Development and Evaluation of a Component Phosphorus Index for the State of Kansas

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USDA United States Department of Agriculture
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Background

Phosphorous loss is a big problem across the United States. Most notably this can cause algal blooms which can lead to low oxygen levels in the water and thus to fish kills or even Cyanobacteria that creates toxins that kill or cause illness to both animals and humans.

P-Indices: Concept proposed in 1992/93 because of water quality issues which many states have developed guidelines for P application and watershed management based on tools that rate the potential for P loss in agriculture runoff. Many different index tools were developed. First generation is the Additive Index, where the risk of each source and transport factor are added together. Second generation is the Multiplicative Index, and third generation is the Component Index.

Kansas P-Index: Used as a planning tool and qualitative risk assessment.
General structure of a multiplicative index is as followed:

			(2)	Erosion	(+)
	Soil Test P	(+)		Soil Runoff Class	(+)
(0.1)	P Application rate	(+)		Distance to water body	(+)
	Application Method/Timing			Irrigation Erosion	
	P Source Factors	**X**		**Transport Factors**	**= Risk**

Issues with the KS P-Index:
- The original authors of the P-index recognized that the weighting factors were arbitrarily selected (like Soil Test Phosphorus and Runoff components.
- The P-index must "zero-out" at some point (environmental threshold).
- ➢ **Why can't we just update the multiplicative index?**
- Separating the source and transport factors is inconsistent with how process-based P models describe P loss.
- It would be redundant to multiply all source and transport factors together.
  - (e.g.) STP (x) erosion (+) STP (x) Runoff (+) etc…

Objective

The objective of this research is to develop and evaluate a new approach to the P-index and determine coefficients to the components of the revised P-index.

Methods

Runoff Component: Long-term average annual runoff was estimated with the modified CN method as described by Guswa et al. (2018). In brief, this modification used annual precipitation in place of daily precipitation and then assumed an exponential distribution of rainfall depths throughout the year.

- Used 30-year county precipitation data for the state of Kansas

Calibration and validation datasets were annual measured runoff from edge-of-field runoff studies conducted in four different locations in eastern Kansas, USA.

- Calibration data are from the Kansas Agricultural Watershed (KAW) field laboratory from 2016 through 2021. Data are average runoff from no-till corn-soybean cropping systems either with cover crops or without cover crops, for a total of 12 site-years (6 years, two cropping systems).
- Validation data were collected in Crawford County, Franklin County, and Geary County, Kansas.

Application Method and Timing Component: Updated based on seasonal runoff estimates published data. Based the values ranging from 0.2 to 1 off of the Pennsylvania index and used fraction of runoff occurring in each month to develop monthly grouping in application timing.

Component P-Index Coefficients: The coefficients for the P-index components were developed through multiple linear regression with SAS proc mixed using a database of P-loss estimates for 1360 cropping scenarios. P-loss were estimated with a processed based model (APEX).

Component Phosphorus Index:
The new component P-index is a modification of the multiplicative index, each one of the components represents a specific combination of P sources and interconnected transport processes.

					(+)
(Soil Test P	(x)	Runoff: Long-term average annual)			(+)
(Soil Test P	(x)	Erosion: RUSLE 2 sediment loss)			(+)
(P Application Rate	(x)	Runoff: Long-term average annual	(x)	Application Method and Timing)	(+)
P Source Factors	(x)	**Transport Factor**	(x)	**Source Factor**	**= Risk**

Results and Discussion

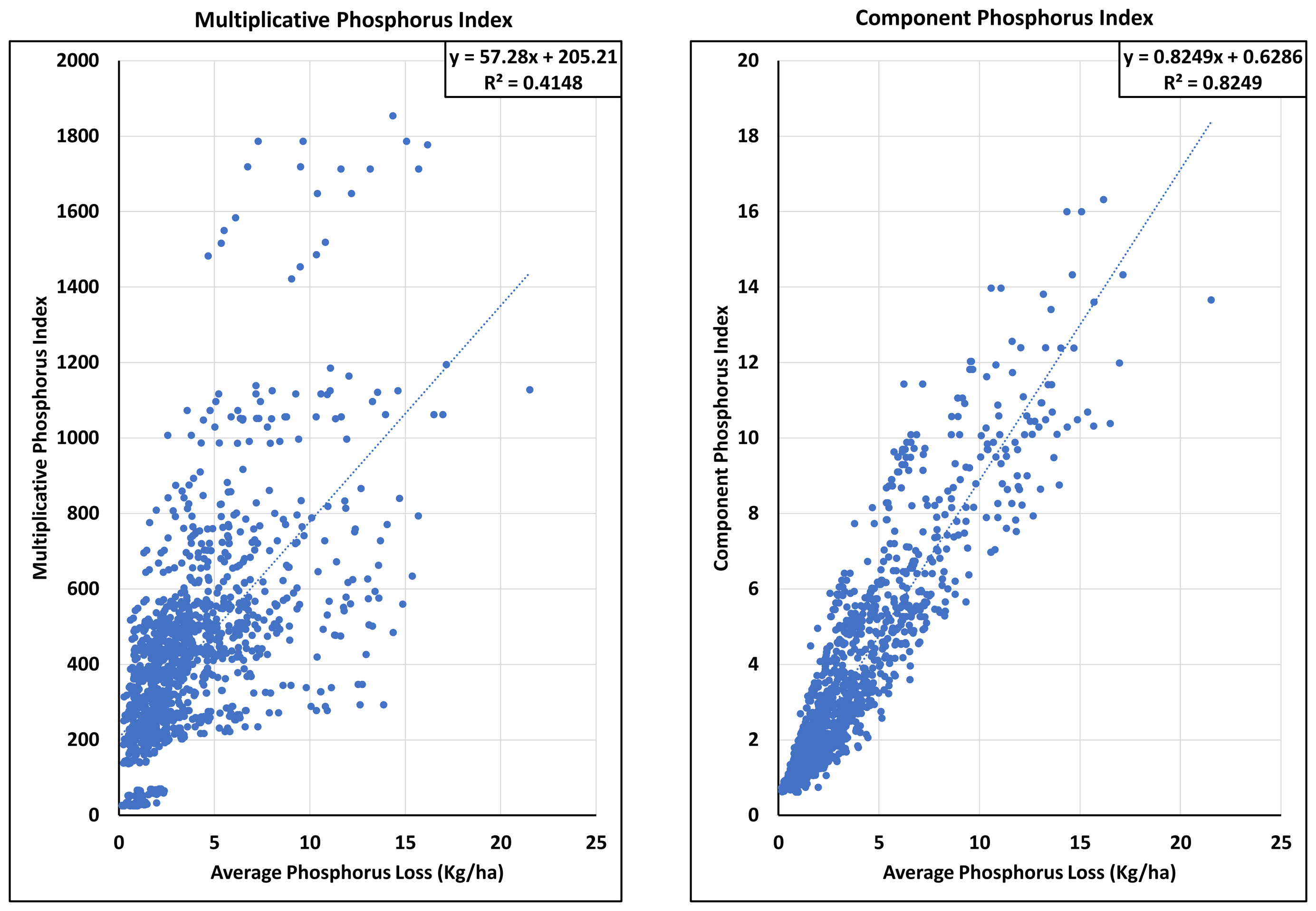


Figure 1: Relationship between the current Kansas multiplicative phosphorus index (left) or a component phosphorus index and average annual P-loss estimates from the APEX model. The new component index uses an equation:

β_1					(+)
β_2	(Soil Test P	(x) Runoff: Long-term average annual)			(+)
β_3	(Soil Test P	(x) Erosion: RUSLE 2 sediment loss)			(+)
β_4	(P Application Rate	(x) Runoff: Long-term average annual	(x)	Application Method and Timing)	(+)
	P Source Factors	(x) **Transport Factor**	(x)	**Source Factor**	**= Risk**

- β_1, β_2, β_3, and β_4 are fitting parameters 0.4251, 0.04128, 0.002990, and 0.1220 respectively (all significant at $p<0.0001$).

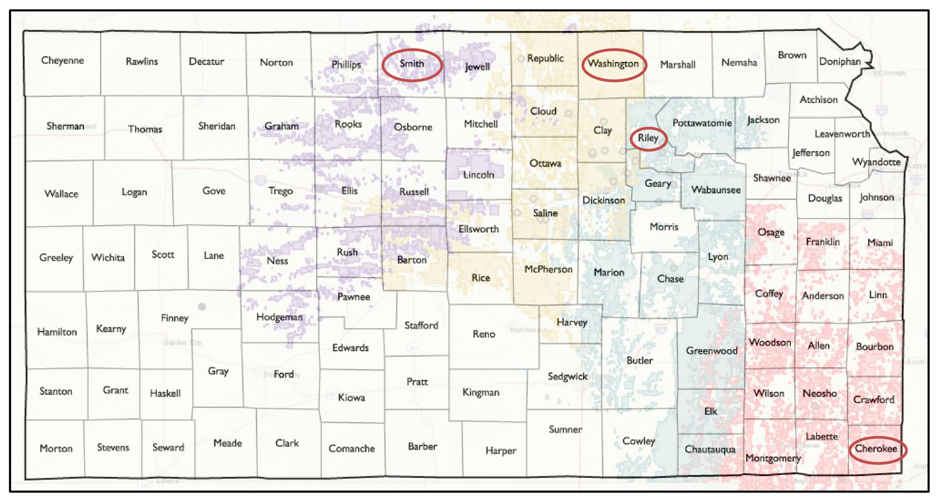
The component P-index has a much better relationship with the APEX estimated P loss (R^2 = 0.8249) indicating that it may be an improvement over the current multiplicative P-index for estimating the relative risk of P-loss from agricultural fields.

Table 1: Application method and timing factors used for the new component P-index.

Application method	Application Timing	Value
Injected		0.2
Incorporated		0.4
Surface Application	(November – March)	0.6
Surface Application	(April, July, August – October)	0.8
Surface Application	(May and June)	1

Issues with the KS P-Index Runoff Component:

P-index uses soil runoff classes (very low, low, medium, high, very high) to estimate the risk of transport by runoff rather than using a quantitative estimate of runoff.



(From NRCS Kansas Map Unit Descriptions)	Index
Very Low	0
Low	2
Medium	4
High	8
Very High	16

Map Legend
Red: Dennis Soil Series – High Runoff Class
Blue: Clime soil Series – High Runoff Class
Yellow: Crete Soil Series – High Runoff Class
Purple: Wakeen Soil Series – High Runoff Class

Figure 2: The runoff factor used in the Kansas P-index is the same for each series even though the annual rainfall varies from 26 inches (for Smith) up to over 50 inches (for Cherokee). Therefore, even if you are using the same cropping management practices within any one of the four-soil series, you will get the same P-loss risk factor.

Improved Results from Updating The Runoff Component:

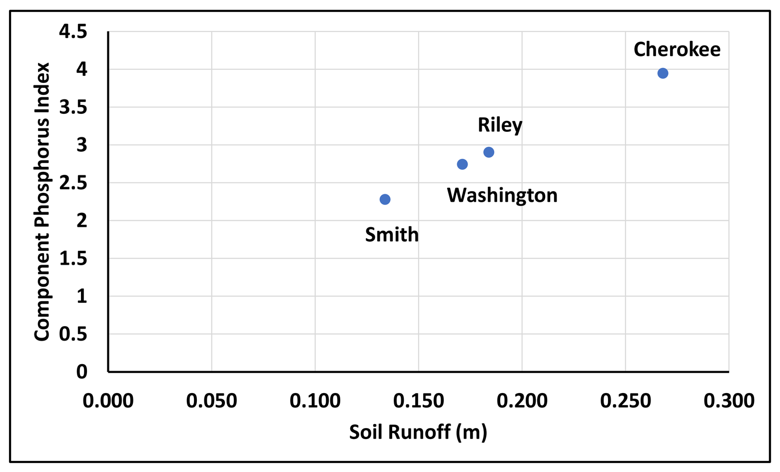


Figure 3: Effect of increasing runoff (due to changes in annual rainfall) on the Component P-index ratings. Phosphorus index ratings increase linearly with increases in runoff.

Issues with the KS P-Index Soil Test Phosphorus Component:
- Soil Test P components are not continuous.
- (Categorical index of 1 to 10)

Bray P1 or Mehlich III Soil P Test	Olsen Soil P Test	Index
< 25 ppm	< 16 ppm	1
26 - 50 ppm	17 - 31 ppm	2
51 - 75 ppm	32 - 47 ppm	4
76 - 200 ppm	48 - 62 ppm	8
>200 ppm	> 62 ppm	10

Problematic because soils with dramatically increased soil test P (e.g. 2000 ppm), which may have increased environmental impact, have the same index rating as soils with 201 ppm soil test P. As STP increases, the P-index ratings should also increase.

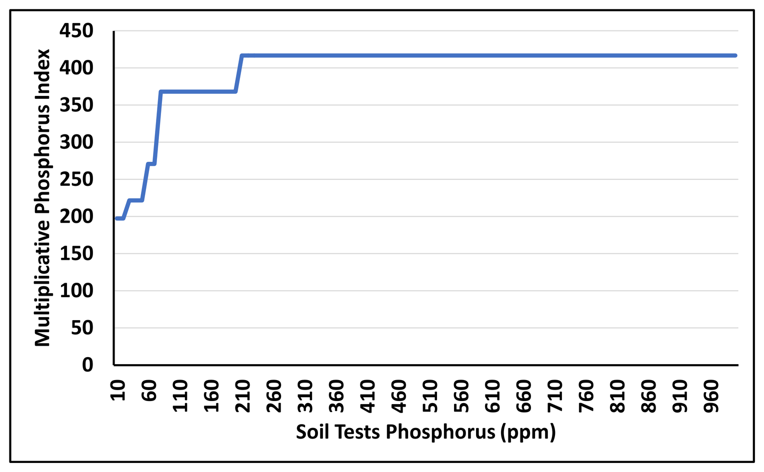


Figure 4: Illustration of STP effect on the multiplicative Kansas P-index ratings. Phosphorus index ratings increase stepwise with increases in STP up to 200 ppm, after which the P-index ratings do not change regardless of changes in STP.

Improved Results from Updating The Soil Test P Component:

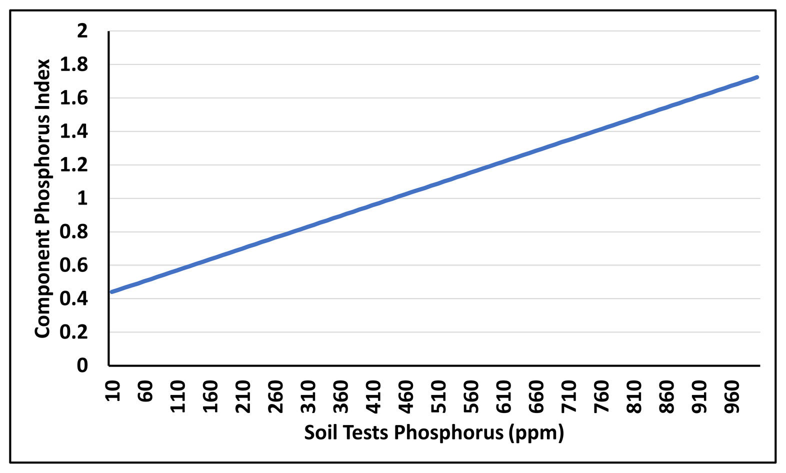


Figure 5: Illustration of STP effect on component P-index ratings. Phosphorus index ratings increase linearly with increased STP, indicating increased risk of P loss, which agrees with published data.

Conclusion / Future Research

- The component P-index had a better relationship with average P-loss than did the multiplicative P-index, indicting that it may be a better method for estimating the risk of P loss from agricultural fields.
- The component P-index was sensitive to changes in precipitation and runoff, adjusting for different precipitation gradients across Kansas.
- The component P-index results increased linearly with STP.

Future research includes validating the proposed Component P-index with measured data collected from various location in Kansas and seeing how it compares with the current P-Index.

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