Soil and fecal coliform trapping by grass filter strips during simulated rain

M.S. Coyne, R.A. Gilfillen, R.W. Rhodes, and R.L. Blevins

ABSTRACT: Poultry production is increasing in Kentucky. The wastes produced are typically added to soil but surface runoff from agricultural soils treated with poultry waste may exceed water quality standards for fecal indicator bacteria and contribute to agricultural nonpoint-source pollution. While soil erosion in surface runoff is frequently managed by grass filter strips, this management practice may not be an equally effective control for fecal bacteria. We measured soil and fecal coliform trapping in surface runoff from two poultry manure-amended plots in a simulated rain study. The simulation reflected a worst-case event in which poultry waste application was followed by high intensity rain. Grass filter strips, 9 meters long, trapped more than 99% of the soil in surface runoff but fecal coliform trapping was less effective. The efficiency of fecal coliform removal from surface runoff was 74% and 43% in the two plots studied. Fecal coliforms in surface runoff always exceeded primary contact water standards of 200 fecal coliforms/100 mL. These data indicated that grass filter strips which adequately controlled sediment runoff were inadequate to bring surface water contaminated with fecal bacteria into compliance with current primary water contact standards.

Wastes produced in livestock production and processing facilities in Kentucky, particularly by an expanding poultry industry, are increasingly applied to agricultural soils (Kentucky Agricultural Statistics Service). Two important objectives accomplished by adding animal wastes to soil are disposal and nutrient recycling. The wastes are often added to soil in excess of plant nutrient uptake and in excess of the soil's capacity to recycle them in a timely manner. This degrades the environment and promotes bacterial contamination of groundwater, which is the principal drinking water source in rural Kentucky (Ilvento et al.).

Long-term waste storage is an effective method for decreasing bacterial concentrations (Walker et al.), but it is not a practical solution when storage facilities are limited. Incorporating wastes into soil is as effective as long-term storage, but more costly (Walker et al.). The interval between incorporation and potential runoff influences this practice; the longer the interval, the smaller the loss of waste constituents (Edwards and Daniel). Typically, the greatest loss is in the first runoff following waste application (Edwards and Daniel).

Runoff from agricultural land is usually studied in the context of soil erosion and is controlled by tillage (Blevins et al.) and other best management practices like grass filter strips (Gross et al.). Bacterial runoff studies have ranged in scale from watershed-sized areas (Baxter-Potter and Gilliland; Jawson et al.; Tiedemann et al.) to sites typical of point-source pollution in which vegetated filters receive runoff from feedlots (Dickey and Vanderholm; Young et al.). However, studies of bacterial runoff and edge-of-field effects are lacking. Walker et al. suggested that grass filter strips alone would not reduce bacterial concentrations enough to meet water quality goals, but indicated that no field data was available to validate this prediction.

As the poultry industry grows in Kentucky, poultry waste application to agricultural land will increase (Kentucky Agricultural Statistics Service). Since grass filters are one of the most accessible technologies to control surface runoff, and since we have extensive experience with grass filters as a management tool for soil erosion (Seta et al.), we decided to examine whether grass filters are an adequate management practice to control both bacteria and soil runoff from poultry waste-amended fields. The objective of this study was to obtain field data to determine if fecal coliform trapping by grass filter strips intercepting runoff from a poultry-manured soil was comparable to soil trapping from the same runoff.

Materials and methods

Location. We did our experiment at the University of Kentucky Agricultural Experiment Station in Lexington during June and July, 1992. The soil was a Maury silt loam soil (fine, mixed, mesic Typic Paleudalf) with an average natural slope of 9%. The experimental plots consisted of an erosion strip, 4.6 m wide by 22.1 m long (15 ft × 73 ft), and a grass filter strip, 4.6 m wide by 9.0 m (15 ft × 30 ft) long, which abutted it (Figure 1). No tillage (Plot 1) and conventional tillage (Plot 2) had been used as the tillage method on the erosion strips since 1984. However, in 1992, both erosion strips used in our study were cultivated using a chisel plow plus disking as the only management practice. The grass filter in each plot was mowed to a height of 4.0 cm (1.6 in) and consisted of tall fescue (*Festuca arundinacea* L.) and Kentucky bluegrass (*Poa pratensis* L.) sod.

Site treatment. Poultry litter mixed with sawdust and shavings from a laying house was briefly stockpiled and uniformly spread over each erosion strip at 16.5 $Mg\ ha^{-1}$ (7 ton/ac) (wet weight) on June 30, 1992. It was 60 to 80% incorporated to a depth of 15 cm (6 in) with a chisel

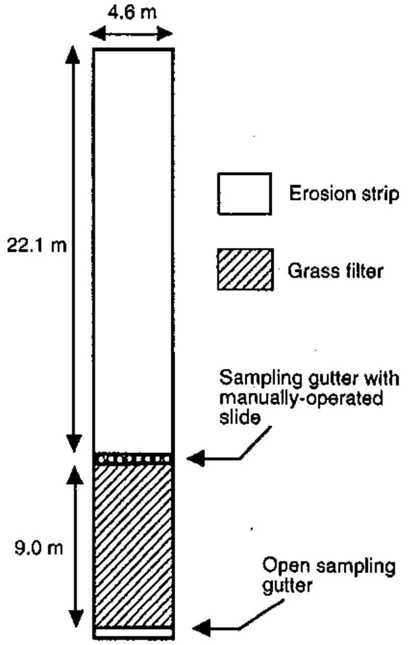

Figure 1. Schematic diagram of a study plot used for rain simulation

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Table 1. Summary of water infiltration and sediment trapping (per plot)

Plot	Peak inflow rate (L/min)	Peak outflow rate (L/min)	Liters inflow (Mi)	Liters outflow (Mo)	Percent infiltrated (%)	Peak sediment inflow (g/min)	Peak sediment outflow (g/min)	Grams sediment inflow (Mi)	Grams sediment outflow (Mo)	Percent sediment trapped (%)
1	58.0	10.9	2788	318	88.6	145	2	6862	60	99
2	69.4	14.8	4620	547	88.2	214	4	13,871	144	99

plow and disk as the only tillage practices. The litter contained 2.8% total nitrogen, 2.9% total P, and 1.8% total K (wet weight) at a moisture content of 34.2%.

Moore et al. have previously described the rain simulator. It has five individual units, hooked in tandem, with dimensions of 4.6 × 6.1 m. Nozzles were set 3.1 m above the erosion strip surface. The simulator mimics natural drop size distribution, impact velocity, and energy. We used it to minimize differences in rain intensity and duration, and to negate the unpredictability of natural rainfall. The five individual units were situated directly over the erosion strip during rain simulations. A metal border, 15 cm high, was inserted at the sides and upper end of the erosion strip to confine runoff. Metal borders were also placed at the sides of the filter strips. To protect the erosion strips from natural rain, we covered them with black plastic tarpaulins. The live grass filters were not covered during the study. Temperature and rainfall during the experiment are shown in Figure 2.

We began the rain simulations one week after adding poultry manure to the erosion plots. Plot 1 was rained on July 7, and Plot 2 on July 9. In each plot, we removed the plastic tarpaulin and simulated rain at a rate of 6.4 cm h^{-1} (2.5 in h^{-1}). This approximates the intensity of a one-in-10-year storm event in central Kentucky. A storm of this intensity occurred in Lexington one week after the last simulation. We did not rain on the grass filters. They were pre-wet by a water hose before each simulated rain.

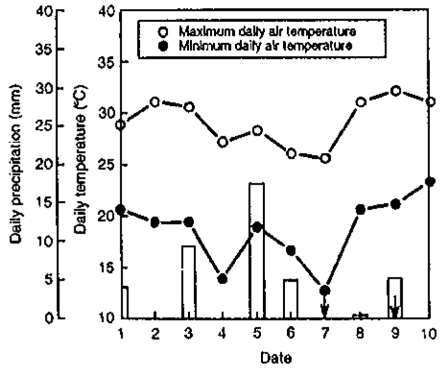

Figure 2. Precipitation and daily temperature at the experiment site during July 1992 (arrows indicate the dates of simulated rain)

Surface runoff from erosion strips began 47 minutes after simulated rain started in Plot 1 and 45 minutes after rain started in Plot 2. Runoff from grass filters began 30 to 40 minutes after erosion strip runoff began. When we observed surface runoff from the grass filter strip for an hour, we stopped simulated rain. The total period of rain simulation was 132 minutes in Plot 1 and 140 minutes in Plot 2.

Sampling protocol. We collected runoff at 5 minute intervals in 10 cm (4 in) wide gutters below both the erosion strip and the grass filter strip. The gutter below the erosion strip had a manually-operated aluminum slide that could be opened and closed to direct surface runoff onto the grass filter strips or into the gutter for sampling (Fogle and Barfield).

Runoff from the erosion strip was collected in an 18 L (4.8 gal) plastic bucket for short periods (10 to 30 seconds) and weighed to determine runoff rate. The contents of the bucket were stirred to uniformly resuspend soil particles and a representative one liter sample was removed for sediment analysis. A second uniformly mixed sample was removed for fecal coliform enumeration and stored in a sterile 500 mL (17 oz) plastic bag.

Runoff rates from the grass filter strip were determined at 5 minute intervals by the time required to fill an 8 L (2 gal) plastic bucket. As with runoff from the erosion strips, after the collected runoff was uniformly resuspended, subsamples were removed for sediment and fecal coliform analysis.

We collected 10 soil samples for fecal coliform enumeration from random locations in both the erosion strips and the grass filter strips to a 15 cm (6 in) depth immediately before rain simulation and within 48 hours after rain simulation. Most of the grass filter did not receive runoff because variations in elevation diverted surface flow to a few relatively narrow channels (a few cm wide in most cases). Consequently, the soil samples removed from grass filter strips after rain simulation were confined to the upper portion of the filters — within 1 m (3.2 ft) of the erosion strips. This was where most sediment and presumably bacterial trapping occurred. Soil samples were not removed from the rest of the grass filter to avoid grossly underestimating the fecal coliforms trapped in the filter strips. The 10 soil samples from each site (erosion strip or grass filter), at each sample period, were separately pooled and uniformly mixed before analysis.

Chemical and microbiological analyses. Chemical analysis of poultry litter was done in the University of Kentucky Regulatory Services soil testing laboratory. Sediment in runoff was determined gravimetrically after water removal and drying at 105°C (221°F). Fecal coliforms (i.e., *Escherichia coli*) were enumerated because these are the principal indicator organisms used to assess water quality (American Public Health Association). The fecal coliforms in water samples were stored on ice in the field and at 4°C (39.2°F) in the laboratory and enumerated within 24 hours to minimize cell growth or mortality. Both soil and water samples were diluted in physiological saline (0.8% NaCl in distilled water) prior to their enumeration by membrane filtration technique (American Public Health Association). Fecal coliforms were incubated on mFC agar (Difco, Detroit, MI) for 24 hours at 44.5°C (112.1°F) in an incubating water bath. Typical colonies (dark blue for fecal coliforms) were counted manually after incubation.

Calculation of trapping efficiency. The trapping efficiency of the grass filter strips for sediment and fecal coliforms was estimated using a variation of the trapezoidal rule used for hydrographs and sedigraphs (Barfield and Albrecht). Trapping efficiency, *Tr*, was estimated by

$$T_r = \frac{M_i - M_o}{M_i}$$

where M_i and M_o are the total mass of sediment or number of fecal coliforms in the inflow and outflow of the grass filter strip. The mass inflow was estimated from

$$M_i = \sum_{j=1}^{n} C_{ij}\, q_{ij}\, \Delta t_j$$

where C_{ij}, q_{ij}, and Δt_j are the sediment or fecal coliform concentrations, flow rate, and time interval of the *j*th measurement of inflow. M_o was estimated by

$$M_o = \sum_{j=1}^{n} C_{oj}\, q_{oj}\, \Delta t_j$$

where C_{oj} and q_{oj} are the concentrations and flow rate of the jth measurement of outflow and Δtj is the time interval of outflow. Concentration and flow were conservatively estimated by the average value of C_j and C_{j-1} or q_j and q_{j-1} for the period during which runoff occurred.

Results and discussion

The rain simulation imitated a worst-case event in which waste application was followed after only a brief interval by a high intensity rain. Longer intervals between waste application and potential runoff, and a rain of lesser intensity and duration would decrease erosive loss of fecal coliforms and soil (Crane et al.). Since the grass filter strips were not rained on, our results must be interpreted with some caution since rain falling on the grass filter strips would help keep both soil particles and bacteria in suspension.

Surface runoff increased rapidly in erosion strip 1 and reached a maximum of about 58 L min^{-1} per plot (Figure 3). The maximum surface runoff in erosion strip 2, reached about 69 L min^{-1} per plot. Surface runoff and sediment loss in erosion strip 1 were delayed about 15 minutes with respect to erosion strip 2. This could reflect greater infiltration and increased time to soil sealing. These differences may be due to the previous tillage practice. Erosion strip 1 had been in no-till since 1984 while erosion strip 2 was in chisel-plow tillage for the same period. Previous research showed that rainfall infiltration was greater in no-till managed erosion strips (Madison) and this property may have carried over to our study. About 88% of the surface runoff infiltrated before leaving the grass filters of Plots 1 and 2 (Table 1).

Total soil loss corresponded with increased surface water runoff, and was dramatically reduced in grass filters compared to erosion strips (Figure 4). The mean sediment concentration in runoff from erosion strip 1 was 2.4 g L^{-1} and ranged from 2.1 to 3.5 g L^{-1}. The mean sediment concentration in runoff from erosion strip 2 was 3.0 g L^{-1} and ranged from 2.9 to 3.1 g L^{-1}. Peak sediment flow was 145 g min^{-1} in Plot 1 and 214 g min^{-1} in Plot 2 (Table 1). Soil loss from the grass filters of Plots 1 and 2 was minimal (Figure 4, Table 1) and the apparent trapping efficiency for both plots was 99%.

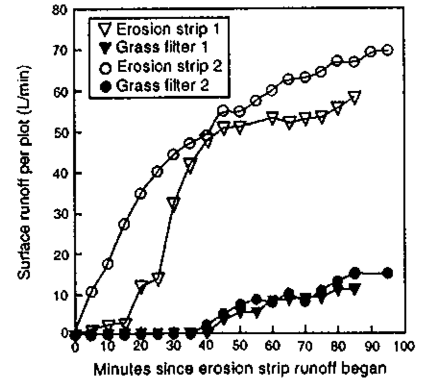

Figure 3. Surface flow from Plots 1 and 2 during simulated rain

Madison previously observed efficient soil trapping on these plots under similar rainfall conditions. The soil trapping efficiency is potentially overestimated, because the grass filter strips were not rained on simultaneously with the erosion plots. Although not directly comparable with our experiment, Hayes et al. reported trapping efficiencies of 94 to 99% in a saturated filter strip that received a sediment plume, while Albrecht and Barfield observed soil trapping efficiencies of greater than 98% in grass filters down slope of surface mines that received natural rainfall. Gross et al. indicate that even low density turf stands greatly affect soil runoff.

Bacterial loss in runoff can be as high as 90% from freshly manured soil (Crane et al.). In Plot 1, maximum fecal coliform loss in erosion strip runoff occurred between 30 and 40 minutes after simulated rain began (Figure 5). The data for fecal coliform loss in erosion strip 2 showed that fecal coliforms had peaked or were already declining within 10 minutes (Figure 6). Fecal coliform trapping was not as effective as soil trapping. In Plot 1, the apparent trapping efficiency of the grass filters for fecal coliforms was 74%. In Plot 2 the apparent trapping efficiency was only 43% (Table 3). Fecal coliform runoff occurred more rapidly in Plot 2 than Plot 1. Consequently, the frequency of bacterial sampling in this plot probably did not reflect the period of maximum bacterial runoff and the apparent trapping efficiency of the grass filter for fecal coliforms in Plot 2 could be underestimated.

Dickey and Vanderholm found that filter strips did not greatly reduce bacteria levels in surface runoff. Young et al. found that grass filters reduced fecal coliforms by about 70% and that there was a linear relationship between filter strip length and bacteria removal. Compared to Young et al.'s study, the grass filter in our experiment had a greater slope (9% vs. 4%) and shorter length (9 m vs. 27.4 m [30 ft × 90 ft]) (Young et al.). Consequently, runoff velocity was probably greater, and the area permitting infiltration and trapping reduced.

We observed channelized flow which meant that much of the grass filter did not participate in runoff filtration. Albrect and Barfield noted that while filter strips effectively trap fine particles, they are less effective at trapping clay-sized particles. Fecal bacteria are 1 to 2 µm (0.04–0.08 in) or smaller in diameter and would behave much like clay particles in terms of solution transport.

Table 2. Fecal coliform concentrations in soil before and after simulated rain

	Fecal coliforms (CFU g-1 soil)†	
	Plot 1	Plot 2
Erosion strip before rain	2000	134
Erosion strip after rain	113	< 3‡
Grass filter after rain	141	349

†CFU = Colony forming units
‡Detection limit is 3 CFU g^{-1} soil

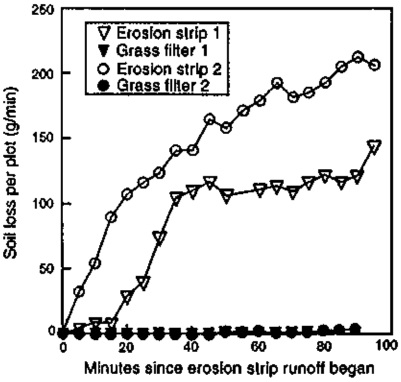

Figure 4. Soil loss from Plots 1 and 2 during simulated rain

Fecal coliform loss in erosion strip runoff peaked and then declined as one would expect from a finite source of manure (Figure 5, 6). In contrast, the decline in fecal coliform loss in grass filter runoff was more gradual. We did not continue rain simulation long enough to determine if fecal coliform loss from the grass filters persisted. We suspect that the upper edge of the grass filter acted as a reservoir for

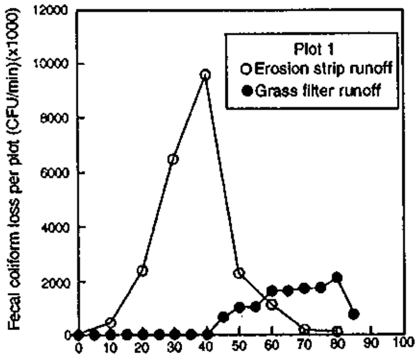

Figure 5. Fecal coliform loss in surface runoff from erosion strips and grass filters—Plot 1

Table 3. Summary of fecal coliform trapping (per plot)

Plot	Peak fecal coliform inflow rate (CFU/min)†	Peak fecal coliform outflow rate (CFU/min)	Total fecal coliform inflow (CFU) (M_i)	Total fecal coliform outflow (CFU) (M_o)	Percent fecal coliforms trapped (%)
1	9,580,000	2,120,000	225,793,000	59,213,000	74
2	3,473,000	2,960,000	144,929,000	82,968,000	43

†CFU = Colony forming units

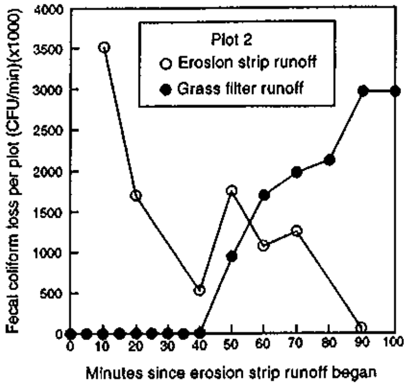

Figure 6. Fecal coliform loss in surface runoff from erosion strips and grass filters—Plot 2

fecal coliforms, which were steadily released as rain continued. We did not try to examine, however, whether fecal coliforms in the grass filters were unassociated or adsorbed to soil and vegetation .

The fecal coliform concentration in erosion strip soil prior to rain was higher in Plot 1 than Plot 2 (Table 2). By covering the erosion strips with plastic tarpaulins during a period when maximum daily temperatures consistently exceeded 27 °C (81°F) we probably increased fecal coliform mortality. Fecal coliforms were not detected in the grass filters before simulated rain (Table 2). In Plot 1, fecal coliform concentrations in soil were reduced by 94% after simulated rain and were below our detection limit in Plot 2 (Table 2). The number of fecal coliforms in the grass filters increased as expected. It is not surprising that the fecal coliform concentrations in soil from the grass filter strips after rainfall were higher than in the erosion plots (Table 2). Since the upper edge of the filter strip trapped sediment from a much larger area (0.01 ha [0.02 ac]) this probably represents a concentration effect.

The increased concentration of fecal coliforms in filter strip soil represented only a fraction of the total fecal coliforms which entered the grass filters. The balance of fecal coliforms which remained in the grass filters presumably infiltrated the filter strip soil. If infiltration was less in Plot 2 than Plot 1, it may be because more sediment was deposited. One reason why trapping efficiency could have been less in Plot 2 than Plot 1 was reduced infiltration due to the greater sediment load. Albrecht and Barfield observed that the trapping efficiency of grass filter strips decreased from greater than 98% to 75% with increased sediment deposition. The combination of decreased infiltration and channelized flow would have contributed to higher fecal coliform runoff in this plot.

Bacterial contamination of agricultural waters often exceeds the primary contact standard of 200 fecal coliforms per 100 mL water (3.4 oz) (Walker et al.). The fecal coliform concentration exceeded the primary water contact standard in runoff from the grass filters in every sample we analyzed. It should be noted, however, that this study reflected very heavy storm conditions and relatively recent manure addition. In an actual storm, some dilution of grass filter runoff would also occur. Nevertheless, even with the grass filters in place, significant numbers of fecal coliforms were lost in surface runoff.

Conclusions

Grass filter strips are an effective management practice for controlling soil erosion. The 9 m (30 ft) grass filter strips we employed in this study trapped 99% of the soil from erosion strips subjected to simulated rain. These results cannot be uniformly extended to fecal coliforms in the same runoff. Under similar conditions, the grass filters only trapped up to 74% of the fecal coliforms. Heavy rain and rapid surface flow may keep fecal coliforms in solution while denser soil particles are trapped. Our field data support Walker et al.'s conclusion that grass filter strips will not reduce bacterial concentrations sufficiently to meet water quality goals for control of fecal coliforms, and by association, other bacterial contaminants in runoff from manured soils. Grass filters trapped many, but not all, of the fecal coliforms in runoff. In conditions which maximized soil trapping, fecal coliforms were still found in surface runoff at concentrations in excess of 200 /100 mL (3.4 oz) which would exceed minimum contamination standards for primary contact water. As long as runoff from grass filters occurs shortly after poultry wastes are deposited on soil, our data suggests that inadequate bacterial removal could contribute to groundwater contamination even while adequate best management practices for soil erosion are in place.

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