MANAGEMENT PRACTICE EFFECTS ON PHOSPHORUS LOSSES IN RUNOFF

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Introduction

Phosphorus (P) loss in runoff from cropland is an environmental concern because this P often promotes weed and algae growth in lakes and streams. When these weeds and algae die and decompose, dissolved oxygen levels in lakes and streams are depleted, which can lead to odors, fish kills, and a general degradation of the aesthetic and recreational value of the environment. Concerns about P losses from agricultural land are increasing because P soil test values which reflect the amounts of plant available P in soils, have increased substantially over the past 25 years. Average soil test P levels in Wisconsin exceed the levels needed for optimum production of most crops. For most crops and soils in Wisconsin, P soil tests are considered to be excessively high if they exceed 30-35 ppm Bray-1 P. These above-optimum soil P levels have accumulated because long-term P additions in fertilizer and/or manure have exceeded P removals in the harvested portion of crops (Bundy, 1998).

Recently, NRCS has adopted a revised national policy for nutrient management that emphasizes consideration of both phosphorus and nitrogen application rates in the development of nutrient management plans (NRCS, 1999). A phosphorus standard is required where manure or other organic wastes are applied under various field specific conditions. Usually these conditions include those that increase the probability of P losses in runoff such as excessively high soil P levels, close proximity to water bodies, or slope or erosion risks that make runoff likely. While specific critical values for use of a P standard are to be defined by individual states, several approaches for identifying acceptable P application rates are given in the NRCS policy. These include use of a P index to assess the risk of P loss in runoff on a site specific basis (Lemunyon and Gilbert, 1993, Gburek et al., 1998), soil specific phosphorus threshold levels indicating the soil P level at which unacceptable P losses are probable, and soil test P levels for the field (NRCS, 1999). Of these options, the P index approach appears to provide the best method of assessing the risk of P loss on a site specific basis and allowing development of practical nutrient management plans to minimize these losses.

Soil P levels on many Wisconsin livestock farms are higher than needed for optimum crop yields, yet continued land application of manure is the only practical management option. Required use of a P standard for nutrient management could create manure management problems for these farms in terms of shortages of suitable land for manure application, and because manure could not be used to provide all of the nitrogen needs of the crops to be grown where a P strategy is necessary.

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Management effects on P losses in runoff from cropland have been noted for several practices such as soil test P (Sharpley et al., 1977; 1978; 1994; Daniel et al., 1994; Pote et al., 1996), manure or fertilizer applications, and tillage. Much of the work relating soil P and manure effects on P concentrations in runoff has been done in pasture systems, and little information is available about the effects of these practices in tilled production systems. Since specific critical values for use of a P standard are needed in Wisconsin, and the influence of various management options on P losses have not been determined, research is needed to determine the relationships between management practices and P losses in runoff.

Materials and Methods

During 1998 and 1999, the influence of several management practices on P concentrations and loads in runoff were determined using simulated rainfall in field experiments. The management practices evaluated were soil test P levels, tillage, manure and biosolids applications, manure separation, and dairy diet P concentration effects on dissolved reactive P (soluble P) in runoff and soluble P load in runoff in corn production systems.

Experimental Sites and Procedures

Soil test P in no-till corn – This study was conducted at the University of Wisconsin Agricultural Research Station at Arlington on a Plano silt loam soil with an existing range of soil phosphorus (P) levels. Soil test P levels were established by periodic variable inorganic fertilizer P applications since the early 1960's. The agricultural interpretation of 0-6 inch soil test P levels ranged from very low to excessively high (3, 6, 33, and 51 ppm, Bray P1) (Kelling et al., 1998). Four plots (30 ft wide x 60 ft long) in the long-term study with a range of soil test P levels were identified and each plot was subdivided into four quadrants (replicates) for simulated rainfall application and runoff collection. The site was in no-till corn during 1997 and 1998, and simulated rainfall was applied in July 1998.

Manure and tillage combinations – The effects of tillage (no-till, shallow tillage, and chisel plow) and manure applied as unfractionated solid dairy manure or as the fiber fraction of dairy manure separated using a Vincent KP-10 screwpress on P losses in runoff under simulated rainfall were determined in field studies conducted during 1998 and 1999 at the Agricultural Research Station at Arlington, Wisconsin. Manure treatments consisted of a control (no manure), and whole and fiber fraction manure applied at a target rate of 60 lb P/acre. This required application rates of 32.5 tons/acre of the solid dairy manure and 55.5 tons/acre of the fiber manure fraction. A randomized complete block design with a split-plot treatment arrangement and four replications was used. In each year, experiments were installed on separate sites with corn residue from the previous year's corn crop remaining on the surface. Manure treatments were applied in spring before corn planting, and the tillage treatments were installed immediately after the manure applications. Following corn planting, plot frames for simulated rainfall application and runoff collection were installed in a representative area of each plot. Rainfall simulations were performed in the spring of both years and in fall of 1999.

Manure and biosolids application history - The study site was established 1994 at the University of Wisconsin Agricultural Research Station at Madison on a Plano silt loam soil (fine-silty, mixed, mesic Typic Argiudoll) (Peterson et al., 1998). A range of soil P levels were established during this period through various applications of biosolids and dairy manure. The site was planted to corn annually and harvested as grain with stover returned to the field. Starter fertilizer was applied 2 inches below and 2 inches laterally to the seed at planting at a rate of 100 lb/acre of 6-24-24 ($N-P_2O_5-K_2O$). The field was chisel plowed in the fall, spring disked prior to surface-treatment application, and rototilled prior to planting. In October 1998, four treatments were chosen to represent a range of biosolids and manure application histories and soil test P levels for use in simulated rainfall studies to determine sediment and P losses in runoff. Treatments included: a control (no N or P addition except starter fertilizer); biosolids applied at 93,500 L ha^{-1} (10,000 gal/a) in 1994 and 1997 (2-Y biosolids); biosolids applied at 93,500 L ha^{-1} (10,000 gal/a) annually from 1994 through 1998 (annual biosolids); and dairy manure applied at 89.6 Mg ha^{-1} (40 tons/a) annually from 1994 through 1998 (annual manure). Average dry matter contents of biosolids and dairy manure were 6 and 20%, respectively. Following corn grain harvest and prior to simulated rainfall application, corn stover was chopped and plot frames were installed in each treatment (4 treatments x 4 replicates = 16 plots).

Dairy diet P concentrations - Dairy manures with differing P concentrations were hand applied to plots 8 ft wide and 8 ft long in spring 1999, on a Plano silt loam soil at the University of Wisconsin Arlington Research Station. The manures were obtained from a dairy cow feeding study with ration P concentrations of 0.32 and 0.48% P (Satter and Wu, 1999). These dietary P levels produced manures with P concentrations of 0.48 and 1.28% P, respectively. These preliminary manure P concentrations were used to calculate manure application rates in the field experiments. Manure samples from each plot were subsequently analyzed to determine the actual P additions. Manure applications were made at a site that was not tilled in 1999 and had corn residue from the previous year's corn crop remaining on the surface. Manure applications were not incorporated by tillage. Plot frames (3 ft x 3 ft) for runoff collection from simulated rainfall were installed in a representative area of each plot. Simulated rain applications were performed in Spring, 1999, immediately following manure application and again on the same plots in Fall, 1999. Corn was planted on the manure-treated plots during the 1999 growing season.

A randomized complete block statistical design with four replications was used in the experiment. Manure treatments were: control (no manure); low P manure (0.48% P) applied at 25 wet tons/acre to provide 36 lb P/acre; high P manure (1.28% P) applied at 25 wet tons/acre to provide 96 lb P/acre; and high P manure (1.28% P) applied at 9.4 wet tons/acre to provide the same P addition as the 25 tons/acre of the low P manure (36 lb P/acre).

Soil Sampling and P Tests

Soil test levels in each plot were obtained by analysis of soil samples collected by compositing ten soil cores from the area immediately adjacent to the plot frames used for simulated rainfall application and runoff collection. Soil samples were collected from the 0-1 and 0-6 inch soil depths to provide samples representing the reactive zone for the soil-simulated rain interface and the traditional sampling depth for agronomic soil testing.

Soil tests performed on the soil samples included Bray P-1 (Bray and Kurtz, 1945), Mehlich III (Mehlich, 1984), distilled water extraction (Pote et al., 1996), and the iron oxide paper strip method (Sharpley, 1993). Phosphorus in the extracts obtained by each method was determined colorimetrically by the molybdenum-blue method (Murphy and Riley, 1962). The Bray and Mehlich methods are widely used to evaluate soil P levels for crop production, while the distilled water extraction and iron oxide paper strip methods have potential for predicting the environmental risk associated with various soil P levels. The P saturation of each soil sample was determined as described by Pote et al. (1996). In this procedure, oxalate-extractable P is divided by oxalate-extractable iron and aluminum and expressed as a percentage. This value reflects the percentage of the soil's P sorption capacity that is occupied by P. Research in the Netherlands suggests that P concentration in runoff may be related to P saturation of the soil, and has identified a P saturation of 25% as a threshold value to avoid excessive P losses in runoff (Sharpley et al., 1996). For the purposes of this paper, only the Bray P-1 test results are presented.

Soil samples for antecedent moisture determinations were collected from 0-1 and 1-7 cm soil depths immediately before simulated rainfall application. These samples were obtained adjacent to, but outside the simulated rain test areas in each plot. Soil moisture was determined by weighing the samples before and after drying at 105°C. Surface residue cover was measured inside each plot frame before simulated rainfall using the pin drop method.

Simulated Rainfall Method

Simulated rainfall was applied using techniques similar to those described by Zemenchik et al. (1996). A portable rainfall simulator equipped with a Veejet 80150 nozzle (Spraying Systems, Wheaton, IL) located 10 ft above a 9 sq. ft test area was used to deliver rainfall at an intensity of 2.83 inches per hour (75 mm/hr). This rainfall intensity has an approximate recurrence interval of about 45 years. The test area for each plot was surrounded by a square steel frame 3 ft wide by 1 ft high. The frame was driven into the soil to a 6-inch depth before simulated rain was applied. Runoff collected at the down slope side of the plot frame was continuously removed by vacuum and placed in a holding tank. Runoff was collected for a 30-minute period following runoff initiation, and the total volume of runoff from each plot was recorded. In some experiments a separate runoff sample was collected after 60 minutes of simulated rainfall application. After mixing to resuspend sediment, a subsample of the runoff was dried at 105°C and weighed to determine sediment concentration in the runoff.

A second subsample of the runoff from each plot was filtered (0.45-um pore diameter) in the field, and soluble P in the filtrate was determined by the molybdenum-blue method (Murphy and Riley, 1962). An additional sample of the mixed runoff was refrigerated until analyzed for bioavailable P using the iron oxide paper strip method (Sharpley, 1993).

Statistical Analyses

An analysis of variance for the appropriate statistical design was used to identify treatment (management practice) effects on P loss in runoff (SAS Institute, Inc, 1992). Regression techniques were used to determine the relationships between soil test P values by each method and the soluble and bioavailable P concentrations found in the runoff from the corresponding field plots.

Results and Discussion

Soil Test P in No-till Corn

The effects of Bray P1 soil test level on dissolved (soluble) P concentration and load (total amount of soluble P lost in the runoff event) in runoff from no-till corn following simulated rainfall are summarized in Table 1. Soil test values ranged from 8 to 62 ppm in the 0-1 inch soil depth and from 3 to 51 ppm in the 0-6 inch soil depth. Both P concentration and load in runoff increased with increasing soil test P values. Previous studies (Sharpley et al., 1977; 1978; 1994; Daniel et al., 1994, Pote et al., 1996) have consistently shown increased P concentration in runoff as soil P levels were increased, but P load in runoff was not always well related to soil test P values (Pote et al., 1996, Sharpley et al., 1996). Soluble P concentrations in runoff ranged from 0.02 ppm at the lowest soil P level to 0.12 to 0.15 ppm at the highest soil P levels. Thus, P concentrations in runoff increased by about seven times due to soil test P increases. Soluble P load values ranged from 3 to 17 g/ha (1.2 to 7 grams/acre).

The relationship between soil test P value (Bray P1) at three sampling depths (0-1, 0-2, and 0-6 inches) and dissolved reactive P (DRP) and bioavailable P (BAP) concentrations in runoff at two sampling times (30 minutes after runoff initiation and following 60 minutes of simulated rainfall) is shown in Table 2. These results show a good relationship between soil test P (STP) and P concentration in runoff at all soil depths. This is in contrast to other studies which showed shallow soil sampling depths are better related to P concentrations in runoff due to greater interaction between rainfall and soil nearer the soil surface. The good relationship between STP and P in runoff at this site may be due to the length of time since P fertilizer was applied ($\geq$ 3 years) and that the fertilizer was repeatedly and uniformly incorporated into the soil by tillage following application. Therefore, management histories and practices are likely to influence the distribution of soil P, subsequently affecting the relationship between STP and P in runoff.

Manure and Tillage Combinations

Tillage and manure treatment effects on soluble P concentrations and loads in runoff in corn production systems are illustrated by the data in Figs. 1 and 2 obtained in spring 1999. Although some variation between years and times of simulated rainfall application was observed, the findings reported in Figs. 1 and 2 are representative. Soil test P (Bray P1) at the site was in the optimum range for corn production (17 ppm in the 0-6 inch depth and 18 ppm in the 0-1 inch depth). Data in Fig. 1 show that manure additions greatly increased soluble P concentrations in runoff in the no-till and shallow tillage systems, but had little influence on runoff P concentrations in chisel plow tillage where the manure was more thoroughly incorporated. This is consistent with results from earlier studies (Mueller et al., 1984) of the effects of tillage on manure P losses. In the no-till system, runoff P concentrations in the control (no manure) were similar to those reported earlier for no-till corn (Table 1), but the concentrations were about 10 times higher where manure was applied. Shallow tillage reduced runoff P concentrations relative to no-till, and further reductions were observed with chisel plowing. Runoff P concentrations were higher were the fiber fraction manure was applied compared with the unfractionated solid dairy manure, particularly in the no-till and shallow tillage systems.

Soluble P loads in runoff were highest in the no-till treatments and generally decreased with increasing intensity of tillage. Manure additions increased P loads in runoff in the no-till and shallow tillage systems. Phosphorus loads in the manured no-till treatments were substantially lower than in the unmanured no-till treatments with high soil P levels reported in Table 1. This is likely due to the role of increased surface residue from the relatively high manure application rates in promoting infiltration and reducing runoff volumes compared to unmanured treatments. For example, runoff volumes in the manured no-till treatments averaged less than 1 mm compared with 9 mm in the control and about 15 mm in the no-till study reported in Table 1.

Manure and Biosolids Application History

The effects of various manure and biosolids application histories on soil test P and soluble P losses in runoff under simulated rainfall are summarized in Table 3. The initial soil test value at the site is in the optimum range for corn production on this soil. As expected, biosolids additions in two years (1994 and 1997) substantially increased the soil test P level. Annual applications (1994 through 1998, five additions) of biosolids and solid dairy manure caused even greater increases in the P soil test value. Substantial stratification of P is indicated by the higher P test values in the 0-1 inch soil depth compared to the 0-6 inch depth. Soil test P in the 0-1 inch depth was a much better predictor of P concentrations in runoff than the 0-6 inch P test results. This is in contrast to results in Table 2 showing similar predictive value for both depths, and this difference is likely due to the absence of repeated applications of organic P sources in the Arlington no-till corn study. Long-term annual applications of manure or biosolids (annually since 1994) substantially increased soluble P in runoff relative to the control and a treatment receiving only two biosolids applications. The annual manure treatment had the highest DRP value, but the annual biosolid treatment had the highest P load. The lower P load in the annual manure treatment is probably due to accumulation of organic residues on the surface of this treatment from the bedding components of the manure which substantially reduced runoff volume (Table 3).

Dairy Diet P Concentrations

The influence of dairy diet P concentrations on P losses in runoff when the manures from these diets are land-applied is summarized in Table 4. All of the manure applications were surface applied without incorporation, and all treatments increased soluble P concentrations in runoff relative to the control. When manures from lactating cows receiving 0.32 and 0.48 % P in their rations were land applied at the same rates (25 wet tons/acre), the soluble P concentration and load in runoff was about ten times higher for the high P diet. When these manures were applied at equivalent rates of P, the high P manure had runoff a concentration and load about four to five times that of the low P manure. The higher soluble P from the high P manure at the same P application rate suggests that the forms of P in the manures are different. The high P manure probably contains more P in a water soluble form consistent with inorganic P added to feeds being passed through the animal, while the low P diet probably contains mostly organic P. These results indicate that high or excessive P in dairy diets is likely to greatly increase the risk of P losses in runoff when the manures are land applied.

Interpretation of P Concentrations in Runoff

Results from the studies described above indicate that management practices have a major influence on P concentrations and loads in runoff. The implications from these studies for agricultural management and environmental protection decisions depend on the interpretation of the data in terms of environmental risk at specific runoff P levels. The practicality of achieving specific runoff P concentrations or loads with available agricultural management options must also be considered. Wood (1998) has summarized critical P concentration values in terms of water quality impacts. These range from 0.01 ppm soluble P for lakes to 1.0 ppm P for water discharged by municipal sewage treatment facilities and initially proposed as an allowable limit for agricultural runoff (USEPA, 1986). Results reported in this paper indicate that unfertilized control plots in corn production systems with agriculturally optimum soil P test levels typically have runoff soluble P concentrations greater than 0.01 ppm, therefore none of the systems studied could meet a 0.01 ppm P criteria. On the other hand, most of the systems studied had runoff soluble P concentrations less than 1.0 ppm. Goals for acceptable P concentrations in runoff are needed so that management practices can be developed to meet these criteria.

Summary

Studies of management practice effects on P losses in runoff from corn production systems support earlier studies showing that runoff P concentrations increase with increasing soil P levels. In no-till corn without organic P additions, soil test P in the 0-1 or 0-6 inch soil depths was a good predictor of runoff P concentrations. Combinations of tillage and manure treatments applied before corn planting showed that manure additions increased soluble P concentration in runoff relative to the control, and this increase was greatest in no-till where the manure was not incorporated into the soil. Treatment effects on P load were less consistent, but the highest loads usually occurred in no-till. These results support the idea that incorporating or injecting manure reduces the risk of P loss in runoff. Long-term annual applications of manure or biosolids (annually from 1994 through 1998) substantially increased soluble P in runoff relative to the control and a treatment receiving only two applications. The annual manure treatment had the highest soluble P value, but the annual biosolid treatment had the highest P load. Manures from a dairy feeding study with dietary P levels ranging from 0.32 to 0.48% P were land-applied in a no-till corn system and subjected to simulated rainfall. At an equivalent manure application rate of 25 wet tons/acre, soluble P in runoff was about 10 times higher with the high P manure, and at equivalent P rates of 36 lb P/acre, soluble P was about four times higher than with the manure from the low P diet. These results emphasize the need to avoid excess P supplementation in dairy diets. Overall, the work reported in this paper shows that management practices have a dramatic effect on P losses from corn productions systems, and suggests that management practices have a greater influence on P losses than differences between soils.

References

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available form of phosphorus in soils. Soil Sci. 59:39-45.

Bundy, L.G. 1998. A phosphorus budget for Wisconsin cropland. WDNR &WDATCP Report. 20 p. Dept. of Soil Science, Univ. of Wisconsin, Madison, WI.

Daniel, T.C., A.N. Sharpley, D.R. Edwards, R. Wedepohl, and J.L. Lemunyon. 1994. Minimizing surface water eutrophication from agriculture by phosphorus management. J. Soil Water Conserv. Suppl. 49(2):30-38.

Gburek, W.J., A.N. Sharpley, and G.J. Folmar. 1998. Modifying the P index to account for transport pathways. Report to the SERA Transport Workgroup. USDA-ARS, University Park, PA.

Kelling, K.A., L.G. Bundy, S.M. Combs, and J.B. Peters. 1998. Soil test commendations for field, vegetable and fruit crops. Univ. of Wisconsin Ext. Publ. A2809, Madison.

Lemunyon, J.L., and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. J. Prod. Agric. 6:483-486.

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

Mueller, D.H., R.C. Wendt, and T.C. Daniel. 1984. Phosphorus losses as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48:901-905.

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

NRCS. 1999. General Manual, 190-GM, Issue 9, Part 402-Nutrient Management. April, 1999.

Peterson, A.E., R. P. Wolkowski, L.G. Bundy, T. H. Wright, and D.S. Taylor. 1998. Effect of land application of biosolids, dairy manure, and fertilizer on nutrient movement in soils and crops. Agron. Abstr. p. 29.

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.

SAS Institute, Inc. 1992. SAS/STAT user's guide. Release 6.03/4th ed. SAS Inst., Cary, NC.

Satter, L.D. and Z. Wu. 1999. Reducing manure phosphorus by dairy diet manipulation. Proc. Wis. Fert. Aglime and Pest Mgmt. Conf. 38:183-192.

Sharpley, A.N. 1993. An innovative approach to estimate bioavailable phosphorus in agricultural runoff using iron oxide-impregnated paper. J. Environ. Qual. 22:597-601.

Sharpley, A.N., R.W. Tillman, and J.K. Syers. 1977. Use of laboratory extraction data to predict losses of dissolved inorganic phosphate in surface runoff and tile drainage. J. Environ. Qual. 6(1):33-36.

Sharpley, A.N., R.W. Tillman, and J.K. Syers. 1978. An improved soil sampling procedure for the prediction of dissolved inorganic phosphate concentrations in surface runoff from pasture. J. Environ. Qual. 7:455-456.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, K.R. Reddy. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. J. Environ. Qual. 23:437-451.

Sharpley, A., T.C. Daniel, J.T. Sims, D.H. Pote. 1996. Determining environmentally sound soil phosphorus levels. J. Soil Water Conserv. 51:160-166.

USEPA. 1986. Quality criteria for water. Office of Water Regulation and Standards. EPA-440/5-86-001. May, 1986.

Wood, C.W. 1998. Agricultural phosphorus and water quality: An overview. p. 5-12. *In* J.T. Sims (ed.), Soil testing for phosphorus: Environmental uses and implications. Bull. No. 389, a publication of SERA-IEG 17. Univ. of Delaware.

Zemenchik, R.A., N.C. Wollenhaupt, K.A. Albrecht, and A.H. Bosworth. 1996. Runoff, erosion, and forage production from established alfalfa and smooth bromegrass. Agron. J. 88:461-466.

Table 1. Soil test P effects on runoff volume, dissolved reactive phosphorus (DRP) concentration, and DRP load in runoff from no-till corn following simulated rainfall, Arlington , WI, 1998.

		Soil depth (in)		Runoff @ 30 minutes		
Soil test P level	n	0-1	0-6	Volume	DRP	DRP load
		Bray P1, ppm		mm	ppm	g/ha
Low	4	8	3	13	0.02	3
Medium	4	10	6	17	0.02	4
High	4	39	33	12	0.15	17
Excessively High	4	62	51	14	0.12	15
Total (CV, %)	16			(21)	(26)	(17)

Table 2. Relationship between Bray P1 extractable soil P at three sampling depths and dissolved reactive P (DRP) and biologically available P (BAP) concentration in runoff 30 minutes after runoff initiation and following 60 minutes of simulated rainfall, Arlington, July, 1998.

	DRP		BAP	
Soil depth, in	@ 30	@ 60	@ 30	@ 60
	r^2			
0 – 1	0.70	0.66	0.61	0.70
0 – 2	0.75	0.72	0.67	0.75
0 - 6	0.73	0.70	0.66	0.74

Number of observations = 4.

Table 3. Manure and biosolids application history effects on runoff volume, dissolved reactive phosphorus (DRP) concentration, and DRP load in runoff following simulated rainfall, Madison, WI, 1998.

Treatment	n	Soil depth (in) 0-1	Soil depth (in) 0-6	Runoff @ 30 minutes Volume	Runoff @ 30 minutes DRP	Runoff @ 30 minutes DRP load
		Bray P1, ppm		mm	ppm	g/ha
None	4	18	15	29	0.02	4
2-Yr Biosolids	4	90	63	28	0.10	27
Annual Biosolids	4	169	94	24	0.27	64
Annual Manure	4	177	85	6	0.53	29
Total (CV, %)	16			(10)	(46)	(39)

Table 4. Dairy diet P concentration effects on manure P concentrations and on runoff volume, dissolved reactive phosphorus (DRP) concentration, and DRP load in runoff under simulated rainfall following land application of manure, Arlington, WI, 1999.

Diet / Manure Treatment	n	Soil depth (in) 0-1	Soil depth (in) 0-6	Runoff @ 30 minutes Volume	Runoff @ 30 minutes DRP	Runoff @ 30 minutes DRP load
		Bray P1, ppm		mm	ppm	g/ha
No Manure	4	16	11	3	0.06	2
Low P, 25t/a (36 lb P/a)	4			2	0.27	7
High P, 25 t/a (96 lb P/a)	4			3	2.87	80
High P, 9.4 t/a (36 lb P/a)	4			2	1.20	28
Total (CV, %)	16			(55)	(29)	(69)

Fig. 1. Tillage and manure treatment effects on dissolved reactive phosphorus (DRP) concentrations in runoff. Arlington, WI, 1999

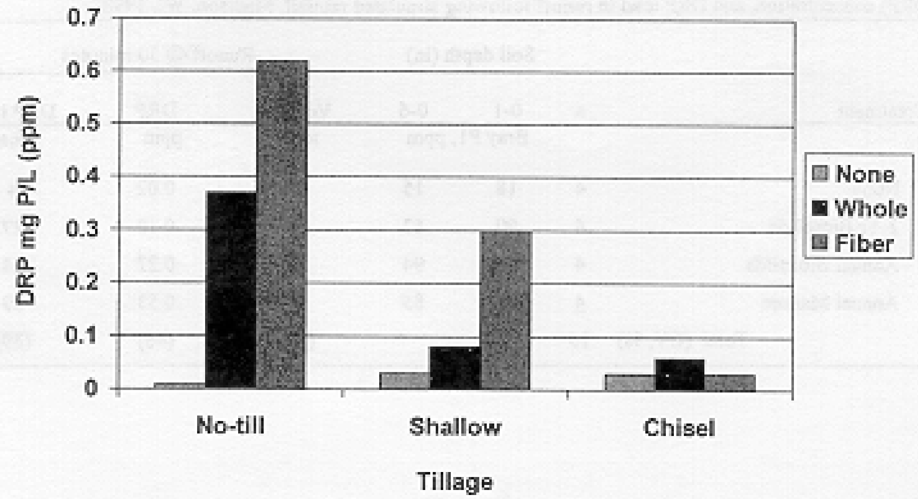

Fig. 2. Tillage and manure treatment effects on phosphorus load in runoff. Arlington, WI, 1999