PHOSPHORUS LOSSES FROM CORN FIELDS [1/]

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Abstract

A principal focus of water quality management efforts in the U.S. is related to nutrient, specifically nitrogen (N) and phosphorus (P), export in runoff from agricultural lands. The focus of this discussion is to investigate the influence of residue levels and manure addition on particulate P delivery by runoff. Rainfall runoff samples were collected from three hydrologically isolated hillslope tracts in conservation tillage with the following treatments: corn-grain (CG); corn-silage (CS); and corn-silage with fall manure addition (SM). Rainfall-runoff, frost free (FF) events were sampled from May 2004 through September 2005. Samples were analyzed for solids mass, P in the dissolved and particulate forms, sediment P-mass distribution in five different particle-size classes along with particle and aggregate size distributions, and aggregate stability. This discussion is limited to soil and total phosphorus (TP) loss and the distribution of TP mass over five particle size classes in the sediment.

The runoff volume and soil loss from the CG treatment was significantly lower than the lower residue CS treatments. The majority of the annual P loss occurred in the particulate P form for all the monitored events. The majority (~ 57%) of the sediment P mass was contained in particles less than or equal to 50 µm in size (clay and silt). The increased transport of fine P enriched particles increases the potential for downstream water quality degradation. This research highlighted how differences in land management practices influence nutrient and sediment export from corn fields. The increased interest in bio-fuel production could result in high rates of bio-mass removal. The corresponding decrease in surface residue could, if not properly managed, increase soil loss in-turn degrading soil health and downstream water quality.

Introduction

Water quality management efforts in the U.S. over the past 30 years have been driven primarily by the passage of the Clean Water Act in 1972. Initially, pollution control efforts focused on point source controls resulting in great progress toward reducing contributions from these sources. However, surface and groundwater quality problems still persist for which non-point sources have been implicated. Nutrient export from agricultural lands, specifically N and P, has been identified by the U.S. Environmental Protection Agency (USEPA) as the major cause of excessive aquatic plant growth in lakes and rivers of the U.S. (Parry, 1989; USEPA, 1995; USEPA, 1996) reducing beneficial use of the receiving water. Accelerated aquatic plant growth or *cultural eutrophication* impacts aesthetics, fisheries, recreation, industrial and drinking water use resulting in local, regional and national economic impacts.

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Phosphorus is transported in both dissolved (dissolved P, DP) and particulate-bound (PP) forms, with the latter dominating overall P losses in row-cropped agricultural systems (Logan, 1980, 1982; Ginting et al., 1998; Gillinghan and Thorrold, 2000; Uusitalo et al., 2001). Because clay and other fine-grained materials (i.e., organic matter (OM), silt) have a high specific surface area, P and other chemical contaminants are strongly sorbed to, and readily transported with these particles. The reduction in soil loss therefore has a secondary benefit of P loss reduction.

The overall goal of this study was to investigate the influence of agricultural management practices (e.g., residue cover, tillage, manure management) on the delivery of P in particulate and dissolved forms in both rainfall and snowmelt runoff. This discussion uses sediment particle size data collected during the 2004-05 frost-melt (November-March) (FM) and the 2004 frost free (April-October) (FF) periods. Data collected during the 2004 FF period were used to evaluate the sediment and total P losses, while both FM and FF data were used to determine the sediment P mass-particle size relationship. This study will focus on three areas: (1) the relationship between crop residue and soil loss, (2) the relationship between soil loss and P loss, and (3) the distribution of P by particle size.

Methods and Materials

Field monitoring was conducted on a terraced hill-slope at the Univ. of Wisconsin Arlington Agricultural Research Station. The southern halves of three terraced fields, designated as corn-grain (CG); corn-silage (CS); and corn-silage with fall manure addition (SM), respectively, were instrumented and monitored for this research project. Soils were silt loam - Ripon series (fine-silty, mixed, mesic Typic Argiudolls). Each field was an independent first order watershed due to the existence of terrace channels at the up- and down-slope boundaries. Within each field, storm-event surface runoff samples were collected from hydrologically isolated hill-slope tracts 15 ft wide and 120 ft long resulting in a tract area of 1,800 ft^2 (0.04 ac). The average slopes for the (CG), (CS) and (SM) tracts were 7.0, 8.2, and 8.4%, respectively.

Edge-of-field runoff sample collectors were installed at the downstream end for each hillslope tract. Rainfall data were collected from continuous and bulk gauges located on-site and from the Arlington Agricultural Research Station headquarters located approximately 3.7 miles due south of the site. The NOAA-certified gauge at the Arlington Agricultural Research Station was used to provide the 30-yr (1971-2000) normal precipitation data, to fill gaps in the absence of on-site data or when precipitation occurred primarily as snowfall. The edge-of-field monitoring sites used a flow-dividing bulk collection system. Runoff and sediment were collected on plastic-covered triangular collectors designed, to direct flow into a 4-inch diameter PVC collector pipe. The collector pipe then discharged into a series of three buckets, the first two (B1 and B2), which were 5-gallon Samson® HDPE buckets equipped with flow-dividing crowns as specified by Pinson et al. (2004). The third bucket (B3) was a 10-gallon tank that did not include a flow divider. Each divider head was laser-cut from stainless steel and designed with twenty-four V-notch weirs (2.5 inches in height) circumscribing its perimeter, and capable of passing a total flow of 106 gpm. The flow-divider crowns are designed to collect only a fraction of the total runoff volume.

Land Management

All tracts were planted with corn (*Zea mays* L.) under conservation tillage, fall chisel plow followed by spring field cultivation prior to planting. The primary tillage depth was 8 inches using a Glencoe chisel plow with twisted shovel followed by secondary tillage using a field cultivator to a depth of 3 inches. The planting density was 32,000 seeds/ac and a row spacing of 32 in was used throughout the study. The tillage orientation was up-and-down the slope for all treatments. The management operations included in the study are summarized in Table 1.

Table 1. Field management operations, dates, residue cover and crop yields by site.

Site ID	Year	Crop Type	Plant Date	Harv. Date	Tillage Date	Tillage Implement	Crop Row Orientation	Residue Cover [1]	Initial Bray-1 P [2]	Fert. Appl. [3]	Manure App. [4]	Crop Yield [5]
AR1	2003	Corn Grain	17-May	16-Oct	10/23/2002 5/16/2003	Fall chisel plow Field cultivator	On contour	51%	58	Starter only	None	95
AR1	2004	Corn Grain	7-May	26-Oct	11/7/2003 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	57%	ND	Starter only	None	130
AR1	2005	Corn Grain	26-Apr	10-Oct	10/12/2005 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	41%	38	Starter only	None	130
AR2	2003	Corn Silage	17-May	6-Nov	10/23/2002 5/16/2003	Fall chisel plow Field cultivator	On contour	10%	66	Starter only	None	1.9
AR2	2004	Corn Silage	7-May	27-Sep	11/7/2003 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	25%	ND	Starter only	None	1.7
AR2	2005	Corn Silage	26-Apr	8-Sep	10/12/2005 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	21%	51	Starter only	None	1.9
AR3	2003	Corn Silage	17-May	6-Nov	10/23/2002 5/16/2003	Fall chisel plow Field cultivator	On contour	15%	17	Starter only	Fall + plowed 29 lb P/ac	2.0
AR3	2004	Corn Silage	7-May	27-Sep	11/7/2003 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	18%	ND	Starter only	Fall + plowed 48 lb P/ac	1.7
AR3	2005	Corn Silage	26-Apr	8-Sep	10/4/2005 5/7/2004	Fall chisel plow Field cultivator	Up / Down Slope	15%	74	Starter only	Fall + plowed 38 lb P/ac	1.9

Notes:
1. The average of 3 frequency measurements at 1ft. intervals along a 50 ft transect within the tract.
2. Sample depth = top 2 in.
3. Starter fertilizer 5 - 14 - 42 applied at 80 lb / ac.
4. The 2003, 2004 and 2005 manure application rates were 8,500, 9,400 and 10,000 gal/ac, respectively. No records were available for the fall 2002 application which was + 10,200 gal/ac.
5. Corn silage yield = tons dry matter (DM) / acre and corn grain is reported in Bu / ac at 15.5 % moisture.

All tracts were cropped in continuous corn for the entire duration of the study. Two herbicide treatments were completed during the growing season, a pre-emergent application in spring (typically April) and a post-emergent application in early summer (typically June). Liquid dairy manure containing sawdust bedding was applied to the SM treatment each fall after harvest at the rates specified in Table 1 and incorporated by chisel plowing after application. Residue levels were measured every fall after tillage operations using the transect method.

<u>Runoff Sample Collection and Preparation</u>

If runoff samples were present, the water level in each bucket was measured and recorded to the nearest 1/8 inch, and a 60-mL filtered (< 0.45 µm polypropylene syringe filter) sub-sample was collected within 24 h of the runoff event, transported to the laboratory on ice and stored at 4^oC for subsequent analysis. The water level in each bucket was used in the calculation of the total storm-event runoff volume, which in-turn was used to determine the storm-event constituent loading. Bucket #1 (B1) was removed from the field, replaced by a clean, empty bucket and transported to the laboratory for reapportioning and subsequent analysis. Buckets #2 (B2) and #3 (B3) were completely mixed in the field and two 1-L sub-samples were collected from each bucket, transported on ice to the laboratory and stored at 4^oC for subsequent analysis. Due to the large volume of sample from B1 (maximum 5 gallons), a reapportioning procedure was developed to obtain a representative sub-sample (~ 0.5 gallon) using a Phipps and Bird Jar Tester (Model PB-900; Richmond, VA).

Some storm events (primarily the spring of 2004) produced excessively high sediment loads. This resulted in the filling of B1 and/or B2 with sediments or buckets containing sub-stantially more sediment volume than could be handled by the above procedure. For these cases, sediment core samples were taken from each bucket. Six 1-3/8 inch diameter clear plastic tubes were inserted to the bottom of the bucket for sampling in an evenly spaced pattern. The contents from the six tubes were then transferred to a standard (~ 0.5 gallon) storage container for subsequent analysis.

Chemical Analysis

Prior to analysis, all stored unfiltered samples were mixed and sub-sampled using a Phipps and Bird Jar Tester (Model PB-900; Richmond, VA). Total phosphorus (TP) analysis was run on the unfiltered samples, while dissolved reactive P (DRP), electrical conductivity (EC), pH, and total dissolved P (TDP) were run on filtered samples. The solids analysis included total solids (TS) and total volatile solids (VS). The chemical analyses included: TS, VS, TP, TDP, DRP, EC and pH for B1-B3. The TP mass distribution in five different particle size classes was conducted only for B1. The solids mass in B2 and B3 was typically below the minimum solids mass needed to perform the gravity sedimentation procedure, therefore limiting this analysis only to B1. The analysis suite completed for B1, B2 or B3 was conducted in accordance with Standard Methods (APHA et al., 1995).

Sediment Particle Size by Gravity Settling

Sediments were separated into five different size classes via gravity settling, namely, < 2 µm (clay), 2 to 10 µm (fine silt), 10 to 50 µm (coarse silt), 50 to 500 µm (very fine to medium sand) and > 500 µm (coarse sand) (Toy et al., 2002). Since the focus was on aggregates rather than primary particles, no dispersing agents were used. Initially, each sample was passed through a #35 sieve (0.02 inch) to remove organic crop residue and coarse sand particles. Fractionation into different size classes was achieved using first order settling (Stokes' Law) in a step-wise manner starting with the largest size class first. Stokes' Law was used to determine the settling time for particles of a given diameter over a specified vertical distance. The specific gravity was assumed to be 2.20 g/cm^3 for aggregates greater than 2 µm in diameter and 2.65 g/cm^3 for smaller particles (Alberts et al., 1983, Grande et al., 2005). For the 50- to 500-µm and the 10- to 50-µm fractions, aggregates were allowed to settle in a 1000-mL graduated cylinder for a predetermined time based on fall distance and ambient temperature. The sample temperature was monitored frequently throughout the process. The supernatant was then aspirated and remaining sediments resuspended with MilliQ - grade DI water (Millipore, Billerica, MA) three times for each size class. The process of repeated washing and settling was used to maximize recovery and eliminate particles outside of the desired size range (Alberts and Moldenhauer, 1981; Alberts et al., 1983). The 2- to 10-µm fraction was separated initially by settling followed by resuspention and centrifugation (800 rpm for 7 min). The remaining supernatant contained only particles < 2 µm (clay-sized) in diameter. Once the sediments had been separated by size class, each suspension containing aggregates of a certain size class was placed in a 105^{o}C drying oven for at least 24 h. After drying, each fraction was weighed, scraped from its container and stored in a sealed vial for subsequent TP analysis.

Results and Discussion

The monthly precipitation totals for 2003 to 2005 from the field station and the Arlington Agricultural Research Station rain gauge are shown in Table 2 along with their departures from the 1971-2000 normals. There were 14 runoff producing rainfall events monitored by bulk sampling during 2004. A runoff event was defined as a rainfall that produced sufficient runoff volume to fill bucket number 1 (B1) (minimum volume = 5 gallons).

Table 2. Monthly precipitation totals and departures from normal.

	Monthly Precipitation Totals and Departures from Normal (in)												
Year	**Jan ***	**Feb ***	**Mar ***	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec ***	**Total**
2003	**0.43**	**0.18**	**1.41**	2.01	3.79	2.56	2.69	0.45	4.26	1.00	5.80	**2.08**	**26.66**
Departure	-0.65	-0.98	-0.58	-1.23	0.37	-1.48	-1.17	-3.79	0.62	-1.43	3.42	0.75	-6.15
2004	**0.28**	**1.20**	**2.66**	0.79	8.68	3.29	3.08	2.46	0.77	2.32	1.21	**1.64**	**28.38**
Departure	-0.80	0.04	0.67	-2.45	5.26	-0.75	-0.78	-1.78	-2.87	-0.11	-1.17	0.31	-4.43
2005	**1.45**	**1.15**	**1.81**	0.65	2.13	1.15	3.34	2.32	3.38	0.30	3.74	**0.95**	**22.37**
Departure	0.37	-0.01	-0.18	-2.59	-1.29	-2.89	-0.52	-1.92	-0.26	-2.13	1.36	-0.38	-10.44
Normal	**1.08**	**1.16**	**1.99**	**3.24**	**3.42**	**4.04**	**3.86**	**4.24**	**3.64**	**2.43**	**2.38**	**1.33**	**32.81**

*** Data in bold are from the Arlington Agricultural Research Station.**

Of the runoff-producing rainfall events monitored during the FF period, the median rainfall depth per event was 0.62 in. The median duration for a rainfall event was 8 hours (range 1-32 h) and the median event intensity was 0.09 inch/h. Precipitation during the study period was generally below average annual values, but there were periods of abnormally high rainfall such as during spring 2004. As shown in 21, the 2004 total annual precipitation was below normal but included the record setting high rainfall in May. The monthly total precipitation in May 2004 was 5.26 in above normal, making it the wettest May in Wisconsin history according to records maintained by the Wisconsin State Climatology office (Anderson, 2006). During May, June, and July of 2004, the frequency of occurrence of runoff events was every 5, 6 and 8 days, respectively.

Runoff Volume and Sediment Losses

The largest runoff event occurred on May 22-23, 2004 and the runoff volume and coefficient were significantly higher for all sites from these events when compared to other events that occurred during the study. A disproportionately large fraction of the 2004 FF period runoff volume was generated by rainfall events during May and June. For the CG, CS and SM sites this comprised 98, 93 and 93%, respectively. Statistical analysis of the median runoff coefficients for the three sites indicated that the CG treatment (median runoff coefficient = 0.04) differed significantly ($p < 0.01$) from the CS (0.13) and SM (0.14) treatments, which were similar. Increased residue cover creates ponding and delays surface crust formation, thus increasing infiltration and decreasing runoff volume.

For rainfall-runoff events, a combination of energy available in raindrop impact and shear stress in flowing water dictate the extent of soil detachment and sediment transport. Crop canopy and residue both play an important role in reducing rainfall erosivity by intercepting rainfall and retarding overland flow, thereby decreasing soil loss.

The majority of the specific water quality constituent values in Table 3 for the CG treatment were less than those for CS, while CS and SM had levels similar to each other. The only exception to this was the percent VS values for which the CG treatment was greater. This is not surprising considering that the percent VS values represent the sediment OM fraction and the CG grain treatment had the highest residue levels of the three treatments. These results suggest that the presence of residue significantly reduced soil loss which, in turn, reduced TP export given the strong relationship ($r^2 = 0.97$) between TS and TP losses (Fig. 1). The majority of the P

Table 3. Comparison of runoff constituents among sites for the frost-free period, 2004.

Parameter	Comparison of Median Values	Parameter	Comparison of Median Values
TS EMC (mg/L)	AR1 < AR2 = AR3	**Percent VS**	AR1 > AR3 > AR2
VS EMC (mg/L)	AR1 < AR2 = AR3	**TP EMC (mg/L)**	AR1 < AR2 = AR3
TS Load (lb/ac)	AR1< AR2 = AR3	**DRP EMC (mg/L)**	AR1 < AR2 = AR3
VS Load (lb/ac)	AR1< AR2 = AR3	**DRP Load (lb/ac)**	AR1 < AR2 = AR3
TP Load (lb/ac)	AR1< AR2 = AR3	**TDP Load (lb/ac)**	AR1 < AR2 = AR3

Note : All comparisons were significant at the 0.01 probability level.

loss was found to occur in the particulate-bound form. The close relationship between TP and soil loss has been reported in several previous studies as well (Alberts and Moldenhauer, 1981; Sharpley et al., 1992; Gburek et al., 2005). As the storm-event TP and TS load plots show (Fig. 2 and 3), the within-site variability was greatest for the CS sites.

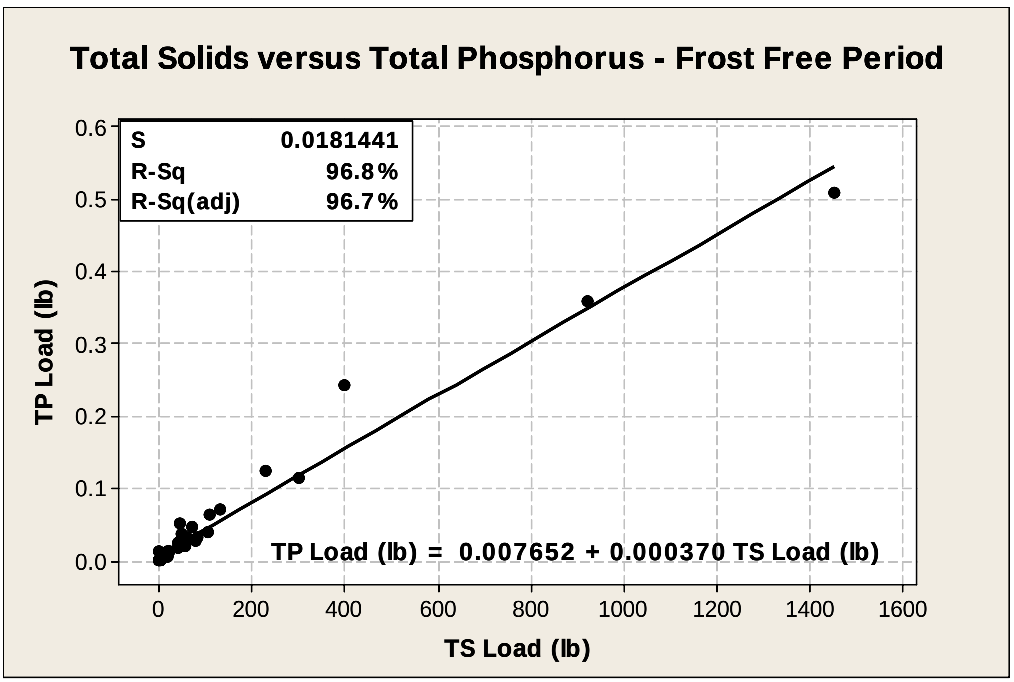

Figure 1. Sediment (TS) versus total phosphorus (TP) loss by tillage type.

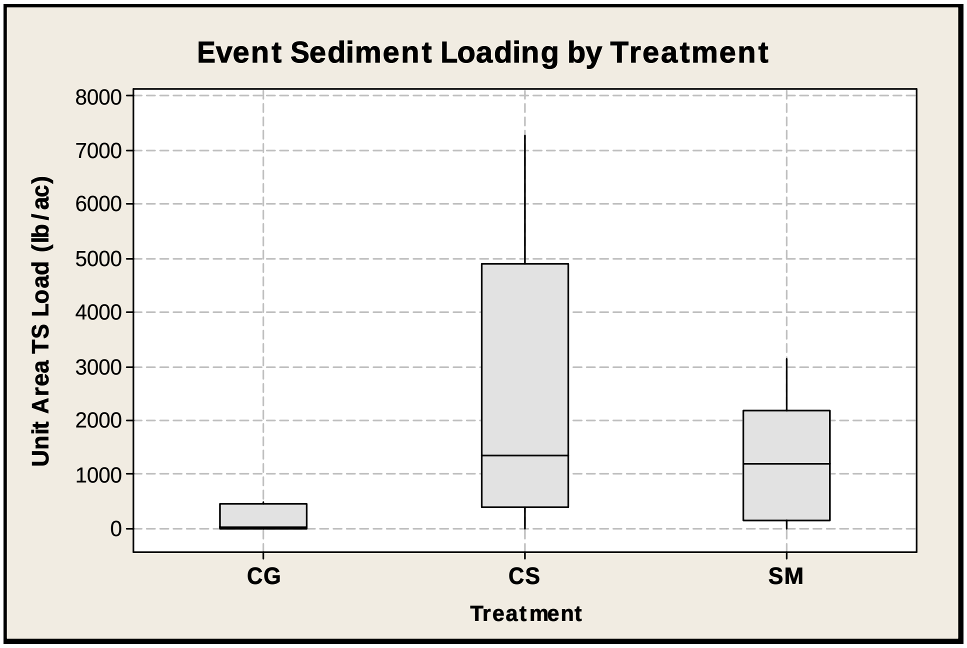

Figure 2. Unit area sediment load by tillage type.

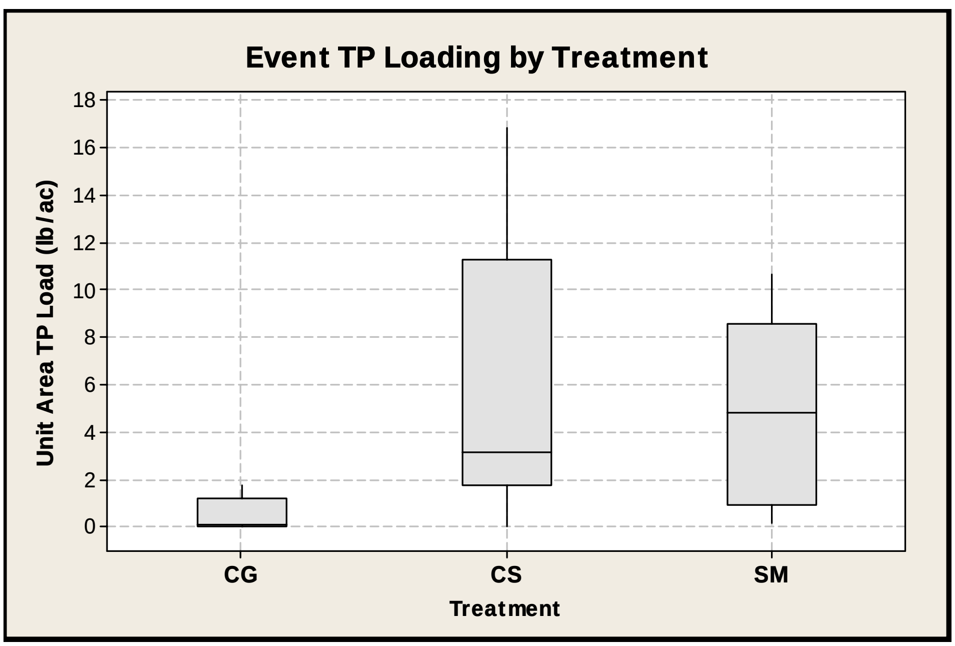

Figure 3. Unit area total phosphorus (TP) export by tillage type.

In Figures 2 and 3, the top and bottom of the boxes are the 75th and 25th percentiles, respectively. The horizontal line within each box is the median, while the extents of the vertical lines are the maximum and minimum values for each treatment. Data from the extreme outlier storm events (May 21 and 23) have been omitted to better illustrate the relationship between treatments under more typical conditions.

Sediment Phosphorus Mass and Particle Size

The gravity settling results are summarized by sediment particle size class in Table 4. The data include the TP concentration (mg/kg), the fraction of TP mass by particle size and the cumulative TP mass by particle-size. The TP mass by size fraction did not differ among treatments across the different particle size classes during the FF period nor were there significant differences in P mass among particle size fractions between sites when the FM and FF data were combined ($p < 0.05$). It is interesting to note that the median TP concentration in the < 2 µm particle size range for the FM (2,140 mg/kg) is greater than that of the FF (1,670 mg/kg) period. This is likely the result of the preferential transport of enriched fine particles and OM by the low flow velocities produced by the snowmelt. The highest sediment TP concentration for both the FM and FF periods was found in the smallest (< 2 and 2 to 10 µm) sediment particle size classes. Similar results were obtained by Dong et al. (1983), Grande et al. (2005), and Sharpley (1980). Because of their size, the < 2 and 2 to 10 µm size particles have high specific surface area that favors greater chemical accumulation including P (Dong et al., 1983; Pierzynski et al., 1990).

Table 4. Gravity settling values for percent TS and TP concentration for five sediment particle size classes from the frost melt and frost-free periods.

	Particle Size (µm)				
	<2	2 - 10	10 - 50	50 - 500	> 500
FM Period, (N = 10)					
Median TS (%)	4.10	8.55	30.1	50.9	4.45
Range *	3.00 - 6.08	7.28 - 18.5	23.8 - 34.5	37.4 - 56.3	1.81 - 7.38
Median TP (mg/kg)	2140	1080	498	571	717
Range *	1,800 - 2,490	956 - 1,310	404 - 612	472 - 677	621 - 908
FF Period, (N = 36)					
Median TS (%)	3.00	10.7	23.0	53.4	7.31
Range *	1.89 - 4.17	8.21 - 12.2	19.7 - 30.1	41.6 - 53.4	4.30 - 13.0
Median TP (mg/kg)	1670	1140	483	367	514
Range *	1,550 - 2,080	992 - 1,310	417 - 549	297 - 450	428 - 633
Percent P mass	11	22.4	23.3	35.8	7.6
Cumulative P Mass	11	33	57	93	100

* Range equals the 1st and 3rd quartile values.

The absence of a significant effect on P-mass distribution in different size classes due to differences in management (i.e., corn harvesting practices and/or manure management) suggests that the particle size-P mass relationship may be unique for a given soil type, clay content and mineralogy, when a narrow range in soil OM exists. As shown in Table 4, 57% of the P mass was associated with particles < 50 µm in size. The small (< 50 µm) size particles also have the greatest transport potential. These results suggest that if reside removal is not managed, excessive soil loss could occur, in-turn adversely impact water quality and soil productivity. As discussed in Wilhelm et al. (2004), residue removal rates must be must be carefully managed to minimize water quality impacts and ensure sustainable soil productivity.

Conclusions

The presence of residue was found to significantly reduce soil loss which, in turn, reduced TP export. The transport of particulate-bound P was the principal mechanism for P export from conservation tillage corn fields. The transport potential of sediment particles is directly influenced by particle size and density suggesting that smaller, less dense particles have greater transported potential. These results indicated that 57% of the P mass was associated with particles < 50 µm (clay and silt) size. The increased transport of fine P enriched particles increases the potential for downstream water quality degradation. The demand for bio-based fuel production will likely increase the production of corn and other row crops. The implementation of sound land management practices will, therefore, be essential to minimize water quality degradation and maintain soil health and productivity.

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