Residue Level and Manure Application Timing Effects on Runoff and Sediment Losses

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ABSTRACT

There is growing interest in evaluating the effects of corn silage harvesting methods on erosion control. Increasing the silage cutting height will increase residue cover and could conceivably minimize off-site migration of sediments compared with conventional silage harvesting. The effects of residue level and manure application timing on runoff and sediment losses from no-till corn were examined. Treatments included conventional corn grain (G) and silage (SL) and nonconventional, high-cut (60–65 cm) silage (SH). Corn harvesting treatments were subjected to different manure application regimes: no manure (N) or surface application in fall (F) or spring (S). Simulated rainfall (76 mm/h; 1 h) was applied in spring and fall for two years (2002–2003), runoff from 2.0- × 1.5-m plots collected, and a subsample analyzed for sediment concentration and aggregate size distribution. Runoff volume was inversely related to residue cover. Manure addition to silage plots reduced spring runoff by 71 to 88%, attributable to an increase in soil organic matter content, compared with SH–N and SL–N. Differences in sediment concentration between SH and SL were not significant. For silage plots, spring-applied manure had the greatest influence on sediment export reducing it by 84 to 93% in spring runoff compared with corresponding N plots. Sediment loads were also 85 to 97% lower from SH–S compared with SL–N in all four seasons. Except for spring 2003, sediment export was lower from G compared with SL. The combination of manure and higher residue associated with high-cut silage often lowered sediment export compared with low-cut silage. Nearly identical aggregate size distributions were observed in sediments from SH and SL plots. High residue levels combined with spring-applied manure led to enrichment in the clay-sized fraction of runoff sediment. Recently applied manure and higher residue levels achieved by high-cutting silage can substantially lower sediment losses in spring runoff when soil is most susceptible to erosion.

Soil loss from agricultural lands in the United States exceeds 2.0 billion U.S. tons (1.8 billion Mg) annually (Trimble and Crosson, 2000). In addition to reducing soil productivity, these sediments choke streams, impair shipping lanes, and degrade aquatic ecosystems. More importantly, however, are the nutrients associated with the sediments. They lead to eutrophic conditions characterized by algal blooms whose decomposition by bacteria diminishes the availability of oxygen. In extreme situations, anoxic conditions can result, followed by massive fish kills (Carpenter et al., 1998).

Manure and crop residues that remain on the soil surface are known to have similar inhibitory effects on soil loss. They protect soil from raindrop impact, reduce particle detachment, and prevent surface sealing (Potter et al., 1995; Gilley and Risse, 2000). Crop residue also helps impound rainwater, reduce runoff velocity, and consequently promote infiltration that lowers sediment losses (Gilley et al., 1986), while manure addition provides the same beneficial effect by improving soil aggregation and porosity (Bundy et al., 2001; Gilley et al., 2002). In combination, these factors can significantly lower overall runoff and soil losses from agricultural lands. However, with a few notable exceptions (e.g., Bundy et al., 2001), studies that involve the simultaneous evaluation of residue cover and manure application on runoff and soil losses are rare.

Management practices aimed at retaining topsoil have been developed and implemented for many decades. However, growing interest in corn silage utilization in the United States, in response to changing animal farm dynamics and more favorable economics, threatens to make topsoil more susceptible to soil erosion. A 15% increase in cropland area harvested as corn silage in Wisconsin from 1994 to 1998 (Battaglia, 1999) and a survey of nutritional consultants (Shaver, 2000) support this trend. Furthermore, acreage for corn silage in Wisconsin has increased an additional 20% since 1998 (USDA, 2004). In addition, Klemme (1998) reported a net advantage of $100/acre ($250/ha) for growing corn silage compared with alfalfa, due primarily to the difference in dry matter yield. Since the extent of residue cover influences runoff production and soil erosion, this trend of increasing corn silage production may affect sediment export from croplands.

One option that would allow producers to harvest silage while maintaining a somewhat greater level of soil surface residue cover is to increase the cutting height for silage. On-going research in Wisconsin and other states shows that improved silage quality concomitant with increased milk production can be obtained when the cutting height is raised from the conventional height (10–15 cm) to 45 cm or higher (Curran and Posch, 2000; Neylon and Kung, 2003). Greater crop residue cover associated with high-cut silage (SH) could minimize water quality degradation that would otherwise result from harvesting corn for silage instead of grain.

Knowledge of the size distribution of eroded sediments is of practical importance for the development and implementation of management practices aimed at minimizing water quality impacts of agricultural runoff. Fine grain particles (clay and silt) with high specific surface areas and sorption potentials typically have a higher

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Abbreviations: AARS, Arlington Agricultural Research Station; F, fall-applied manure; G, corn grain; N, no manure application; S, spring-applied manure; SH, corn silage, high-cut; SL, corn silage, low-cut.

P concentration than coarser and relatively inert sand particles (Young and Onstad, 1976; Dong et al., 1983). However, sediment erodes mainly as aggregates rather than as primary particles (Meyer et al., 1980) and this pathway accounts for a majority of clay transport (Young, 1980). Alberts et al. (1980, 1981) reported that primary clay particles accounted for less than 5% of eroded sediments and that the percentage was slightly higher from interrill compared with rill areas. Since manure can enhance soil aggregation (Gilley et al., 2002), its application may shift the size distribution of soil and runoff sediments from finer particles to relatively larger aggregates. Although some earlier works have explored the impact of tillage and residue on size fractionation of sediments transported in runoff (Alberts and Moldenhauer, 1981; Alberts et al., 1981), investigations focusing on the impact of manure application on aggregate size distribution are very limited.

The major goal of this study, therefore, was to evaluate potential environmental benefits associated with higher crop residue cover achieved by high-cutting silage. Specific objectives included examining the effect of residue cover on (i) runoff amount, (ii) sediment concentration and load, and (iii) the size distribution of eroded sediments. We also investigated the impact of manure application and its timing on runoff and sediment losses over a range of crop residue levels resulting from three harvesting methods, namely, corn grain (G), SH, and conventional corn silage (SL). Two different seasons were also compared, fall (after harvesting) and spring (before planting), to determine the effectiveness of increasing silage cutting height in reducing sediment losses from no-till cropland.

MATERIALS AND METHODS

Field experiments were conducted at the University of Wisconsin (UW) Arlington Agricultural Research Station (AARS) (89°20′ W, 43°17′ N) on a Plano silt loam soil (fine-silty, mixed, superactive, mesic Typic Argiudoll) during the spring and fall of 2002 and 2003. The 1.2-ha field was gently sloping, 3 to 5%. Experiments were performed on cropland previously planted in corn (*Zea mays* L.) under no-till conditions. For this study, corn (Renk 232 RR) was sown at a density of 32 000 to 34 000 seeds per acre (79 000 to 84 000 per ha) in rows spaced 76 cm apart. Corn was also grown in 2001, 1998, and 1997; while soybean [*Glycine max* (L.) Merr.] was grown in 2000 and oat (*Avena sativa* L.) in 1999. Grain harvest was 160 bu/ac (10.1 Mg/ha) in 2001 and 130 bu/ac (8.2 Mg/ha) in 2003, while corn silage yielded 30.7 Mg/ha in 2002 and 25.8 Mg/ha in 2003. Dry matter yield was measured in fall 2003; treatments receiving manure had higher dry matter (17.5 Mg/ha) compared with those having none (15.2 Mg/ha).

The experimental layout consisted of a completely randomized design with two independent blocks (Fig. 1). Rainfall experiments were replicated twice (within a block) for every treatment and data from quadruplicates were pooled to perform the statistical analysis. The 4.5-m-wide plots were separated by a 4.5-m-wide buffer planted in corn grain and a 0.3-m-deep dead furrow. A 0.3-m ridge was located between the furrow and adjacent corn grain buffer. The ridge–furrow system was at least 0.8 m wide. Steel frames inserted to a depth of 7.5 cm delineated 36 microplots each measuring 2.0 × 1.5 m. Frames were situated to contain exactly three rows of corn with the down-slope end 0.3 m from the nearest corn row. Planted on the contour, corn rows ran perpendicular to the down-slope orientation of the microplots. New microplots were established for each of the four rainfall simulation periods (24 May–14 June and 21 Sept.–30 Oct. 2002, 13–25 May and 4–26 Oct. 2003).

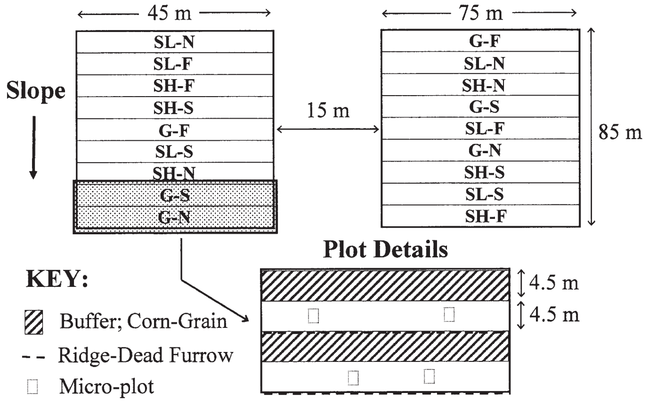


Fig. 1. Arrangement of treatment plots showing details of microplot location.

Three crop residue levels were achieved by different harvest methods. Grain harvest (13 Oct. 2002, 17 Oct. 2003) was performed with a combine while a chopper with adjustable cutting bar for height was used for silage harvesting (10 Sept. 2002, 24 Sept. 2003). The cutting bar was adjusted to 10 to 15 cm for SL and 60 to 65 cm for SH. The cutting height for SH was selected due to the lower nutritive value associated with the lower 60 to 65 cm of the corn plant (Larry Satter, personal communication, 2001). The additional crop residue left in the field following SH harvesting could reduce runoff and soil losses. Any corn residue remaining in the field after harvest was chopped on the high (G) and intermediate (SH) residue plots. In addition, all standing biomass (i.e., weeds) was cut at ground level and removed from the microplot before each rainfall simulation. Residue cover in each microplot was estimated by the pin drop method (Morrison et al., 1996) using a rill-o-meter with 37 pins spaced 2.5 cm apart; both diagonals were used to estimate percent cover (Table 1).

Each residue level also received one of three manure treatments: manure applied in the spring (S) or preceding fall (F), or no manure (N). A Calumet spreader (Imperial Industries, Wausau, WI) surface-applied liquid dairy manure (90% moisture) at a rate of 106 Mg/ha on 15 Nov. 2001, 16 Apr. 2002, 19 Nov. 2002, and 15 Apr. 2003. Produced by the dairy herd at the AARS, the manure was obtained from a storage pit and had water added to facilitate pumping. It also contained sawdust as bedding material. Manure was (nearly) uniformly spread on each microplot and appeared as a mulching layer even several weeks after application. Because of the sawdust bedding material, the mulch layer was noticeably different from crop residues and soil, but was not included as part of the residue cover. The method and rate of manure application resulted in a high areal coverage of manure, but it was not explicitly measured. Before this study, the field had a prolonged period of no manure application.

Rainfall simulations were performed just before planting (24 May–14 June 2002, 13–25 May 2003) and after harvesting (21 Sept.–30 Oct. 2002, 4–26 Oct. 2003). A rainfall simulator based on the standard design for the National Phosphorus Research Project (2002) with a 1/2-inch HH 50WSQ Fulljet nozzle (Spraying Systems, Wheaton, IL) positioned 3 m above the soil surface delivered rainfall at a rate of 76 mm/h for 1 h. This intensity is equivalent to a 50-yr, 1-h event (Huff and

Table 1. Effect of corn harvesting method on soil surface coverage.

		Percentage of soil surface covered†			
Harvest method	**Residue level**	**Spring 2002**	**Fall 2002**	**Spring 2003**	**Fall 2003**
		%			
Grain	**high**	**56 ± 12 a‡**	**66 ± 12 a**	**43 ± 9 a**	**88 ± 4 a**
High-cut silage	**intermediate**	**16 ± 9 b**	**33 ± 3 b**	**25 ± 9 b**	**43 ± 10 b**
Low-cut silage	**low**	**4 ± 1 c**	**11 ± 3 c**	**7 ± 3 c**	**17 ± 7 c**

† Mean and standard deviation ($n = 12$).

‡ Numbers in each column followed by the same letter are not significantly different at the 0.05 probability level.

Angel, 1992). Runoff was collected continuously from the down-slope end of each microplot for the duration of the 1-h simulation using a 0.02-MPa vacuum (Dixon and Peterson, 1968) and stored in a tared, 55-gallon (208-L) drum placed on a scale. Final runoff weight and volume were recorded after cessation of runoff. A 3.8-L runoff subsample was collected for subsequent laboratory analysis. Water for the rainfall simulations came from a ground water well at the AARS and had average pH, electrical conductivity, and total dissolved solids of 8.1, 669 μS/cm, and 428 mg/L, respectively.

Before each rainfall simulation, crop residue cover was measured and ten, 0- to 5-cm-deep soil cores were collected from immediately outside of each microplot, and a sample composited for later analysis. Soil organic matter (Schulte and Hopkins, 1996) and physical composition (Gee and Bauder, 1986) were analyzed at the UW Soil & Plant Analysis Laboratory. Eighteen samples collected in spring and fall 2002 were randomly selected, one per experimental treatment, and evaluated for their physical composition. The analysis indicated a silt loam texture composed of 11.2% sand (>50 μm), 73.5% silt (2–50 μm), and 15.3% clay (<2 μm). Antecedent soil moisture was determined by weighing soil before and after drying at 105°C for 48 h.

Sediment concentration (total solids) of runoff samples was determined by weighing before and after drying at 105°C for 24 to 48 h. The sediment load was calculated by multiplying the sediment concentration by the total runoff volume. Analysis of the size distribution of nondispersed sediments was performed for samples with volumes in excess of 500 mL ($n = 108$). It involved the separation of sediments into four size classes according to the USDA classification system (Toy et al., 2002): 0 to 2 μm (clay), 2 to 50 μm (silt), 50 to 500 μm (very fine to medium sand), and greater than 500 μm (coarse sand). The silt fraction was further subdivided into fine (2–10 μm) and coarse silt (10–50 μm) fractions (Haan et al., 1994). Because aggregate rather than primary particle size distributions were desired, no dispersing agents were used before size fractionation. Initially, samples were filtered with a #35 sieve (0.5 mm) to remove floating crop residue and other particulate matter. Fractionation was accomplished through settling and involved the step-wise removal of sediment from the largest size class. Stokes' law was used to determine the time required for particles of a given diameter to settle to a designated depth. Specific gravity was assumed to be 2.20 g/cm^3 for aggregates greater than 2 μm in diameter and 2.65 g/cm^3 for smaller particles (Alberts et al., 1981). For both the 50- to 500- and 10- to 50-μm fractions, the aggregates were allowed to settle, the supernatant aspirated, and sediment resuspended with MilliQ-grade deionized water (Millipore, Billerica, MA) for a total of three times. Repeated washing and settling was used to maximize recovery and eliminate particles outside the desired size range (Alberts et al., 1981). Separation of the 2- to 10-μm fraction involved initial settling followed by resuspension and centrifugation (77 relative centrifugal force, 7 min). The remaining suspension contained only particles <2 μm in diameter (clay-sized). Once sediments had been separated by size class, each suspension containing aggregates of a designated size class was placed in a drying oven (105°C) for 24 h.

Statistical analysis was performed using Minitab Release 14.1 (Minitab, 2003) computer software. Analysis of variance (ANOVA), based on the general linear model for unbalanced data, was performed to determine whether a significant residue level, manure effect, residue × manure interaction, or inter-season difference were present for each response variable. Tukey's method for pair wise comparisons was also used to determine whether the differences between distributions were significant. A critical value of $\alpha = 0.05$ was used for all hypothesis testing. Two assumptions of an ANOVA are that the data are normally distributed and the variance within the groups being compared is the same. These assumptions are often not satisfied when working with water resources data and some type of data transformation or nonparametric statistical test must be performed. Since nearly all of the data collected in this study did not satisfy the ANOVA assumptions, ANOVA was performed using ranked rather than raw data (Bradley, 1968; Helsel and Hirsch, 2002). Ranked data produced a more normally distributed data set with near equal variances between groups and increased the power of the statistics to determine differences between the treatment groups. Nonlinear exponential models were used to fit the data in Fig. 2, 3, and 4 using exponential trend line analysis. Further model statistical analyses were performed using GraphPad's Prism Version 4.03 (GraphPad Software, 2004). Statistical significance of the fit models was determined by evaluating the F statistic of the regression, the coefficient of determination (R^2), and the confidence levels of the model parameters.

RESULTS AND DISCUSSION

Seasonal and inter-annual differences in antecedent soil water conditions before the rainfall experiments (Table 2) were not significant. When averaged over all seasons, the soil moisture was influenced by residue level ($p < 0.01$) and manure application timing ($p = 0.03$); it was higher for the grain (0.27 kg/kg soil) compared with the silage treatments (0.24–0.25 kg/kg soil) and for plots receiving spring manure (0.26 kg/kg soil) compared with plots with no manure (0.24 kg/kg soil). The organic matter content of soil from plots having received manure was higher (4.4%) compared with those not receiving manure (4.1%, $p < 0.01$).

Runoff

The extent of crop residue cover was found to influence runoff depth (Fig. 2). In general, when no manure was applied, high residue cover associated with G (Table 1) lowered runoff amounts compared with either SH or SL (Table 3). This trend held for all seasons except fall 2003, when there were no statistical differences in

Table 2. Effect of harvesting method and manure application on antecedent soil moisture conditions.

	Soil moisture†				
Treatment	Spring 2002	Spring 2003	Fall 2002	Fall 2003	All seasons
	kg/kg soil				
Grain	0.25 ± 0.06 a‡	0.28 ± 0.04 a	0.28 ± 0.02 a	0.29 ± 0.02 a	0.27 ± 0.04 a
High-cut silage	0.24 ± 0.05 a	0.26 ± 0.04 a	0.26 ± 0.04 a	0.24 ± 0.02 b	0.25 ± 0.04 b
Low-cut silage	0.23 ± 0.04 a	0.24 ± 0.05 a	0.26 ± 0.03 a	0.22 ± 0.02 b	0.24 ± 0.04 b
No manure	0.23 ± 0.06 a	0.24 ± 0.05 a	0.27 ± 0.04 a	0.24 ± 0.04 a	0.24 ± 0.05 c
Fall manure	0.22 ± 0.05 a	0.27 ± 0.06 a	0.27 ± 0.04 a	0.25 ± 0.03 a	0.25 ± 0.05 bc
Spring manure	0.27 ± 0.04 a	0.27 ± 0.03 a	0.26 ± 0.03 a	0.26 ± 0.04 a	0.26 ± 0.04 ab
Overall mean	0.24 ± 0.05 a	0.26 ± 0.05 a	0.27 ± 0.03 a	0.25 ± 0.04 a	

† Mean and standard deviation (n = 12).

‡ Numbers in a column corresponding to a residue level or manure treatment followed by the same letter are not significantly different at the 0.05 probability level.

runoff amounts among the three residue levels despite a 90% difference in runoff between G and SL. Lower runoff amounts in fall 2003 compared with fall 2002 (Table 3), attributable to the higher residue cover in fall 2003 (Table 1), limited the ability to detect differences in runoff amounts between the residue level treatments. Figure 2 better illustrates the residue effect, highlighting the inverse relationship between percent residue cover and runoff generation. The curvilinear models represent statistically significant trends. The residue cover ranges for the three different harvesting methods are also shown. In general, greater residue cover can insulate the soil surface from raindrop impact and reduce particle detachment. This effect likely inhibited the development of a surface seal by minimizing soil slaking, which could quickly fill macropores and increase runoff production (Potter et al., 1995). In addition, higher residue cover may have helped pond water, impede flow, and promote infiltration.

Previous studies have shown that residue cover and runoff volume are inversely related. For example, Baker and Laflen (1982) observed 30 and 72% less runoff from plots having 750 and 1500 kg/ha, respectively, of corn residue compared with no-residue plots. Mostaghimi et al. (1988) reported runoff reductions of 43 and 96% when levels of rye residues on no-till plots were similar to Baker and Laflen (1982). Many others have reported similar results (Romkens et al., 1973; Andraski et al., 1985; Hansen et al., 2000; Bundy et al., 2001): as the residue cover increases, runoff amounts decrease; and each attributed at least some, if not all, of the runoff reductions to increased residue cover associated with conservation tillage.

Runoff amounts were 14 to 87% lower from SH compared with SL when no manure was applied, but because of the high variability between replicates, differences were not statistically significant (α = 0.05). Following manure addition in either fall or spring, differences in runoff between SH and SL were significant in fall 2002 (Table 3). Increasing the silage cutting height alone did not significantly affect runoff volume, but higher residue cover in combination with the application of manure lowered runoff. For example, compared with SL–N, a residue level–manure treatment interaction resulted in less runoff from SH–F in all seasons except fall 2003. Runoff was also lower from SH–S compared with SL–N

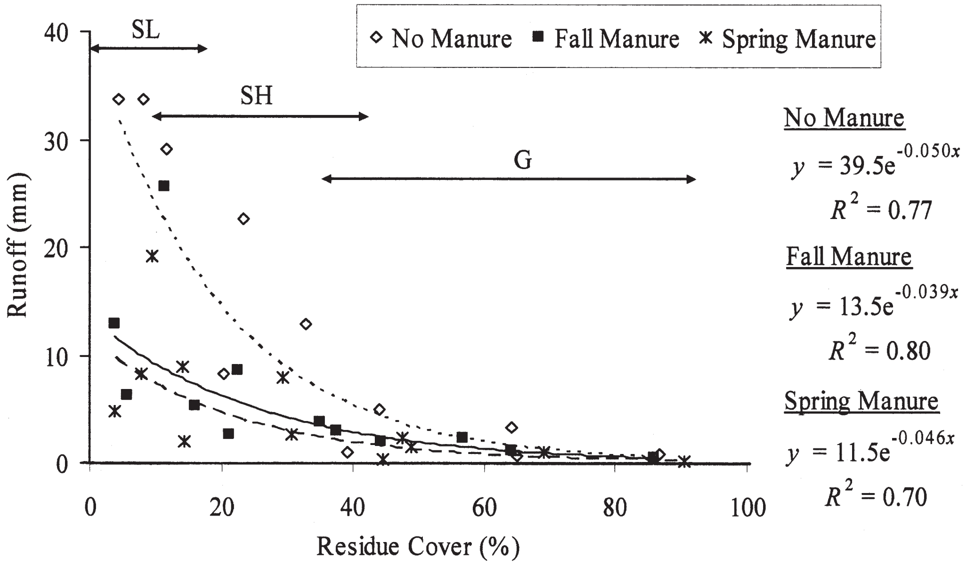


Fig. 2. Effect of crop residue cover (%) on runoff depth for three manure treatments. Data points are an average of four replicates from each of the four seasons. Residue cover ranges for the three harvesting schemes (G, grain; SH, high-cut silage; SL, low-cut silage) are highlighted. For clarity, confidence intervals were not plotted.

Table 3. Average runoff depth for each treatment.

Treatment†		Runoff‡			
Residue	Manure	Spring 2002	Spring 2003	Fall 2002	Fall 2003
		mm			
G	N	3.3 ± 1.7 bc§	4.9 ± 2.1 efg	0.7 ± 0.7 c	0.8 ± 0.7 abcd
SH	N	29.1 ± 6.7 a	22.6 ± 5.3 bc	12.9 ± 8.8 ab	1.0 ± 1.0 abcd
SL	N	33.8 ± 13.1 a	33.7 ± 10.5 ab	27.6 ± 15.7 a	8.2 ± 4.6 a
G	F	2.3 ± 2.4 bc	2.9 ± 1.4 eg	1.2 ± 1.2 c	0.4 ± 0.7 cd
SH	F	8.5 ± 7.9 bc	2.6 ± 2.6 dg	3.9 ± 3.1 bc	1.9 ± 2.2 abcd
SL	F	13.0 ± 5.7 ab	6.3 ± 1.1 def	25.6 ± 5.4 a	5.3 ± 5.3 ab
G	S	2.4 ± 2.5 c	1.5 ± 1.6 g	1.1 ± 1.7 c	0.1 ± 0.1 d
SH	S	8.9 ± 1.9 abc	7.9 ± 1.5 acf	2.7 ± 1.2 bc	0.3 ± 0.2 bcd
SL	S	4.8 ± 5.2 bc	8.3 ± 5.4 cef	19.1 ± 6.1 a	2.0 ± 1.2 abc

† G, grain; SH, high-cut silage; SL, low-cut silage; N, no manure; F, fall manure; S, spring manure.

‡ Average of four replicates.

§ Numbers in each column followed by the same letter are not significantly different at the 0.05 probability level; letters correspond to nonparametric analysis based on data ranks rather than mean and standard deviation as shown.

in both fall seasons. Differences in residue levels between SH and SL in the spring were insufficient to have a significant effect on reducing runoff regardless of manure regimen; similar amounts of spring runoff were observed for SH and SL plots with the same manure treatment (Table 3).

Manure application and timing also influenced runoff reductions. Compared with silage plots receiving no manure, spring runoff from SH was lowered 71 to 88% by fall-applied manure while spring runoff from SL was reduced 75 to 86% by spring manure. As noted earlier, manure application reduced runoff in fall 2002 from SH compared with SL plots. The addition of manure increased soil organic matter, thereby improving porosity, water-holding capacity, and overall infiltration potential. Although manure application over such a short period (two years) would not be expected to substantially improve soil properties, addition of manure with sawdust bedding had an immediate and pronounced impact. By creating a mulching layer on top of the soil surface, the manure appeared to increase the water-holding capacity resulting in substantially less runoff. Interestingly, manure application did not affect runoff volume from G plots in any season (Table 3). The presence of high amounts of residue cover after harvesting grain appeared capable of reducing runoff generation by itself and, therefore, any additional effects due to manure could not be detected.

Figure 2 further illustrates the beneficial effect of manure addition on reducing runoff. A much steeper decline in runoff depth was observed with increasing residue cover, especially in the low range, for the no manure compared with manured conditions. The statistical models for the spring- and fall-applied manure were similar over the entire range; however, below 22% residue cover, differences between the no manure and spring or fall manure models were significant. After this point, the 95% confidence intervals began to overlap as all treatments converged to 0 runoff. Interestingly, below 22%, for the same level of crop residue cover (%), the presence of manure had a pronounced effect on decreasing (up to 67%) the runoff volume. At low residue levels (3–5%), the addition of manure resulted in runoff amounts equivalent to the no manure plots with 24 to 29% residue cover. Runoff reductions following manure addition have been observed by others (Converse et al., 1976; Ginting et al., 1998; Gilley and Risse, 2000; Bundy et al., 2001). Bundy et al. (2001) reported that manure containing high amounts of organic matter was more influential than crop residue in promoting infiltration. Our results indicate that the actual magnitudes or differences between treatments in runoff generation were accentuated by manure addition.

Averaged across all residue level treatments, the presence of manure had a significant impact on reducing runoff ($p < 0.01$), especially in the spring season when crop residue levels tend to be lowest. Spring runoff exceeded 20 mm when no manure was applied but it was less than 7.5 mm when either spring or fall manure had been added. Interestingly, within the same residue treatment, fall runoff was not affected by manure application (Table 3). The absence of a manure effect in the fall season can be attributed to the dominating effect of crop residue. Immediately after harvest, when surface cover is highest for all treatments, residue alone appears to be sufficient to achieve reductions in runoff volume, and incremental effects due to previous manure application may be less noticeable.

Sediment Concentration

No consistent trend was observed for the influence of residue cover on sediment concentration (Table 4). Less sediment coincided with higher residue cover (G < SL) only in fall 2003, when the relationship may have been influenced by lower runoff volumes. Importantly, differences between SH and SL were not significant in any of the four seasons of the study. A weaker relationship existed between percent residue cover and sediment concentration compared with residue cover and runoff volume (Fig. 3). Although the curvilinear models shown in Fig. 3 are statistically significant, the differences between them are not.

The presence of manure, especially when spring-applied, appeared to reduce the sediment concentration in spring runoff; however, few of the differences were statistically significant due to the high variability among replicates. In spring 2002, SH–S plots produced significantly lower sediment concentrations (76–80%) compared with those measured in runoff from SH–F and

Table 4. Average sediment concentration in runoff for each treatment.

Treatment†		Sediment concentration‡			
Residue	**Manure**	**Spring 2002**	**Spring 2003**	**Fall 2002**	**Fall 2003**
		g/kg			
G	N	3.13 ± 1.12 abc§	9.47 ± 2.97 a	2.65 ± 1.33 a	1.14 ± 0.41 cd
SH	N	5.05 ± 1.10 a	4.15 ± 1.94 abc	2.66 ± 0.89 a	2.99 ± 0.59 ab
SL	N	5.14 ± 3.07 ab	4.78 ± 1.32 ab	2.56 ± 0.40 a	2.94 ± 0.54 ab
G	F	1.86 ± 1.13 abc	5.29 ± 3.10 ab	2.74 ± 1.29 a	1.59 ± 0.81 bd
SH	F	6.11 ± 2.83 a	3.11 ± 0.13 abc	2.81 ± 1.50 a	4.41 ± 3.07 abc
SL	F	4.20 ± 2.95 abc	4.76 ± 3.28 abc	2.72 ± 0.49 a	4.23 ± 1.23 a
G	S	0.83 ± 0.22 c	1.58 ± 1.00 c	1.44 ± 0.58 a	0.85 ± 0.14 d
SH	S	1.23 ± 0.79 bc	1.83 ± 0.67 c	3.92 ± 0.92 a	1.80 ± 0.69 abd
SL	S	1.84 ± 1.04 abc	2.10 ± 1.18 bc	4.20 ± 1.00 a	3.05 ± 1.14 abc

† G, grain; SH, high-cut silage; SL, low-cut silage; N, no manure; F, fall manure; S, spring manure.

‡ Average of four replicates.

§ Numbers in each column followed by the same letter are not significantly different at the 0.05 probability level; letters correspond to nonparametric analysis based on data ranks rather than mean and standard deviation as shown.

SH–N plots. Spring runoff in 2002 from SL–S plots had 36 to 44% of the sediment concentration compared with SL–F and SL–N plots while in spring 2003 runoff from SH–S had 44 to 59% of the sediment concentration compared with SH–F and SH–N, but these reductions were not statistically significant. Interestingly, the fall-applied and no manure treatments yielded similar sediment levels (Table 4), attributable perhaps to differences in runoff volumes or diminishing beneficial effects with time from manure addition. Differences in sediment concentration in fall runoff for the various harvesting methods were not affected by manure application.

Manure that contains sawdust bedding material and applied at a rate similar to the one in this study most likely provides a protective mulch layer that insulates the soil surface from raindrop impact and particle detachment (Gilley and Risse, 2000). These benefits are probably greatest immediately after the manure is applied and diminish with time as the organic matter becomes incorporated into the soil structure. When averaged across all residue levels, plots receiving spring manure (2002: 1.34 g/kg; 2003: 1.84 g/kg) had the lowest sediment levels in spring runoff ($p < 0.001$), which were 70% lower than in runoff from the no-manure plots (2002: 4.44 g/kg; 2003: 6.31 g/kg). Also, sediment concentrations were lower in fall runoff compared with spring runoff but were generally unaffected by manure application. Mueller et al. (1984) reported a 55% reduction in the sediment concentration of runoff from no-till plots that received spring manure compared with those that received no manure (0.29 vs. 0.60 g/L). They also observed that beneficial effects due to manure addition in lowering sediment concentration persisted even later in the season (August), but the difference was not statistically significant. A more recent study by Bundy et al. (2001) found sediment concentrations from no-till plots that were within the range observed in this study (0.6–4.3 g/L) and their results showed the same seasonal effect as reported by Mueller et al. (1984) and observed in this study.

Sediment Load

Sediment loss reductions accompanied increases in crop residue cover (Fig. 4) and trends mirrored those

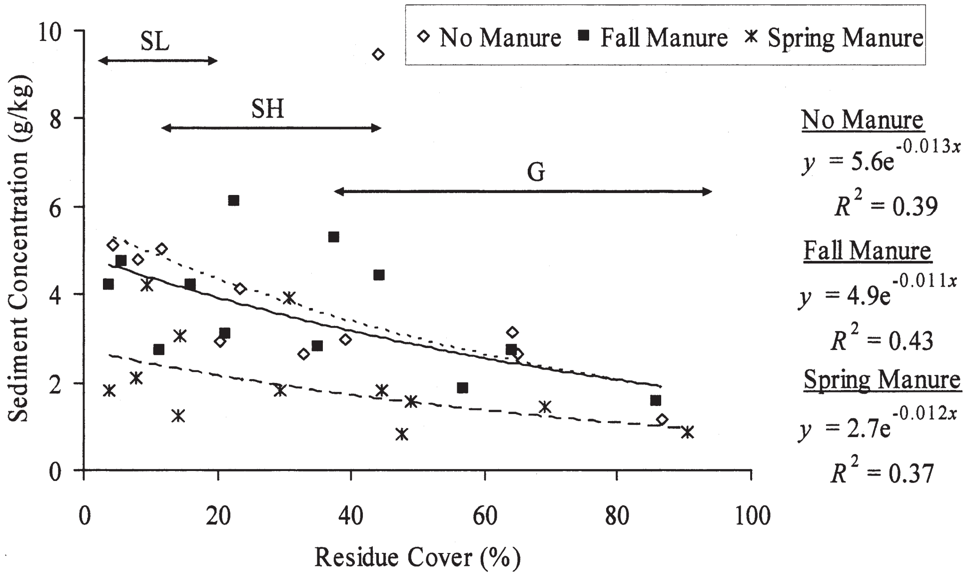


Fig. 3. Effect of crop residue cover (%) on sediment concentration for three manure treatments. Data points are an average of four replicates from each of the four seasons. Residue cover ranges for the three harvesting schemes (G, grain; SH, high-cut silage; SL, low-cut silage) are highlighted. For clarity, confidence intervals were not plotted.

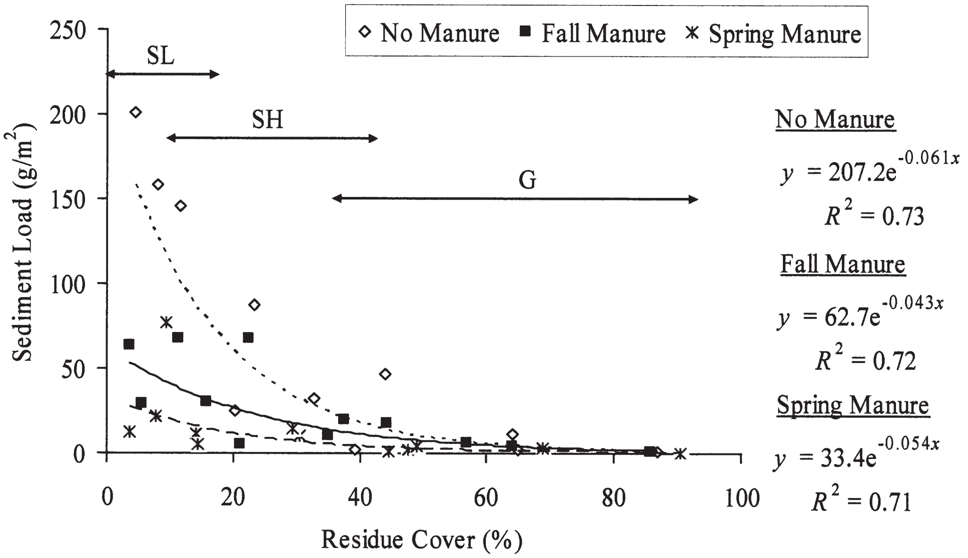


Fig. 4. Effect of crop residue cover (%) on sediment load in runoff for three manure treatments. Data points are an average of four replicates from each of the four seasons. Residue cover ranges for the three harvesting schemes (G, grain; SH, high-cut silage; SL, low-cut silage) are highlighted. For clarity, confidence intervals were not plotted.

for runoff volume. Similar to runoff, below about 22% residue cover, differences between the no manure and spring or fall manure models were significant; above that point, the 95% confidence intervals began to overlap. A more pronounced residue effect on sediment loss, including differences between SH and SL, was observed for fall runoff (Table 5). In fall 2002, sediment export exceeded 68 g/m^2 from SL plots, ranged from 10 to 33 g/m^2 for SH, and was 4 g/m^2 or less for G. Although the magnitudes of sediment loss were lower in 2003, a similar inverse relationship with residue cover was evident. In spring 2002, high crop residue level (G) caused a >91% reduction in sediment loss compared with SL and SH when either no or fall manure had been applied. Otherwise, the differences in sediment losses between harvesting methods were not statistically significant for spring runoff.

Manure application and timing had a significant effect on sediment export, but only for spring runoff. Silage plots that received manure most recently (in the spring) experienced the lowest loss while those receiving no manure had the highest (Table 5). Spring-applied manure lowered sediment export from SH and SL by 84 to 93% in 2002 and 2003 compared with plots at the same residue level but receiving no manure. In 2003, manure applied in the spring reduced sediment loss from G by 91%; otherwise, manure had no effect on sediment losses from G. Similar to runoff reductions, higher residue levels associated with G were sufficient to lower sediment loads and any additional benefits attributed to manure were less noticeable. Sediment loss in fall runoff was not significantly affected by manure application history, reflecting the dominating effect of high residue levels. Overall, sediment losses in spring runoff were similar to fall 2002 ($p = 0.10$) but greater than fall 2003.

Although differences in sediment losses between SH–N and SL–N were not significant in any of the four seasons, manure applied to SH plots often lowered the sediment load in runoff compared with SL–N. For example, spring-applied manure affected the sediment load in all four seasons, lowering it by 85 to 97%, while fall manure reduced the sediment load by 97% in spring 2003 and 86% in fall 2002. As noted earlier for runoff volume, increased residue in combination with the application

Table 5. Average sediment load in runoff for each treatment.

Treatment†		Sediment load‡			
Residue	Manure	Spring 2002	Spring 2003	Fall 2002	Fall 2003
		g/m^2			
G	N	11.7 ± 8.9 bc§	47.1 ± 23.8 abcd	2.0 ± 1.6 c	1.1 ± 1.0 bc
SH	N	146.3 ± 44.8 a	87.9 ± 41.0 ab	32.7 ± 25.2 ab	1.8 ± 1.3 abc
SL	N	200.5 ± 187.9 a	158.0 ± 59.4 a	72.0 ± 43.6 a	24.6 ± 15.2 a
G	F	5.8 ± 8.8 c	19.5 ± 19.9 de	4.1 ± 4.4 bc	1.2 ± 1.9 bc
SH	F	67.9 ± 57.4 ab	5.1 ± 0.8 de	10.0 ± 8.2 bc	17.3 ± 21.8 ab
SL	F	63.1 ± 47.6 ab	28.9 ± 14.3 abde	68.0 ± 8.2 a	30.0 ± 29.7 a
G	S	2.3 ± 1.5 c	4.0 ± 5.8 e	3.4 ± 4.6 bc	0.1 ± 0.05 c
SH	S	11.2 ± 7.1 bc	14.2 ± 4.4 de	10.8 ± 6.7 bc	0.7 ± 0.6 bc
SL	S	12.6 ± 16.7 bc	21.5 ± 18.4 bde	77.6 ± 18.7 a	5.7 ± 4.2 ab

† G, grain; SH, high-cut silage; SL, low-cut silage; N, no manure; F, fall manure; S, spring manure.

‡ Average of four replicates.

§ Numbers in each column followed by the same letter are not significantly different at the 0.05 probability level; letters correspond to nonparametric analysis based on data ranks rather than mean and standard deviation as shown.

of manure helps to exceed a threshold level at which differences in sediment loss between SH and SL are detectable. Since sediment concentrations in runoff from SH–S and SH–F were not different from SL–N, sediment load reductions following manure application are due to differences in runoff volume.

Due to the strong dependence on runoff volumes, a stronger inverse relationship was observed between percent residue cover and sediment load (Fig. 4) than between percent residue cover and sediment concentration. Others have also reported that increasing residue levels decrease sediment in runoff. Baker and Laflen (1982) reported a significant reduction in erosion, from 11.4 to 0.8 Mg/ha, when corn residue level was increased from 0 to 1500 kg/ha. Andraski et al. (1985) noted that surface residue coverage appeared to be a dominant factor in determining soil losses among tillage systems, but that inconsistencies in losses between seasons and years suggested that other soil characteristics might also influence sediment losses. In general, our study showed that spring manure addition resulted in the lowest sediment loss. Bundy et al. (2001) observed that surface residue cover and sediment loads were inversely related and manure generally lowered sediment export. They reported that sediment yields from no-till plots receiving manure were 8 and 125 kg/ha in May and September, respectively, compared with 438 and 855 kg/ha when no manure was applied. Our results and the work of others indicate that surface-applied manure can play a significant role in reducing sediment export.

Aggregate Size Distribution

The percentage of total sediment mass (dry basis) observed for each size class, averaged over the four seasons, is depicted in Fig. 5. Spring-applied manure had a significant effect on the size distribution, especially when combined with the higher residue levels (G and SH). The percentage of sediment in the 0- to 2-μm fraction was highest in runoff from G–S compared with all other residue–manure treatment combinations, except for SH–S, which was not statistically different. The clay-sized fraction represented 47% of the total sediment mass when spring manure was added to G compared with 15 to 23% when either no or fall manure was applied to any residue level treatment. Spring-applied manure also increased the clay-sized fraction from SH plots compared with SH–N and SL–N. Increases in fines following spring manure addition were offset by reductions in the more coarse 50- to 500- and 10- to 50-μm fractions. These fractions had a narrow range, 12 to 16% (50–500 μm) and 46 to 53% (10–50 μm), particularly when either no or fall manure was applied (Fig. 5). The 2- to 10-μm fraction was the least variable, with a range of 17 to 19%, and was not affected by either the residue level or manure application. Consisting mostly of crop residue and organic debris, the >500-μm fraction was not a significant contributor of sediments (<1%) and is barely detectable in Fig. 5. Partitioning of sediments among the size classes was not affected by residue level. The high residue treatment (G) had less sediment in the 50- to 500- and 10- to 50-μm fractions, and more in the 0- to 2-μm fraction compared with either silage treatment; however, these differences were not significant (Fig. 5). Interestingly, the size distributions of sediment from the SH and SL plots with the same manure treatment were almost identical.

Examining interrill erosion from mostly silt loam soils, Meyer et al. (1980) found that most undispersed sediment was in the coarse silt range. A majority of those soils had 50 to 60% of the sediment in this range while a few had >75%. These results are consistent with the current study. However, compared with the current study, they observed a slightly higher percentage of sediment in the sand-sized fractions and a much lower percentage of sediment in the <4-μm fraction (3.4–12.4%). A steeper slope, 20% compared with 4% in this study,

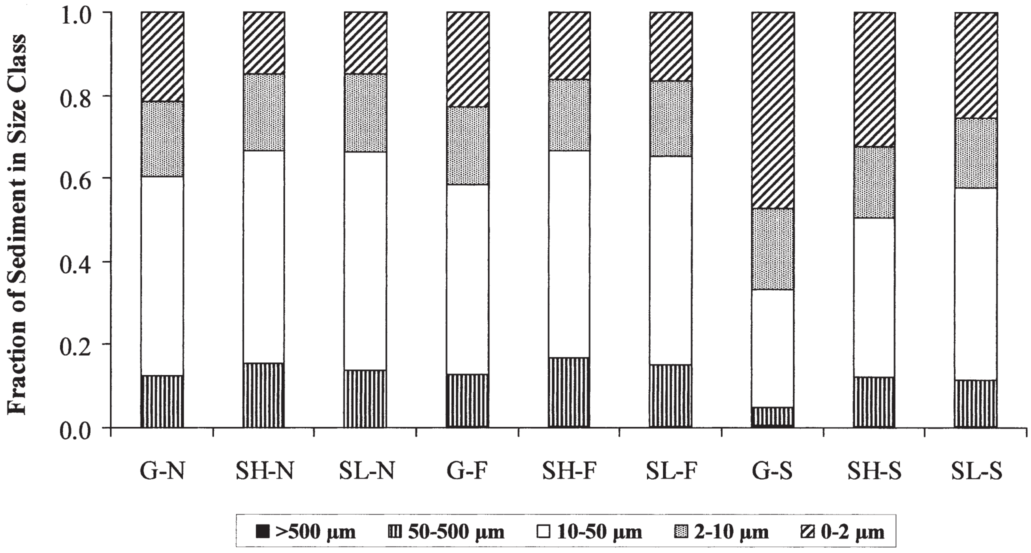
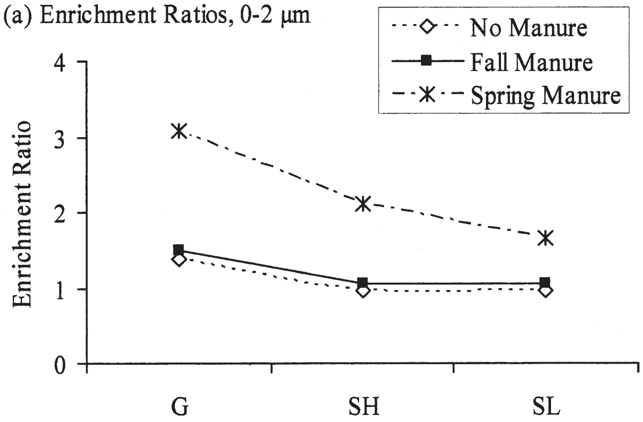


Fig. 5. Particle size distribution of sediments for nine treatments (G, grain; SH, high-cut silage; SL, low-cut silage; N, no manure; F, fall manure; S, spring manure). Each bar represents a composite distribution of 10 to 16 replicates, based on the number of available samples, averaged over the four seasons.

could account for more sediment in the sand size range due to a greater runoff velocity and a higher transport capacity. Other studies (Alberts et al., 1980, 1981) in addition to the one by Meyer et al. (1980) found much lower amounts of undispersed clay in runoff, most likely due to cohesive forces between soil particles that prevent detachment of the smallest particles (Young, 1980). It is possible that higher residue cover (Alberts and Moldenhauer, 1981) or differences in the site conditions, soil type, organic matter, soil mineralogy, and runoff sample collection protocol could have caused this divergence in the relative amount of sediment in the clay-sized fraction.

Finally, enrichment ratios (Pierzynski et al., 2000) were calculated by comparing the percentage of sand-, silt-, and clay-sized sediments to the matrix silt loam soil composed of 11.2% sand (>50 µm), 73.5% silt (2–50 µm), and 15.3% clay (<2 µm). Residue level did not affect the enrichment ratios under the no and fall manure regimens (Fig. 6). As the residue level varied, enrichment ratios for the clay- and sand-sized fractions ranged from 0.97 to 1.49, but differences between residue levels were not significant in either fraction. The silt-sized fraction, with an enrichment ratio slightly less than 1 (data not shown), was not affected by residue level or manure application. Spring-applied manure had the greatest effect on the enrichment ratios, particularly for the clay-sized fraction (Fig. 6). The enrichment ratio for the 0- to 2-µm fraction was significantly higher for G–S compared with all other treatment combinations except for SH–S. Spring manure produced concomitant reductions in the enrichment ratio of the sand (50–500 µm) fraction (Fig. 6). The results suggest that higher residue levels, especially when combined with recently surface-applied manure, can lead to enrichment in the clay-sized fraction of runoff sediment.

(a) Enrichment Ratios, 0-2 µm



(b) Enrichment ratios, 50-500 µm

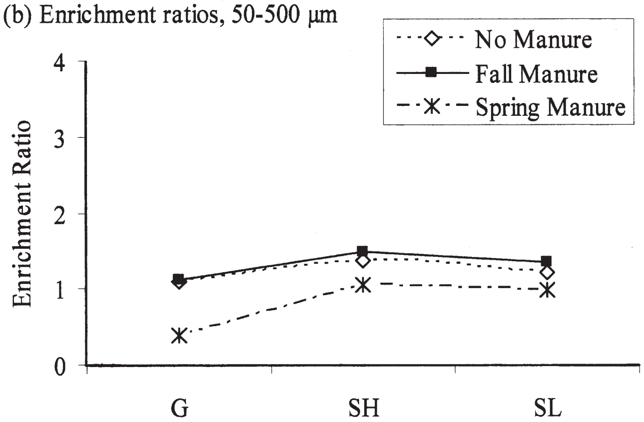


Fig. 6. Effect of manure application timing and harvesting method (G, grain; SH, high-cut silage; SL, low-cut silage) on enrichment ratios of the (a) clay-sized and (b) sand-sized fractions. Data points are an average of 9 to 16 replicates with samples from each of the four seasons.

CONCLUSIONS

Crop residue level and manure application can significantly affect runoff generation and sediment losses. These amendments provide a protective surface layer that helps shield soil particles from detachment. Furthermore, surface-applied manure provides additional cover and is capable of improving soil characteristics that promote infiltration. Residue and manure help to lower sediment losses by reducing runoff volume and, consequently, its transport capacity. However, no-till croplands with higher residue levels and receiving surface-applied manure may be more vulnerable to nutrient losses due to enrichment in the clay-sized sediment fraction.

Increases in residue cover achieved by raising the silage cutting height conferred benefits compared with conventional silage harvesting only when manure was added. They included reductions in runoff and sediment losses that were greatest immediately after harvesting when residue levels were at their highest. Interestingly, the sediment concentrations were similar for SH and SL under all treatment combinations and seasons. Similar to residue cover effects, beneficial aspects of surface-applied manure were greatest immediately after application and diminished over time. Manure often interacted with crop residue levels to reduce runoff and sediment loads. Apparently, additional residue resulting from manure application exceeded a threshold cover level above which differences were observed between the two silage treatments. Finally, differences in crop residue level between the silage treatments had no impact on the aggregate size distribution of sediments under no or fall manure conditions while spring-applied manure combined with higher residue levels increased the percentage of sediment in the 0- to 2-µm fraction. As acreage of corn harvested for silage increases, manure management may offer the potential to lower runoff and sediment losses. Surface-applied manure combined with higher residue, achieved by increasing silage cutting height, can provide short-term environmental benefits.

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