July 1998

Runoff and Erosion Following Field Application of Beef Cattle Manure and Compost

John E. Gilley
University of Nebraska-Lincoln, john.gilley@ars.usda.gov

Bahman Eghball
University of Nebraska-Lincoln

RUNOFF AND EROSION FOLLOWING FIELD APPLICATION OF BEEF CATTLE MANURE AND COMPOST

J. E. Gilley, B. Eghball

ABSTRACT. *Manure or compost from beef cattle feedlots can be excellent sources of nutrients and organic matter when added to soils. This study was conducted to determine the effect of a single application of manure and compost on runoff and erosion under no-till and tillage conditions. Tillage consisted of a single disking operation up and down the slope on a Sharpsburg soil which was cropped to grain sorghum or wheat the previous season. Manure and compost were applied at rates required to meet corn fertility requirements. Additional experimental treatments included the application of inorganic fertilizer and an untreated check. The addition of manure or compost to the no-till plots containing sorghum or wheat residue resulted in significant reductions in residue cover. However, residue cover following tillage was unaffected by the earlier addition of manure or compost. Runoff and erosion from simulated rainfall were not significantly influenced by the single application of manure or compost. On the no-till sorghum residue treatments, total solids transport represented 5.1% and 3.3% of the mass of applied manure and compost, respectively. Total solids transport was 1.3% and 1.4% of the mass of applied manure and compost, respectively, on the no-till wheat residue treatments.*
Keywords. *Beef cattle, Compost, Erosion, Manure, Manure runoff, No-till systems, Runoff.*

Beef cattle manure is a resource which can be effectively utilized for crop production and soil improvement. Manure contains salt and nutrients which are essential for plant growth. Soil organic matter (an ion exchange material, chelating agent and buffering material important in soil aggregation) can also be increased by the addition of manure or compost (Eghball and Power, 1994).

Composting manure is a useful method of producing a stabilized product that can be stored or spread with little odor problem (Sweeten, 1988). The composting process occurs through biological action and spontaneous chemical reactions that produce heat. Other advantages of composting include the destruction of pathogens and weed seeds, and improved handling characteristics by reducing the volume and weight of material (Willson and Hummel, 1975).

Manure and compost should be managed and applied at rates that do not adversely affect the environment. A significant increase in salt and nutrients may occur in soils as a result of manure or compost application in excess of crop requirements (Vitosh et al., 1973). The excessive accumulation of salt and nutrients may also increase the potential for groundwater contamination (Mathers et al., 1975).

Runoff loss of solids and nutrients which contributes to pollution in surface water may occur from fields receiving manure or compost. The amount of runoff is influenced by soil and cropping management practices, and timing, rate, and method of manure or compost application (Khaleel et al., 1980). Runoff events occurring soon after application may result in nutrient loss. Incorporation of manure or compost after application conserves nutrients and improves soil physical properties as compared to surface application.

The reduction in surface cover caused by tillage can increase erosion potential. When surface residue is limited, it may not be possible to incorporate manure and compost and still maintain an effective residue cover. Few experiments have been conducted where manure or compost have been applied to soils under no-till cropping conditions.

No-till cropping systems are now used extensively to reduce soil loss, improve soil drainage, and decrease labor costs. No-till farming systems leave the previous year's crop residue undisturbed, and planting occurs on the undisturbed surface. No-till farming has been found to be an effective erosion control measure (McGregor and Greer, 1982; Van Doren et al., 1984; Pesant et al., 1987; Dabney et al., 1993; King et al., 1995). The soil erosion benefit obtained from no-till farming may be offset by the increased potential for nutrient loss resulting from surface application of manure or compost.

Mitchell and Gunther (1976) conducted a laboratory study to measure runoff and erosion from small plots on which liquid swine manure had been applied. The liquid manure provided a stabilizing effect on the soil surface, resulting in reduced rates of runoff and erosion.

The effects of incorporated cattle manure on water intake into grain sorghum [*Sorghum bicolor* (L.) Moench] plots was examined by Mathers et al. (1977). They found the advance of irrigation water in graded furrows was

Article was submitted for publication in November 1997; reviewed and approved for publication by the Soil & Water Div. of ASAE in July 1998.

This article is a contribution from USDA-ARS in cooperation with the Agricultural Research Division, University of Nebraska, Lincoln, and is published as Journal Series No. 11837.

The authors are **John E. Gilley,** ***ASAE Member Engineer,*** Agricultural Engineer, USDA-ARS, and **Bahman Eghball,** Assistant Professor, Department of Agronomy, University of Nebraska, Lincoln; **Corresponding author:** John E. Gilley, USDA-ARS, University of Nebraska, 251 L. W. Chase Hall, Lincoln, NE 68583-0934; voice: (402) 472-2975; fax: (402) 472-6338; e-mail: jgilley@unlinfo.unl.edu.

slower and water intake greater on manure-treated plots. Chandra and De (1982) conducted a laboratory study to measure erosion from soils on which cattle manure had been applied. They found that after a 30-day incubation period, erosion was reduced on soils where manure had been incorporated. Soil and water losses from small corn (*Zea mays* L.) plots on which dairy manure had been applied were measured by Mueller et al. (1984). The application of manure reduced soil losses.

Giddens and Barnett (1980) used a rainfall simulator to study the effects of the application of poultry litter on runoff and soil loss. Runoff and soil loss were substantially reduced by litter application on fallow soil, and runoff was much less on grassed sod. Erosion from laboratory test plots on which poultry manure had been applied was measured by Westerman et al. (1983). Erosion rates were influenced by manure characteristics, loading rates, incorporation, and the time between application and the first rainfall.

Edwards and Daniel (1993) used a rainfall simulator to measure runoff from fescue plots (*Festuca arundinacea* Schred) receiving poultry litter. No significant differences in runoff were found between the check and poultry litter treatments. Simulated rainfall was also used by Edwards et al. (1994) to measure the transport of solids from poultry litter applied to fescue. Solid yields increased with both litter application rate and simulated rainfall intensity. The objective of this study was to determine the effect of a single application of beef cattle manure or compost on runoff and erosion under no-till and tillage conditions.

MATERIALS AND METHODS

This study was conducted at the University of Nebraska Rogers Memorial Farm in Lancaster County, approximately 18 km east of Lincoln, Nebraska. The Sharpsburg soil (fine montmorillonitic, mesic, *Typic Argiudoll*) at the site formed on loess under prairie vegetation. The soil consisted of 11% sand, 54% silt, and 35% clay.

The investigation occurred on an area that had been cropped for several years as part of a no-till management system which used a grain sorghum [*Sorghum bicolor* (L.) Moench], soybean [*Glycine max* (L.) Merr], winter wheat (*Triticum aestivum* L.) rotation. The experimental methods were selected to simulate conditions that exist in the spring when manure, compost or fertilizer are typically applied. On the no-till plots, the manure, compost, and fertilizer were left undisturbed on the soil surface. A single disking operation to a depth of approximately 8 cm was performed up and down the slope on the tilled treatments to incorporate the manure, compost, and fertilizer. The disking operation was the first tillage which occurred on the study site in several years. Erosion occurring from areas where tillage has been performed up and down the slope represents a soil loss extreme. Differences between no-till and tilled conditions would be most likely to occur under this tillage condition.

A portable rainfall simulator based on a design by Swanson (1965) was used to apply rainfall simultaneously to two plots. Each 3.7 m wide × 10.7 m long plot was established using sheet metal borders. The plots were covered with plastic between the initial and wet runs to eliminate the input of natural rainfall into the system.

An initial 1-h rainfall application at an intensity of approximately 64 mm h^{-1} occurred over the entire plot area at existing soil-water conditions. A second one-hour application (wet run) was conducted approximately 24 h later. A 64 mm rainfall of one hour duration in this area would have a recurrence interval of approximately once every 10 years (Hershfield, 1961). Thus, the testing routine used in this study represents an extreme condition, since two 64 mm h^{-1} rainfall simulation events were applied within approximately a 24-h period.

A trough extending across the bottom of each plot gathered runoff, which was measured using a flume with stage recorder. Runoff samples were collected in plastic bottles at 5-min intervals from each trough. The plastic bottles were later placed in an oven maintained at a temperature of approximately 106°C. This temperature was not great enough to significantly affect the solid material contained in the manure or compost. Both sediment and manure or compost remained in the plastic bottles following drying. Since the solid material transported from the plots was a fraction of the mass of applied manure or compost, solid materials transported in runoff were reported simply as erosion.

Colored slides were taken at three locations (top, middle, and bottom) on each plot following completion of the two rainfall simulation runs. The resulting slides were then projected onto a screen containing a grid and the number of residue elements intersecting the grid points were determined (Mannering and Meyer, 1963). The ratio of intersection points over total grid points times 100 was the percentage of the soil surface covered by residue.

SORGHUM RESIDUE STUDY

The investigation using sorghum residue occurred in July and August 1996. Except for herbicide application to maintain weed control, the study area was left undisturbed and fallow following sorghum harvest in the fall of 1995. Due to decomposition and weathering, sorghum residue cover at the time of testing would have been expected to have been less than that present in the spring when application of manure would typically occur.

This study was conducted as a split plot each with three replications (36 total plots). Main plots consisted of no-till and tilled conditions and subplots included the following treatments (application rates are all reported on a dry weight basis): (1) Manure applied at a rate of 49.4 Mg ha^{-1} to meet corn N requirements; (2) Manure applied at a rate of 11.5 Mg ha^{-1} to meet corn P requirements plus 104 kg N ha^{-1}; (3) Compost applied at a rate of 126 Mg ha^{-1} to meet corn N requirements; (4) Compost applied at a rate of 24.7 Mg ha^{-1} to meet corn P requirements plus 116 kg N ha^{-1}; (5) Inorganic commercial fertilizer applied at rates of 151 kg N ha^{-1} and 26 kg P ha^{-1} as 18-20-0 (N, P, K); and (6) Untreated (check). The manure, compost, and fertilizer were applied by hand just before the rainfall simulation tests at the approximate rates required to produce a corn crop with a target yield of 9.4 Mg ha^{-1}.

It was recognized that the relatively small amounts of inorganic commercial fertilizer applied in this study could have only a minimal impact on runoff and erosion. However, this important source of nutrients was included as an experimental treatment so it could be compared with manure and compost.

Manure and compost had total N contents of 0.76% and 0.60%, and total P contents of 0.45% and 0.29%, respectively. When compared to manure, the composting operation in 1996 resulted in a reduced concentration of N and P. It was assumed that the plant N availability of manure and compost was 40% and 20%, respectively, during the year of application (Gilbertson et al., 1979). In contrast, the P availability of both manure and compost was assumed to be 50%.

Wheat Residue Study

The investigation involving wheat residue was conducted in July and August 1997. The study area was left undisturbed and fallow following wheat harvest during the summer of 1996, except for the application of herbicide to maintain weed control. Considerable decomposition and weathering of the residue material appeared to have occurred between wheat harvest and the simulation tests.

A split plot with three replications (24 total plots) was used in this investigation. Main plots consisted of no-till and tilled conditions and subplots included the following treatments (application rates are all reported on a dry weight basis): (1) Manure applied at a rate of 47.7 Mg ha^{-1} to meet corn N requirements; (2) Compost applied at a rate of 77.5 Mg ha^{-1} to meet corn N requirements; (3) Inorganic commercial fertilizer applied at a rate of 151 kg N ha^{-1}; and (4) Untreated (check).

The manure, compost, and fertilizer were applied by hand just before the rainfall simulation tests at the approximate rates required to produce a corn crop with a target yield of 9.4 Mg ha^{-1}. A variety of crops could have been chosen to follow wheat. Corn was selected because it is grown extensively in the area and it has a relatively large nutrient requirement. By applying greater amounts of manure, compost, or fertilizer, there was an increased opportunity to show a treatment response in this study.

The manure and compost had total N contents of 0.79% and 0.98%, respectively. In contrast to 1996, the N content of the compost produced in 1997 was greater than that of the manure. The animal stocking rate, ration, amount of soil removed, and other factors may influence the characteristics of manure and compost.

The amount of manure or compost needed to provide P requirements is substantially less than that necessary for N requirements. Some difficulty was encountered in obtaining a treatment response in 1996 to the addition of manure or compost for meeting corn P requirements. As a result, the experimental treatments involving manure or compost application to meet P requirements were not included in the 1997 study using wheat residue.

Results and Discussion

Duncan's multiple range test was used to identify possible tillage effects on residue cover, runoff, and erosion (table 1). In general, residue cover and erosion were both found to be significantly influenced by tillage. Thus, separate statistical analyses were conducted for the individual experimental treatments under both no-till and tilled conditions (tables 2, 3, and 4).

Table 1. Tillage effects on residue cover, runoff, and erosion for selected experimental treatments

Residue Type	Residue Cover (%)*	Initial Run: Runoff (mm)	Initial Run: Erosion (Mg ha^{-1})	Wet Run†: Runoff (mm)	Wet Run†: Erosion (Mg ha^{-1})
Sorghum					
No-till	46 a	11 a	1.0 b	31 a	1.8 b
Tillage	23 b	10 a	3.2 a	30 a	8.1 a
Wheat					
No-till	65 a	8 a	0.3 a	25 b	0.6 b
Tillage	17 b	10 a	1.3 a	40 a	7.6 a

* For a given residue type, differences in residue cover, runoff, and erosion are significant at the 10% level (Duncan's multiple range test) if followed by a different letter.

† Metric to English unit conversion: 25.4 mm = 1 in.; 2.24 Mg/ha = 1 ton/acre.

Table 2. Residue cover for selected experimental treatments*

Residue Type	Treatment†	Residue Cover (%): No-till‡	Residue Cover (%): Tilled
Sorghum	Check	56 a	25 a
Sorghum	Fertilizer	56 a	25 a
Sorghum	Manure P	50 ab	22 a
Sorghum	Manure N	43 b	24 a
Sorghum	Compost P	50 ab	24 a
Sorghum	Compost N	23 c	20 a
Wheat	Check	80 a	18 a
Wheat	Fertilizer	75 ab	14 a
Wheat	Manure N	59 bc	18 a
Wheat	Compost N	45 c	18 a

* Values given are the average of nine measurements.

† P (Manure or compost applied to meet phosphorous requirements).
N (Manure or compost applied to meet nitrogen requirements).

‡ For a given residue type and tillage condition, differences in residue cover are significant at the 10% level (Duncan's multiple range test) if followed by a different letter.

Table 3. Runoff and erosion for the initial and wet rainfall simulation runs on the sorghum residue*

Tillage	Treatment†	Initial Run: Runoff‡ (mm)	Initial Run: Erosion§ (Mg ha^{-1})	Wet Run: Runoff (mm)	Wet Run: Erosion (Mg ha^{-1})
No-till	Check	7 a	0.6 a	23 a	1.4 b
No-till	Fertilizer	10 a	0.4 a	25 a	0.7 b
No-till	Manure P	13 a	1.4 a	29 a	1.3 b
No-till	Manure N	13 a	1.0 a	38 a	1.5 b
No-till	Compost P	13 a	1.2 a	38 a	2.9 a
No-till	Compost N	9 a	1.3 a	32 a	2.8 a
Tilled	Check	6 ab	2.5 a	22 a	5.3 b
Tilled	Fertilizer	13 ab	4.1 a	35 a	9.9 ab
Tilled	Manure P	4 b	0.9 a	23 a	6.1 ab
Tilled	Manure N	13 ab	4.4 a	37 a	12.1 a
Tilled	Compost P	10 ab	3.1 a	36 a	8.6 ab
Tilled	Compost N	14 a	4.1 a	29 a	6.6 ab

* Values given are the average of three replications. Runs lasted for a 60-min duration. Average rainfall intensity was 64 mm/h.

† P (Manure or compost applied to meet corn phosphorous requirements).
N (Manure or compost applied to meet corn nitrogen requirements).

‡ For a given tillage condition and rainfall simulation run, differences in runoff and erosion are significant at the 10% level (Duncan's multiple range test) if followed by a different letter.

§ Metric to English unit conversion: 25.4 mm = 1 in.; 2.24 Mg/ha = 1 ton/acre.

Table 4. Runoff and erosion from the initial and wet rainfall simulation runs on the wheat residue*

Tillage	Treatment	Initial Run Runoff† (mm)	Initial Run Erosion‡ (Mg ha^{-1})	Wet Run Runoff (mm)	Wet Run Erosion (Mg ha^{-1})
No-till	Check	9 a	0.3 ab	27ab	0.6 ab
No-till	Fertilizer	8 a	0.3 ab	27ab	0.8 a
No-till	Manure	7 a	0.2 b	20 b	0.4 b
No-till	Compost	9 a	0.4 a	28 a	0.7 a
Tilled	Check	12 a	1.4 a	42 a	8.8 a
Tilled	Fertilizer	7 a	0.8 a	40 a	6.3 a
Tilled	Manure	10 a	1.4 a	37 a	8.4 a
Tilled	Compost	11 a	1.6 a	39 a	6.8 a

* Values given are the average of three replications. Runs lasted for a 60-min duration. Average rainfall intensity was 64 mm/h.

† For a given tillage condition and rainfall simulation run, differences in runoff and erosion are significant at the 10% level (Duncan's multiple range test) if followed by a different letter.

‡ Metric to English unit conversion: 25.4 mm = 1 in.; 2.24 Mg/ha = 1 ton/acre.

Sorghum Residue Study

The mean value of the slope gradient for the sorghum residue study was 7%, while individual plots had slopes which ranged from 5% to 9%. Slope gradients varied little within a given experimental block.

Residue cover ranged from 17% to 65% on the no-till treatments, and 16% to 30% on the tilled plots. Mean residue covers for the no-till and tilled treatments were 46% and 23%, respectively (table 1). Thus, the single disking operation caused mean sorghum residue cover to be reduced by 50%. This value was similar to the 40% reduction estimated by Colvin and Gilley (1987) following disking of sorghum residue.

The application of manure (49.4 Mg ha^{-1}) or compost (126 Mg ha^{-1}) to meet corn N requirements on the no-till plots resulted in significant reductions in residue cover (table 2). No significant differences in residue cover were found between the check and the no-till plots where smaller rates of manure (11.5 Mg ha^{-1}) or compost (18.0 Mg ha^{-1}) were applied to meet corn P requirements.

The placement of relatively large quantities of manure or compost on the soil surface caused some of the residue to be buried. The disking operation resulted in an inversion and mixing of the manure, compost, and residue materials. As a result, no significant differences in residue cover were found between the tilled plots regardless of the fertility treatment (table 2).

For both the initial and wet rainfall simulation runs, similar amounts of runoff were measured on the no-till and tilled treatments (table 1). The sorghum residue cover remaining following tillage was large enough to help maintain infiltration rates similar to those occurring under no-till conditions. When the individual experimental treatments were examined under no-till and tilled conditions during both rainfall simulation runs (table 3), the application of manure or compost did not significantly affect runoff.

Tillage of the soil surface resulted in a significant increase in erosion during both the initial and wet rainfall simulation runs (table 1). The reduction in surface cover caused by tillage can have a substantial impact on erosion. The fact that tillage can significantly affect erosion is well documented (Laflen et al., 1978; Cogo et al., 1984; and Yoo et al., 1987).

During the initial run on both the no-till and tilled plots, erosion measurements were similar between experimental treatments (table 3). However, a significant difference in erosion was found during the wet run between the no-till compost plots and the other no-till treatments. Reduced surface cover resulting from the addition of compost may have influenced erosion. In addition, the composted material may have been easier to detach and transport than either soil or manure.

Erosion during the wet run on the tilled manure N treatment was significantly greater than the check. Most of the increase was contributed by a single plot. With the exception of the check and manure N treatment, no significant differences in erosion were found between the tilled sorghum residue treatments during the wet run.

Erosion measurements from the sorghum residue plots can be used to obtain a relative estimate of the amount of manure or compost transported in runoff. To meet nitrogen requirements for corn production, manure and compost were applied at rates of 49.4 and 126 Mg ha^{-1}, respectively. Total erosion during both the initial and wet rainfall simulation runs on the no-till manure N and compost N treatments was 2.5 Mg ha^{-1} and 4.1 Mg ha^{-1}, respectively (table 3). If all of the solids transport were manure or compost, this would represent 5.1% and 3.3% of the amount of manure or compost, respectively, which was applied.

Wheat Residue Study

Slopes varied from 4% to 7% on individual plots within the wheat residue study, while the mean value of the slope gradient was 6%. Residue cover ranged from 36% to 84%, and 11% to 24% on the no-till and tilled plots, respectively. Mean residue covers for the no-till and tilled treatments were 65% and 17%, respectively (table 1). The single disking operation caused mean residue cover to be reduced by 74%.

A significant reduction in residue cover resulted from the application of manure (47.7 Mg ha^{-1}) or compost (77.5 Mg ha^{-1}) on the no-till wheat residue treatments (table 2). For the tilled wheat residue plots, no significant differences in residue cover were found among experimental treatments. Following disking, the earlier addition of manure or compost did not appear to influence residue cover.

When runoff measurements for the individual treatments were combined, no significant differences were found between the no-till and tilled treatments for the initial rainfall simulation runs (table 1). However, significantly more runoff occurred on the tilled treatments during the wet run. The reduced wheat residue cover resulting from tillage may have caused greater surface sealing and increased runoff. The application of manure or compost did not significantly affect runoff when the individual experimental treatments were examined under both no-till and tilled conditions during the initial and wet rainfall simulation runs (table 4).

A significant increase in erosion resulted from tillage of the soil surface during the wet rainfall simulation run (table 1). The reduction in surface cover caused by tillage appeared to have a substantial impact on erosion. No significant differences in erosion were found between the check and the other experimental treatments during the initial and wet runs under both no-till and tilled conditions (table 4).

A relative estimate of the amount of manure or compost transported in runoff from the wheat residue plots can also be obtained from the erosion data. Manure and compost were applied at rates of 47.7 and 77.5 Mg ha^{-1}, respectively. During both the initial and wet rainfall simulation runs on the no-till manure and compost treatments, total erosion was 0.6 Mg ha^{-1} and 1.1 Mg ha^{-1}, respectively. This would represent 1.3% and 1.4% of the total amount of manure or compost, respectively, which was applied, if all the solids transported were manure or compost.

Runoff and erosion were measured in this study immediately after a single application of manure or compost. When manure or compost is applied to a site over a period of several years, the soil's physical characteristics may be changed substantially. Additional field testing is needed to determine the long-term effects of repeated applications of manure or compost on runoff and erosion.

Runoff and erosion were measured on a site which had a mean sorghum and wheat residue cover following tillage of 23% and 17%, respectively. This amount of sorghum and wheat residue would reduce erosion by approximately 80% and 40%, respectively, of the amount expected for bare soil conditions (Colvin and Gilley, 1987). Additional field testing is also needed to evaluate the effects of manure and compost application on runoff and erosion for conditions where little crop residue is available.

Summary and Conclusions

Following application, areas on which manure or compost are applied are frequently tilled to conserve nutrients and minimize surface water quality concerns. However, tillage may also substantially reduce residue cover thus increasing the potential for erosion. In this study, a rainfall simulator was used to measure runoff and erosion following a single application of manure or compost under no-till and tilled conditions.

Under no-till conditions, the application of manure or compost at rates needed to meet corn nitrogen requirements resulted in significant reductions in residue cover on sites containing sorghum and wheat residue. A single disking operation reduced mean residue cover on the sorghum and wheat residue plots by 50% and 74%, respectively. Applying manure or compost to an area that was later tilled did not significantly affect residue cover on sites containing either sorghum or wheat residue. In general, the application of manure or compost to sorghum or wheat residue did not significantly affect runoff or erosion under either no-till or tilled conditions.

Under no-till conditions, total solids transport was approximately 5.1% and 3.3% of the mass of manure or compost, respectively, which was applied to the sorghum residue treatments. On the no-till wheat residue treatments, 1.3% and 1.4% of the mass of applied manure and compost, respectively, was represented by solids transport. Since total solids transport may contain both sediment and manure or compost, the amount of manure or compost transported from the no-till plots under the extreme rainfall conditions used in this study was minimal. This fact serves to support the application of beef cattle manure and compost under no-till conditions. However, the transport of nutrients and pathogens in runoff must also be considered when evaluating manure and compost application under various tillage conditions.

References

Chandra, S., and S. K. De. 1982. Effect of cattle manure on soil erosion by water. *Soil Sci.* 133(4): 228-231.

Cogo, N. P., W. C. Moldenhauer, and G. R. Foster. 1984. Soil loss reductions from conservation tillage practices. *Soil Sci. Soc. Am. J.* 48(2): 368-373.

Colvin, T. S., and J. E. Gilley. 1987. Crop residue—soil erosion combatant. *Crops & Soils* 39(7): 7-9.

Dabney, S. M., C. E. Murphree, and L. D. Meyer. 1993. Tillage, row spacing, and cultivation affect erosion from soybean cropland. *Transactions of the ASAE* 36(1): 87-94.

Edwards, D. R., and T. C. Daniel. 1993. Abstractions and runoff from fescue plots receiving poultry litter and swine manure. *Transactions of the ASAE* 36(2): 405-411.

Edwards, D. R., T. C. Daniel, P. A. Moore, and A. N. Sharpley. 1994. Solids transport and erodibility of poultry litter surface—applied to fescue. *Transactions of the ASAE* 37(3): 771-776.

Eghball, B., and J. F. Power. 1994. Beef cattle feedlot manure management. *J. Soil Water Conserv.* 49(2): 113-122.

Giddens, J., and A. P. Barnett. 1980. Soil loss and microbiological quality of runoff from land treated with poultry litter. *J. Environ. Qual.* 9(3): 518-520.

Gilbertson, C. B., F. A. Norstadt, A. C. Mathers, R. F. Holt, I. R. Shyler, A. P. Barnett, T. M. McCalla, C. A. Onstad, R. A. Young, L. A. Christensen, and D. L. Van Dyne. 1979. Animal waste utilization on cropland and pastureland: A manual for evaluating agronomic and environmental effects. USDA Utilization Research Report No. 6. Washington, D.C.: USDA.

Hershfield, D. M. 1961. Rainfall frequency atlas of the United States. Weather Bureau Tech. Paper No. 40. Washington, D.C.: U.S. GPO.

Khaleel, R., K. R. Reddy, and M. R. Overcash. 1980. Transport of potential pollutants in runoff from land areas receiving animal wastes: A review. *Water Research* 14(5): 421-436.

King, K. W., D. C. Flanagan, L. D. Norton, and J. M. Laflen. 1995. Rill erodibility parameters influenced by long-term management practices. *Transactions of the ASAE* 38(1): 159-164.

Laflen, J. M., J. L. Baker, R. O. Hartwig, W. F. Buchele, and H. P. Johnson. 1978. Soil and water loss from conservation tillage systems. *Transactions of the ASAE* 21(5): 881-885.

Mannering, J. V., and L. D. Meyer. 1963. The effects of various rates of surface mulch on infiltration and erosion. *Soil Sci. Soc. Am. Proc.* 27(1): 84-86.

Mathers, A. C., B. A. Stewart, and B. Blair. 1975. Nitrate-nitrogen removal from soil profiles by alfalfa. *J. Environ. Qual.* 4(3): 403-405.

Mathers, A. C., B. A. Stewart, and J. D. Thomas. 1977. Manure effects on water intake and runoff quality from irrigated grain sorghum plots. *Soil Sci. Soc. Am. J.* 41(4): 782-785.

McGregor, K. C., and J. D. Greer. 1982. Erosion control with no-till and reduced-till corn for silage and grain. *Transactions of the ASAE* 25(1): 154-159.

Mitchell, J. K., and R. W. Gunther. 1976. The effects of manure applications on runoff, erosion and nitrate losses. *Transactions of the ASAE* 19(6): 1104-1106.

Mueller, D. H., R. C. Wendt, and T. C. Daniel. 1984. Soil and water losses as affected by tillage and manure application. *Soil Sci. Soc. Am. J.* 48(4): 896-900.

Pesant, A. R., J. L. Dionne, and J. Genest. 1987. Soil and nutrient losses in surface runoff from conventional and no-till systems. *Canadian J. Soil Sci.* 67: 835-843.

Swanson, N. P. 1965. Rotating boom rainfall simulator. *Transactions of the ASAE* 8(1): 71-72.

Sweeten, J. M. 1988. Composting manure and sludge. In *Proc. Nat. Poultry Waste Manage. Symp.*, 38-44. Columbus, Ohio: Ohio State University Press.

Van Doren, S. M., W. C. Moldenhauer, and G. B. Triplett. 1984. Influence of long-term tillage and crop rotation on water erosion. *Soil Sci. Soc. Am. J.* 48(3): 636-640.

Vitosh, M. L., J. F. Davis, and B. D. Knezek. 1973. Long-term effects of manure, fertilizer, and plow depth on chemical properties of soils and nutrient movement in monoculture corn system. *J. Environ. Qual.* 2(2): 296-299.

Westerman, P. W., T. L. Donnelly, and M. R. Overcash. 1983. Erosion of soil and poultry manure—A laboratory study. *Transactions of the ASAE* 26(4): 1070-1078, 1084.

Willson, G. B., and J. W. Hummel. 1975. Conservation of nitrogen in dairy manure during composting. In *Managing Livestock Wastes, Proc. 3rd Int'l. Symp. on Livestock Wastes*, 490-496, eds. F. R. Hore et al. St. Joseph, Mich.: ASAE.

Yoo, K. H., J. T. Touchton, and R. H. Walker. 1987. Effect of tillage on surface runoff and soil loss from cotton. *Transactions of the ASAE* 30(1): 166-168.