Phosphorus Losses as Affected by Tillage and Manure Application[1]

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ABSTRACT

There is a lack of data on conservation tillage under field conditions characteristic of a dairy operation. Thus, simulated rainfall was used to compare total P (TP), algal-available P (AAP), and dissolved molybdate-reactive P (DMRP) losses from the conventional, chisel, and no-till systems for corn both with and without surface-applied manure prior to tillage. Rainfall was applied at several times during the growing season of 1978 and 1979. A portion of the previous year's residue was removed in 1978 and all the residue was left in 1979. Concentrations and losses of TP and AAP among unmanured tillage treatments were similar to trends observed for sediment concentrations and losses. In 1978, the chisel and no-till systems were ineffective in reducing TP and AAP losses relative to the conventional system. In contrast in 1979, lower TP and AAP losses occurred from unmanured chisel and no-till sites relative to unmanured conventional sites. In both years of the experiment, surface spread manure increased DMRP concentrations where the manure was not completely incorporated by tillage. In contrast, little difference was observed in DMRP concentrations among unmanured treatments. Manure also increased AAP concentrations for no-till but had only a slight effect and no effect for the chisel and conventional systems, respectively. AAP concentrations from manured sites followed the order no-till > conventional = chisel. Differences in runoff volumes among treatments influenced P losses. Runoff losses were relatively high for no-till, particularly after planting, and losses of DMRP and AAP were very high where manure was surface applied. Often, runoff was reduced for the chisel system relative to other tillage systems, and consequently these reductions increased the effectiveness of this system in reducing P losses.

Additional Index Words: **conservation tillage, no-till, chisel, best management practices, nonpoint pollution, water quality, rainfall simulation.**

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NUTRIENTS in runoff from agricultural lands can contribute to overfertilization of receiving waters (Loehr, 1974). Of the elements known to influence algal growth, there is general agreement that phosphorus (P) is the key nutrient in limiting eutrophication in the Great Lakes Region (Wetzel, 1975; Schindler, 1977). Thus, reducing the amount of available and potentially available P in runoff is a logical means of reducing the impact of agriculture on rates of eutrophication.

The majority of P in agricultural runoff is normally attached to sediment. Because of this, erosion control practices show promise for reducing total P (TP) in runoff and, presumably, TP inputs to surface waters. Normally, however, not all of the TP in runoff is equally available to aquatic plants. Soluble inorganic P is considered to be the most readily available P form (Wetzel, 1975). A portion of the sediment-bound P may also become available by desorbing from sediment as soluble levels are depleted (Sonzogni et al., 1982). Most runoff studies have emphasized soluble P and/or TP as indicators of the pollution potential of runoff (Klausner et al., 1974; Olness et al., 1975). Chemical extractants developed to test P availability in soils have also been applied to sediments (Burwell et al., 1975; Barisas et al., 1978). However, a lack of calibration data for aquatic plants make the results of these tests uncertain. Recently, a routine method has been developed for estimating the relative availability of sediment-bound P forms (Huettl et al., 1979). Use of such a method should allow for a more adequate assessment of the pollution potential of surface runoff and, thus, improve the evaluation of management alternatives for reducing the amount of pollutants in runoff from agricultural land.

Recently, conservation tillage (CT) methods have received considerable attention as management alternatives for reducing pollutant loads in agricultural runoff. Many of these practices have been shown to reduce erosion and, as a result, TP losses (Romkens et al., 1973; Siemens and Oschwald, 1976). However, studies have also shown that soluble P concentrations and losses may be greater with CT (Romkens et al., 1973; Barisas et al., 1978; McDowell and McGregor, 1980). These researchers concluded that higher concentrations of soluble P were attributable to a lack of incorporation of fertilizer P and to a release of P from unincorporated crop residues. Research by Timmons et al. (1973) supports the contention that unincorporated fertilizer P and crop residues can contribute to higher soluble P concentrations in runoff.

Surface applications of fertilizer P may also increase concentrations of available P on eroded sediment. Studies by Barisas et al. (1978) and Johnson et al. (1979) found that available P concentrations in sediments increased with decreasing tillage where fertilizer P was broadcast. This tended to compensate for the lower soil losses from CT and resulted in sediment P losses which were similar among tillage systems. A recent study by Baker and Laflen (1982) found that injecting fertilizer P eliminated any influence of this input on levels of dissolved and sediment available P.

Most studies of CT systems have been performed under field conditions characteristic of corn grown by a cash grain farmer. Residue is usually left, fertilizer P is commonly surface applied, and there is seldom application of animal wastes to cropland. In the Great Lakes Basin and particularly in Wisconsin, many dairy and livestock farmers remove a portion of crop residue for feed or bedding purposes. They also commonly dispose of animal wastes by surface applications. The companion paper showed that soil losses were reduced for chisel and no-till systems relative to the conventional system when manure was surface applied (Mueller et al., 1984). Often the reductions were

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due in part to lower sediment concentrations. These reductions may lead to lower TP concentrations for chisel and no-till systems but may increase bioavailable P forms. Little data are available regarding losses of TP or more bioavailable P forms under these conditions. Thus, a study was undertaken comparing differences in P losses from three tillage methods, both with and without surface-applied manure. In the first year of the study, comparisons were made after a portion of the residue was removed. The following year all the residue was left.

MATERIALS AND METHODS

Phosphorus losses were compared among the conventional, chisel, and no-till systems on a Dresden silt loam (Mollic Hapludolls). All tillage was performed across slope. Four plots were established for each tillage system—two with surface-applied manure prior to tillage and two without. A completely random experimental design was used. Manured plots received a surface application of 8 metric tons ha^{-1} (dry weight) of dairy manure prior to tillage. A corrective application of 112 kg of K ha^{-1} was broadcast on all plots prior to tillage. At planting, 250 kg ha^{-1} of 10-26-26 fertilizer was banded and in June, 125 kg N ha^{-1} as ammonium nitrate was side-dressed.

Runoff generated by simulated rain was collected during late May, mid-July and early September 1978 and early June and late August 1979. Simulated rainfall was applied for 1 h on duplicate 1.35 m^2 areas within each plot using a modified sprinkling infiltrometer (Dixon and Peterson, 1965, 1968). The rainfall application rate was 14.5 ± 0.4 cm h^{-1}. The 1.35 m^2 plots contained one corn row. Total runoff during each 1-h event was measured continuously and collected. A 1-L sample was taken after each event for P analysis. A portion of each sample was filtered within 1 h of collection through a 0.45-m pore size filter. Both filtered and unfiltered runoff samples were stored in polyethylene bottles and frozen until analyzed. Except for May 1978, the dissolved molybdate-reactive P (DMRP— concentration in water applied averaged 0.007 mg P L^{-1}. This is in the range of concentrations observed in natural rainfall (Verry and Timmons, 1977).

In May 1978, periodic and variable P contamination of the water supply used biased much of the data. For comparison purposes, data for sites receiving water having 0.075 mg P L^{-1} were used. This cutoff level was chosen because it encompassed the lower-level P contamination. Greater contamination ranged from two to nine times the aforementioned cutoff level. Because P added with simulated rain will react with both soil and sediment that it comes in contace with, it is difficult to accurately correct for P contamination in the various P fractions measured. Thus, no correction has been attempted.

Total P was determined by nitric-perchloric acid digestion of an aliquot of runoff suspension. Phosphorus in the digested sample was determined after neutralization using the method of Murphy and Riley (1962). DMRP was determined on the filtered portion of runoff samples using the method of Murphy and Riley (1962). Algal-available P (AAP) was determined on an aliquot of unfiltered sample using the resin extraction method developed by Huettl et al. (1979) and modified by Wendt and Corey (1980). Concentrations of AAP include P in solution and P which desorbs from sediment. All analyses were performed in duplicate.

Data were analyzed using a three-way analysis of variance for individual years. Logarithmic transformations of TP and AAP concentrations and losses were made prior to the above statistical computations to obtain greater homogeneity among variances. For significant main effects and interactions, significance was determined at the 0.10 level using the least significant difference method (Steel and Torrie, 1980). The May 1978 data were not included in the statistical analysis because the data are incomplete and in some cases subject to contamination bias. Where appropriate, the May data are included within the text to show trends that occurred at this sampling time. Further details regarding the area sampled and the sampling methods used are given in a companion paper (Mueller et al., 1984).

Table 1—Analysis of variance (F values) for total, dissolved molybdate-reactive and algal-available phosphorus concentrations and losses as influenced by tillage, manure, and date of sampling.

Source	TP† conc.	TP loss	DMRP conc.	DMRP loss	AAP conc.	AAP loss
			1978			
Tillage (T)	2.49	2.56	7.8**	11.9**	0.58	3.0***
Manure (M)	0.9	2.47	16.0**	16.4**	2.68	0.3
Date (D)	0.7	0.46	4.5***	1.3	2.59	0.3
$T \times M$	0.4	0.50	5.9*	1.3**	1.69	0.9
$T \times D$	0.9	0.17	1.4	1.2	0.1	0.8
$M \times D$	0.6	0.1	2.0	1.2	0.1	0.6
$T \times M \times D$	1.0	0.2	0.8	0.7	0.1	0.6
			1979			
Tillage	39.2**	9.4**	3.1***	92.1**	1.4	9.2***
Manure	1.5	4.5*	13.3**	78.5**	14.1**	1.2
Date	2.5	0.1	0.4	23.7**	2.1	0.1
$T \times M$	8.2**	6.3**	5.6*	75.1**	7.6**	5.7**
$T \times D$	0.1	0.8	3.7*	21.7**	1.3	1.4
$M \times D$	1.5	0.1	1.1	20.3**	3.0***	0.4
$T \times M \times D$	1.8	0.1	3.4*	22.9**	0.7	0.1

*,**,*** Significant F ratios at $p = 0.05$, $p = 0.01$, and $p = 0.1$, respectively.

† TP = total phosphorus; DMRP = dissolved molybdate-reactive phosphorus; AAP = algal-available phosphorus.

RESULTS

Values of F from the analysis of variance are given in Table 1. Listed are the main effects of tillage, manure, and date, and the interactions of these factors. When the factors under consideration have a significant F and no significant interactions exist, the data and interpretation are only presented for the main effects. If significant interactions are present, then the factors cannot be interpreted independently and comparisons are made at each level of the interacting factors.

TP Losses

Although no significant main effects or interactions were observed for TP concentrations or losses in July and September 1978 (Table 1), several consistent trends were observed. At both sampling periods, TP losses were lower from manured chisel and no-till sites relative to equivalent unmanured sites while little difference was observed between manured and unmanured conventional sites. TP losses, averaged for July and September at unmanured sites, followed the order conventional (241 g m^{-2}) > chisel (185 g m^{-2}) > no-till (163 g m^{-2}). At manured sites, TP losses were conventional (243 g m^{-2}) > chisel (116 g m^{-2}) = no-till (112 g m^{-2}). The May 1978 data, at least for no-till, show results contrary to July and September. TP concentrations and losses were greater at manured no-till sites (2.69 mg L^{-1}, 228 g m^{-2}) relative to equivalent unmanured sites (1.42 mg L^{-1}, 143 g m^{-2}). In addition, in May TP losses were greater from manured no-till treatments (228 g m^{-2}) than from manured conventional (60 g m^{-2}) or chisel 37 g m^{-2}) sites.

In 1979, a two-way interaction between tillage (T) and manure (M) was observed for TP concentrations and losses (Table 1). At both sampling periods, TP concentrations and losses for unmanured sites followed the order conventional > chisel > no-till (Table 2). Manure had little effect on these parameters at conventional sites, but increased and decreased TP losses at no-till and chisel sites, respectively. As a result, TP losses were significantly lower from manured chisel sites than either manured no-till or conventional sites.

Table 2—Total phosphorus concentrations and losses for 1979 ($T \times M$ interaction).

	Concentrations all dates	Losses all dates
	mg L^{-1}	g m^{-2}
Conventional/wo†	3.56a**	237a
Conventional/w	3.36a	158ab
Chisel/wo	2.23b	92bc
Chisel/w	1.70bc	10d
No-till/wo	0.70d	71cd
No-till/w	1.50c	133bc

** Within each column, values followed by the same letter are not significantly different at $p = 0.1$, as tested by the least significant difference test.
† wo = without manure; w = with manure.

DMRP Losses

In July and September 1978, a significant $T \times M$ interaction occurred for DMRP concentrations and losses (Table 1). The $T \times M$ interaction for DMRP concentrations was due to increases in concentrations where manure was spread on no-till and chisel sites, while little increase was observed at conventional sites (Table 3). In July and September, DMRP concentrations for manured treatments followed the order no-till > chisel > conventional. A similar trend was observed in May with DMRP concentrations averaging 0.096, 0.218 and 0.804 mg L^{-1} for manured conventional, chisel, and no-till, respectively. In contrast, little difference was observed in DMRP concentrations among unmanured tillage treatments. The significant $T \times M$ interaction for DMRP losses was due to significantly higher losses from manured no-till sites than from all other treatments. Similarly, in May DMRP losses were greater from manured no-till sites (77 g m^{-2}) than manured chisel (5 g m^{-2}) or manured conventional (3 g m^{-2}) sites.

In July and September 1978, ANOVA also indicated that DMRP concentrations were affected by the date of sampling (Table 1). Concentrations were significantly higher in July (0.114 mg L^{-1}) than in September (0.066 mg L^{-1}). Similarly, DMRP concentrations were higher in May (0.315 mg L^{-1}) than in July or September.

In 1979, a three-way interaction was observed among tillage (T), manure (M), and date (D) for DMRP concentrations and losses (Table 1). Similar to 1978, DMRP concentrations at manured sites followed the order no-till > chisel > conventional, whereas little difference was observed among unmanured tillage treatments (Table 3). The date of sampling also affected DMRP concentrations in that significantly higher concentrations occurred at manured chisel and no-till sites in June relative to August. The significant $T \times M \times D$ interaction for DMRP losses resulted because significantly higher losses occurred at manured no-till sites in June and again in August relative to all other treatments (Table 3). In addition the DMRP losses from manured no-till sites were significantly higher in June than in August. Within dates, no other significant differences were observed among the other tillage treatments.

Table 3—Dissolved molybdate-reaction phosphorus concentrations and losses for 1978 ($T \times M$ interaction) and 1979 ($T \times M \times D$ interaction).

Treatment	1978 Conc. all dates	1978 Losses all dates	1979 Conc. June	1979 Conc. August	1979 Losses June	1979 Losses August
	mg L^{-1}	g m^{-2}	mg L^{-1}	mg L^{-1}	g m^{-2}	g m^{-2}
Conventional/wo†	0.037c**	4b	0.050d	0.032d	2c	3c
Conventional/w	0.044c	5b	0.047d	0.064cd	2c	5c
Chisel/wo	0.043c	4b	0.072cd	0.035d	4c	1c
Chisel/w	0.116b	10b	0.278b	0.115c	4c	1c
No-till/wo	0.052c	7b	0.053d	0.041d	5c	5c
No-till/w	0.248a	28a	0.936a	0.258b	80a	26b

** Within each year and column, values followed by the same letter are not significantly different at $p = 0.1$, as tested by the least significant difference test.
† wo = without manure; w = with manure.

AAP Losses

In July and September 1978, a tillage effect was observed for AAP losses (Table 1). Losses of AAP followed the order no-till > conventional > chisel (Table 4). However, only the difference between the no-till and chisel were significantly different. Although ANOVA indicated no interaction between tillage and manure, the data for July and September indicate that AAP concentrations were greater from manured no-till sites (0.470 mg L^{-1}) than unmanured no-till sites (0.224). This was more apparent in May of 1978 where AAP concentrations for manured no-till sites were 2.81 mg L^{-1} compared to 0.498 mg L^{-1} for unmanured no-till sites. In addition the May data indicated that AAP losses were much higher from manured no-till sites

Table 4—Algal-available phosphorus concentrations and losses for 1978 (tillage effect) and 1979 ($T \times M$ interaction).

1978 Treatment	1978 Losses all dates	1979 Treatment	1979 Conc. all dates	1979 Losses all dates
	g m^{-2}		mg L^{-1}	g m^{-2}
Conventional	33ab**	Conventional/wo‡	0.726ab	52b
		Conventional/w	0.758ab	39bc
Chisel	24b	Chisel/wo	0.488b	20cd
		Chisel/w	0.746ab	7e
No-till	41a	No-till/wo	0.235c	24cd
		No-till/w	1.140a	98a

** Within each year and column, values followed by the same letter are not significantly different at $p = 0.1$, as tested by the least significant difference test.
† wo = without manure; w = with manure.

(278 g m^{-2}) than from chisel (9 g m^{-2}) or conventional (6 g m^{-2} sites).

In 1979, a $T \times M$ interaction was observed for AAP concentrations and losses (Table 1). The $T \times M$ interaction for AAP concentrations resulted from significant increases in AAP concentrations from manured relative to unmanured no-till sites, while little difference was observed between manured and unmanured chisel or conventional sites (Table 4). AAP concentrations for manured sites followed the order no-till > conventional = chisel. In contrast, at unmanured sites, AAP concentrations followed the order conventional > chisel > no-till. AAP losses among treatments were influenced not only by AAP concentrations but also by relative runoff amounts. Losses of AAP from manured sites followed the order no-till > conventional > chisel. In contrast, AAP losses were significantly higher from unmanured conventional sites than from unmanured chisel or no-till sites.

A $M \times D$ interaction was also observed for AAP concentrations in 1979. In June, concentrations of AAP over all manured treatments were significantly higher (1.10 mg L^{-1}) than over all unmanured treatments (0.47 mg L^{-1}). In addition, AAP concentrations in June for manured treatments were significantly higher than either manured (0.661 mg L^{-1}) or unmanured (0.491 mg L^{-1}) treatments in August.

DISCUSSION

In the companion paper, the first paragraph of the Discussion reviews the advantages and limitations of the rainfall simulator used in this study (Mueller et al., 1984). As was stated, results cannot be directly extrapolated to natural events. However, the main objective was to compare relative differences among tillage treatments. Comparisons of natural runoff to runoff generated from the simulator used in this study have shown similar relative trends (Andraski et al., 1983). Although limited, this research indicates that this simulator should provide representative results of relative differences among tillage treatments.

In 1978 at unmanured sites, little difference was observed in TP concentrations and losses among tillage treatments. This was similar to the trends observed for sediment concentrations and losses (Mueller et al., 1984), and is to be expected since the majority of TP in surface runoff is normally attached to sediment. Part of the residue was removed in 1978 and apparently this was the reason the chisel and no-till systems were ineffective in reducing TP losses relative to the conventional system. In contrast in 1979, lower soil and in turn TP losses occurred from unmanured chisel and no-till sites relative to unmanured conventional sites. Apparently the increase in residue cover in 1979 increased the effectiveness of both unmanured chisel and no-till treatments relative to the unmanured conventional treatment in reducing TP losses.

Surface spread manure was responsible for decreasing soil losses for chisel and no-till treatments relative to the conventional treatment in 1978, and consequently, a similar trend was observed for TP losses at the later sampling periods. However, manure increased TP losses for the no-till system in May 1978 and at both sampling periods in 1979. This indicated that P in the manure more than offset the reductions that occurred from lower sediment concentrations. In contrast, the low TP losses from the manured chisel treatments in 1979 resulted primarily from relatively low runoff (Mueller et al., 1984).

In previous studies where fertilizer P was broadcast, DMRP concentrations were significantly higher from CT systems than from the conventional system (Romkens et al., 1973; Barisas et al., 1978). In contrast, Baker and Laflen (1982) found that injecting fertilizer P eliminated the influence of this input on P levels. In this study, little difference was observed in DMRP concentrations among unmanured tillage treatments. This suggests that similar to Baker and Laflen's findings, banding of fertilizer P 7 to 10 cm below the surface reduced the effect of this P input on P losses for the chisel and no-till systems.

Another indication that incorporating P inputs was desirable for CT systems was that DMRP concentrations increased with decreasing tillage at sites where manure was spread. Although DMRP concentrations were greater from chisel sites than conventional sites, partially incorporating the manure by chiseling decreased DMRP concentrations relative to no-till sites. Where manure was applied and not completely incorporated, the greatest DMRP concentrations occurred at the early sampling periods. At these sites, early rains will probably leach much of the P from the manure, and consequently, early runoff events may contain relatively high DMRP concentrations.

Comparisons of AAP are probably the best assessment of relative pollution potential because this method includes P in solution and P which readily desorbs from the sediment. Thus, this parameter is influenced by both dissolved and sediment associated P. Manure may influence AAP by influencing dissolved P or by affecting sediment P amounts. For no-till, it was found that surface-applied manure greatly increased AAP concentrations relative to other tillage treatments. Manure had lowered sediment concentrations at no-till sites (Mueller et al., 1984), but the large increase in DMRP concentrations offset any reductions in P associated with sediment. In contrast, partial incorporation of the manure by chisel plowing reduced the influence of P in manure since AAP concentrations were similar from manured chisel sites relative to unmanured chisel sites, or manured conventional sites where the manure was completely incorporated. Manure decreased sediment concentrations from chisel sites and this apparently resulted in lower sediment P concentrations offsetting higher DMRP concentrations.

Similar to DMRP data, AAP concentrations were greatest from manured sites at the early sampling periods. This indicated that AAP was more easily leached from the manure in early rainfall events.

At unmanured sites the relative ranks of AAP concentrations among tillage treatments were different than manured sites. Because there was no surface-applied input of P at unmanured sites, AAP concentrations were affected primarily by sediment associated P in the runoff. Consequently, the results showed that when the chisel and no-till systems reduced sediment concentrations, these systems were also effective in reducing AAP concentrations relative to the conventional system. In this study, residue management appeared to influence the results. Residue was partially removed in 1978 and little difference was observed in sediment or AAP concentrations among unmanured tillage treatments. In contrast, in 1979 the increase in residue cover apparently explains why sediment concentrations were reduced from no-till and chisel sites relative to conventional sites and why AAP concentrations were also reduced from these sites.

Differences in runoff volumes among tillage treatments influenced P losses. Runoff from no-till sites was generally higher than other tillage treatments, particularly after planting (Mueller et al., 1984). This resulted in very high losses of DMRP and AAP from the manured no-till treatment. Runoff from chisel sites was often lower than other tillage treatments throughout the study. For example, in July and September 1978, AAP losses were significantly lower from chisel sites relative to no-till sites largely because of significantly less runoff from the former. In 1979, because of low runoff, AAP losses were no greater from chisel sites relative to no-till sites even though AAP concentrations were significantly higher from the former. An even more graphic example in 1979 was the relatively low P losses from manured chisel sites due to low runoff. Even though concentrations were often as great or greater from manured chisel sites relative to other tillage treatments, P losses were lower from the manured chisel treatment than from any of the other treatments.

Results from this study indicate that fertilizer as well as residue management for CT may influence P losses. The practice of banding fertilizer P appears to reduce the impact of this input for the no-till and chisel systems. Also, in this study the removal of residue apparently reduced the effectiveness of both CT systems for reducing AAP losses. However, data from unmanured sites indicate that when all residue was left, AAP losses were reduced for the chisel and no-till systems relative to the conventional system.

Because of both potentially high DMRP and AAP losses, surface spreading of manure in conjunction with the no-till system cannot be considered desirable from a water-quality standpoint. Injecting the manure would appear to be a better method of application. Because of the potential reductions in runoff and P losses, surface spreading manure prior to chisel plowing is an effective method of disposing of animal wastes.

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