SCALE OF MEASUREMENT EFFECTS ON PHOSPHORUS IN RUNOFF FROM CROPLAND [1]

Nancy L. Bohl[2], Chris A. Baxter[3], Larry G. Bundy[4], Todd W. Andraski[5], and Laura Ward Good[5]

Abstract

As phosphorus (P)-based nutrient management planning becomes necessary for some farms in Wisconsin, it will be critical to have reliable, research-based planning tools. The Wisconsin P-Index provides one method for preparing P-based nutrient management plans. The P-Index was developed largely from small plot-scale data showing the relationships between various site and management variables and runoff P losses. This study was conducted to compare runoff composition measurements at the subwatershed scale with those obtained from natural runoff at the small plot (1 m^2) scale. We intend to use this information to refine the Wisconsin P Index estimates of P concentrations in runoff. Sediment, soluble P, and total P in natural runoff from small plots located in two subwatersheds instrumented to measure and sample runoff events over a 12-month period were compared with similar measurements from the subwatersheds. The subwatersheds, cropped with either corn or alfalfa, were located on a Tama silt loam in southwest Wisconsin. The total dissolved P relationships at the two scales of measurement were very good with the corn having an R^2 value of 0.86 and the alfalfa having a R^2 of 0.91. The sediment P enrichment ratios varied by crop and were similar in the small plot and subwatershed runoff. The agreement of small plot and subwatershed runoff dissolved P and sediment P concentrations supports use of small plot data in constructing the Wisconsin P index.

Introduction

Phosphorus-based nutrient management planning will likely be required for some farms in Wisconsin. Wisconsin has developed and is continuing to refine a P Index as a management tool to assess the risk of runoff P loss on a site-specific basis. The P Index, a component of the NRCS 590 Nutrient Management standard, uses a semi-quantitative modeling approach to estimate P losses from fields to surface waters. The Wisconsin P Index allows users to assess the effects of various management alternatives, such as crop rotation, tillage options, and P applications to reduce P losses where high P index values are found. Much of the information used to create the algorithms used in the P index comes from small plot simulated rainfall and natural runoff studies. Little information is currently available on how small plot runoff P data compares with field or sub-watershed scale measurements. The Wisconsin P Index uses the approach described in the following equations to estimate total P delivery to surface waters.

P Index= (Particulate P+Soluble P+Losses from surfaces applied P) x Field-to-stream P delivery ratio (Eq. 1)

Soluble P = (Runoff volume) x (Dissolved P concentration) (Eq. 2)

Particulate P = (Sediment load) x (Sediment P concentration) (Eq. 3)

Sediment-bound P=Soil total P x Sediment P enrichment ratio (Eq. 4)

---

[1] Paper modified from 2005 North Central Extension-Industry Soil Fertility Conference, Des Moines, Iowa.

[2] Graduate student, UW-Madison Dept. of Soil Science, 1525 Observatory Dr., Madison, WI 53706.

[3] Assistant Professor, Soil and Crop Science, UW-Platteville, Tower 208, 1 University Plaza, Platteville, WI 53818-3001.

[4] Professor, UW-Madison Dept. of Soil Science.

[5] Research Associates, UW-Madison Dept. of Soil Science.

Sediment load values are found by using RUSLE2. Runoff volume (Eq. 2) is obtained using a modification of the NRCS system for rainfall runoff calculation and uses long-term winter runoff averages for calculating winter runoff. Small plot data has been used to develop the algorithms for dissolved P concentration (Eq. 2) and sediment P concentration (Eq. 3). Specifically, average total dissolved P concentrations in runoff are estimated using soil test P and soil type. Concentrations of P in eroded sediment (sediment-bound P) are based upon soil total P concentrations approximated using soil test P and soil percent organic matter and multiplied by a sediment P enrichment ratio (Eq. 4).

The objective of this project is to evaluate how well small plot runoff P loss measurements relate to actual field-scale P loss. Specifically, it is to ascertain whether the predictive equations developed from small plot data are valid at the subwatershed scale. The critical scale of measurement comparisons needed are those related to the annual average total dissolved P concentrations and sediment P concentrations in runoff. If differences in runoff P concentrations between small and subwatershed-scale exist, adjustments to the P Index will make the tool more realistic and improve its predictive value.

Materials and Methods

This study was located at the University of Wisconsin – Platteville's Pioneer Farm in southwestern Wisconsin. The research was initiated in spring 2004 on two subwatersheds, one planted in first year corn following alfalfa [7.2 hectares (ha), 17.7 acres (ac)], and the other in predominately first year alfalfa (12 ha, 29.7 ac). Existing subwatershed runoff collectors installed, monitored, and maintained by USGS personnel at the Pioneer Farm were used to collect year-around runoff at the subwatershed scale. Each monitoring station has a flume capable of measuring runoff volume and taking periodic runoff samples for analyses. Four small plot (1 m^2) runoff collectors were installed within each of these subwatersheds in June 2004. These collectors consisted of three galvanized steel panels (1 m long by 23 cm wide) inserted 15 cm deep in the soil on the upslope edges and sides of the plot. The other panel (1 m long by 15 cm wide) was placed flush with the ground level on the collector's down-slope edge. This panel was fitted with a galvanized steel gutter (1 m long) with a 3 cm diameter outflow tube connected to a copper hose (3 cm in diameter). Runoff was collected by gravity in a 115 L covered galvanized pail placed flush with the soil surface. A smaller 8 L polyethylene collection bucket covered with a coarse screen was placed in the pail. The gutter was covered with plexiglass to prevent precipitation from going directly into the collector.

Soil samples were collected near the small plots at 0 to 2, 2 to 5, and 5 to 15 cm depth increments. These samples were analyzed using Bray P1 (Frank et al., 1998), Mehlich III (Mehlich, 1984), and distilled water extraction (Pote et al., 1996) methods. These soil extracts were analyzed colorimetrically using the ascorbic acid method (Murphy and Riley, 1962). Total P also was measured in the soil using ICP analysis following nitric-perchloric digestion. The subwatersheds were grid sampled at two depths, 0 to 2 cm and 0 to 15 cm using a 100-foot grid size. These samples were analyzed for P using the Bray P1 method and selected samples were analyzed for total P. Bray P1 and soil total P values for corn and alfalfa subwatersheds and small plots are summarized in Table 1.

Table 1. Soil phosphorus levels in subwatersheds and small plots at the Pioneer Farm, Platteville, Wisconsin.

Field	Depth (cm)	Bray soil test P		Total P	
		Subwatersheds	Small plots	Subwatersheds	Small plots
		-----------------------	ppm	-----------------------	
Corn	0-2	49	31	613	490
	0-15	37	19	593	465
Alfalfa	0-2	133	141	827	784
	0-15	114	137	762	742

Runoff volumes from the subwatershed and small plot collectors were measured and samples taken for total dissolved P (TDP), total P (TP), and total solids (TS). For total dissolved P, filtered runoff samples were digested and analyzed colorimetrically using the ascorbic acid method. Unfiltered runoff samples were acidified with 0.01 M H_2SO_4 and analyzed for total P following ammonium persulfate and sulfuric acid digestion. Unfiltered runoff samples were weighed before and after drying at 105° C for total solids (sediment) determination. The four replicate small plot runoff volumes and concentrations were volume-weight-averaged for small plot runoff values.

The corn and alfalfa subwatersheds used in the scale of measurement studies were managed as a part of the total Pioneer Farm operation. In the corn subwatershed, this included fall chisel plowing and spring tillage with a soil finisher before corn planting in the spring. Solid manure (13.8 tons per acre) was applied to the subwatershed including the small plots in the fall before chisel plowing, and additional solid manure was applied at a low rate (5.9 tons per acre) in winter. Corn was harvested for grain in 2004 and the average yield was 181 bushels per acre. In the alfalfa subwatershed, three cuttings were harvested in 2004, and one cutting was taken in May 2005.

Results and Discussion

Phosphorus and sediment concentrations and loads in runoff from the corn and alfalfa subwatersheds and small plots are summarized in Tables 2 and 3, respectively. Runoff P concentrations were similar in small plots and subwatersheds, but varied by crop and season. From June 2004 to June 2005, there were nine runoff events in both the corn subwatershed and small plots and seven runoff events in both the alfalfa subwatershed and small plots. There were about twelve other dates with runoff in some of the small plots, but no runoff in the subwatershed. To separate winter and summer runoff events, periods when the soil is frozen are called winter and the rest of the year is designated as summer. Four of the runoff events in the corn subwatershed occurred when the soils were frozen (winter). Six of the alfalfa subwatershed runoff events happened with frozen soil. In both subwatersheds, most of the runoff volume occurred in the winter. Only 3% of the alfalfa runoff volume was collected in the summer while 37% of the corn runoff volume was collected in the summer. The precipitation levels during the summers of 2004 and 2005 were below average, while the winter of 2004-2005 had above average precipitation. The small plots had greater runoff volumes per unit area in all cases compared to the subwatersheds. Because of longer flow paths (transport distances) in the subwatershed, there are more opportunities for infiltration and deposition, resulting in lower per unit area runoff volumes (Table 2).

Table 2. Phosphorus and sediment concentrations in annual runoff from corn and alfalfa subwatersheds and small plots from June 2004 to June 2005 at the Pioneer Farm, UW-Platteville.

Field	Season	n	Scale	TDP[2]	TP[3]	TS[4]	Runoff
					-------ppm-------		L/m^2
Corn	Annual	9	Subwatershed	2.24	4.48	3920	31
			Small Plot[1]	1.85	2.87	1100	218
	Winter	4	Subwatershed	3.32	3.97	440	20
			Small Plot	2.12	2.92	380	186
	Summer	5	Subwatershed	0.45	5.33	9670	12
			Small Plot	0.22	2.59	5390	31
Alfalfa	Annual	7	Subwatershed	1.15	1.45	120	54
			Small Plot	1.74	2.36	220	176
	Winter	6	Subwatershed	1.13	1.43	120	52
			Small Plot	1.78	2.36	180	167
	Summer	1	Subwatershed	1.60	1.92	230	2
			Small Plot	1.14	2.31	860	9

[1] Small plot values are weighted-average of four replications in each subwatershed
[2]Total dissolved phosphorus
[3]Total phosphorus
[4]Total solids

For the whole year, the corn subwatershed had higher annual P concentrations, P loads, solid concentrations, and solid loads compared to the alfalfa subwatershed (Table 2 and Table 3). The corn subwatershed P concentrations were higher than in the small plots. However, the small plot loads were greater than the subwatershed loads in both corn and alfalfa subwatersheds due to the greater per unit area runoff volumes in the small plots. The TDP concentration and loads were higher in the winter than the summer for both scale sizes. This is most likely due to lower sediment losses during winter, greater dissolved P losses due to winter manure applications in corn, and possible soluble P leaching from plant material, especially in the alfalfa field. The fact that this seasonal change in TDP concentration was seen at both scales of measurement adds validity to use of small plot data for constructing P indices. Total P concentrations and loads and total solids (sediment) concentrations and loads were greater in the corn field than the alfalfa field. The absence of tillage and presence of high residue cover for most of the year effectively control sediment loss in the alfalfa subwatershed.

Table 3. Phosphorus and sediment loads in annual runoff from corn and alfalfa subwatersheds and small plots from June 2004 to June 2005 at the Pioneer Farm, UW-Platteville.

Field	Season	n	Scale	TDP[2]	TP[3]	TS[4]
				--------lb/ac-------		
Corn	Annual	9	Subwatershed	0.63	1.26	1097
			Small Plot[1]	3.59	5.58	2133
	Winter	4	Subwatershed	0.58	0.69	78
			Small Plot	3.53	4.86	627
	Summer	5	Subwatershed	0.05	0.56	1026
			Small Plot	0.06	0.72	1507
Alfalfa	Annual	7	Subwatershed	0.55	0.69	60
			Small Plot	2.73	3.69	340
	Winter	6	Subwatershed	0.52	0.66	56
			Small Plot	2.64	3.51	274
	Summer	1	Subwatershed	0.02	0.03	3.57
			Small Plot	0.09	0.18	67

[1] Small plot values are weight-averaged of four replications in each subwatershed.
[2]Total dissolved phosphorus
[3]Total phosphorus
[4]Total solids

The P Index dissolved P concentration equation (Eq. 2) is based on small plot research results showing that runoff total dissolved P increases with increasing Bray P1 soil test levels. This relationship is evident from the TDP values for the small plots and subwatersheds in Table 2. In the corn field, the subwatersheds had higher average Bray P1 soil test values than the small plots (Table 1). In each comparison, the corn subwatershed had higher TDP concentrations than the small plots. In the alfalfa subwatershed, the small plots had the higher Bray P1 soil test values and higher runoff TDP concentrations.

Relationships between the Small Plot and the Subwatershed Runoff P

Phosphorus runoff from small plots and subwatersheds were compared on an event by event basis using regression analysis (Table 4 and Figure 1). The annual runoff volumes at the two scales were related with R^2 values of 0.71 and 0.72 for the corn and alfalfa fields, respectively. For annual concentrations, the TDP relationships were highly correlated, with the corn having an R^2 value of 0.86 and the alfalfa having a R^2 of 0.91. However, as illustrated in Figure 1, the small plot vs. subwatershed relationships for TDP concentration were quite different in the corn and alfalfa subwatersheds. Alfalfa subwatershed and small plot data for TP and TS concentration were more closely related than the corresponding corn data. As expected, the runoff P load relationships between small plots and subwatersheds were generally not as strong as those found for runoff P concentrations.

Table 4. Relationship between small plot and subwatershed measurements of P concentrations and load in runoff from June 2004-2005.

Field	Season	Events n	Concentration TDP[1]	TP[2]	TS[3]	Load TDP	TP	TS	Runoff
			R^2						
Corn	Annual	9	0.86	0.35	0.44	0.96	0.55	0.24	0.71
	Winter	4	0.01	0.54	0.46	0.97	0.98	0.99	0.97
	Summer	5	0.98	0.32	0.13	0.23	0.44	0.22	0.57
Alfalfa	Annual	7	0.91	0.68	0.74	0.60	0.52	0.17	0.72
	Winter	6	0.93	0.82	0.67	0.56	0.49	0.24	0.72
	Summer	1	-	-	-	-	-	-	-

[1]Total dissolved phosphorus
[2]Total phosphorus
[3]Total solids

Sediment-based P Concentrations

Sediment P enrichment ratios indicate how the P concentration in sediment contained in runoff relates to the total P concentration of the original soil. The enrichment ratios are calculated by dividing sediment-bound P by soil total P. Enrichment ratios are often greater than one because finer sized soil particles usually have higher P concentrations than coarse soil particles and the fine particles are the most likely to be lost in runoff. In the summer runoff events from the corn subwatershed, sediment losses were relatively high (Table 5), and enrichment ratios were near 1.0, indicating little sorting of eroded particles during runoff. Runoff sediment P and total P concentrations for these events were similar. In contrast, for the winter events from the corn subwatershed and for all events from the alfalfa subwatershed, sediment losses in runoff were low and enrichment ratios indicate substantially higher P concentrations in eroded sediment than in the original soil. This concentration is likely due to selective transport of finer sized soil particles. Within crop and season variables, sediment P enrichment ratios were usually similar in small plot and subwatershed measurements.

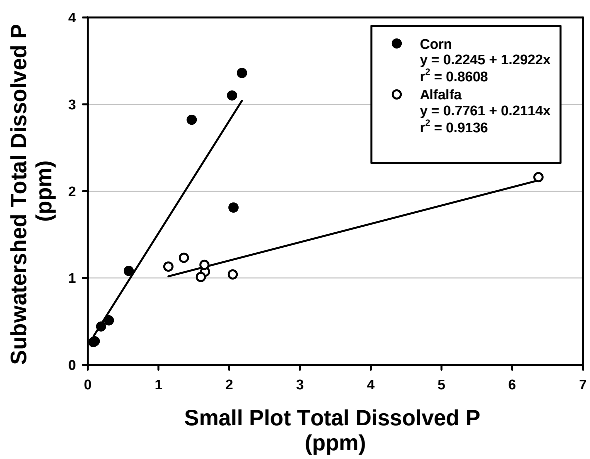

Figure 1. Relationships between corn and alfalfa subwatershed and small plot total dissolved P concentrations in runoff during June 2004-June 2005 at the Pioneer Farm, UW-Platteville.

Table 5. Sediment P enrichment ratios, sediment bound P concentrations, soil total P, and total solids concentrations in runoff from subwatersheds and small plots by crop and season, Pioneer Farm, UW-Platteville.

Field	Season	n		Sediment bound P[1]	Soil total P	Enrichment ratio[2]	Total solids
				ppm	ppm		ppm
Corn	Summer	5	Subwatershed	507	603	0.84	9670
			Small plot	484	490	0.99	5390
	Winter	4	Subwatershed	1467	603	2.43	440
			Small plot	1685	490	3.44	380
Alfalfa	Summer	1	Subwatershed	1382	795	1.74	120
			Small plot	1343	784	1.71	220
	Winter	6	Subwatershed	2455	795	3.09	120
			Small plot	3212	784	4.10	180

[1]Sediment bound P (mg/kg) = Particulate P load/Total solids load
[2]Enrichment ratio = Sediment bound P/Soil total P

Conclusions

Total dissolved P (TDP) concentrations in runoff were similar at the small plot and subwatershed scales. Crop and season effects on runoff TDP concentrations were reflected at both scales of measurement. Per unit area runoff volumes and sediment loads were higher in small plots than in subwatersheds. Phosphorus concentrations in eroded sediment varied substantially with crop and season, but were generally similar in the small plot and subwatershed measurements. Sediment P enrichment ratios also varied with crop and season of measurement, but were not greatly affected by scale of measurement. Since P index equations for predicting runoff soluble P and sediment P concentration are based on data from small plot measurements, the finding that these parameters are similar at plot and subwatershed scales of measurement lends support to use of plot scale data for the development of P indices.

Acknowledgments

Research supported by the University of Wisconsin Consortium for Extension and Research in Agriculture and Natural Resources, the University of Wisconsin Graduate School, and the College of Agriculture and Life Sciences, University of Wisconsin-Madison.

References

Bohl, N., L. Bundy, C. Baxter, T. Andraski, and L.W. Good. 2005. Scale of measurement effects on phosphorus runoff losses from cropland. In Proc. North Central Extension-Industry Soil Fertility Conference, Des Moines, IA, 16-17 November 2005. 21:130-137.

Frank, K., D. Beegle, and J. Denning. 1998. Phosphorus. p. 21-26. In J. R. Brown (ed.) Recommended chemical soil test procedures for the North Central Region. NC Regional Res. Publ. no. 221 (Rev.). Missouri Agric. Exp. Stn., Columbia, MO.

Good, L.W. 2005. Wisconsin Phosphorus Index [Online] http://wpindex.soils.wisc.edu/ (verified December 13, 2005).

Good, L.W., P. Karaaka, S. Porter, and K. Beckard. 2005. SNAP-Plus Wisconsin's Nutrient Management Software [Online] http://www.snapplus.net/ (verified December 13, 2005).

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.

Murphy, J., and J.R. Riley. 1962. A modified single solution method for the determination of phosphate in natural water. Anal. Chem. 27:31-36.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P. A. Moore, Jr., D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil. Sci. Soc. Am. J. 60:855-859.