Comparing ratings of the southern phosphorus indices

D.L. Osmond, M.L. Cabrera, S.E. Feagley, G.E. Hardee, C.C. Mitchell, P.A. Moore Jr., R.S. Mylavarapu, J.L. Oldham, J.C. Stevens, W.O. Thom, F. Walker, and H. Zhang

ABSTRACT: The use of site assessment indices to guide agricultural phosphorus (P) nutrient management has been widely adopted in the United States. This study compares P-index ratings from 12 southern states (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas) on fields representing three dominant southern agricultural systems: upland pasture, upland cornfield, and artificially drained field. The structure of each P-index varied enough to produce widely divergent ratings when applied to similar scenarios where individual factors (such as soil test P, poultry broiler litter application rate, or buffer absence or presence) were adjusted across a broad range of P-index input values. Variation in P-index ratings was the unique combination of each state's selected factors, weighting of the factors, and factor combination (added, multiplied, or a mixture of both addition and multiplication). Although the flexibility of and differences among the southern states' P-indices result in dramatically diverse P-index ratings for the same set of conditions, the diversity in P-index construction allows for indices designed to match individual state conditions and concerns. The substantial differences in P-index results identified in this survey highlight the need for close coordination between states in revising P-indices if they are to be applied across state lines.

Keywords: P-index, Southern CSREES region

Nutrient management policy in the United States is framed by the U.S. Department of Agriculture (USDA)—Natural Resources Conservation Service (NRCS) Code 590 (USDA/NRCS, 1999). This policy, stemming from a joint agreement between the U.S. Environmental Protection Agency (USEPA) and USDA, requires all states to adopt one of three approaches to controlling non-point source phosphorus (P) losses from fields receiving manure: 1) establish a soil test P threshold based upon crop requirements above which P applications are restricted; 2) establish an alternative soil test P threshold using water quality rather than agronomic criteria; or 3) develop a P-index to target remedial measures at fields of greatest risk to P loss. The P-index option was developed by NRCS (Lemunyon and Gilbert, 1993), because the use of soil test P thresholds (options 1 and 2) was widely viewed as unduly restrictive and potentially ineffective at curtailing non-point source P losses. The intent of the P-index is that conservation and nutrient management planners will use it to identify critical sources of P loss in agricultural watersheds, and to evaluate alternative management options to reduce these risks (Lemunyon and Gilbert, 1993). Nearly all states have embraced the P-index approach. Twenty-three states adopted the P-index, either directly or with modifications from the original concept, 25 states use a combination of the P-index and/or environmental P threshold, and two states (California and Connecticut) use soil test P crop response (Sharpley et al., 2003).

The initial P-index ranked transport and source factors and added them together (Lemunyon and Gilbert, 1993). Because individual states were allowed to write their own NRCS 590 standard and modify the original P-index to address local priorities and conditions, there exist large structural variations in the P-indices. Most states have made one or more of the following changes to the original design and formula proposed by Lemunyon and Gilbert (1993): 1) source and transport factors are multiplied rather than added; 2) distance from water resources is considered; and 3) some factors, such as soil loss, soil test P and P application rate, are quantified (Sharpley et al., 2003). In addition, some states, such as Georgia, Arkansas, Iowa, and North Carolina have developed "predictive" P-indices, or loading models, that calculate edge-of-field P loss in kg P ha^{-1} yr^{-1}.

Other factors, such as resources available to individual states and priorities of experts involved in P-index development committees, helped to shape each state's final P-index. For example, Alabama adopted a very simple P-index that could be completed on paper (Charles Mitchell, personal communication), whereas North Carolina placed a priority on ensuring that their P-index reflected the most advanced scientific understanding of P transport (Carroll Pierce, personal communication). Elsewhere, Tennessee

Deanna L. Osmond is professor of soil science in the Department of Soil Science at North Carolina State University in Raleigh, North Carolina. **Miguel L. Cabrera** is professor of agronomy in the Department of Crop and Soil Sciences at the University of Georgia in Athens, Georgia. **Sam E. Feagley** is a professor of soils in the Department of Soil and Crop Science at Texas A&M University in College Station, Texas. **Gene E. Hardee** is a conservation agronomist in South Carolina's U.S. Department of Agriculture, Natural Resources Conservation Service in Colombia, South Carolina. **Charles C. Mitchell** is a professor of soil science in the Department of Agronomy and Soils at Auburn University in Auburn, Alabama. **Rao S. Mylavarapu** is an associate professor of soil and nutrient management in the Soil and Water Science Department at the University of Florida in Gainesville, Florida. **Philip A. Moore, Jr.** is a soil scientist in the Poultry Production and Product Safety Research Unit with the U.S. Department of Agriculture Agricultural Research Service in Fayetteville, Arkansas. **James L. Oldham** is an extension professor of soils in the Department of Plant and Soil Sciences, Mississippi State University in Starkville, Mississippi. **J. Cheston Stevens** is an associate extension professor at Louisiana State University in Baton Rouge, Louisiana. **William O. Thom** is a professor of extension in the Department of Plant and Soil Science at the University of Kentucky in Lexington, Kentucky. **Forbes R. Walker** is an associate professor of environmental soils in the Department of Biosystems Engineering and Soil Sciences at the University of Tennessee in Knoxville, Tennessee. **Hailin Zhang** is a professor of nutrient management in the Department of Plant and Soil Sciences at Oklahoma State University in Stillwater, Oklahoma.

and Kentucky designed P-indices that require a lower workload so that a smaller work force could complete field evaluations. Tennessee did this by approximating erosion rather than calculating it through the Revised Universal Soil Loss Equation (RUSLE) (Forbes Walker, personal communication), whereas Kentucky uses a screening tool to determine those fields that need a P-index assessment (William Thom, personal communication).

Despite widespread implementation of the P-index and associated research in developing components of the P-index (e.g., National P Research Project, Sharpley et al., 1999), there has been limited validation of the P-index. DeLaune et al. (2004b), using simulated rainfall and small runoff plots, were able to demonstrate a highly significant correlation between values generated by the Arkansas P-index and runoff P concentrations. In addition the Arkansas index, without calibration, was able to predict well mass P losses from pastures to which litter was applied. In Pennsylvania, Sharpley et al. (2001), also using simulated rainfall and small plots, showed that P-index ratings had a correlation of 83 percent with P loss. In the only known field-scale study relating P-index values to water quality, Harmel et al. (2005) compared ratings from the Texas, Iowa, and Arkansas P-indices to measured P loads from pasture and croplands located in the Texas Blackland Prairie. Their findings demonstrated reasonable relative loss estimates of P using the P-indices for Texas and Iowa even though the two P-indices are very different. To our knowledge, no watershed-scale validation of the P-index has yet occurred.

Development of the P-index required varied coordination at state, regional and national scales. In the southern United States, the Southern Region Water Quality Planning Committee was developed to coordinate information on water quality and, as a result, started working on nutrient management issues in 2004. Four representatives (nutrient management extension specialist and personnel from state water quality and agricultural divisions as well as USDA-NRCS) from each of the 13 states (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas) participated in the group (SRWQPC, 2006). Recognizing the wide range of P-indices that had been developed in the southern U.S., the Southern Region Water Quality Planning Committee set forth to compare ratings from the different indices, particularly because several southern states have Conservation Security Program (CSP) watersheds that cross state boundaries (USDA-NRCS, 2005): Alabama-Tennessee, Alabama-Mississippi, Oklahoma-Arkansas, and South Carolina-North Carolina. Thus, the objective of this study is to compare the P-index ratings from states participating in the Southern Region Water Quality Planning Committee.

Materials and Methods

Phosphorus indices from a total of 12 of the 13 southern states participating in the Southern Region Water Quality Planning Committee were included in the study (Table 1). Notably, the west Texas and New Mexico P-indices were excluded because they represent the semi-arid agro-ecological zone, while all the other states P-indices (including the east Texas P-index) represent a humid agro-ecological zone. All of the P-indices selected for evaluation in the study contain source and transport components, as well as miscellaneous components or "factors." A total of 37 source, transport, and other factors are contained in the P-indices of the 12 southern states (Table 1). In addition to these factors, there are other field characteristics that are used to calculate factors; they are not included however in Table 1. For instance, many states use soil erosion as a factor, which is calculated using Revised Universal Soil Loss Equation (RUSLE). The information needed to calculate RUSLE, such as erosivity, rainfall, etc, is not included in Table 1. The minimum number of factors necessary to determine a P-index rating ranged from eight (Mississippi) to 12 (North Carolina).

Using the factors, scenarios were developed for upland pasture (Table 2a), upland cornfield (Table 2b), and artificially drained cropped or hayed bottomland on mineral and organic soils (Table 2c). Since only North Carolina and Florida were able to make comparisons for organic soils, these data are not presented. Even though any number of factors could have been varied, we focused on changing the four that the Southern Region Water Quality Planning Committee working group believed to be the most likely to affect P-index ratings: soil test P, P application rate, riparian buffer, and soil erosion. Brandt and Elliott (2005) conducted a sensitivity analysis on the Pennsylvania P-index for biosolids, finding that the most sensitive factors were P rate, application method, P source coefficient, and connectivity (buffers). Interestingly three of these variables (P rate, application method, and connectivity) were selected for this study. Because P source coefficient is not included in most southern P-indices, it was not varied for the current study.

Two soil test P values were selected: 75 and 150 mg kg^{-1} (150 and 300 lbs ac^{-1}) Mehlich-3 P (M3-P) for the pasture and upland comparisons. The ranges selected represent levels above which there is no additional crop response. For the drained scenario, four soil test levels were selected: 75, 150, 225, and 300 mg kg^{-1} (150, 300, 450, 600 lbs ac^{-1}) M3-P. The greater soil test P levels were selected because they are increasingly common and indicative of sites where manure is routinely applied to meet waste-disposal rather than resource conservation objectives. Not all southern states use Mehlich-3 as a soil test extract, thus states like Florida had to use conversion equations that they have developed to translate local soil testing data to a Mehlich-3 equivalent (Mylavarapu et al., 2002).

Because broiler poultry production is widespread throughout the southern states, a range of poultry litter application rates was selected (2.2, 4.5, 9.0, 13.5, and 17.9 Mg ha^{-1} or 1, 2, 4, 6, and 8 t ac^{-1}), translating into P application rates of (79, 158, 316, 474, and 948 kg P_2O_5 ha^{-1} or 70, 140, 280, 420, and 840 lb P_2O_5 ac^{-1}). Most crops require no more than 2.2 to 4.5 Mg ha^{-} (1 to 2 t ac^{-1}) to meet N fertility demand. Some hay and pasture systems in the south, however, are receiving upwards of 9.0 to 17.9 Mg ha^{-} (4 to 8 t ac^{-1}) and we wanted to represent these maximum rates.

A range of soil erosion rates were selected to correspond to crop (hay or corn) and tillage (none, conservation, minimum, or conventional) conditions (1.1, 2.2, 9.0, and 17.9 Mg ha^{-1} or 0.5, 1, 4, 8 t ac^{-1}). These erosion rates are typical for the cropping systems, soil type, slope, and rainfall contained in the scenarios.

Phosphorus-index ratings were generated by each state for the three scenarios, except when indices were not suited. For example, the Arkansas P-index was developed only for pasture conditions. For simplicity's sake, in reporting the ratings only one factor was varied at a time, thus isolating the effect of that single factor on the outcome (rating) of a particular state's P Index. For instance

Table 1. Phosphorus (P)-index characteristics and factors used in the southern region of the United States.

Characteristics	Southern states											
	AL	AR	FL	GA	KY	LA	MS	NC	OK	SC	TN	TX
	General properties of P tool											
Quantitative index		x		x				x				
Qualitative index	x		x	x	x	x	x	x	x	x	x	x
Factors added	x	x	x	x	x	x	x	x		x	x	x
Factors multiplied		x	x	x		x	x	x		x	x	
Index used under specific conditions[*]		x			x							
Factors	**General information**											
Crop, tillage and/or groundcover					x			x				
County			x					x				
MLRA					x							
	Source											
Soil test P[*]	M1	M3	M1	M1	M3	Bray	Lancaster	M3	M3	M1	M1	M3
Total P added	x		x	x		x	x			x	x	x
Source type			x	x		x	x	x			x	x
Source content								x				
Soluble manure P		x										
Method of application	x	x[§]	x	x	x	x	x	x	x	x	x	x
Time of application		x[§]		x	x	x	x		x		x	x
Amount of waste water applied			x									
Animals present/grazing	x	x										
	Transport											
Soil erosion	x	x	x	x		x	x	x	x[†]	x	x[‡]	x
Slope	x	x			x	x						
Distance to water resource	x		x		x	x	x		x	x	x	
Buffer/filter strip width	x			x	x			x			x	
Buffer/filter strip present		x										
Buffer zone runoff class										x		
Depth to water table				x		x						
Drain spacing								x				
Drain depth								x				
Underground outlet system	x											
Flood potential		x							x			
Soil series/map unit								x				
Soil hydrologic group	x			x						x	x	
Soil hydrologic condition								x				
Soil runoff class		x					x			x		x
Runoff potential			x							x		
Leaching or subsurface drainage potential			x							x		
Receiving slope width								x				
Curve number				x						x		
Depth of Soil									x			
Rock Fragments									x			
Rocks > 10-inch diameter									x			
Precipitation		x										x
Other conservation practices		x						x				
	Watershed-stream											
Impaired, protected, or priority	x				x	x			x			x

[*] AR only uses their index for pasture conditions; KY index usage is triggered only if soil test P > 200 mg kg^{-1}.

[†] Soil erosion based on greater than or less than T.

[‡] Erosion potential rather than erosion rate.

[§] AR lists these factors under transport rather than source.

Table 2a. Twelve scenarios for an upland pasture. All potential categories utilized in the 12 southern phosphorus (P)-indices are listed. Test 1-8 are without a buffer and Test 5-8 are with a buffer.

Category	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Soil test P	Mehlich-3 P (mg kg^{-1} or ppm)							
	75	150	75	150	75	150	75	150
Source P-type	Broiler litter							
Source P-amount	4.5 Mg ha^{-1}	4.5 Mg ha^{-1}	9.0 Mg ha^{-1}	9.0 Mg ha^{-1}	13.5 Mg ha^{-1}	13.5 Mg ha^{-1}	17.9 Mg ha^{-1}	17.9 Mg ha^{-1}
Source content	79 kg P_2O_5 Mg^{-1} litter or 70 lb P_2O_5 /ton^{-1}							
Litter P solubility	30 percent (NC); 0.54 kg P_2O_5 Mg^{-1} litter or 1 lb P_2O_5 t^{-1} litter							
Waste moisture percent	30 percent							
Source application	Surface							
Timing	April							
Crop	Hay							
County	Wake (NC); Santa Rosa (FL)							
Soil map unit	Norfolk (NC); Orangeburg (FL); Pacolet (GA)							
Erosion rate	2.2 Mg ha^{-1} or 1 t ac^{-1}							
Receiving slope	No							
Hydrologic group	B							
Hydrologic condition	Good							
Slope	5 percent							
Slope length	30.5 m or 100 ft							
Runoff class	Low							
Soil drainage class	Well drained							
Curve number	58							
Rainfall	117 cm yr^{1} or 46 in yr^{1}							
Depth to water table	> 1.22 m or 4 ft							
Drain spacing	Not applicable (NC)							
Drain depth	Not applicable (NC)							
Distance to water	15.3 m or 50 ft							
Flooding frequency	Occasional							
Buffer	No (Test 1-8); Yes (Test 5-8)							
Impaired water	Yes							
MLRA	Other (KY)							
Irrigation	None							
Depth of soil	> 50.8 cm or 20 in							
Rock fragments	No							
Rocks >25.4 cm or 10-in diameter	No							

under *Soil Test Changes*, ratings for the soil test P levels are compared while the other possible factors (buffer, litter application rate, and tillage/crop) remain the same.

Once the numeric ratings were derived, they were transformed into the risk categories. All state P-indices, except three (Alabama, Oklahoma, and Texas), use a Low, Medium, High, and Very High rating system (Table 3). The Alabama P-index 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 11 of the 12 states, the management decisions associated with the ratings differ among states (Table 4). 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.

Overview of P-indices. No two southern P-indices are alike. Some indices multiply sections—source, transport, other—(Arkansas, Florida, Louisiana, Mississippi, and South Carolina), while others (Alabama, Oklahoma, Kentucky, Tennessee, and Texas) add all factors together, even if they may be divided into transport and source sections. The Georgia and North Carolina P-indices combine source and transport for different loss pathways (e.g. erosion, runoff). Three P-indices (Arkansas, Georgia, and North Carolina) are set up to predict edge-of-field P loads (quantitative P-index), although two of these (Georgia and North Carolina) convert the predictions to unit-less index values. The remainder of P-indices we describe as qualitative; P runoff from fields is calculated as a relative risk. Not surprisingly, 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 (Table 4). 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).

Table 2b. Twenty-four scenarios for upland corn fields. All potential categories utilized in the 11 southern phosphorus (P)-indices are listed. Test 1-4 are with and without a buffer for three tillage practices -minimum, conservation, and conventional tillage.

Category	Test 1	Test 2	Test 3	Test 4
Soil test P	Mehlich-3 P (mg kg^{-1} or ppm)			
	75 High	150 Very high	75 High	150 Very high
Source P-type	Broiler litter			
Source P-amount	4.5 Mg ha^{-1} or 2 t ac^{-1}	4.5 Mg ha^{-1} or 2 t ac^{-1}	9.0 Mg kg^{-1} or 4 t ac^{-1}	9.0 Mg kg^{-1} or 4 t ac^{-1}
Source content	79 kg P_2O_5 Mg^{-1} litter or 70 lb P_2O_5 t^{-1} litter			
Litter P solubility	30 percent (NC); 0.54 kg P_2O_5 Mg^{-1} litter or 1 lb P_2O_5 t^{-1} litter			
Waste moisture content	30 percent			
Source application	Disked (conventional or minimum tillage); Surface (conservation tillage)			
Timing	15 days before planting (please specify month)			
Crop	Corn, Minimum tillage (<30 percent residue); Corn, Conservation tillage (>30 percent residue); Corn, Conventional			
County	Wake (NC); Santa Rosa (FL)			
Map unit	Norfolk (NC); Orangeburg (FL); Pacolet (GA)			
Erosion rate	2.2 Mg ha^{-1} or 1 t ac^{-1} (conservation tillage); 9.0 Mg ha^{-1} or 4 t ac^{-1} (minimum tillage); 17.9 Mg ha^{-1} or 8 t ac^{-1} (conventional tillage)			
Receiving slope	No			
Hydrologic group	B			
Hydrologic condition	Good			
Slope	5 percent			
Slope length	30.5 m or 100 ft			
Runoff class	Moderate			
Soil drainage class	Well drained			
Curve number	83 (conventional tillage); 75 (conservation tillage)			
Rainfall	117 cm yr^{-1} or 46 in yr^{-1}			
Depth to water table	> 1.22 m or 4 ft			
Drain spacing	Not applicable (NC)			
Drain depth	Not applicable (NC)			
Distance to water	15.3 m or 50 ft			
Flooding frequency	Occasional			
Buffer	No; Yes, 15 m or 50 ft			
Impaired water	Yes			
MLRA	Other (KY)			
Irrigation	None			
Depth of soil	> 50.8 cm or 20 in			
Rock fragments	No			
Rocks >25.4 cm or 10-in diameter	No			

Alabama. The Alabama P-index is a qualitative P-index that adds source, transport, and receiving water characteristics (NRCS - AL, 2001). Source factors are soil test P, P application rate, nutrient application method, and grazing animals, whereas transport factors are underground outlets, erosion rate, hydrologic soil group, field slope, P application distance to water, and filter strip width. Receiving waters are rated as either "impaired" or "outstanding."

Arkansas. The Arkansas P-index For Pastures was developed specifically for pasture systems that are fertilized with animal manure. This index predicts edge-of-field P loads (DeLaune et al., 2004a). Arkansas P-index factors are divided into four categories: P source (soil test P and amount of soluble P being applied); P transport (soil erosion, soil runoff class, flooding frequency, application timing, application method, and grazing management); precipitation (annual precipitation total); and best management practices (buffer strips, contour strips or terracing, and fencing cattle from streams). The final Arkansas P-index value is calculated by multiplying transport, precipitation, site, and each best management practice (BMP).

Florida. The Florida P-index is a site-specific, qualitative vulnerability assessment tool (Hurt et al., 2004). Part 1 of the Florida P-index qualitatively evaluates transport mechanisms (soil erosion, runoff, and leaching characteristics of the soil), as well as the potential to reach a water body, by adding numeric ratings for the transport factors. Part 2 evaluates the application site: soil test P values, types, and amounts of P applied from fertilizer, animal waste, biosolids, or wastewater; application method; and the amount of waste water applied per year. The two parts are then multiplied to produce a Florida P-index value that gives the producer a vulnerability rating for off-site P transport.

Georgia. The Georgia P-index was designed to predict edge-of-field bioavailable P loss from grasslands and cropped fields to surface waters (Cabrera et al., 2002.) The Georgia P-index considers the main path-

Table 2c. Twenty-four scenarios for artificially drained fields. All potential categories utilized in the 11 southern phosphorus (P)-indices are listed. Test 1-4 are with and without a buffer for three crop combinations—corn either minimum/conventional or conservation tillage, and hay.

Category	Test 1	Test 2	Test 3	Test 4
Soil test P	Mehlich-3 P (mg kg^{-1})			
	75 High	150 Very high	225 Very high	300 Very high
Source P-type	Broiler litter			
Source P-amount	3.4 Mg ha^{-1} or 2.5 t ac^{-1}			
Source content	79 kg P_2O_5 Mg^{-1} litter or 70 lb P_2O_5 t^{-1} litter			
Litter P solubility	30 percent (NC); 0.54 kg P_2O_5 Mg^{-1} litter or 1 lb P_2O_5 t^{-1} litter			
Waste moisture content	30 percent			
Source application	Disked (conventional or minimum tillage); Surface (conservation tillage)			
Timing	15 days before planting (please specify month)			
Crop	Corn, Minimum tillage/Conventional (<30 percent residue); Corn, Conservation tillage (>30 percent residue); Hay			
County	Carteret (NC); Gulf (FL, mineral); Palm Beach (FL, organic)			
Map unit	Mineral: Rains, (NC, FL); Pelham (GA); Organic: Belhaven, (NC, FL)			
Erosion rate	1.1 Mg ha^{-1} or 0.5 t ac^{-1} regardless of map unit, tillage, or crop			
Receiving slope	No			
Hydrologic group	Undrained - D; Drained - B			
Hydrologic condition	Good			
Slope	1 percent			
Slope length	> 152 m or 500 ft			
Runoff class	High			
Soil drainage class	Poorly drained			
Curve number	Rains 59 (Hay); 79 (minimum/conventional tillage); 74 (conservation tillage); Belhaven 78 (Hay); 89 (minimum/conventional tillage); 85 (conservation tillage)			
Rainfall	142 cm yr^{-1} or 56 in yr^{-1}			
Depth to water table	~ 0.3 m or 1 ft			
Distance to water	15.3 m or 50 ft			
Drain spacing	91 m or 300 ft (NC)			
Drain depth	91 cm or 36 in (NC); 51-94 cm or 20-37 in (FL)			
Flooding frequency	Occasional			
Buffer	No; Yes, 15.3 m or 50 ft			
Impaired water	Yes			
MLRA	Other (KY)			
Depth of soil	> 51 cm or 20 in			
Rock fragments	No			
Rocks >25.4 cm or 10-in diameter	No			

ways of P loss, namely 1) soluble P in surface runoff, 2) particulate P in surface runoff, and 3) soluble P in leachate. For each of these pathways, the Georgia P-index estimates edge-of-field losses (kg P ha^{-1} yr^{-1}) by considering sources of P, transport mechanisms involved, and management practices used. The total P loss is computed by adding the loss from each of the three pathways and is converted into a unit-less rating.

Kentucky. Kentucky is the only southern state to use a screening tool prior to the use of their P-index (NRCS - KY, 2001). Mehlich-3 soil test P must reach 448 kg ha^{-1} (400 lb P ac^{-1}) before the Kentucky P-index is used. At this soil test P level, producers can either use the Kentucky P-index or soil test P levels to determine animal waste application rates. When the qualitative Kentucky P-index is used, 10 features are evaluated, and each feature is weighted (i.e. the field feature value rating is multiplied by the weighted factor): hydrologic soil group, field slope percent, impaired water resource, and MLRA (weighting factor 1); soil test P, land cover percent, vegetative buffer width, application timing, and application method (weighting factor 3); downstream distance to water resource (weighting factor 2). The factors are added to achieve the final Kentucky P-index rating.

Louisiana. The qualitative Louisiana P-index is used only when there are animal waste concerns (NRCS - LA, 2003). The Louisiana P-index considers the P loss potential due to site transport characteristics and management practices. Site transport characteristics include soil erosion, runoff, drainage, distance to surface water, and the priority of receiving water [soon to be released total maximum daily load (TMDL) values]. The management practices include a soil test P fertility index value, fertilization application rate, P fertilizer application method, organic P application rate, and organic P application method. Using the Louisiana P-index worksheet, the numbers/values assigned within each part are added and then each of the two parts (transport and management) is multiplied to arrive at a P loss rating.

Mississippi. The Mississippi P-index rating is a field/site-specific qualitative analysis of

Table 3. Numerical values associated with the four rating classes for each of the 12 southern phosphorus (P)-indices.

	P-index numerical ratings			
State	Low	Medium	High	Very high
AL	< 65	66-75	76-85	> 86
AR	< 0.6	0.6-1.2	1.2-1.8	> 1.8
FL	< 75	75-150	151-225	> 225
GA	0 < 40	40-75	75 < 100	≥ 100
KY	< 30	30-60	61-112	> 112
LA	< 600	600-1200	1200-1800	> 1800
MS	< 5	5-9	10-22	> 22
NC	< 25	26-50	51-100	> 100
OK	Not applicable			
SC	< 6	6-10	11-25	> 25
TN	< 100	100-200	201-301	> 301
TX	< 12	12-22.75	23-32	> 32

potential P loss used where there are resource concerns about animal waste (NRCS - MS, 2000). There are three transport factors (erosion, runoff, and distance to water) and five source characteristics (soil test P, inorganic P_2O_5 rate applied, inorganic P_2O_5 application method, organic P_2O_5 rate applied, and organic P_2O_5 application method). All factors are weighted with a value of one, except inorganic P_2O_5 rate applied (0.75) and inorganic P_2O_5 application method (0.5). The final Mississippi P-index rating is derived from the following equation: (erosion * runoff * distance to water) * [soil test P + (inorganic applied * 0.75) + (inorganic method * 0.5) + organic applied + organic method].

North Carolina. The North Carolina P Loss Assessment Tool is a field-scale, mechanistic model that estimates potential loss of P (lb ac^{-1} yr^{-1}) from a field by considering three loss pathways: 1) P attached to eroded sediments (particulate P) and solid waste, 2) soluble P derived from residual soil P and delivered in surface runoff (dissolved P), and P from applied sources in surface runoff (P source effects), and 3) phosphorus in subsurface drainage (leachate P) (N.C. PLAT Committee, 2005). Modeled data are prestored in Phosphorus Loss Assessment Tool and P loss for each pathway is a function of transport, source, and BMP effects. Pathway losses are added, and the final Phosphorus Loss Assessment Tool score is transformed from lb P ac^{-1} yr^{-1} to a unit-less rating scale.

Oklahoma. The current official P-index in Oklahoma is a qualitative P assessment tool (NRCS - OK, 2004). This tool was developed to guide manure land application before the P-index concept was promoted, so the input and output parameters are somewhat different from many other P-indices. It takes into account soil test P, application method, slope, erosion (greater and smaller than "T"), flooding frequency, distance of manure application to water source, depth of soil, and rock fragments greater than 10 inches (NRCS-OK, 2004). The outputs of the Oklahoma P-index include a P risk rating, the amount of P_2O_5 allowed to apply, recommended method, and BMPs to minimize P loss. The site assessment is done before any P is applied, so the amount of P addition is not an input factor. Different criteria are set for nutrient-limited and non-nutrient-limited watersheds.

South Carolina. The P-index for South Carolina is a site specific, qualitative vulnerability assessment tool that provides a mechanism for assessment of the risk to water quality associated with the land application of P-containing fertilizers, particularly animal manures (NRCS - SC, 2001). The tool considers source (P application rate and method), transport (soil erosion, runoff factor, and subsurface drainage factor), and buffer features (buffer zone runoff class and distance to water body). Scores within each section are added and then scores for all three sections are multiplied for the total rating.

Tennessee. The Tennessee P-index uses four transport and four source factors to obtain an overall rating for each field (NRCS - TN, 2001). The qualitative risk score is obtained by multiplying the sum of all site and transport factors with the sum of all source and management factors. Phosphorus transport factors include soil hydrologic group (based on soil series), erosion potential (derived from a table based on RUSLE), width of permanent vegetative buffer, and non-application buffer widths. Source factors include the University of Tennessee soil test laboratory's interpretation of Mehlich 1 soil test P values, P application rates and availability (depending on whether the source of P is commercial fertilizer, biosolids, animal manure, or alum treated or untreated poultry litter), application timing, and application method.

Texas. The Texas P-index is a qualitative tool that employs an 8 by 5 matrix, which relates site characteristics with a range of value categories (NRCS - TX, 2000). The site characteristics fall into two main categories: source factors and transport factors. The source factors include soil test P ratings (low, medium, high, and very high), fertilizer P application rate, organic P application rate, fertilizer P application method and timing, and organic P application method and timing. The transport factors include proximity of the nearest field application area to named stream or lake, soil erosion, and runoff class. The individual site characteristic factors for each source and transport factor are multiplied by a weighting factor from 0 to 8 (0, 1, 2, 4, and 8). Once weighted, these values are then added together for the final P-index runoff potential rating.

Results and Discussion

Upland pasture scenario. The pasture scenario was the simplest one developed, with only three factors varied: soil test P, broiler litter rates (P application rate), and the existence or absence of a buffer (Table 2a). For the pasture scenarios, two state P-index ratings were always Low (North Carolina and Mississippi) and two states were always High (Kentucky and Texas), indicating that the P-indices of these states were insensitive to the three factors that were evaluated. The remaining states had P-index ratings that varied with site conditions. The states with the greatest rating changes for the pasture scenarios were Alabama and Louisiana. The P-index ratings for Alabama would have been lower and less variable, however, if the receiving water resource had not been impaired. It is important to note that because Kentucky uses an soil test P threshold to determine whether or not to apply the P-index to a particular field, in actuality the Kentucky P-index would not been required at soil test P levels below 200 mg kg^{-1} M3-P.

Soil test P. Changing soil test P on pastures had no effect on the P-index ratings for Kentucky, Mississippi, North Carolina, Oklahoma, and Texas (Table 5). Ratings for Alabama, Arkansas, and Tennessee shifted from High to Very High assuming similar

Table 4. Animal waste management recommendations for the four ratings from the 12 southern phosphorus (P)-indices.

	P-index rating			
State	Low	Medium	High	Very high
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 (up to 1x crop removal P)
AR	N-based plan	Conservation or reduce P application to maintain risk at PI to1.2	Conservation and reduce P rates to drop risk to PI to 1.2	No litter Conservation to reduce PI to 1.0
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 rate to drop PI below 75 within 5 years	Add buffers and/or reduce P rate to drop PI below 75 within 5 years
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)
MS	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (50 percent crop removal P)
NC	N-based plan	N-based plan	P-based plan (crop removal P)	P-based plan (no P application)
OK	N-based plan	N-based plan if slop <8 percent, P-based plan if slop >8 percent	P-based plan (reduced amount)	P-based plan (no P application)
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
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 non-impaired;	1.5x crop removal P for impaired for non-impaired;	1x crop removal P for impaired for non-impaired;
		1.5x crop removal P for impaired	1x crop removal P for impaired for impaired	1x crop removal P for impaired every other year for impaired

* **AL has an Extremely High rating, which has the management implication of no P.**

† **TX has a Very Low rating, which has the management implication of N-based plan.**

broiler litter application rates and the presence of a field buffer. As soil test P increased from 75 to 150 mg M3-P kg^{-1}, the Georgia P-index rating increased from Low to Medium category, while the South Carolina rating changed from Medium to High. The Florida P-index rating increased from Medium to High as soil test P changed to 150 M3-P when no buffer was present.

Litter application rate. Varying broiler litter application rates produced substantial changes in P-index ratings for six of the 12 states (Table 5). When broiler litter application rate was increased from 4.5 Mg ha^{-1} (2.0 t ac^{-1}) to 9.0 Mg ha^{-1} (4.0 t ac^{-1}), four state ratings increased: Alabama, Florida, and South Carolina P-indices shifted from Low to Medium categories, while Arkansas moved from Medium to Very High (Table 5). As litter application rate increased to 13.5 Mg ha^{-1} (6.0 t ac^{-1}) without the presence of a field buffer, ratings increased for Louisiana (Low to Medium), South Carolina (Medium to High), Alabama (Medium to Very High), and Tennessee (High to Very High). A further increase in litter application rate (17.9 Mg ha^{-1}; 8.0 t ac^{-1}) only changed Florida's P-index rating from Medium to High. In general, changes in litter application rates had the greatest effect on Alabama's P-index rating.

The P-indices of Oklahoma and Kentucky do not include applied P as a source factor. Consequently, adjusting litter application rates did not affect the outcome of these indices. Unlike the other P-indices, the Oklahoma P-index recommends the rate that P in fertilizer or manure can be applied, rather than treating applied P as an input variable (source factor). Without a buffer, the Oklahoma P-index indicated that no P could be applied, even when site conditions were adjusted to be as amenable to receiving litter as possible (e.g., the water resource was changed from impaired to non-impaired).

Field buffers. Changes in the presence of a field buffer resulted in substantial changes in the ratings of the Alabama, Florida, Georgia, Louisiana, Oklahoma, South Carolina, and Tennessee P-indices (Table 5). Regardless of soil test P level or litter application rate, Oklahoma P-index ratings were always Very High when no buffer existed and High with the presence of a buffer. At soil test P level of 75 mg kg^{-1} and litter application rates of 13.5 Mg ha^{-1} (6.0 t ac^{-1}), the existence of a buffer reduced ratings as follows: South Carolina from High to Medium; Louisiana from High to Low; and Alabama and Tennessee from Very High to High. For the same litter conditions but at a soil test P level of 150 mg kg^{-1}, the presence of a buffer decreased Georgia P-index ratings from Medium to Low, Louisiana P-index ratings from High to Low, and Florida and South Carolina P-index ratings from High to Medium. The presence or absence of a buffer did not affect P-index ratings at 150 mg kg^{-1} soil test P for Alabama, Arkansas, and Tennessee; all ratings were Very High.

At the lower soil test P level of 75 mg kg^{-1} but higher litter application rates of 17.9 Mg ha^{-1} (8.0 t ac^{-1}), the existence of a buffer reduced P-index ratings as follows: Georgia from Medium to Low; Louisiana from High to Low; Florida from High to Medium; and Alabama, Arkansas, and Tennessee from Very High to High (Table 5). These rating changes were identical to those at the lower litter application rate except for Georgia and Florida, which demonstrated rating changes with the presence of a buffer. At the highest soil test P levels and litter application rates, the presence of a buffer only reduced two state's P-indices: Georgia (Medium to Low)

Table 5. Southern phosphorus (P)-index ratings for different scenario conditions in upland pastures.

Pasture scenario comparisons			P-index rating			
STP (mg kg^{-1})	Broiler litter (Mg ha^{-1} or t^{-1} ac^{-1})	Buffer	Low	Medium	High	Very high
75	4.5/2.0	No	AL, FL, GA, LA, MS, NC, SC	AR	KY*, TN, TX*	OK†
75	9.0/4.0	No	GA, LA, MS, NC	AL, FL, SC	KY, TN, TX	AR, OK
75	13.5/6.0	No	GA, MS, NC	FL	KY, LA, SC, TX	AL, AR, OK, TN
75	13.5/6.0	Yes	GA, LA, MS, NC	FL, SC	AL, KY, OK, TN, TX	AR
75	17.9/8.0	No	GA, MS, NC		FL, KY, LA, SC, TX	AL, AR, OK, TN
75	17.9/8.0	Yes	GA, LA, MS, NC	FL, SC	AL, KY, OK, TN, TX	AR
150	13.5/6.0	No	MS, NC	GA	FL, KY, LA, SC, TX	AL, AR, OK, TN
150	13.5/6.0	Yes	GA, LA, MS, NC	FL, SC	KY, OK, TX	AL, AR, TN
150	17.9/8.0	No	MS, NC	GA	FL, KY, SC, TX	AL, AR, LA, OK, TN
150	17.9/8.0	Yes	GA, MS, NC	LA	FL, KY, OK, SC, TX	AL, AR, TN

* The soil test levels are below threshold levels for using the P-index in Kentucky and Texas, which allows these states to continue to apply animal waste using N-based plans.

† The Oklahoma Index makes an assessment prior to P application so it is insensitive to litter amount. A maximum of 100 lbs P_2O_5 can be surface applied at a High P-index rating.

and Louisiana (Very High to High). The Louisiana P-index rating was most affected by buffers for pasture conditions.

Upland cornfield scenario. The upland cropped (corn) scenarios are similar to the pasture conditions (Table 2b). The same two soil test P levels were used (75 and 150 M3-P), as were two of the four litter rates (4.5 and 9.0 Mg ha^{-1}; 2 and 4 t ac^{-1}) and the presence or absence of buffers. The primary difference between the pasture and upland conditions was tillage practice and the ensuing soil loss related to each tillage type: conservation tillage and pasture (2.2 Mg ha^{-1}; 1 t ac^{-1}); minimum tillage (9.0 Mg ha^{-1}; 4 t ac^{-1}); and conventional tillage (17.9 Mg ha^{-1}; 8 t ac^{-1}). It was assumed that conservation tillage maintained at least 30 percent crop cover, minimum tillage left some crop cover but not as much as 30 percent, and conventional tillage produced a clean seedbed. In addition to differences in soil erosion rates, tillage practices affected source application because conventional and minimum tillage afforded mixing of the litter and conservation tillage did not. Because the Arkansas P-index was only developed for pasture conditions, it is not included in the cropland analysis. In addition, no rating is available for conservation tillage scenarios in Florida because conservation tillage is not utilized. However, the Florida's P-index was insensitive to the majority of the comparison factors for upland cropping systems as most of the ratings were Medium (Table 6).

***Soil test P*.** State ratings were compared between the two soil test P levels at the same P application rate (Table 6). The only state with a consistent trend in P-index ratings was Mississippi; ratings increased from Low to High as soil test P changed from 75 to 150 M3-P, regardless of tillage. The Texas rating increased from High to Very High for the following scenarios: 1) minimum tillage, high litter application 9.0 Mg ha^{-1} (4 t ac^{-1}), buffer present or absent; 2) minimum tillage, low litter application rate, and a buffer present; 3) and conventional tillage, low litter application rate, and no buffer. Alabama, Florida, Louisiana, North Carolina, and South Carolina had random changes in P-index ratings when soil test P levels increased, but no pattern based on buffer, litter application rate, or tillage emerged.

Litter application rate. If no buffer was present, Georgia P-index ratings increased at the higher litter application rates (Table 6). Ratings increased from High to Very High with conservation tillage but only changed from Low to Medium with minimum and conventional tillage. Doubling litter application rates to 9.0 Mg ha^{-1} (4 t ac^{-1}) for the Louisiana P-index increased some of the scenario ratings, but increases were dependent on tillage. Like the Georgia P-index, ratings for the North Carolina P-index only increased when litter was increased and no buffer was present. Index ratings for South Carolina generally increased when greater P was applied, but the increase was dependant on the soil test P level, presence of a buffer, and tillage type. The Tennessee rating was fairly insensitive to soil test P but very sensitive to litter and the presence of buffers. Regardless of soil test P or buffer presence, litter rates of 9.0 Mg ha^{-1} (4 t ac^{-1}) always produced a Very High rating for Tennessee. Because most of the Texas P-index ratings were Very High, higher P application rates only affected soil test P levels at 75 M3-P; the ratings changed from High to Very High for conventional tillage as the applied litter rate increased.

Field buffers. Kentucky ratings were insensitive to changes in soil test P, litter application rate, or tillage (High), but the presence of buffers reduced the rating to Medium from High but only for minimum tillage (Table 6). For the Georgia P-index, all ratings for fields with buffers were Low regardless of soil test P, litter rate, and tillage. For conservation tillage, the P-index rating increased to High (low litter rate) or Very High (high litter rate) when a buffer did not exist, regardless of soil test P. When a buffer was absent, Georgia P-index ratings only increased from Medium or Low (conventional or minimal tillage) when the litter rates were high, regardless of soil test P.

The presence of a buffer in the Louisiana P-index does not automatically lower the rating, rather it is a complex relationship between soil test P, litter application rate, and tillage type (Table 6). North Carolina ratings were Low if a buffer was present, regardless of litter application rate, soil test P, or tillage. If, however, the buffer was absent, soil test P, litter application rate, and conventional tillage all increased the rating to Medium or High. Regardless of soil test P level, litter application rate, or tillage, Oklahoma P-index ratings were always Very High when no buffer existed and High with the presence of a buffer.

At the lower litter application rates, regardless of soil test P, buffers tended to lower

Table 6. Southern phosphorus (P)-index ratings for different scenario conditions in the upland cornfield.

Cropland scenario comparisons				P-index rating			
STP mg kg^{-1}	Litter (Mg ha^{-1} or t^{-1} ac^{-1})	Buffer	Tillage	Low	Medium	High	Very high
75	4.5/2.0	No	Conserv.	MS, NC	LA	KY, GA, SC, TX	AL, OK, TN
75	4.5/2.0	No	Minimum	GA, MS	FL, LA, SC, NC	KY, TX	AL, OK, TN
75	4.5/2.0	No	Convent.	GA, MS	FL, LA, NC	KY, TX, SC	AL, OK, TN
75	4.5/2.0	Yes	Conserv.	GA, LA, MS, NC	SC, TN	AL, KY, OK, TX	
75	4.5/2.0	Yes	Minimum	GA, LA, MS, NC	FL, KY, TN, SC	AL, OK, TX	
75	4.5/2.0	Yes	Convent.	FL, GA, LA, MS, NC	SC	AL, KY, OK, TN, TX	
150	4.5/2.0	No	Conserv.	MS, NC	LA	GA, KY, SC, TX	AL, OK, TN
150	4.5/2.0	No	Minimum	GA	FL, MS, NC	KY, LA, SC	AL, OK, TN, TX
150	4.5/2.0	No	Convent.	GA	FL, MS	KY, LA, NC, SC	AL, OK, TN, TX
150	4.5/2.0	Yes	Conserv.	GA, LA, NC	TN, MS, SC	KY, OK, TX	AL
150	4.5/2.0	Yes	Minimum	GA, LA, NC	FL, KY, MS, SC, TN	OK	AL, TX
150	4.5/2.0	Yes	Convent.	GA, NC	FL, LA, MS	KY, OK, SC, TN	AL, TX
75	9.0/4.0	No	Conserv.	MS	LA, NC	KY, SC, TX	AL, GA, OK, TN
75	9.0/4.0	No	Minimum	MS, NC	FL, GA	KY, LA, SC, TX	AL, OK, TN
75	9.0/4.0	No	Convent.	MS	FL, GA, NC	KY, LA, SC	AL, OK, TN, TX
75	9.0/4.0	Yes	Conserv.	GA, LA, MS, NC		KY, OK, SC, TN, TX	AL
75	9.0/4.0	Yes	Minimum	GA, MS, NC	FL, KY, LA	OK, SC, TN, TX	AL
75	9.0/4.0	Yes	Convent.	GA, MS, NC	FL, LA	KY, OK, SC	AL, TN, TX
150	9.0/4.0	No	Conserv.		MS, NC	KY, LA, TX	AL, GA, OK, SC, TN
150	9.0/4.0	No	Minimum		FL, GA, MS, NC	KY, LA, SC	AL, OK, TN, TX
150	9.0/4.0	No	Convent.		FL, MS, GA	KY, NC, SC	AL, LA, OK, TN, TX
150	9.0/4.0	Yes	Conserv.	GA, LA, NC	MS	KY, OK, SC, TN, TX	AL
150	9.0/4.0	Yes	Minimum	GA, NC	FL, KY, LA, MS	OK, SC, TN	AL, TX
150	9.0/4.0	Yes	Convent.	GA, NC	FL, LA, MS	KY, OK, SC	AL, TN, TX

[Note: Not all states were able to do their P-index ratings. The Arkansas P-index is only applicable to pasture conditions and therefore is not included. Florida does not use conservation tillage, and the soil test P levels are below the threshold level set by Kentucky, thereby nullifying the use of the P-index. This allows Kentucky to continue to apply animal waste using N-based plans.]

ratings in the South Carolina P-index by one rating level (High to Medium) but only for conservation and conventional tillage (Table 6). Lastly, the presence of buffers strongly affected the Tennessee P-index. Ratings changed from Very High to Medium for conservation and minimum tillage at the lower litter application rate, regardless of soil test P. At the higher litter application rate, ratings were reduced from Very High to High when buffers were present and conservation or minimum tillage was used. Only at the lower P application rate did conventional tilled fields have a reduced P-index rating (Very High to High) in the Tennessee system.

Tillage. Tillage was important in reducing P-index ratings for Georgia. When no buffer existed, regardless of soil test P or litter application rate, minimum and conventional tillage reduced the P-index rating by one to two levels (Table 6); ratings increased from Low (Minimum or Conventional Tillage) to High (Conservation Tillage) when soil test P was 75 M3-P regardless of litter rate and from Medium to Very High when soil test P was 150 M3-P and P application rate was 9.0 Mg ha^{-1} (4 t ac^{-1}). In Kentucky, ratings changed from Medium (minimum tillage) to High (conservation or conventional tillage) when no buffer was present, regardless of soil test P or litter application rate. Tillage effects on ratings for the Louisiana, North Carolina, and South Carolina P-indices are highly variable depending on the soil test P and P application rate; no pattern exists. The Tennessee P-index rating was Very High, unless a buffer existed. Buffers lowered the rating to Medium when conservation or minimum tillage was used and High with conventional tillage. At M3-P levels of 150, conservation tillage reduced Texas P-index ratings from Very High to High, regardless of the presence or absence of a buffer and litter application rate. At the lower M3-P (75), only the condition with no buffer and high litter application rates led to a rating change (High for conservation tillage and Very High for minimum and conventional tillage).

Artificially drained field scenario. Many agricultural fields in the South are on poorly drained soils that must be drained to be productive. The P addition, as poultry litter, was maintained at a constant rate of 3.4 Mg ha^{-1} (2.5 t ac^{-1}), as was the erosion rate (1.1 Mg ha^{-1} (0.5 t ac^{-1})), while tillage and cropping system, soil test P, and the presence or absence of buffers were modified (Table 2c). Alabama and Tennessee had Very High P-index ratings, regardless of the changes in variables (Table 7). If the water had not been impaired, all of the Alabama ratings would have been Medium. Water quality impairment is an extremely important factor in the Alabama P-index.

Soil test P. At the lower soil test P levels (75 or 150 M3-P), the Florida P-index was Medium irrespective of the presence or absence of a buffer (Table 7). At the higher soil test P values (M3-P 225 or 300) for both the hay and the minimum-tilled corn, when the buffer was present the P-index ratings were Medium, whereas the ratings were High when no buffer was present. Florida does not use conservation tillage, thus there was not a rating for these fields. Increases in soil test

Table 7. Southern P-index ratings for different scenario conditions in artificially drained mineral soil.

		Crop/Tillage Scenario Comparisons P-index Rating				
STP mg kg^{-1}	Buffer	Crop/Tillage	Low	Medium	High	Very high
75	No	Corn/Conservation	MS	NC, TX	KY, LA, SC	AL, GA, OK, TN
75	No	Corn/Minimum	GA, MS, NC	FL, TX	KY, LA, SC	AL, OK, TN
75	No	Hay	MS	FL, GA, NC, TX	KY, LA, SC	AL, OK, TN
75	Yes	Corn/Conservation	GA, MS	LA, NC, TX	KY, OK, SC	AL, TN
75	Yes	Corn/Minimum	GA, MS, NC	FL, KY, LA, SC, TX	OK	AL, TN
75	Yes	Hay	GA, MS	FL, KY, LA, NC, TX	OK, SC	AL, TN
150	No	Corn/Conservation		MS, TX	KY, LA, NC, SC	AL, GA, OK, TN
150	No	Corn/Minimum		FL, GA, MS, NC, TX	KY, LA, SC	AL, OK, TN
150	No	Hay		FL, GA, MS, TX	KY, LA, NC, SC	AL, OK, TN
150	Yes	Corn/Conservation	GA	LA, MS, SC, TX	KY, NC, OK	AL, TN
150	Yes	Corn/Minimum	GA	FL, KY, LA, MS, NC, TX	OK, SC	AL, TN
150	Yes	Hay	GA	FL, KY, LA, MS, TX	NC, OK, SC	AL, TN
225	No	Corn/Conservation		MS, TX	KY, SC	AL, GA, LA, NC, OK, TN
225	No	Corn/Minimum		GA, MS, TX	FL, KY, NC, SC	AL, LA, OK, TN
225	No	Hay		MS, TX	FL, GA, KY, SC	AL, LA, NC, OK, TN
225	Yes	Corn/Conservation	GA	KY, MS, TX	LA, NC	AL, OK, SC, TN
225	Yes	Corn/Minimum	GA	FL, KY, MS, TX	LA, NC, SC	AL, OK, TN
225	Yes	Hay	GA	FL, KY, MS, TX	LA, NC	AL, OK SC, TN
300	No	Corn/Conservation		MS, TX	KY	AL, GA, LA, NC, OK, SC, TN
300	No	Corn/Minimum		GA, MS, TX	FL, KY, NC	AL, LA, OK, SC, TN
300	No	Hay		MS, TX	FL, GA, KY	AL, LA, NC, OK, SC, TN
300	Yes	Corn/Conservation	GA	MS, TX	KY	AL, LA, NC, OK, SC, TN
300	Yes	Corn/Minimum	GA	FL, KY, MS, TX	NC	AL, LA, OK, SC, TN
300	Yes	Hay	GA	FL, KY, MS, TX		AL, LA, NC, OK, SC, TN

[Note: Not all states were able to do their P-index ratings. The Arkansas P-index is only applicable to pasture conditions and therefore is not applicable. Florida does not use conservation tillage, and some of the Kentucky soil test-P levels are below the threshold level set by the state of Kentucky, thereby nullifying the use of the P-index. Above a M3-P of 150, producers in Oklahoma would not be allowed to apply any animal waste.]

P rarely changed Georgia ratings, whereas ratings for the Mississippi P-index were Medium for the three highest soil test P levels (150, 225, 300 M3-P) and Low at 75 M3-P, regardless of buffer, tillage, or cropping differences. The North Carolina P-index showed the greatest amount of change as soil test P increased; the changes, however, were variable depending on cropping system, tillage, and buffer. For example, as soil test P increased from 75 to 150 M3-P, the North Carolina P-index rating increased from Medium to High for both hay and conservation-tilled corn, regardless of buffer status. As soil test P further increased from 150 to 225 M3-P only non-buffered scenarios were affected; the ratings increased from High to Very High (hay and conservation-tilled corn) and Medium to High for minimum-tilled corn.

Buffer. As in the upland cropping scenarios, the presence of a buffer drastically changed ratings in the Georgia P-index (Table 7); all buffered fields had Low ratings, whereas when buffers were absent all conservation tillage fields had Very High ratings, minimum tillage fields were mostly rated at Medium, and hay fields were either Medium (M3-P 75 or 150) or High (M3-P 225 or 300). Clearly the presence or absence of buffers is the most important variable in the Georgia P-index for those factors that were varied.

The Louisiana P-index was High when buffers were absent and for soil test P levels of M3-P 75 or 150, regardless of cropping system or tillage (Table 7). When soil test P was equal to or greater than 225, the P-index was Very High, again regardless of cropping system and tillage. The presence of a buffer lowered the Louisiana P-index to Low at M3-P 75 or 150 and High at M3-P of 225. At a M3-P of 300, all ratings—even fields with a buffer present—were rated as Very High. Soil test P levels and buffers were the most important variables determining the Louisiana P-index rating.

The Kentucky P-index is only used when soil test P is greater than 200 M3-P, but for comparison purposes we rated all fields again (Table 7). The Kentucky P-index is insensitive to soil test P; all non-buffered treatments and buffered conventional tillage were High, while buffered hay and conservation tillage crop fields were Medium, regardless of soil test P. At the lower M3-P levels (75 and 150), the Oklahoma P-index ratings were always Very High when no buffer existed and High with the presence of a buffer; however, above a M3-P of 150, buffers did not affect the Oklahoma P-index as all the ratings were Very High.

The North Carolina P-index was relatively insensitive to the presence or absence of a buffer (Table 7). As M3-P increased, the ratings moved from Low or Medium to High or Very High. Ratings for hay and conservation tillage corn were the same at a given soil test P level, whereas the ratings for minimum-tilled corn were lower, primarily because the litter was tilled into the soil, thus reducing the risk of P losses from animal waste. When buffers were absent in the South Carolina P-index, all scenarios except for M3-P 300 had

High ratings, regardless of tillage or cropping system. The presence of buffers made only a slight rating difference for the minimum tillage system.

All southern states developed state-specific P-indices to meet the USDA-NRCS Code No. 590 Practice Standard. The structure of each P-index varied enough to produce widely divergent ratings when applied to similar scenarios where individual factors were adjusted across a broad range of input values. The pasture scenario afforded the simplest comparison. The North Carolina and Mississippi ratings were always Low, while Alabama, Arkansas, Oklahoma, and Tennessee ratings were almost always Very High. The Alabama, Oklahoma, Mississippi and Tennessee P-indices are considered qualitative P-indices that predict potential for P runoff, while the North Carolina, Georgia, and Arkansas predicted edge-of-field losses. Divergence in ratings between these two types of P-indices did not reveal similarities within a P index category (e.g., the P-indices that predict edge-of-field losses were no more similar to each other than were the qualitative P-indices). Mississippi ratings were very different from Alabama, Oklahoma, and Tennessee ratings, just as Arkansas, Georgia, and North Carolina ratings were quite diverse. The Arkansas P-index was calibrated using experimentally derived coefficients and is used only for pasture or hay land conditions. Under cropland conditions, soil test P had a greater effect on the North Carolina ratings than on Georgia ratings, whereas tillage seemed to affect ratings for both comparisons (Tables 5, 6, and 7). Buffers were important to reducing the P ratings in both states, although buffers were more important in Georgia than North Carolina. The North Carolina Phosphorus 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 soil test P 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.

The year that each index was finalized differed, but that did not seem to affect ranking similarities. A number of states had their P-indices developed by 2000 or 2001: Alabama, Kentucky, Mississippi, South Carolina, Tennessee, and Texas. For the same scenario comparisons, ratings were as diverse between early adopting states' P-indices (Mississippi vs Alabama, Tennessee, and Texas) as later adopting states, such as Louisiana and North Carolina. Variation in P-index ratings was the unique combination of each state's selected factors, weighting of the factors, and the factor combination (added, multiplied, or a mixture of both addition and multiplication).

Another source of variation among state P-indices, besides structure, is rating scale. Each state matched numeric scores to the rating values of Low, Medium, High, and Very High (Table 3). Few P-indices described the criteria used to relate these numeric values to ratings. These criteria were established by each state based upon the factors used in the index and the relative value each state put on these factors.

Because there has been little validation of P-indices, it is difficult to determine whether each state's accurately reflect P losses for that state. Arkansas (DeLaune et al., 2004b) and Texas (Jacoby, 2005) have validated their P-index ratings against experimental data. De Laune et al. (2004b) concluded that the Arkansas P-index provided an accurate assessment of P loss without extensive calibration in Arkansas. Jacoby (2005) has suggested modifications to the Texas P-index. In the southern region, only North Carolina has published a sensitivity analysis of their P-index (Johnson, 2004) and quantified its effects on producers (Johnson et al., 2005). Many other states have or are trying to validate their tools or quantify the effects of their P-index on their producers, while others have done some without publishing the results. For example, a survey in Alabama found that implementation of the P-index could restrict P application to 1X crop P removal or less on only 22 percent of the row crop fields. Implementation of one or more BMPs would allow continued P application at 2X crop removal or greater. As many as 46 percent of Alabama's pastures and hayfields would see a restriction of P application as a result of the P-index if no additional BMPs were implemented. However, P application could continue on these same fields if one or more BMPs were implemented. (Charles Mitchell, personal communication). Until additional validation is conducted, it is impossible to determine if the rating differences suggested in this paper are valid or simply an artifact of diversity in structure.

The rating differences among the P-indices for the same set of conditions demonstrate the flexibility of the USDA-NRCS 590 standard. Each state committee determined the factors it believed to be most important to P loss from agricultural fields within their state. Because these factors, the weighting associated with these factors, and the combination of the factors varied by state, it is not surprising that state P-index ratings differed. In addition, states addressed work-load issues when designing their indices. Because of the state-specific nature of the P-index, states such as Florida, Georgia, and North Carolina could include drainage, which is an important concern for the many poorly drained soils found in these states. Although the flexibility of the P-indices results in differences in ratings across the southern states, it also allows for indices designed to match conditions and concerns from each state.

Summary and Conclusion

This study identifies some similarities and considerable differences in P-indices when they are compared across state boundaries. These differences are to be expected in a program that was developed by individual states and designed to emphasize unique soil, landscape, environmental, and land use differences by the states. In addition, some states may have enacted environmental regulations that reference their P-index or NRCS's Code No. 590 (e.g. AFO/CAFO rules). Undoubtedly, political situations in each state may have contributed to some of the differences. Because each state's P-index was developed for a slightly different purpose, variations were apparent. Some with strong research support developed edge-of-field P loss P-indices, no doubt with a vision toward using the index to calculate total maximum daily loads for watersheds. Others viewed the index as an educational tool to effect implementation of BMPs. Some indices require extensive modeling and highly technical support to implement. Others can be estimated by a producer from the windshield of a pickup truck. This survey was not designed with the purpose of developing a uniform P-index across the southern region. Neither was it intended to effect changes in existing P-indices. This survey, however, demonstrates that P-indices as they have been developed and are being used should not be utilized across state lines unless the states were involved in developing that particular index.

This survey may help with the design and development of BMPs region-wide on a watershed, river basin, or physiographic basis, and thus making implementation and monitoring easier and more effective. This comparison also helps participating states to modify or revise their respective P-indices to enhance uniformity if the states consider this to be an issue.

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