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A Procedure Using the Wind Erosion Prediction System (WEPS) Model to Predict Soil and Phosphorus Losses with Cover Crops. J.J. Grigar, USDA NRCS E. Lansing, MI, M. S. Sporcic, J. L. Lemunyon, USDA NRCS Fort Worth, TX, T. M. Zobeck, ARS Lubbock TX, D. G. Baas, MSUE SARE KBS Hickory Corners, MI

Abstract

According to the 2003 USDA-NRCS National Resource Inventory (NRI), the average annual wind erosion rate from cropland in the United States was 1.7 billion Mg/yr (about 777 million tons). In Michigan, wind erosion events transport soil by saltation and surface creep from level glacial lake bed soils to connecting water bodies. Farming in the Saginaw Bay watershed is possible because of deep, open surface drains (county drains), subsurface drainage, and roadside ditches. Soils are predominately loam, sandy loam and loamy sand texture and occasional sand beach ridges all susceptible to wind erosion. In Michigan, the average annual wind erosion rate was 2.20 tons/yr in the 2003 NRI survey. However, most of the fence rows and small field boundaries are gone, leaving wide, unsheltered, level and bare (fall moldboard plowed) fields. Many fields have an unsheltered distance greater than 800 meters (2640 ft.). County drains and adjacent berms, the predominant stable border, catch most of the saltation, surface creep and sediment eroding from wind erosion. This windblown sediment is deposited directly into the county and road side drains. The USDA Wind Erosion Prediction System Model (WEPS) can predict wind erosion rates and field boundary sediment loss by partitioning wind erosion into saltation, surface creep, and suspension, including PM_{10}. For this study a procedure was developed with WEPS using a phosphorus enrichment factor to estimate the total phosphorus loss by wind erosion transported with sediment to open drains. Using historical soil test P levels for the Saginaw Bay Watershed with a Total P enrichment equation indicated average Total P loss of about 8 pounds per acre without conservation practices. However, adding cover crops and conservation tillage in the typical crop rotation can reduce Total phosphorus loss to surface drains up to 50%. Additional wind erosion research and soil testing is needed to validate the P enrichment factor procedure to predict the affect conservation practices such as cover crops have on environmental planning and water quality assessment.

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Introduction

In Michigan, wind erosion events transport soil to deep, open surface drains (county drains) which eventually flush into Saginaw Bay. The wind eroded sediment reaches the drains primarily as surface creep and saltation, while the finer suspended particles are usually moved off the site to be deposited on the landscape or in bodies of water. Loam, sandy loam, and loamy sand soils and sand beach ridges are susceptible to wind erosion in the watershed. However, most field fence rows are gone, leaving wide, unsheltered, level and bare (fall moldboard plowed) fields with unsheltered distances greater than 800 meters (2640 ft.). The USDA Wind Erosion Prediction System Model (WEPS) can predict wind erosion rates and field boundary sediment loss by partitioning wind erosion into saltation, surface creep, suspension including PM_{10}.

Loss of phosphorus from farmland due to soil loss increases operating costs and use of fertilizers and degrades water quality.

> "Phosphorus…can increase the biological productivity of surface waters by accelerating eutrophication. Eutrophication is the natural aging of streams brought on by nutrient enrichment…and is the main cause of surface water quality …that restricts water use for fisheries, recreation, industry, and drinking, because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition." (ARS-149)

Management practices are needed that reduce off-site transport of soil (and associated nutrients). Erosion models provide a method to test alternative management practices to estimate reductions of nutrient movement.

Below is the method we used to calculate the average P loss using the WEPS model, comparing three soil types, a phosphorus enrichment equation, three alternative cropping systems, and five years of historical soil test P data from the MSU Soil Testing Lab for nineteen counties in the Saginaw Bay Watershed. We compared typical 3 and 4 year crop rotations with and without cover crops to estimate the potential P loss savings cover crops can provide by reducing wind erosion.

Objective

Develop a procedure to estimate the potential phosphorus savings or loss using cover crops in the crop rotation, the wind erosion prediction model WEPS, a Total Phosphorus Enrichment Equation from Wisconsin and the average soil test P data by county for nineteen counties in the Saginaw Bay watershed.

Phosphorus Enrichment

Phosphorus Enrichment data from snow and blowing dirt (Snirt) was first obtained from sampling downwind from the Innovative Farmer tillage plots in Huron County as follows:

> *"The snow sampling was done by Jim LeCureux, MSUE and Greg Renn, Huron SCS technician in the late 90's. Snow fence was set up on undisturbed corn stalks, chiseled corn stalks and fall plowed corn stalks. The strips were side by side in the same field. The snow samples were then analyzed for nutrients."*

The tillage plots for this study were on Shebeon loam, *(Fine-loamy, mixed, mesic Aeric Ochraqualfs)* and Kilmanagh loam *(Fine-loamy, mixed, nonacid, mesic, Aeric Haplaquepts).* These soils are in the Wind Erosion Equation (WEQ) Wind Erodibility Group (WEG) 5 or a Soil Erodibility Index (I) of 56. The average Bray P1 Phosphorus soil test level on the RV farm tillage plot site was 194-205 mg kg-1. The soil analysis from the snirt samples had soil test P levels 7 times higher than the same soil in the field tillage plots (E-2738.)

Phosphorus Calculation Procedure

The average Bray P1 soil test P level was calculated to predict the Total P loss from wind erosion using the WEPS model and a Phosphorus Enrichment calculation developed by Dr. L. Good at the University of Wisconsin. Good et al (2010).

Total Phosphorus is all the phosphorus contained in the eroded sediment, including the plant available STP along with the phosphorus that is attached to the iron, aluminum, and calcium sites, as well as the phosphorus tied up in organic material. Total phosphorus is always several times higher than STP because of the fixed P that is rarely plant available.

The Michigan State University (MSU) Soil Testing Lab provided a summary (Table 1) of average soil test P and K levels for nineteen counties in the Saginaw Bay Watershed from 2003-2008 for mineral soil in Michigan. Good's Total P equation was used to estimate the potential wind erosion P loss with and without cover crops using WEPS wind erosion predictions and typical Saginaw Bay crop rotations. (Table 2)

Total P is estimated by using a simple equation developed by Good et al. (2010) in Wisconsin which accounts for phosphorus contained in soil organic matter and Bray P1 soil test analysis.

Total P = (13 + (2.7 X OM %) + (0.03 X Bray P1*)) ^2

*Bray P1 ppm

The following is a Total P example calculation: If the % SOM is 3%, and the STP of the eroded sediment is: 1500 mg/kg (3000 lbs/acre-furrow slice).

Total P*(wind-eroded sediment) = (13 + (2.7 X 3) + (0.03 X 1500 mg/kg) ^2=4369 mg/kg (ppm) P.

WIND EROSION ESTIMATES

WEPS calculations were used to compare wind erosion on 3 soil types in Saginaw Bay and the same unsheltered distance of 2640 feet or 160 acres square (Table 2). Two baseline three and four year crop rotations without cover crops with fall tillage were compare to a 3 year crop rotation with cover crops, spring tillage and strip tillage. The three soil types tested were the Tappan loam (*Fine-loamy, mixed, active, calcareous, mesic Typic Endoaquolls*), Tappan sandy loam, and the Belleville sand (*Sandy over loamy, mixed, active, mesic Typic Endoaquolls*) (Table 4).

Table 1: Crop Rotations Compared

YR	Crop Rotation 4 years (baseline)
1	Fall Plow/disk for Corn Grain
2	Fall Plow/disk for Dry Beans
3	Tandem Disk for Winter Wheat
4	Fall Plow & disk for Sugar Beets

YR	Crop Rotation 3 years (baseline)
1	Fall Plow/disk for Corn Grain
2	Fall Plow/disk for Dry Beans
3	Fall Plow/ disk for Sugar Beets

YR	Crop Rotation 3 years with cover crops
1	Fall Plow/disk for Corn Grain aerial seed cereal rye cover crop in standing corn
2	Spring Plow/disk for Dry Beans no till drill winter wheat cover crop
3	Strip Till for Sugar beets

Using WEPS to Calculate Eroded P

Using the WEPS output for saltation and surface creep in tons/ ac, the average soil test P level (ppm) for the nineteen counties in the Saginaw Bay Watershed, and the Total P equation, we calculated the effect of adding winter wheat and /or cereal rye as the cover crops in a 3 year crop rotation as follows:

The following steps and assumptions are given to estimate the Total P loss from the fields with varying soils and cropping conditions:

1. Determine the average annual surface creep and saltation soil loss rate at the edge of the field (presumed to be adjacent to a drainage ditch). This will be calculated by using the ARS/NRCS WEPS model to predict wind erosion sediment reaching the edge of the field

for the three soil types and with or without a cover crop in the rotation. Answer is in tons per acre per year. See Table 4.

2. Convert tons per acre to pounds per acre by multiplying by 2000.

3. Estimate average soil test phosphorus (STP) for the five years that soil test analyses data is available. The average STP of 53 PPM for study. (Table 2)

4. Convert STP from mg/kg or ppm to pounds per acre. One part per million can be doubled to convert to parts per two million, which is the approximate weight of an acre furrow slice (6 2/3 inches depth of soil over a surface area). Answer is in pounds per acre (lbs. / ac. Furrow slice).

5. Calculate an estimate of the STP and Total P contained in the eroded material deposited at the edge of the field (and adjacent to a drainage ditch). Use the following formula setup:

Example Calculation to estimate STP loss at edge of field as follows:

1: Wind erosion rate (tons/acre/year) (WEPS Model Run Summary Gross Erosion Net Surface Creep/ Saltation)

2: To convert wind erosion rate from (t/ac/yr) to lbs/ac/yr multiply by 2000
Wind erosion rate (t/ac/y) X 2000 lbs/t = erosion in lbs/ac/yr

3: Calculate Total P as: `(13 + (2.7 X 3) + (0.03 X 53*)) ^2` ppm or mg/kg

4: Convert Total P from ppm to lbs/ ac furrow slice by multiplying by 2

5: Convert Total P from lbs. /ac furrow slice to P lbs. /lb. of soil by dividing by 2,000,000

6: Determine Total P loss by multiplying Total P lbs. /lb. soil by multiplying by the soil erosion rate in lbs. /acre.

Example Calculation for Belleville sand with the 4-Year baseline system:

Wind erosion rate = 11.4 t/ t Net Saltation & Surface Creep or 22,800 lbs. /ac/yr. soil
STP in ppm = 53
SOM= 3%
Total P = `(13 + (2.7 X 3) + (0.03 X 53*)) ^2` =515 ppm =515*2=1030 lb. P/acre furrow slice
Total P = 1030 lbs. P/acre furrow slice/2,000,000 lbs/acre furrow slice = 0.000514 lbs. P/lb. eroded soil
STP Loss = 22,800 lbs. eroded soil/ac*0.000514 lbs. P/lb. eroded soil=11.74 lbs. Total P/ac (See Table 5, Column I for Belleville)

Table 3 compares the WEPS run summary Gross, Net Creep/Saltation, Net Suspension and Net PM10 wind erosion rate for the 4 year crop rotation (corn grain, dry beans, winter wheat and beets with fall tillage and 3 year crop rotations with cover crops or spring tillage on 3 soil types.

TABLE 3 WIND EROSION ESTIMATES PROVIDED BY WEPS FOR ALTERNATIVE CROPPING SYSTEMS IN MICHIGAN

MI County	Soil (SMG)	Alternative Cropping System	Years	Field Size (acres)	Gross (tn/ac)	Net Total (tn/ac)	Net Creep/Saltation (tn/ac)	Net Suspension (tn/ac)	Net PM10 (tn/ac)
Saginaw	Tappan Loam (2.5c)	FPCG,FPDB, TDWW, FPSBt	4	160	9.16	9.16	3.45	5.71	0.11
		FPCG,FPDBwwcc*, Strip Till SBt	3	160	7.50	7.5	2.76	4.73	0.09
		FPCG rye cc**,SPDBwwcc*, Strip Till SBt	3	160	4.32	4.32	1.64	2.67	0.05
Saginaw	Tappan Sandy Loam (3c)	FPCG,FPDB, TDWW, FPSBt	4	160	19.48	19.48	6.58	12.9	0.24
		FPCG,FPDBwwcc*, Strip Till SBt	3	160	17.33	17.33	5.87	11.46	0.21
		FPCG rye cc**,SPDBwwcc*, Strip Till SBt	3	160	9.12	9.12	3.27	5.85	0.11
Saginaw	Belleville Sand (5c)	FPCG,FPDB, TDWW, FPSBt	4	160	60.82	60.82	11.40	49.42	2.11
		FPCG,FPDBwwcc*, Strip Till SBt	3	160	58.33	58.33	10.77	47.56	2.01
		FPCG rye cc**,SPDBwwcc*, Strip Till SBt	3	160	34.57	34.57	6.46	28.12	1.18

SMG- MSU Soil Management Group

*winter wheat cover crop
**Cereal rye cover crop aerial seeded

Field Size is 160 acres. The N-S (Y) length is 2640 feet and an E- W (X) length of 2640 feet with stable (non eroding) field borders on all sides

Crop	**Cover Crop**	**Primary Tillage**	**Secondary Tilllage**
CG-Corn, grain	**ryecc- cereal rye cover crop aerial seeded**	FC- Fall Chisel	Spring tandem disk
DB-Dry Bean	**wwcc-winter wheat cover crop no tilled**	FP - Fall Plow	Spring tandem disk
Sb-Sugarbeets		SC- Spring Chisel	Spring tandem disk
WW-Winter Wheat		SP- Spring Plow	Spring tandem disk
		TD- Tandem Disk	
		ST - Strip Tillage	

In Table 4 calculations of eroded P were based on the Net surface creep/saltation wind erosion soil loss transport processes reported for each WEPS Run in the Run Summary Report. Net Surface Creep and Saltation soil loss was estimated for each alternative soil, crop rotation and tillage system with or without cover crops shown in Table 3.

Table 4. Wind erosion soil loss and P loss for three soils and three management systems in Michigan.

A	B	C	D	E	F	G	H	I	J	K	L
Soil Series	Soil Erodiblity Index	Soil Management Group	Surface Texture	4-Year Baseline Erosion	3-Year Baseline Erosion	3-Year Cover Crop Erosion	4-Year Baseline Eroded P	3-Year Baseline Eroded P	3-Year Cover Crop Eroded P	Reduction 1	Reduction 2
				---------- tons/ac ----------			---------- lbs/ac ----------			---------- % ----------	
Tappan	5	2.5c	Loam	3.45	2.76	1.64	3.55	2.84	1.69	52	40
Tappan	3	3c	Sandy Loam	6.58	5.87	3.27	6.78	6.04	3.37	50	44
Belleville	1	5c	Sand	11.4	10.77	6.46	11.74	11.09	6.65	43	40
		Total		21.43	19.4	11.37	22.07	19.97	11.71		
		Average		7.14	6.47	3.79	7.36	6.66	3.90	47	41

Table 4 shows the average net surface creep and saltation soil loss from wind erosion on 160 acres with the base 4 yr. base line crop rotation of Corn Grain, Dry beans, Winter Wheat, and Sugar Beets with fall tillage on 3 typical soil types (Column E, F, G). The amount of eroded P (lbs. /ac) for each soil is shown in Table 4 columns H, I, and J. The soil loss does not include the soil loss in tn/ac/yr from suspension. WEPS calculates wind erosion soil loss from all sides of the field and wind erosion from all directions.

The amount of reduction on eroded P after applying the 3-Year cover crop rotation (Table 4, column J) was determined by comparing the eroded P from the 3-Year Cover crop system to the 4-Year Baseline system (Table 4, Column H) and the 3-Year system without a cover crop (Table 4, column I). Eroded P was reduced by an average of 47% for the 3-Year system with a cover crop compared with the 4-Year baseline system (Table 4, column L) and was reduced 41% compared with the 3-Year baseline system (table 4 columns L).

Conclusions and Observations

The WEPS wind erosion prediction model provides more detailed output of wind erosion by separating the wind erosion processes and prediction wind erosion losses by saltation, surface creep, suspension processes, including PM_{10} suspension. We developed a procedure to estimate the impact of using an alternative 3 year crop rotation with cover crops and spring tillage verses the traditional 4 year crop rotation with fall tillage.

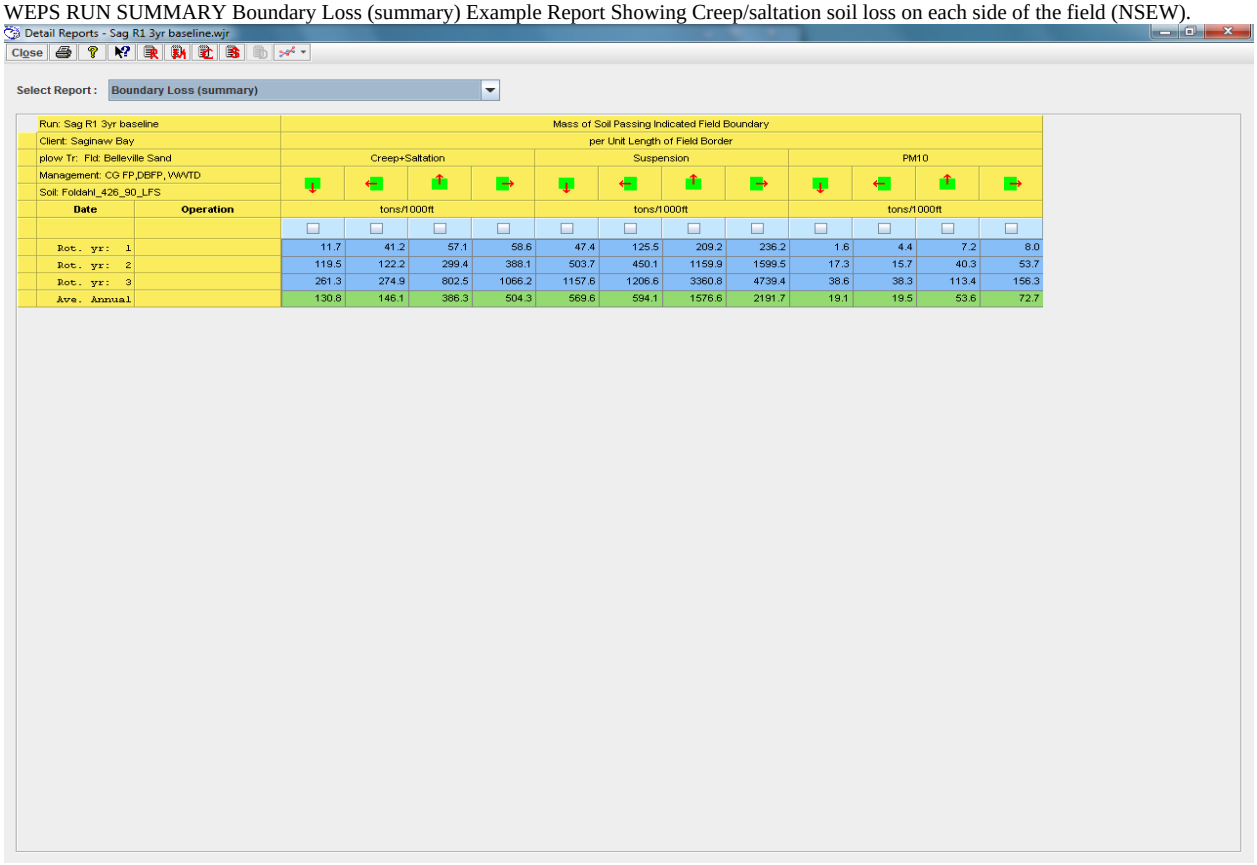
Studies in Michigan have shown that wind-blown soil collected in the snow had a seven fold higher STP level compared to the field contributing area. (Sanchez, 2001) This raises a legitimate concern that wind eroded sediment is adding significant phosphorus to surface water. This WEPS analysis estimates a 41-47 % reduction of wind erosion and P loss by using the 3 year cropping alternative with the addition of cover crops in the crop rotation. Further, accurate estimates of the nutrient enrichment ratio are needed to ensure estimates of nutrient loss due to wind erosion are correct. One study in North Dakota found the sediment to be only twice as high in P as the contributing field. (Cihacek, 1993) A P enrichment ratio of 2 was found in a study by Hagen and Lyles (1985). Another study by Zobeck and Fryrear (1986) found the enrichment ratios to vary from 1 to 3 for OM. P was not measured in this study. Therefore, there is a need to further evaluate and refine the phosphorus enrichment ratio with further validation studies that also include P analysis of the adjacent contributing area upwind. Hopefully, this procedure can be adopted or refined by additional studies to evaluate the impact of installing wind erosion control conservation practices including cover crops and comparing the potential phosphorus loss savings from non point sources to surface water in the next generation of WEPS.

Because WEPS calculates surface creep, saltation and suspension losses on the North, South, East, and West side of a field or contributing area; the predicted Total P loss to surface water can be calculated for each direction the wind blow sediment fills up the “ditch” (county drain) or road drain. The accuracy of the P loss estimate can be improved by using the WEPS Detailed Boundary loss run summary report to calculate the percent of wind erosion from the prevailing wind erosion direction upwind that fills any surface drains on the (E W, N or S) field edge.

Table 2* Medium Soil Test Values for Mineral Soils and Nineteen Counties in the Saginaw Bay Watershed 2003-2008							
		J. Dahl and D. Warncke					
2.5 + Tons**							Sample
County	**Lime/A**	**pH**	**P**	**K**	**Ca**	**Mg**	**Numbers**
	%	- - - - - - - - - - ppm - - - - - - - - - - - - - - - -					
Arenac	9.7	7.1	48	105	1370	161	267
Bay	10.5	7.4	**71**	117	1917	223	574
Clare	19.8	6.4	47	67	815	117	799
Genesee	6.4	7.3	46	92	1747	223	1478
Gladwin	11.4	6.7	32	60	972	116	621
Gratiot	8.2	6.8	47	120	1402	196	1182
Huron	4.7	7.5	42	121	1701	198	724
Iosco	8.4	6.8	46	90	1104	168	682
Isabella	10.2	6.8	58	88	1033	162	893
Lapeer	7.9	6.8	36	85	1217	176	530
Livingston	5.6	7.3	53	82	1463	167	2453
Mecosta	14	6.4	67	75	647	120	1197
Midland	14.7	6.9	60	87	1230	165	955
Oakland	4.6	7.5	56	89	2260	216	3685
Ogemaw	8.2	6.9	39	71	1075	158	497
Roscommon	22.1	6.7	**73**	51	759	83	331
Saginaw	9.2	7.3	62	122	1670	212	1193
Sanilac	8.7	7.1	37	111	1562	234	748
Shiawassee	5.9	6.9	39	112	1297	203	1105
Tuscola	5.1	7.3	47	96	1438	178	752
	%	- - - - - - - - - - ppm - - - - - - - - - - - - - - - -					
Average	10	7	53	97	1404	183	20666

*Dahl & Warncke, 2003-2008 Soil Tests Summary Spreadsheet MSU Soil Test Lab.

WEPS RUN SUMMARY Boundary Loss (summary) Example Report Showing Creep/saltation soil loss on each side of the field (NSEW).



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Appendix

Supporting Calculations:

Example Calculation of Average per cent STP loss reduction

Average annual STP loss rate without cover crops in the 4 year FPCG; FPDB, TDWW; FPS Beet rotation is: 7.14 lbs. /ac STP

Average annual STP loss rate with cover crops in the 3 year FPCG rye cc; SP DB winter wheat cc; Spring Strip till Sugar Beet rotation is: 3.79 lbs. /ac (STP)

Average per cent STP loss reduction is: 47 % or 7.14-3.79 = 3.35; (3.35/7.14)*100 = 47%

Calculation of Total Phosphorus at the edge of the field is calculated by changing STP to total P based on the conversion:

Total P = (13 + (2.7 X OM %) + (0.03 X Bray P1*)) ^2

TP = (13 + (2.7 X 3 %) + (0.03 X 53*)) ^2 [STP =515 ppm

Total P = 515 mg/kg or 1030 lb. P /acre-furrow slice

Total P = 1030 lbs. P / 2,000,000 = 0.00051484 lbs. P/lb. of eroded soil

TP loss for the 4 year FPCG; FPDB, TDWW; FPS Beet (fall plowed without cover crops) crop rotation the average wind erosion rate for the 3 soil types is 7.1 tons /ac/yr. or 14,200 lbs eroded soil. The average lb P/lb. soil = 0.000515

TP Example calculation is: 14,200 lbs. x 0.000515 = 7.31 lbs. Total P/ac

TP loss for the 3-year FPCG rye cc; SP DB winter wheat cc; Spring Strip till Sugar Beet crop rotation, the average wind erosion rate for the 3 soil types is 3.79 tons /ac/yr. or 7580 lbs eroded soil.

TP Example calculation is: 7580 lbs. x 0.0005154 lbs. P/lb. of eroded soil = 3.90 lbs. Total P/ac