Soil and Water Losses as Affected by Tillage and Manure Application[1]

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ABSTRACT

Little data are available on conservation tillage under field conditions characteristic of a dairy operation. Thus, simulated rainfall was used to compare soil and water losses among 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 crop residue was removed in 1978 and all the residue was left in 1979. A tillage × date interaction was observed for runoff losses in both years of the experiment. Significantly lower runoff occurred for the conventional and chisel systems relative to the no-till system immediately after planting. At later sampling periods, runoff significantly increased for the conventional system and runoff losses approached that from no-till. In contrast, lower runoff losses occurred for the chisel system relative to the other tillage systems. This was most apparent in 1979 when more residue was partially incorporated or left on the soil surface. Surface spread manure decreased runoff for all tillage treatments at the September 1978 sampling period and at both sampling periods in 1979. The results indicated the greatest response with the chisel system. In 1978 and 1979, a tillage × manure interaction was observed for soil loss. In 1978, little difference in soil loss was observed among unmanured tillage treatments. However, the application of manure reduced soil losses for chisel and no-till systems relative to the conventional system. In 1979, soil losses were lower from unmanured chisel and unmanured no-till treatments than from the unmanured conventional treatment. Soil losses were significantly lower from the manured chisel treatment than all other treatments.

Additional Index Words: **best management practices, chisel, conservation tillage, erosion, nonpoint pollution, no-till.**

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CONSERVATION TILLAGE has become increasingly popular in the Midwest. In Wisconsin, approximately 1.3 million acres are under some form of conservation tillage, and since 1976 this acreage has been increasing at a rate of 200 000 acres per year (SCS, 1982). Currently the most popular conservation tillage practice in Wisconsin is the chisel system.

Many studies have shown that conservation tillage systems can substantially reduce soil losses compared to the conventional system (Siemans and Oschwald, 1976; Laflen et al., 1978; Johnson and Moldenhauer, 1979; McGregor and Greer, 1982). The rough soil surface and/or surface residue left by these tillage practices have been found to reduce sediment concentrations and in some cases the volume of runoff water. Among conservation tillage systems, the no-till system has generally been found to be the most effective in reducing soil losses. A major reason for this has been low sediment concentrations in runoff water (Romkens et al., 1973; Laflen et al., 1978; Langdale et al., 1979). Moreover, several studies have shown reduced runoff amounts from the no-till system (Johnson et al., 1979; Langdale et al., 1979; McGregor and Greer, 1982). However, other research has reported little reduction or increases in runoff from no-till relative to the conventional system (Mannering et al., 1975; Siemans and Oschwald, 1976; Lindstrom et al., 1981; Lindstrom and Onstad, 1982).

Tillage systems utilizing the chisel plow or disk also substantially reduce soil losses compared to conventional tillage (Siemens and Oschwald, 1976; Johnson and Moldenhauer, 1979). Several studies have reported soil loss reductions for these systems were comparable to those from no-till (Romkens et al., 1973; Griffith et al., 1977; Lindstrom and Onstad, 1982). The effectiveness of chisel and disk systems was due to reductions in both sediment concentrations and runoff volumes. In many of these studies, despite higher sediment concentrations for chisel or disk systems relative to the no-till system, runoff was lower from the former systems, and as a result soil losses

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were similar to those from no-till. Researchers have suggested that greater surface storage and macropore space, and less surface sealing from chisel and disk systems were probable reasons for lower runoff relative to no-till (Romkens et al., 1973; Lindstrom and Onstad, 1982). In contrast, Laflen et al. (1978) found chisel and disk systems less effective than no-till in reducing soil loss. Little difference in runoff was reported among tillage systems in this study, and consequently lower sediment concentrations from no-till resulted in lower soil losses than for other systems.

Inconsistent results among tillage studies, particularly runoff, may be due to differing surface conditions among treatments at the time of sampling. These conditions may include differences in soil porosity, surface storage, and the degree of surface sealing. For example, Burwell et al. (1966) found greater infiltration occurred on plowed compared to unplowed surfaces immediately after tillage. However, such differences may be short-lived as Meyer and Mannering (1961) have shown that surfaces crusts developed rapidly on bare soil surfaces and significantly reduced infiltration rates. In a later study, Burwell et al. (1968) found spring infiltration to be eight times greater for fall mulched surfaces than for fall plowed and spring disked and harrowed surfaces. They suggested that the difference was due to different rates of surface sealing. Thus, as these studies suggest, time of sampling may influence results of studies comparing soil and water losses among tillage systems.

Most research to date has evaluated conservation tillage under field conditions characteristic of corn grown for cash grain. Crop residue is usually left and animal wastes are seldom applied. In the Great Lakes Basin and in Wisconsin particularly, many dairy and livestock farmers remove a portion of crop residue for feed or bedding purposes. This practice may leave marginal residue coverage for erosion control. For example, after residue was removed, Lindstrom and Onstad (1982) reported significantly higher soil losses from no-till compared to conventional or chisel systems. Farmers also commonly dispose of animal wastes by surface applying it to corn land. Researchers have reported that the bedding from manure acts as a mulch cover which can reduce soil and water loss (Converse et al., 1976; Young and Mutchler, 1976; Wendt and Corey, 1980). Consequently, partial residue removal might be compensated for by surface additions of animal wastes.

Thus far, little data are available showing the relative effectiveness of conservation tillage methods under the above conditions. Because of this, a study was undertaken: (i) to evaluate differences in runoff and soil losses among conventional, chisel, and no-till methods for corn both with and without surface-applied manure prior to tillage; (ii) to make evaluations at different times during the growing season; and (iii) to make evaluations both with all the previous crop's residue left and with a portion removed.

MATERIALS AND METHODS

The study site was located near West Bend, Wisconsin on a Dresden silt loam soil (Mollic Hapludolls), a well to moderately well drained soil consisting of 61 to 76 cm of loess over calcareous sand and gravel. The slope was 4 to 6%. Further details regarding this soil can be found in the soil survey of Washington County, Wisconsin (SCS, 1971). Four plots were established for each of the three tillage systems—two with surface-applied manure prior to tillage and two without. The manure application rate used was about 8 metric tons ha^{-1}. Treatments were randomly assigned to 15- by 15-m plots within a 0.81-ha area. The plots had border areas 3 m at the top and bottom and 6 m at each end. In the fall of 1977, a portion of the corn residues were removed leaving about 35% residue cover at the time of planting in 1978. All the residues were left for the subsequent growing season.

The tillage systems evaluated were: (i) Conventional—which was spring moldboard plowed (mid-May) and disk harrowed once immediately prior to planting; (ii) chisel plow—which was spring chisel plowed (mid-May) and planted; and (iii) no-till—which received no tillage. All tillage operations were performed across slope. The chisel plow used had straight points spaced 38 cm apart. Primary tillage was done to a depth of 20 to 25 cm and secondary tillage to a depth of about 7 cm. Corn (*Zea mays* L.) was planted on all plots in rows 96 cm apart at a rate of 54 000 seeds per hectare using a no-till planter. Pre-emergence herbicides were applied for weed control.

In order to investigate differences among treatments, runoff generated by simulated rainfall was collected at different times during the growing season. In 1978, sampling was performed in late May, mid-July and early September and, in 1979, sampling was done in early June and late August. Different areas in each plot were sampled at each successive sampling time. Runoff collected at the May 1978 and June 1979 sampling times occurred during the seedbed period (Wischmeier and Smith, 1978). In July 1978, sampling occurred near the end of crop stage 1, and runoff collected in August 1979 and September 1978 took place in crop stage 3.

Simulated rainfall was applied on duplicate 1.35-m^2 areas in each plot using a modified Purdue springling infiltrometer (Dixon and Peterson, 1965, 1968). Each area sampled contained a single corn row with adjacent rows undisturbed prior to sampling. In 1978, a single rainfall intensity was used. The water application rate averaged 14.5 ± 0.4 cm h^{-1} and delivered the energy equivalent of a natural storm a 50-yr recurrence interval. In 1979, an additional intensity was used having the energy equivalent of a natural storm with a 10-yr recurrence interval. The application rate for the latter averaged 6.5 ± 0.3 cm h^{-1}.

Runoff rates during each 1-h event were measured continuously and total runoff collected. A 1-L subsample of the total runoff suspension was obtained for analysis. Sediment content was determined by drying an aliquot of runoff suspension at 105°C and weighing the residue. Results were corrected for dissolved solids content.

Surface residue cover was estimated after planting by projecting photographs of the soil surface onto a grid (Laflen et al., 1981). Percent residue cover was obtained from the ratio of grid intersections with residue to that of the total number of grid intersections. For the unmanured plots in 1978, percent residue coverages after planting for the three tillage systems were as follows: no-till (35 ± 6), chisel (12 ± 4) and conventional (1). These values were lower than normal because of residue removal. Percent residue coverages in 1979 when all the residues were left were: no-till (45 ± 2), chisel (26 ± 7), and conventional (3 ± 2). A mixture of corn fodder and sawdust from the manure added surface residue to no-till and chisel plots. However, due to a lack of resolution, coverage by manure and crop residue could not be estimated separately. However, differences in coverage between manured and unmanured plots suggested that the manure added approximately 12 to 14% surface cover for no-till plots and 3 to 5% for chisel plots.

Table 1—Analysis of variance for runoff, sediment concentrations and soil losses as influenced by tillage, manure, and date of sampling.

	F values					
	1978			1979		
Source	R†	SC	SL	R	SC	SL
Tillage (*T*)	25.2**	8.53**	3.12***	28.64**	74.9**	11.27**
Manure (*M*)	1.39	2.92*	2.10	3.94*	9.16**	10.63**
Date (*D*)	67.8**	0.66	2.25	7.05**	1.35	0.21
$T \times M$	0.72	3.06***	3.91*	1.01	0.73	5.90
$T \times D$	3.69*	0.14	0.76	5.86**	1.73	0.79
$M \times D$	2.64***	1.09	2.40	0.10	0.12	0.11
$T \times M \times D$	2.02	0.30	0.37	0.09	3.31***	0.12

*,**,*** Significant *F* ratio at $p = 0.05$, $p = 0.01$, and $p = 0.1$, respectively.
† R = runoff; SC = sediment concentration; SL = soil losses.

Antecedent moisture was determined gravimetrically on soil collected to a depth of 7 cm adjacent to sampling sites at each sampling period. Water content at each sampling period was not significantly different ($p=0.10$) among tillage treatments. Antecedent soil moisture contents averaged 18.6, 18.4, and 21.6% for May, July and September 1978, respectively. In 1979, water content averaged 17.9 and 19.8% for June and August, respectively.

Data were analyzed using a three-way factorial analysis of variance procedure (Steel and Torrie, 1980). Data for each year were analyzed separately. Logarithmic transformations of sediment concentrations and soil losses were made prior to analyses to obtain greater homogeneity among variances and thus to increase the reliability of the statistical testing procedure. Treatment means were compared using the least significant difference test (Steel and Torrie, 1980).

RESULTS

Values of *F* from the analysis of variance (ANOVA) 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.

Runoff Volumes

In 1978, a single high rainfall intensity was used. Differences in soil and water losses among treatments were not great and it was thought that the amount of water applied may have masked differences among tillage practices. In 1979, an additional low intensity rainstorm was included. Significant differences in soil

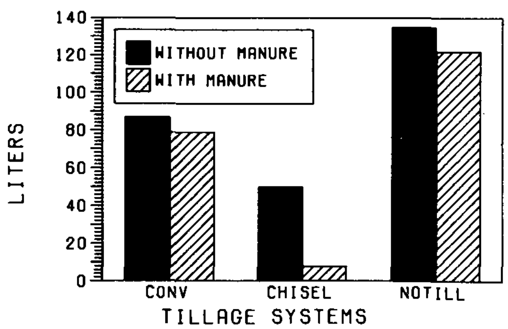

Fig. 1—The effect of tillage and manure on runoff losses in 1979.

Table 2—Water runoff for 1978 and 1979 ($T \times D$ interaction).

	1978			1979	
Treatment	May	July	Sept.	June	August
	L				
Conventional	51d**	126bc	185a	47c	118ab
Chisel	50d	106c	148b	39c	20c
No-till	134b	146b	180a	112b	146a

** Within each year, values followed by the same letter are not significantly different at $p = 0.1$, as tested by the least significant difference test.

and water losses resulted for both intensities but relative differences among the treatments did not vary with rainfall intensity. This suggested that other variables, such as the increased amount of surface residue cover, had a greater influence on differences among tillage practices than rainfall application rates. Because data from the low intensity storm provided little additional information, comparisons for the remainder of the paper are made from the high intensity.

In 1978, ANOVA (Table 1) indicated a tillage (*T*) × date (*D*) interaction for runoff volumes. Runoff losses were significantly higher for the no-till system after planting (May) compared to both the chisel and conventional systems (Table 2). In July, runoff was significantly greater from conventional and chisel sites than in May, while little change occurred at no-till sites. In September, runoff significantly increased from all tillage treatments compared to previous sampling periods. Differences in runoff between conventional and no-till systems were not significant in July and September. In contrast, the magnitude of runoff increases was less for the chisel system and as a result runoff was lower, and significantly lower than other tillage practices in July and September, respectively.

A significant $T \times D$ interaction was also indicated for runoff in 1979. Similar to 1978, runoff was significantly greater from no-till sites relative to conventional and chisel sites immediately after planting (Table 2). In August, runoff significantly increased from conventional and no-till sites relative to the June sampling period. However, runoff at chisel sites remained relatively constant and was significantly less than both conventional and no-till sites in August.

In 1978, surface applying manure had little effect on runoff volumes except in September, when runoff was less on treatments where manure was applied (161 L) relative to unmanured treatments (187 L). However, in 1979, there was a significant main effect of manure (Table 1). Runoff volumes for tillage treatments with manure averaged 70 L compared to 90 L for tillage treatments without manure. Although no interaction between tillage and manure is indicated in Table 2, the relative effect of manure for reducing runoff was consistently greater at chisel sites than at sites for the other tillage treatments (Fig. 1).

Soil Losses

ANOVA for 1978 indicates a tillage (*T*) and manure (*M*) interaction for both sediment concentrations and soil losses (Table 1). In almost all cases, sediment concentration and soil losses were significantly lower for manured chisel and no-till sites relative to unmanured chisel and no-till sites (Tables 3 and 4). In contrast,

Table 3—Sediment concentrations for 1978 ($T \times M$ interaction) and 1979 ($T \times M \times D$ interaction).

Treatment	1978 All dates	1979 June	1979 August
	g L⁻¹		
Conventional/wo†	3.55ab**	5.70ab	7.12a
Conventional/w	5.85a	6.73a	3.86bc
Chisel/wo	3.47ab	3.85ab	2.69cd
Chisel/w	1.91b	1.40de	2.27cd
No-till/wo	2.16b	0.60f	0.85ef
No-till/w	0.98c	0.29g	0.60f

** Within each year, 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.

Table 4—Soil losses for 1978 and 1979 ($T \times M$ interaction).

Treatment	1978 All dates	1979 All dates
	g m⁻²	
Conventional/wo†	304ab**	449a
Conventional/w	436a	246ab
Chisel/wo	259ab	138b
Chisel/w	129c	5c
No-till/wo	248ab	75b
No-till/w	108c	42b

** Within each year, 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.

no significant differences were observed in sediment concentrations or losses between manured and unmanured conventional sites. As a result in 1978, significantly higher sediment concentrations and losses resulted from manured conventional sites relative to either manured chisel or manured no-till sites. Little difference was observed in soil losses between manured chisel and manured no-till sites. This occurred despite significantly lower sediment concentrations at the latter because of significantly lower runoff for the former (Table 2). In 1978, no significant differences in sediment concentrations or soil losses were observed among unmanured tillage treatments.

In 1979, a $T \times M \times D$ interaction was observed for sediment concentrations (Table 1). Similar to 1978, sediment concentrations at manured chisel and no-till sites were lower than unmanured chisel and unmanured no-till sites (Table 3). However, the differences were not always significant. In August, sediment concentrations were significantly lower from manured conventional sites relative to unmanured conventional sites. However, no significant differences were observed between manured and unmanured conventional sites in June. Sediment concentrations decreased in the order conventional > chisel > no-till for both manured and unmanured sites.

In 1979, the primary reason for the $T \times M$ interaction for soil losses was due to significantly lower losses for manured chisel sites relative to unmanured chisel sites. In contrast, no significant differences were observed for manured relative to unmanured no-till sites or manured relative to unmanured conventional sites. Soil losses were significantly higher from unmanured conventional sites relative to either unmanured chisel or unmanured no-till sites. Soil losses were also greater from manured conventional sites relative to manured no-till or manured chisel sites. In addition, soil losses were significantly lower for manured chisel sites relative to manured no-till sites.

DISCUSSION

The rainfall simulator used in this study has advantages over other simulators in that it is more mobile and many samples can be taken in a relatively short time. However, a relatively small area is sampled which limits soil movement to interrill erosion and can lead to large variations among replicates. The reasons why sediment concentrations were higher from manured conventional sites in June 1979 relative to equivalent unmanured sites but reversed in August 1979, or why soil losses from May 1978 unmanured conventional sites were much lower than equivalent manured sites are probably best explained by the inherent variability of this type of research. In addition, the rain intensity used with this simulator delivers more water to the soil surface than during natural events of equivalent energy. For these reasons, soil loss results cannot be directly extrapolated to natural events. However, despite these limitations, comparisons of natural runoff to runoff generated from the simulator used in this study have shown similar relative trends (Andraski et al., 1983). Thus, this simulator should provide representative results of relative differences among tillage treatments.

Significantly lower runoff losses from the chisel and conventional sites immediately after planting in both years indicates that both tillage methods effectively increased infiltration rates relative to no-till. This was apparently due to surface crusts being broken and plow layer porosity being increased. The chisel plow also left ridges perpendicular to the slope which may have reduced runoff by increasing surface storage.

Surface crusting resulted from natural storms that occurred prior to later sampling periods and consequently runoff increased. This was particularly evident for the conventional system. Similar results have been shown by Meyer and Mannering (1961) and Burwell et al. (1968). The September 1978 sampling period produced particularly high runoff losses. Storms with recurrence intervals of 10, 2, 1, and 1 yr occurred within 2 weeks preceding sampling and consequently the soil surface was smooth and crusted with relatively high antecedent soil moisture (21.6%).

While the conventional system lost its effectiveness in reducing runoff at later sampling periods, partially incorporating the residue with the chisel plow maintained higher infiltration rates and thus lower runoff losses than other tillage systems. This was particularly true at the August sampling period in 1979 when little change in runoff occurred for the chisel system relative to the June sampling period. Lower runoff was also observed in 1978 for the chisel system but the reductions were not as substantial. The greater reductions that occurred in 1979 for the chisel system probably resulted from the increased residue cover which was more effective in preventing the redevelopment of surface crusts. As residue decomposition occurs, the partially incorporated residue may also provide larger pore spaces at the soil surface allowing for a higher infiltration rate.

Despite leaving all the residue at the soil surface, no-till resulted in the highest runoff losses. Lindstrom and Onstad (1982) have also reported relatively high runoff losses from no-till relative to the conventional and chisel systems. Their study indicated that the no-till system's soil surface was characterized by a relatively high bulk density, low saturated hydraulic conductivity, and low volumes of macropore space, all of which indicate high runoff is probable.

Consistently lower runoff losses were observed from plots receiving manure in 1979. ANOVA did not indicate a greater response from any particular tillage treatment; however, percent reductions were greater from the manured chisel sites than from other manured treatments. This suggests that partially incorporating both the residue and manure was more effective than plowing it under or leaving it on the surface. There was less of a response to manure in the first year of the experiment; however, lower residue levels may be partially responsible for the lack of response.

Research by Wischmeier (1973) and Laflen et al. (1978) has shown the importance of surface residue cover in reducing soil losses. Sediment concentrations and soil loss results from this 2-yr study also indicate that residue management influenced the relative rank of soil losses among tillage systems. In 1978, the probable reason that there were no significant differences in soil losses or sediment concentrations among unmanured tillage treatments was the partial removal of residue. In contrast, soil losses were significantly lower from unmanured chisel and no-till sites relative to unmanured conventional sites in 1979 when all residues were left. The primary reason for low soil losses from unmanured no-till in 1979 was the significantly lower sediment concentrations. Although sediment concentrations were significantly higher from unmanured chisel sites than from unmanured no-till sites, runoff was lower for the former and, as a result, little difference in soil loss was observed between these systems.

Crop canopy becomes a more significant factor in reducing sediment concentrations as the corn grows beyond crop stage 1 (Wischmeier and Smith, 1978). Although an effect of date on sediment concentrations was not indicated by ANOVA, the results show a trend toward lower concentrations at later sampling periods that may be partially due to canopy cover. For example, in 1978, sediment concentrations from all treatments were 2.28 g L^{-1} in September compared to 3.41 and 3.24 g L^{-1} in May and July, respectively. Slightly lower sediment concentrations occurred in August relative to June 1979.

Surface applications of manure did compensate for the removal of residue for the chisel and no-till systems in 1978. Sediment concentrations and soil losses were reduced from manured chisel and no-till sites relative to equivalent unmanured sites and manured conventional sites. In 1978, the chisel and no-till systems were about equally effective in reducing soil losses where manure was applied. In the second year of the study, where all the residue was left, soil losses were significantly lower from manured chisel sites than from any other treatment. In contrast, the surface application of manure had little additional benefit for the no-till system. Apparently there was already sufficient residue cover on no-till plots.

From these results, it would appear that dairy farmers who use the chisel or no-till systems can increase the effectiveness of both systems in controlling erosion with surface applications of manure when residue is removed for bedding or silage. However, on corn ground where the stalks are left, manure would be most effective spread on chiseled ground.

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