THE EFFECT OF TILLAGE AND PHOSPHORUS FERTILIZER PLACEMENT ON PHOSPHORUS RUNOFF FROM SUGAR BEET PRODUCTION SYSTEMS

M.D. Ruark, J.A. Lamb, and G.W. Rehm
University of Minnesota, St. Paul, Minnesota

Abstract

The objective of this study was to determine the differences in the amount of phosphorus (P) in runoff from land under sugar beet production caused by different management practices and phosphorus fertilizer placement. The study was set up as a split plot experimental design, replicated three times. The whole plot treatments were: 1) corn/soybean rotation, with moldboard plow as primary tillage before soybean; 2) corn/soybean rotation, with chisel plow as primary tillage before corn; 3) sugar beet/soybean/corn rotation, with moldboard plow as primary tillage before sugar beet; 4) sugar beet/ soybean/corn rotation, with a DMI chisel plow as primary tillage before sugar beet; 5) sugar beet/soybean/corn rotation, with a DMI chisel plow as primary tillage before sugar beet with a spring cover crop of oats. The split plot treatments were broadcast or subsurface band application of phosphorus fertilizer. A rainfall simulator was used to create runoff events at an intensity of 5.5 cm hr^{-1} on soybean in whole plot treatment 1, on corn in whole plot treatment 2, and on sugar beet in whole plot treatments 3, 4, and 5. Runoff was collected and analyzed for orthophoshate (DP) and total phosphorus (TP). Runoff flow rate and sediment loss were also measured. Analysis of variance findings concluded no significant differences of DP and TP contents and concentrations among tillage/crop rotation or between P fertilizer placement. Regression analysis was conducted to relate which source, transport, or soil factors were influential in P loss. Six regression models were constructed. Phosphorus concentration models were heavily influenced by soil test phosphorus (STP) levels, while P content losses were influenced by transport factors such as runoff or sediment loss.

Introduction

Environmental concerns over phosphorus (P) management have arisen in the past few decades. Many soils in agricultural production areas have elevated levels of soil test phosphorus (STP). Phosphorus can leave cultivated fields in a dissolved form in runoff (dissolved P, DP) or as an adsorbed form on eroded soil particles (particulate P, PP). Phosphorus can then enter surface water systems and cause accelerated eutrophication in streams, rivers, and lakes. Phosphorus in these surface waters can become long-term as well as short-term sources of nutrients for algae and other biota (Sharpley et al., 1992). The term eutrophication refers to the natural aging of freshwater bodies caused by nutrient enrichment. Since P is generally the limiting nutrient for algae and plant growth in these systems, a population explosion of these organisms is the result of excess P in freshwater (Sharpley et al., 1994). When the algae dies, microorganisms in the water decompose the algae. The microorganisms use the oxygen in the water to facilitate this process, which leads to a state of hypoxia, or fish kill (USEPA, 1996). Water use for recreation, industry, and drinking are also impacted by eutrophication. The United States Environmental Protection Agency (USEPA) has identified eutrophication as the main cause of impaired fresh surface water quality (USEPA, 1996).

Substantial research activity has focused on phosphorus runoff. Phosphorus runoff studies have been conducted with cropping systems that range from corn-soybean rotations in Iowa (Laflen and Tabatabai, 1984) to wheat-fallow rotations in Texas (Sharpley, 1995) to sorghum-soybean rotations in Eastern Kansas (Kimmel et al., 2001). There is little, if any, information of how P in runoff is affected by sugar beet production systems and associated management practices needed for profitable production. The small size of the sugar beet seed and the shallow depth of planting cause sugar beet production fields to have little crop residue from the previous crop at planting. This leaves the field more susceptible to soil erosion and subsequent P losses. An understanding of the impact of varying tillage practices and P fertilizer placement on P loss would lead to better P management on sugar beet production fields.

Materials and Methods

The experimental site was located in Chippewa County, Minnesota on a Colvin-Spicer silty clay loam (fine-silty, mixed, superactive, frigid Typic Calciaquoll and fine-silty, mixed, superactive, calcareous, mesic Typic Endoaquoll) complex. The study was conducted during the 2000 and 2001 growing seasons. Runoff samples were collected in the summer of the 2001.

The experiment was set up as a split-plot design replicated three times. The whole plot treatments (13.4 x 15.2 m) were tillage/crop rotation system. The treatments were as follows: (1) corn/soybean rotation, with moldboard plow as primary tillage before soybean; (2) corn/soybean rotation, with chisel plow as primary tillage before corn; (3) sugar beet/soybean/corn rotation, with moldboard plow as primary tillage before sugar beet and chisel plow as primary tillage before soybean and corn; (4) sugar beet/soybean/corn rotation, with a DMI chisel plow as primary tillage before sugar beet and chisel plow as primary tillage before soybean and corn; and (5) sugar beet/soybean/corn rotation, with a DMI chisel plow as primary tillage before sugar beet, chisel plow as primary tillage before soybean and corn, and a spring cover crop of oats planted before sugar beet.

Whole plots were then split into subplots 4.5 x 15.2 m in size. The two split plot treatments were phosphorus application methods of (1) broadcasting application of 20 kg-P ha^{-1} and (2) knife injection of 20 kg-P ha^{-1} placed at a depth of 12.7 cm. Phosphorus fertilizer used was 0-44-0 triple super phosphate. Fertilizer application rates selected were chosen from the University of Minnesota's fertilizer recommendations. Phosphorus fertilizer application was completed in the spring prior to secondary tillage.

A rainfall simulator was used to generate runoff. Rain simulations took place on soybean in whole plot treatment (1), corn in whole plot treatment (2), and sugar beet on whole plot treatments (3), (4), and (5). An average rainfall intensity of 5.5-cm hr^{-1} was applied to each rain simulation plot.

Runoff was collected to determine runoff flow rate and P concentration. Runoff samples were taken over a period of one hour. Samples for orthophosphate and TP analysis were placed on ice and in the dark until they were transported to the lab for analysis. Orthophosphate was analyzed colormetrically on decanted samples using the method outlined by Murphy and Riley (1962). Total P was analyzed by the same method, after aggressive mixing of the sample and its digestion with sulfuric acid and mercuric acid (Olsen and Sommers, 1982). Particulate P was calculated as the difference between TP and DP.

Soil test P was analyzed using the Olsen-P soil test (Frank et al., 1997). The line intersect method (Laflen et al., 1981) was used to determine residue cover. Soil moisture samples were taken immediately before rainfall simulation, dried at 60°C, and reported as g kg-1. A GPS unit by Astech™ was used to determine slope of the landscape.

Results and Discussion

A summary of the means and ranges of DP, PP, and TP concentrations and contents can be found in Table 1. Also included in Table 1 are the means and ranges of soil and landscape characteristics. Analysis of variance (ANOVA) results show no significant differences in DP, PP, or TP content among tillage/crop rotation and between P fertilizer application. The results were similar for DP, PP, and TP concentrations. No practical differences were found. This may be due to the low sloping landscape, which influenced the low runoff flow rates and sediment loss. Also, the residue cover values are inconsistent with what might be expected for different primary tillage systems. By the time of residue measurement, the soil had been tilled with a field cultivator and planting had occurred. This may hinder the influence of primary tillage on P loss.

Regression models were determined to further analyze the data. Correlation analysis was conducted for regression modeling. Correlations between P loss and other factors were considered strong if r was greater than 0.33 or less than –0.33. To avoid the problem of intercorrelation, factors correlated strongly were not included in the same model. Other rules for regression models include that no more than three factors are included in any model and that each regression model must include one source (STP) or transport (runoff or sediment loss) factor).

The regression model for DP concentration only included the Olsen-P soil test at a depth of 0 to 2.5 cm (Figure 1). The regression models for PP and TP concentration include the Olsen-P soil test at a depth of 0 to 2.5 cm and sediment loss (Figure 2, Figure 3). This indicates the importance of the source factor (STP) on P concentration losses. Also, since PP and TP are largely dependent on sediment bound P, sediment loss is a main transport factor in predicting P loss. The regression model for DP content included runoff, soil moisture, and their interaction (Figure 4). The regression models for PP and TP content include both transport factors of runoff and sediment loss (Figure 5, Figure 6). This indicates that content loss of P (kg ha^{-1}) is more influenced by transport factors than source factors. Statistics relating to regression models are in Table 2.

Conclusions

This study concluded no differences in P loss from any management practices related to sugar beet production. It was also concluded that there were no differences in P loss between sugar beet production systems and a corn/soybean rotation system. This study also determined that P loss was not influenced by any crop rotation system. Phosphorus losses were also not influenced by any primary tillage (including a spring cover crop of oats) system. It was determined that P losses were not influenced by the P fertilizer application method.

Runoff flow rate or sediment loss was also not affected by any management systems. This is most likely a result of the typically low sloping lands that are used in sugar beet production. These results indicate indicated that in order to reduce P losses from sugar beet production fields, any changes to primary tillage or P fertilizer application detailed in this study may not be effective. Other means of mitigating P loss will be necessary.

Further analysis was conducted in this study to determine other aspects or factors of P loss. It was determined that the Olsen-P soil test was a good indicator of DP concentration in runoff. The Olsen-P soil test, together with sediment loss and their interaction term, provided a good model for PP and TP concentration in runoff. For content loss, runoff flow rate and sediment loss were good indicators.

These regression analysis results indicate that reducing the soil test P levels in the soil would provide a way to reduce P concentrations in runoff. It also indicates that over a landscape reducing transport factors of P loss (runoff and sediment) can still be effective on low sloping fields. Further reducing tillage, addition of buffer strips next to waterways, and a denser cover crop may all be possible solutions to reducing P loss.

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Table 1. Means and ranges of P loss, runoff, sediment, and soil and landscape charactersitics.

			range	
		mean	low	high
DP content	kg-P ha-1	0.18	0.08	0.37
PP content	kg-P ha-1	0.82	0.24	1.96
TP content	kg-P ha-1	1.01	0.32	2.2
DP concentration	mg-P L-1	0.96	0.46	1.8
PP concentration	mg-P L-1	4.32	1.10	10.72
TP concentration	mg-P L-1	5.28	1.89	12.52
Runoff	ml s-1	6.38	2.53	18.83
sediment loss	Mg ha-1	0.69	0.11	3.84
residue cover	%	8.5	3	12.3
Olsen-P soil test	mg-P L-1	40	9	109
soil moisture	g kg-1	355	305	403
slope	%	1.87	0.63	2.82

Table 2. Statistics relating to the regression models of P loss.

Variable	Model	R^2	term	p>F
DP concentration	y = 0.59 + 0.0094 (OP1)[1]	0.62	OP1	<0.0001
PP concentration	y = 2.52 + 0.0082(OP1)	0.65	OP1	0.534
	+ 0.51 (SED)[2]		SED	0.255
	+ 0.050 (OP1*SED)		OP1*SED	0.005
TP concentration	y = 3.08 + 0.017 (OP1)	0.67	OP1	0.254
	+ 0.54 (SED)		SED	0.267
	+ 0.052 (OP1*SED)		OP1*SED	0.007
DP content	y = -0.45 - 0.05 (RO)[3]	0.74	RO	0.169
	+ 0.00032 (SM)[4]		SM	0.641
	+ 0.00019 (RO*SM)		RO*SM	0.079
PP content	y = 0.31 + 0.37 (RO)	0.69	RO	0.035
	+ 0.40 (SED)		SED	<0.0001
TP content	y = 0.40 + 0.05 (RO)	0.67	RO	0.016
	+ 0.42 (SED)		SED	0.0001

[1] Olsen P soil test at depth 0 to 2.5 cm

[2] Sediment loss

[3] Runoff flow rate

[4] Soil moisture

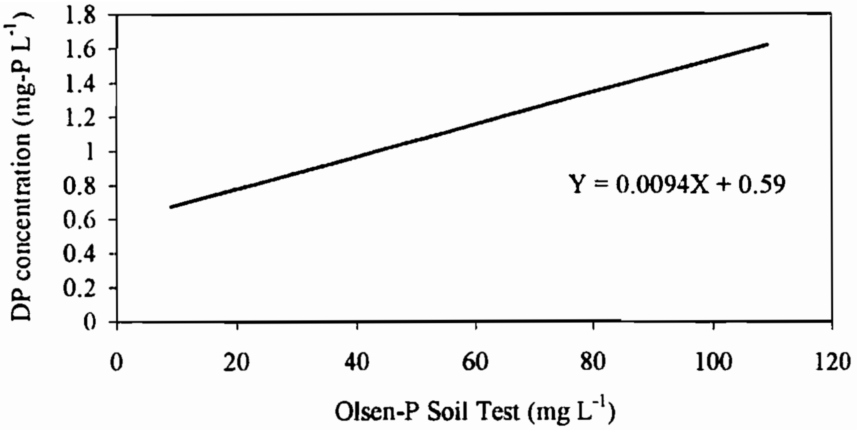

Figure 1. Regression model for DP concentration.

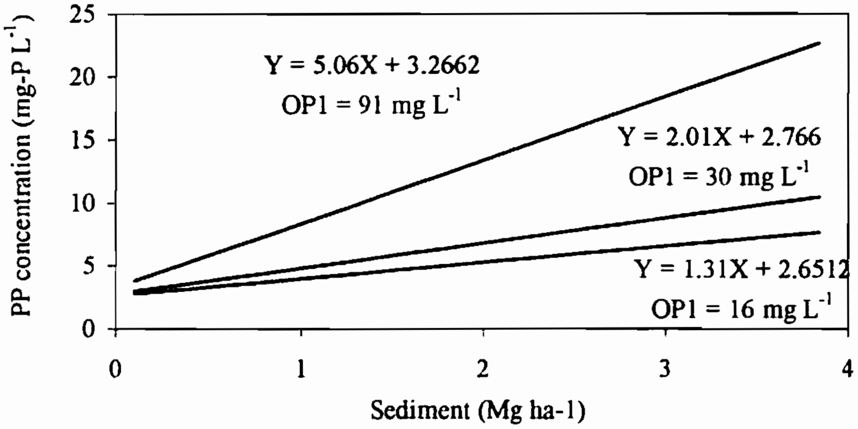

Figure 2. Regression model for PP concentration at three levels of Olsen-P soil test (OP1).

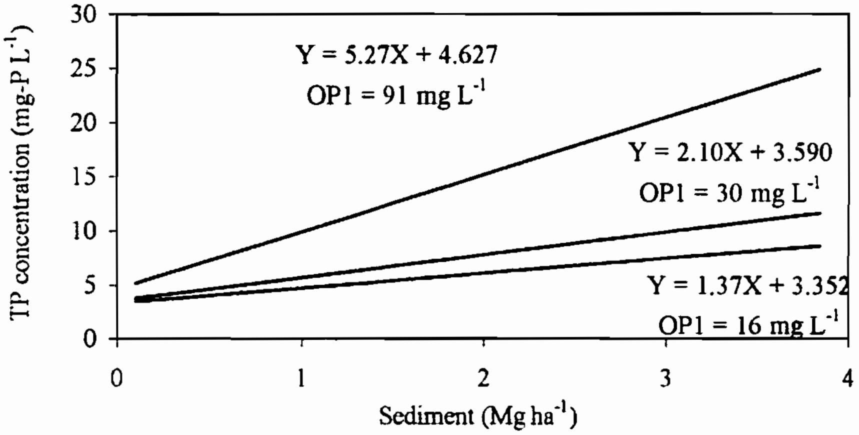

Figure 3. Regression model for TP concentration at three levels of Olsen-P soil test (OP1).

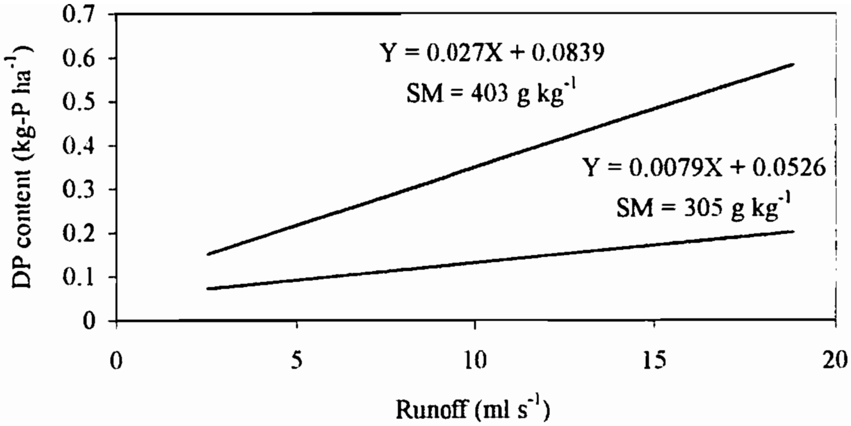

Figure 4. Regression model for DP content at two levels of soil moisture (SM).

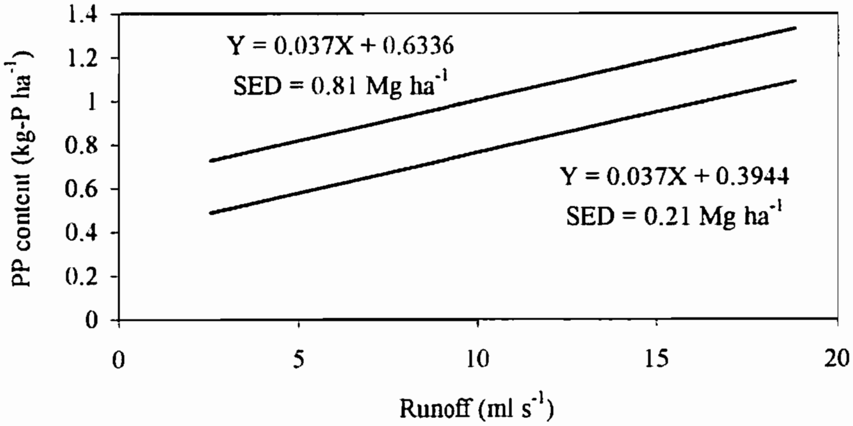

Figure 5. Regression model for PP content at two levels of sediment loss (SED).

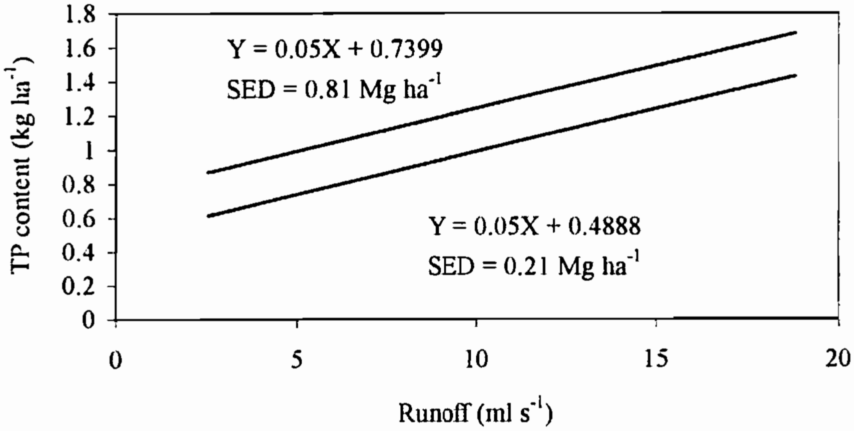

Figure 6. Regression model for TP content at two levels of sediment loss (SED).

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Program Chair:
Larry Bundy
University of Wisconsin
Madison, WI 53706
(608) 263-2889

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772 – 22nd Avenue South
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(605) 692-6280
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