they may not have access to their services in the timeframe needed for tactical planning. Only the largest farms always have people on-site capable of the highest levels of nutrient management. Imposing too complex a system for tactical planning or implementation could potentially be an impediment to timely application of manure.

Table 4 considers specific strategic, tactical, and implementation activities and the ability of potential participants in such activities to accomplish the specific task. When developing P loss assessment strategies, it is critical to keep in mind the skill level of the intended audience for such a tool.

There are farms that have access to highly trained personnel capable of implementing the most complex P loss assessment tools at nearly all phases of the planning process. Some of these farms would choose to use the more complex tools so they can benefit from the flexibility in management that such tools can provide. Other farms put a premium on self-sufficiency and would accept less flexible tools that require less specialized knowledge.

As we develop tools, we must consider audience and complexity. NRCS is focused on a suite of tools that requires specialized planners to complete strategic and tactical planning activities and at times implementation activities. There is a critical need for a suite of tools that allow a farmer to complete some level of strategic planning supplemented by farmer, contract manure applicator, and/or farm worker taking responsibility for some level of tactical and implementation activities.

The tools for each group can be equally protective of water quality. All tools should only be as complex as needed to be effective. The simpler tool set may have less flexibility which will translate into more restrictive requirements. The need for multiple tools is most apparent when considering the intersection of user capability with the three stages of nutrient management.

Table 3. Descriptions of the professional training backgrounds of potential participants in nutrient management on a farm.

Participant	Likely Education	Potential Relevant Professional Certifications	Expected Skill Set
Professional Nutrient Management Planner	• Nutrient Management relevant college education (e.g., agronomist, soil scientist or natural resources. • Post-degree professional training on nutrient management.	• Certified Crop Advisor or Soil Scientist. • NRCS Technical Service Provider (TSP). • State Nutrient Management Certification.	• Complex computer-based decision support tools. • Sophisticated strategic capability to integrate regulations, conservation planning and farm-specific conditions into a planning strategy. • Experienced in the mechanics of nutrient management[1].
Farmer or Farm Manager	• College education or professional (2-year) degree.	• None.	• Familiar with computer including using decision support tools. • Experience with strategic planning but not necessarily nutrient management planning. • Typically capable of most aspects of the mechanics of manure management. May be deficient in training for specific tasks.
Contract or Professional Manure Applicator	• High school diploma. • May have had professional training on nutrient management.	• State Applicator Certification.	• Limited experience with computers. • Capable of job-specific elements of the mechanics of manure management.
Farm worker	• High school diploma. • On-the-job experience.	• None.	• Limited experience with computers. • Capable of job-specific elements of the mechanics of manure management.

[1] Mechanics of nutrient management includes soil and manure testing, calculating a manure rate and calibrating and running manure application equipment.

Table 4. Projected capabilities of potential participants in nutrient management planning to execute specific activities related to strategic, tactical, and implementation planning.

Nutrient Management Activity	**Professional nutrient management planner**	**Farmer or farm manager**	**Contract or professional manure applicator**	**Farm worker**
Strategic Planning				
Software-supported whole-farm strategic planning requiring integration of erosion control into P loss assessment. Currently requires using RUSLE2.	Yes, with extensive training	No	No	No
Software-supported whole-farm strategic planning integrating agronomic and P balance requirements.	Yes	Yes for motivated farmers with training.	No	No
Software-supported whole-farm strategic planning integrating agronomic considerations.	Yes	Yes for motivated farmers with training.	No	No

Table 4 continued. Projected capabilities of potential participants in nutrient management planning to execute specific activities related to strategic, tactical, and implementation planning.

Nutrient Management Activity	**Professional nutrient management planner**	**Farmer or farm manager**	**Contract or professional manure applicator**	**Farm worker**
Tactical Planning				
Software-supported tactical planning that requires using RUSLE2 or similar level software to update P loss assessment for a field.	Yes, with extensive training. Availability could be an issue.	No	No	No
Software-supported tactical planning that facilitates changes in crops and tillage on erosion estimates for P loss assessment.	Yes, with training. Availability could be an issue.	Yes for motivated farmers and the right tool.	Yes for some, with extensive training and the right tool.	Yes for a few, with extensive training and the right tool.
Software-supported tactical planning that calculates changes in manure application rate based on new crop selection, STP results and/or manure test results.	Yes. Availability could be an issue.	Yes, training needed.	Yes, training needed.	Yes for some, with extensive training and the right tool.
Software-supported tactical planning that calculates changes in manure application rate based on new manure test.	Yes. Availability could be an issue.	Yes, some training may be needed.	Yes, some training may be needed.	Yes, training needed.
Implementation				
Use decision support tool to determine if field conditions are appropriate for application.	Availability an issue.	Yes, training needed.	Yes, training needed.	Yes, training needed.
Fill out manure application records.	Availability an issue.	Yes.	Yes.	Yes, training needed.

THE RELATIONSHIP BETWEEN SOIL AND RUNOFF P

In the absence of surface water quality standards oriented toward minimizing eutrophication in the early 1990's, and without research data, several states recommended threshold STP levels that are *perceived* to limit eutrophic runoff. However, care must be taken on how STP results are interpreted for environmental purposes. Interpretations given on soil test reports (e.g., low, medium, optimum, high) were established based on the expected response of a crop to P. Some people simply extended the levels used for interpretation for crop response and to say that if STP was above the level where a crop response is expected, then it is in excess of crop needs and, therefore, is potentially enriching runoff with P.

Considerable field-based research has provided data suggesting the use of water extractable soil P as an environmental test, which is independent of soil type, to assess the potential for soil to enrich runoff with dissolved P (McDowell and Sharpley, 2001; Pote et al., 1996). The extraction of soil with water closely mimics the interaction between surface soil and rainfall and the subsequent release of P to runoff water than do acidic or basic STP extractants. Andraski and Bundy (2003), Andraski et al. (2003), Daverede et al. (2003), Hooda at al. (2000), Pote et al. (1999a, 1999b), and Torbert et al. (2002) all reported water extractable soil P to be closely related to runoff dissolved P for both grassed and cropped plots, at a similar or greater level of significance than Bray-1 and Mehlich-3 extractable soil P (Vadas et al., 2005). Increasingly, investigators are using water extractable P in lieu of runoff data in lab studies aimed at comparing environmental and agronomic effects.

Several studies have found a change or break point in the relationship between STP and the concentration of P in surface runoff and subsurface flow of leached water. One of the first to report this was Heckrath et al. (1995) who found that STP (as Olsen P) >60 mg kg^{-1} in the plow layer of a silt loam, caused the dissolved P concentration in tile drainage water to increase dramatically (0.15 to 2.75 mg L^{-1}). They postulated that this level, which is well above that needed by major crops for optimum yield (about 20 mg kg^{-1}; Ministry of Agriculture, Food and Fisheries, 1994), is a critical change point above which the potential for P movement in land drains greatly increases. Subsequently, Maguire and Sims (2002a) found that STP as estimated by water, 0.01 *M* $CaCl_2$, or Mehlich 3 extraction were related to dissolved P in leachate from 20 cm intact columns of soil from the Delmarva Peninsula. Change points of 1.86, 1.6, and 181 mg kg^{-1} were obtained for water-, $CaCl_2$-, and Mehlich 3-P, respectively, with the slopes of the relationship between soil P and dissolved P five times greater above than below the change point for water, seven times for $CaCl_2$, and 41 times for Mehlich-3 P (Maguire and Sims, 2002a). Bond et al. (2006) reported a Mehlich-3 P change point of 115 mg kg^{-1} using water extractable P as an indicator of potential P concentration in leachate for several North Carolina soils. These and other change points are listed in Table 5.

Another method used to determine environmental soil P thresholds is estimation of the degree of P sorption saturation (DPS), which is based on the premise that the saturation of P sorbing sites for a soil determine P release (intensity factor) as well as the level of soil P (capacity factor) (Breeuwsma and Silva 1992; Kleinman and Sharpley, 2002). For example, soils of similar STP may have differing capacities to release P to runoff, based on the fact that P would be bound more tightly to clay than sandy soils (Sharpley and Tunney, 2000). Phosphorus sorption saturation can also represent the capacity of a soil to sequester further P addition and thereby enrich runoff P (Lookman et al., 1996; Schoumans et al., 1987). The addition of P to a soil with a high DPS will enrich runoff P more than if P was added to a soil with a low P sorption saturation, independent of STP (Leinweber et al., 1997; Sharpley, 1995a). Traditional techniques to estimate soil DPS have relied upon methods that are not commonly performed by soil testing laboratories, such as acid ammonium oxalate extraction in the dark (e.g., Shoumans and Breeuwsma, 1997) and P sorption isotherms (e.g., Sharpley, 1995b). Recent research has shown DPS in acidic soils can be reliably estimated from Mehlich-3 extractable Al and Fe (primary components of P sorption) and P (Beauchemin and Simard, 1999; Kleinman and Sharpley, 2002; Nair and Graetz, 2002). Change points in DPS, above which the concentration of P in runoff or release to soil water increases, have been found to range from 15 to 56% for several studies detailed in Table 5.

In summary, the identification of change or break points in the relationship between STP and runoff P supported the existence of a STP threshold, above which the release of soil P to runoff was greater than below it. However, several studies have not found the existence of such a threshold break point, which limits its widespread use in delineating and upper environmental soil P limit or threshold. Similarly for DPS, change points are not always obtained and use of Mehlich-3 or oxalate extraction derived values, limit the applicability of this method to noncalcareous soils, where soil P reactions and chemistry are dominated by Al and Fe compounds in soil. Again, this limits use of a DPS approach across the U.S., that would encompass calcareous or Ca-reaction dominated soils.

Table 5. Change point values reported for the relationship between soil test P estimates (x) and runoff or leachate P estimates (y).

Reference	Location	# obs.	Soil P estimate (x)	P loss estimate (y)	Change point	Regression slope	
						Before	After
Soil test P estimate, mg kg^{-1}							
Bond et al. (2006)	North Carolina	25	Mehlich-3	Water soluble soil P	115	0.02	0.20
Heckrath et al. (1995)	England	~33	Olsen P	Dissolved leachate P	56	-	-
Jordan et al. (2000)	N. Ireland	42	Olsen P	Dissolved runoff P	22	0.001	0.048
McDowell and Sharpley (2001)	England	43	Olsen P	Dissolved leachate P	35	-	-
	Pennsylvania	75	Mehlich-3	Dissolved runoff P	185	-	-
				Dissolved leachate P	193	-	-
Maguire and Sims (2002a)	Delmarva Peninsula	105	Water	Leachate dissolved P	8.6	0.025	0.12
			0.01 *M* $CaCl_2$		8.6	0.034	0.25
			Mehlich-3		181	0.0003	0.0124
Sims et al. (2002)	Delaware	120	Mehlich-3	Dissolved leachate P	235	0.0023	0.0147
Degree of soil P sorption saturation, %							
Butler and Coale (2005)	Beltsville, MD	40	Oxalate	Water soluble soil P	34	0.11	0.61
	Poplar Hill, MD	40	Oxalate	Water soluble soil P	25	0.04	0.80
	Queenstown, MD	40	Oxalate	Water soluble soil P	30	0.07	1.10
	Upper Marlboro, MD	40	Oxalate	Water soluble soil P	28	0.10	0.79
Casson et al. (2006)	Alberta	47	Mehlich-3	Water soluble soil P	3 - 44	-	-
Hooda et al. (2000)	England	320	Oxalate	Water soluble soil P	10	-	-
Maguire and Sims (2002b)	Delaware	105	Oxalate	Leachate dissolved P	56	0.0026	0.108
Nair et al. (2004)	Florida	69	Mehlich-3	Water soluble soil P	16	0.060	0.201
Nelson et al. (2005)	North Carolina	60	Oxalate	Water soluble soil P	45	0.001	0.140
Sims et al. (2002)	Delaware	120	Mehlich-3	Dissolved runoff P	0.13	0.024	4.33
				Dissolved leachate P	0.2	0.0098	28.44

REASONS FOR DIFFERENT NUTRIENT RECOMMENDATIONS

Soil Test Methods and Recommendations

It is important to recognize there are many aspects to soil testing that cause differences in nutrient recommendations, which have the potential to influence P loss risk assessment interpretations. Aspects of soil testing include different soil test extractants, methodologies, and calibration of nutrient recommendations to yields developed primarily at state institutions. Different soil test philosophies also developed and can affect nutrient recommendations. For instance, many labs use the Mehlich-3 extractant, but the nutrient recommendations will differ due to the "philosophy" of each soil test laboratory; one lab may use a sufficiency philosophy uses (e.g., North Carolina), while another will use a buildup and maintenance strategy (e.g., Missouri). These differences in philosophy will change the fertilizer recommendations.

In addition, states use critical level in their STP results but often with different meanings. In some states, critical nutrient levels indicate there is no additional response from fertilizer (e.g., New York). Other states' critical levels indicates that there will continue to be some response, but often depends on the crop. For example, at a 60 mg kg^{-1} STP, there is no P recommendation for corn but there is for tobacco. Still others use profitability in their guidance; the critical level is defined as the level below which a profitable yield response by most major crops in the year of application is expected. Due to these differences in defining critical levels for nutrients, the same STP level can trigger different nutrient recommendations.

In a comparison of regional (Western, Central, and Eastern) STP recommendations, McFarland et al (2006) found that:

- Overall, STP recommendations for N, P and K in adjoining states within a region (West, Central, and East) were very similar across the range of soil test levels from Very Low to Very High for the major crops and cropping systems evaluated.
- Variations in fertilizer N, P and K recommendations based on soil test and/or yield goal, soil type, organic matter content, or nutrient index (e.g., P Index) typically ranged from 0 to 14%. This application range is often within the range of fertilizer spreader technology and in the area of nutrient application does not represent true differences.
- Variations in N recommendations generally ranged from 0 to 14% for samples in the low to medium soil test categories for regions that can use N soil tests.
- Selected cases of more substantial percentage variation (33 - 150%) in N recommendations were observed, but typically were associated with the Very High soil test range where lesser total amounts of fertilizer N are recommended. For example, N recommendations for 200 bu/acre irrigated corn in soils testing Very High were 20 and 50 lbs N/acre for Idaho and Oregon, respectively.
- Many northcentral and southeastern U.S. states do not utilize a soil test for N; thus, credits for measured N used by some states could result in differences in fertilizer recommendations. In

addition, some states provide N credits based on measured or classified soil organic matter content while others do not.

- Management practices, such as method of application (band vs. broadcast) can significantly affect recommendations and apparent consistency. For example, the Washington recommendation for wheat is based on subsurface banding and is doubled if fertilizer is applied broadcast, while Idaho makes no distinction based on method of application.

There is a perceived lack of current data for soil testing recommendations for high-yield levels, modern cultivars, and new emerging crops in many states. For example, average corn yields in the U.S. were <60 bu acre^{-1} in 1960, but over 165 bu acre^{-1} in 2009; clearly putting a greater demand on the soil nutrient supply, yet in many states, land-grant university nutrient recommendations are no longer routinely reevaluated or updated due to lack of resources. With advancements in irrigation technology (such as drip and microsprinkler), the entire procedure for making fertilizer recommendations might need to be re-evaluated. Many new or specialty crops have limited research information on fertilizer response due to lack of funding for such work at the land-grant universities.

Depth of Soil Sampling

Vertical stratification of STP has been clearly demonstrated under certain management practices where surface applied P is not incorporated, such as in no-till cropping and pasture systems (Pierson et al., 2001; Pote et al., 1999a; Sharpley et al., 1993). This accumulated P can lead to an increase in runoff dissolved P as observed by Daverde et al. (2003) from no-till corn-soybean rotations in Illinois; Krieger et al. (2010) from no-till corn-soybean rotations in the Maumee River Watershed draining into Lake Erie; Sharpley and Smith (1994) from no-till wheat in Oklahoma; and Tiessen et al. (2010) from no-till cereals and oilseeds in South Tobacco Creek Watershed, Manitoba.

As the depth of interaction between surface runoff and surface soil is is often about 2 inches or less (Sharpley, 1985), STP values resulting from typical soil sampling depths (6-8 inches) should be carefully interpreted in no-till situations to account for surface runoff potential under these P-stratified management conditions. In soils where leaching is predominantly by macropore flow, McDowell and Sharpley (2001) found that leachate P concentrations were correlated to surface STP.

590 Standard

Despite a national USDA-NRCS 590 standard, there are variations in interpretation of the standard by states. Osmond et al. (2006a, b) compared P indices from the 12 southern states and found that the range of Index values generated by individual P Indices is broad and the categories of Low, Medium, High, and Very High are associated with a variety of numerical ratings. As examples, Arkansas has the smallest rating range (<0.6 for Low to >1.8 for Very High), whereas Louisiana has the greatest rating range (<600 for Low to > 1800 for Very High). The break point for categorizing P loss in to the different ranking categories is not uniform.

Once the numeric ratings were derived, they were transformed into the risk categories. All state P-indices, except three (Alabama, New Mexico, Oklahoma, and Texas), use a Low, Medium, High, and Very High rating system (Table 6). The Alabama and New Mexico P-indices includes an Extremely High rating and Texas a Very Low rating. A Severe rating replaces the Very High rating in the Oklahoma P-index. Although the rating name is the same for each state, the management decisions associated with the ratings differ among states (Table 6). For instance, a Very High rating for Alabama allows 1X crop P removal rate, while Kentucky, Louisiana, North Carolina, and South Carolina allow no further P applications. Texas management of manure discriminates within the same rating based on water impairment classification. Even if the P indices all lead to the same results, management interpretations are often very different.

Table 6. Management recommendations and interpretations of the four risk categories of P indices in use across the U.S.

State	P-Index Rating			
	Low	Medium	High	Very High
AK	N-based plan	N-based plan	P-based plan (soil test recommendation)	P-based plan (no P application)
AL*	N-based plan	P-based plan (up to 3x crop removal P)	P-based plan (up to 2x crop removal P)	P-based plan (crop removal P)
AZ*, **	N-based plan	N Based	P Based (1.5 x crop removal)	P Based (at crop removal)
AR	N-based plan	Conservation or reduce P application to maintain PI risk at 1.2	Conservation and reduce P rates to drop PI risk to 1.2	P-based plan (conservation to reduce PI to 1.2)
CA	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (no P application)
CO	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (do not apply manure without decreasing the risk for off-site transport)
CT				
DE	N-based plan	N-based plan for no more than 1 of 3 years & P-based plan 2 of 3 years, during which P-application are limited to the amt. expected to be removed by crop harvest or soil-test based P-application rec's (or which is greater)	P based application recommendations. All practical management practices for reducing P losses by surface runoff, subsurface flow, or erosion should be implemented.	No P Active remediation techniques should be implemented
FL	N-based plan	N-based plan	Conservation and/or P-based plan (STP determines P application rate)	Conservation and P-based plan to reduce STP over a defined period
GA	N-based plan	N-based plan	Add buffers and/or reduce P	Add buffers and/or reduce

			rate to drop PI below 75 within 5 years	P rate to drop PI below 75 within 5 years
HI				
ID	Maintain at current management level	Medium potential for nutrient loss. Some remediation measures should be undertaken to minimize the probability of nutrient loss	Soil and water conservation measures and P management plans are needed to reduce the probability of nutrient loss	All necessary soil and water conservation measures and a NMP must be implemented to minimize nutrient loss
IL				
IN				
IA +	Current soil conservation and P management practices keep water quality impairment low.	Careful consideration should be given to further soil conservation and P management practices	New soil and water conservation practices and/ or P management practices are necessary	All necessary soil and water conservation plus a P-management plan, which may require discontinuing P applications must be put into place
KS	N-based plan	Restrict manure applications and a long-term P management plan should be used	P-based plan (crop removal P)	P-based plan (no P application)
KY	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (no P application)
LA	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (no P application)
ME				
MD	N-based plan	N-based plan for no more than 1 of 3 years & P-based plan 2 of 3 years, during which P-application are limited to the amt. expected to be	P-based plan (crop removal P)	No P, active remediation techniques

		removed by crop harvest or soil-test based P-application rec's (or which is greater)		
MA	N-based plan	N-based plan w/ BMPs	P-based plan (crop removal P)	No P
MI				
MN++	Minor management changes are recommended	Small improvements in management may be needed to lower P loss risk. Avoid practices that increase P loss risk	Moderate improvements in management are recommended	Multiple and possibly large improvements in management practices recommended
MS	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (50% crop removal P)
MO	N-based plan	N-based Consider P-based	P-based plan Additional land conservation practices to reduce P loss from this field highly recommended	No-P Implement land conservation practices
MT	N-based plan	N-based plan. Some remedial action (i.e., filter strips, grassed waterways, application setbacks, manure injection or incorporation) needed to lessen potential for P loss	P-based plan (crop removal P)	P-based plan (crop removal P). Conservation practices needed
NE	N-based plan	N-based plan	Remedial action such as alternative conservation measures or P-application, required. Manure can be applied but applied P should not exceed crop removal	No P Improved conservation measures should be implemented
NV*,**	N-based plan	N-based plan	P-Based (1.5 x crop removal)	P-Based (at crop removal)
NH				

NJ				
NM*	N-based plan	N-based plan	P-based plan (up to 1.5 x crop removal P)	P-based plan (crop removal P)
NY	N-based plan	N-based plan w/ BMPs	P-based plan (crop removal P)	No P2O5 fertilizer or manure application
NC	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (no P application)
ND	N-based plan	N-based plan	P-based plan (crop removal P)	No application of organic nutrients
OH	N-based plan	N-based plan Also consider: P-based plan (crop removal P)	P-based plan (crop removal P)	No P
OK	N-based plan	N-based plan if slop <8%, P-based plan if slop >8%	P-based plan (reduced amount)	P-based plan (no P application)
OR	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan. No manure application is allowed on Very High Risk Sites unless BMPs in place to decrease PI transport and source factors
PA	N-based plan	N-based plan	P-based plan (crop removal P)	No P
PR	N-based plan	N-based plan	P-based plan (1-2x crop removal P)	Do not apply P or apply nutrient source on a P base (<1x P crop removal) after implementation of recommended BMPs
RI	N-based plan	N-based plan w/ remedial action	P-based plan	No P
SC	N-based plan	2x crop removal P, not to exceed crop N needs	P-based plan (crop removal P) + conservation	No P application + remediation
SD				
TN	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (crop removal P)
TX**	N-based plan	2x crop removal P for	1.5x crop removal P for	1x crop removal P for

		non-impaired; 1.5x crop removal P for impaired	impaired for non-impaired; 1x crop removal P for impaired for impaired	impaired for non-impaired; 1x crop removal P for impaired every other year for impaired
UT [5]	Maintain at current management level	Some remedial action should be taken to lessen the probability of P movement. Limited or no winter spreading of manure	Manure should not be applied unless BMPs are in place and no winter spreading of manure	
VT	N-based plan	N-based plan w/ remedial action	P-based plan	No P
VA	N-based plan	P-based plan (up to 1.5 x crop removal P)	P-based plan (crop removal P)	No P
WA	Maintain at current management level	Some remedial action should be taken to lessen the probability of P movement	Manure or organic by-products will not be applied on sites considered vulnerable to off-site P transport unless appropriate conservation practices are in place to prevent off-site transport occurring.	Necessary soil and water conservation practices + a P-management plan must be put in place. Manure or organic by-products will not be applied on sites considered vulnerable to off-site P transport unless appropriate conservation practices are in place that will prevent off-site transport occurring.
WV				
WI [6]				
WY	N-based plan	N-based plan	P-based plan (crop removal P)	No application

[1] AL, AZ, NM, and NV have an Extremely High (or *Excessive*) rating, which has the management implication of no P.

[2] AZ, NV, and TX have a Very Low rating, which has the management implication of N-based plan.

[3] IA: VERY LOW– 0-1 A field in which movement of P off site will be VERY LOW. If soil conservation and P management practices are maintained at current levels, impacts on surface water resources from P losses from the field will be small.

[4] MN has a Very Low rating suggesting "no management changes"

[5] UT has a STP (as Olsen P) accompanying the Index: if STP is <50 mg kg^{-1} apply manure based on N needs of the crop; if STP is 50-100 mg kg^{-1} apply based on crop P removal; if STP is >100 mg kg^{-1} application is based on half or less of crop P removal.

[6] WI has a two category system if the P Index is used for 590 planning. At P Index > 6, no manure P can be applied; at $\leq$6, manure can be applied up to allowed N application rates. WI also allows planning using an alternative, STP standard: if STP (Bray P1) is <50 mg kg^{-1} apply manure based on N needs of the crop; if STP is 50-100 mg kg^{-1} apply based on rotation crop P removal; if STP is >100 mg kg^{-1} maximum application is 75% of crop P removal

SOME THOUGHTS ON NEXT GENERATION P INDICES

Temporal Representation

Most P Indices are designed to run as part of a multi-year nutrient management planning process. But there is significant variation in the time period used for assessing critical levels of P loss. For example, there are existing Indices that are applied on a single application basis, seasonal basis, annual basis, and multi-year basis, and often for annual planning purposes, assessment of "worse case scenarios" is done to give producers an upper limit for application (e.g., "manure can be applied up to…., if spring incorporated and up to … if fall applied").

Some Indices focus on specific manure applications estimating if P loss from that application exceeds a loss threshold (units of concentration or mass per area). This approach can result in one field having some applications targeted as P limited and others labeled as N limited on the same field in the same year. Such an approach provides the best opportunity to describe P loss from specific applications but fails to document the benefits and liabilities of moving applications from one time to another or combining multiple applications. Most P Indices assess losses per crop year (units of mass loss per area per crop year). Such Indices may include strategies that benefit applications in specific seasons but cannot assess the benefits of multi-year versus annual applications. Such Indices also label some years as P limited and other years as N limited.

Finally there are Indices that assess average annual losses of P for the planning period (units of average mass loss per area). This approach is analogous to erosion assessment in RUSLE2 where high erosion losses in one year may be offset by low losses in another year, as long as the average for the planning period is below "T." This also fits into the EPA CAFO regulation concept requiring the P loss assessment rating be for the term of the permit. Examples of this approach include North Carolina and Missouri. The primary weakness of this approach is that it will underestimate losses when high erosion years correspond with high P application rates. A hybrid approach may be possible that addresses both annual and planning period losses. For example, the Wisconsin-P Index reports both the annual estimated mass P loss in each year of the rotation and the rotation (i.e., planning period) average.

Next generation P Indices should assess the risk for P loss for individual P applications as well as the combined effects of more than one application at least within a crop year and preferably over the planning period between soil tests. For example, Pennsylvania's P Index addresses the combined effects of multiple applications within a year, to avoid splitting a large P application rate into several applications of smaller rates that would individually each result in an acceptable P Index rating but collectively would be a problem.

Absolute vs. Relative P Indices

Phosphorus Indices were structured to either calculate edge-of-field P loss as a load (lbs P ac^{-1} yr^{-1}) or to describe the relative risk of P loss, which has lead to absolute P Indices (edge-of-field loss) or relative P Indices. Some states with strong research data such as Georgia, Arkansas, Iowa, North Carolina, and Wisconsin have developed edge-of-field P loss Indices (absolute). Other states have viewed the Index as an educational tool to affect implementation of BMPs (relative). Absolute Indices generally require extensive modeling and highly technical support to implement while relative Indices are generally easier to implement.

In a comparison of 12 southern P Indices, Osmond et al. (2006b) found that absolute P Indices were no more similar in their P loss ratings than relative P Indices. Four P Indices (Arkansas, Georgia, Iowa, and North Carolina) are structured to be absolute P Indices; Alabama, Florida, Kentucky, Louisiana, Mississippi, Oklahoma, South Carolina, Tennessee, and Texas are relative P Indices. Divergence in ratings between these two types of P Indices did not reveal similarities within a P Index structure (e.g., the P Indices that predict edge-of-field losses –absolute - were no more similar to each other than were the relative P Indices). Mississippi ratings were very different from Alabama, Oklahoma, and Tennessee ratings, just as Arkansas, Georgia, and North Carolina ratings were quite diverse.

Examples of differences in absolute P Indices are provided to demonstrate nuances that occur in these Indices even when P runoff is calculated in lbs P ac^{-1} yr^{-1} (absolute). The Arkansas P Index was calibrated using experimentally derived coefficients and is used only for pasture or hay land conditions, whereas the North Carolina P Index used modeled runoff and infiltration values as well as STP and applied P levels (North Carolina PLAT Committee, 2005). Under cropland conditions, STP had a greater effect on the North Carolina ratings than on Georgia ratings (Cabrera et al., 2002), whereas tillage seemed to affect ratings for both P Indices. Buffers were important to reduce the P Index ratings in both states, although buffers were more important in Georgia than North Carolina. The North Carolina P Loss Assessment Tool assumes that buffers only reduce sediment attached P, not soluble P, whereas the Georgia P-Index does not discriminate between pathways as long as the STP of the buffer is lower than 225 mg kg^{-1}. Above that threshold, the Georgia P-Index assumes that buffers do not reduce soluble P but still reduce particulate P.

GIS and Database Interfacing

The NRCS and EPA require the use of the Revised Universal Soil Loss Equation, Version 2 (RUSLE2) to determine soil erosion when developing NMPs. The standard approach to estimating a crop field's soil loss with RUSLE2 involves selecting a single soil type in the field. If the field has more than one soil type, the field's "dominant critical area" is supposed to be used as a “surrogate” to determine soil loss for the entire field in the conservation plan. The dominant critical area is usually the most erodible soil that constitutes at least 10% of the field's area and represents the soil type, slope, and length of slope on which conservation treatments are based for the entire field. The goal of conservation treatments is to reduce soil loss to the representative soil's “T” factor. However, the dominant critical area soil may not be the predominant soil in the field and it may not be the soil that should be used in making nutrient recommendations or in assessing the risk of nutrient and sediment loss from the field.

A "spatial" approach to estimating soil loss for a field with RUSLE2 involves estimating soil loss for all digitized soil survey polygons whose boundaries overlap with the field's boundary. This would eliminate the need to select a single soil for a field to run RUSLE2, while allowing traditional conservation planning to be done on the basis of a single soil.

With a spatial approach, the field's RUSLE2 crop management is still used for each soil type. Only the hillslope profile is changed for each soil polygon's RUSLE2 calculation to use the polygon's slope, slope length, and soil type rather than the same field-based values for all soils. Initially, the midpoint of the survey soil's slope range could be used as the RUSLE2 slope input. This could be refined by estimating the polygon's slope using digital elevation data. The initial slope length value is set based on the soil's slope. Slope length could also be refined using elevation data.

Work is underway to develop erosion prediction tools that are GIS/geo-referenced to calculate erosion and runoff on a cell-by-cell basis using DEM and/or LIDAR maps. This will present an opportunity to build P risk assessment tool functions around erosion prediction models. This could account for local climate, soils, management, and topography. In most states, the risk of P loss from a field is estimated using a state-specific P Index.

Like RUSLE2, underlying soil properties are also considered in calculating the P Index. With a P Index this may include commonly used soil properties such as hydrologic group, drainage class, runoff class and annual flooding. However, using the same soil that was used to estimate the field's soil loss may not be appropriate in calculating the field's P Index rating. Further compounding this is the measurement of distance to water, another common input to most P Indices. Instead of using a single distance to water for the field, a distance for each soil polygon could be estimated automatically by the GIS. The GIS could then calculate the distance between any point on a soil polygon's application area boundary and any point on a surface water boundary. Note that a tile inlet or other direct conduit could also be considered surface water and identified as such.

With a spatial assessment, the RUSLE2 input to the P Index could be calculated for each soil as described above. Similarly, the P Index could be also calculated for each soil polygon in the field, using each polygon's underlying soil properties as inputs to the P Index. As with RUSLE2 results, spatially-based P risk results could be visually displayed on a map by coloring any soil areas whose risk level indicates that P application should be restricted using the same color, for example red. This would provide planners with a quick way of identifying areas of the farm landscape where changes in rate or management might be necessary.

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