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FECAL BACTERIA IN SURFACE RUNOFF FROM POULTRY-MANURED FIELDS

M.S. Coyne and R.L. Blevins

INTRODUCTION

Recent growth in Kentucky's poultry industry (from 1.5 million broilers in 1990 to over 43 million broilers in 1993) (Kentucky Agricultural Statistics, 1994) has created an equally large waste disposal problem. As in many states, most of this waste is land-applied without prior processing (Edwards and Daniel, 1992). Manure spreading, while it is a traditional and effective agricultural waste disposal practice, frequently exceeds the rate at which wastes can be processed in agricultural ecosystems. The subsequent runoff of nutrients and fecal bacteria contributes to agricultural non-point source pollution and helps to degrade drinking water supplies.

Vegetative or grass filter strips are typically established to minimize surface runoff from agricultural fields. They principally reduce sediment runoff (Dillaha et al., 1989). Use of grass filters and grassed waterways to control fecal waste runoff from point sources, such as feedlots, has also been studied (Dickey and Vanderholm, 1981; Schellinger and Clausen, 1992; Young et al., 1980). However, there is little information specifically related to the control of fecal bacteria runoff from agricultural fields treated with poultry manure.

Giddens and Barnett (1980) suggested that if runoff water from manured cropland were allowed to flow over grass, its pollution potential would be greatly reduced. However, modeling studies by Walker et al. (1990) implied that buffer strips alone would not be sufficient to bring bacterial concentrations within acceptable limits, for example, below the EPA standard of 200 fecal coliforms/ 100 mL for primary contact water (bathing and swimming water). Crane et al. (1983) suggested that even after passing through a vegetative filter, runoff contaminated by fecal wastes would have concentrations of fecal indicator bacteria inexcess of 10^3 to 10^5/100 mL.

Because of the growth of the poultry industry in Kentucky, and because information related to grass filter strip use in controlling surface runoff of bacteria from manured fields is limited, we decided to see whether grass filters were an effective management practice to reduce fecal contamination of surface and ground water via runoff from poultry-manured fields. We began a continuing series of rain simulation studies in 1992 to examine this question. This chapter summarizes some of our results.

METHODS AND MATERIALS

LOCATION AND PLOT DESIGN

The rain simulations were done at the University of Kentucky Agricultural Experiment Station in Lexington during the summers of 1992, 1993, and 1994. The soil is a Maury silt loam (fine, mixed, mesic Typic Paleudalf) with an average natural slope of 9%.

Each rain simulation plot consisted of an erosion strip abutted by a grass filter at its lower edge. In 1992 the erosion strips were 22.1 m long and paired with 9.0-m-long grass filters, and only the erosion strips were rained on. In 1993 and 1994, 18.3-m erosion strips were paired with 4.5-m filter strips. The design change was made to facilitate raining simultaneously on both the erosion strip and the grass filter (Figure 1).

All erosion strips were tilled, and poultry litter was incorporated by chisel plowing followed by disking. Grass filters consisted of a mixture of tall fescue (*Festuca arundinacea* L.) and Kentucky bluegrass (*Poa pratensis* L.) sod and were mowed to a 4.0-cm height in each plot before rain simulations.

PLOT TREATMENT

Poultry litter that was a mixture of manure, sawdust, and shavings from a laying house was used for these studies. In 1992 and 1993 the application rate (wet weight) was 16.5 Mg/ha, and in 1994 the application rate was 10 Mg/ha. Litter was uniformly applied over the surface of the erosion strips and shallowly incorporated (85% incorporation). In 1992 poultry litter was applied to all plots on a single date. In 1993 and 1994 the poultry litter was applied 48 h before each rain simulation.

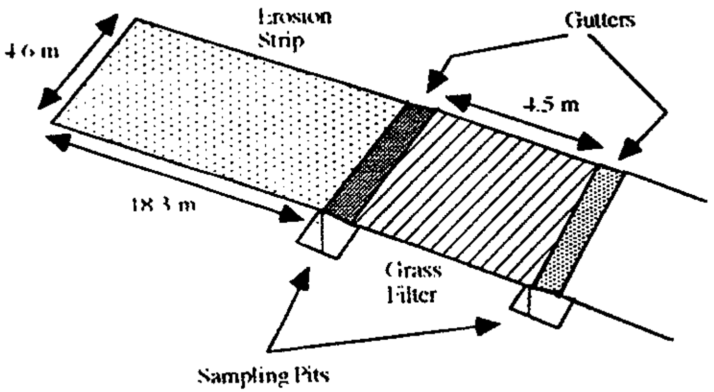

Figure 1. Diagram of a rain simulation plot. Erosion strip and grass filter length varied from year to year.

Rain simulations were at a rate of 6.4 cm/h. This approximates the intensity of a one-in-ten-year storm in central Kentucky, but it was necessary to cause runoff within a reasonable period. In 1994, to improve the reproducibility of runoff, the erosion plots were pre-wet 24 h before rain simulations by raining on them for one hour at a rate of 3.3 cm/h. In addition, in 1994, a second rain simulation was performed on each plot five days after the first simulation.

SAMPLING PROTOCOL

Runoff from the erosion strips started 15 to 30 min after simulated rain began. Runoff from the grass filters began 30 to 45 min after that. Rain simulation continued until runoff from the grass filter was observed for 1 h. Runoff was periodically collected for 10 to 30 sec at 5-min intervals in 10-cm-wide gutters below the erosion strip and grass filter (Figure 1). The gutter below the erosion strip had a slide that directed runoff onto the grass filters or into the gutter for sampling (Fogle and Barfield, 1993).

Runoff samples from the erosion strip and grass filter were uniformly mixed before subsampling and then stored, in sterile plastic bags, on ice in the field and at 4°C in the laboratory to minimize bacterial growth and mortality. Fecal bacteria were enumerated within 24 h of collection. Sediment concentration was determined gravimetrically after representative samples were dried at 105°C.

MICROBIAL ANALYSES

Ten-fold serial dilutions in buffered saline solution (0.85% NaCl) were made of runoff samples to reduce bacterial concentrations to a measurable number. Fecal coliforms (i.e., *Escherichia coli*), fecal streptococci, and *Salmonella* concentrations were determined from manual counts of colony forming units on selective media after spiral plating or membrane filtration. Fecal coliforms were grown on Difco (Detroit, MI) mFC agar incubated at 44°C for 24 h. Fecal streptococci were grown on Difco KFS agar incubated at 37°C for 48 h. *Salmonella* were grown on a medium described by Cox (1993) and incubated at 37°C for 48 h.

CALCULATION OF TRAPPING EFFICIENCY

Trapping efficiency, T_r, of grass filter strips for surface runoff, sediment, and fecal bacteria was estimated using a variation of the trapezoidal rule used for hydrographs and sedigraphs (Barfield and Albrecht, 1982):

$$T_r = (M_i - M_o)/M_i$$

where M_i and M_o are the total liters of water, mass of sediment, or number of fecal bacteria 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 bacteria concentrations, flow rate, and time interval of the jth measurement of inflow, respectively. 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 Δt_j 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

1992 RAIN SIMULATIONS

Fecal bacteria concentrations were typically highest during the initial runoff from erosion strips, and ultimately bacteria concentrations in grass filter runoff exceeded concentrations in erosion strip runoff. Fecal coliform concentrations in grass filter runoff were well above water quality standards for primary contact (200 fecal coliforms/100 mL). Although the grass filters effectively trapped sediment and surface runoff (Table 1), they were less effective at trapping fecal bacteria in plots for which this could be determined.

1993 RAIN SIMULATIONS

Beginning in 1993, the grass filters were also rained on during simulations to better reflect an actual storm. Grass filters were again an effective sediment trap, even at lengths of only 4.5 m (Table 1). Surface runoff trapping decreased in the shorter grass filters relative to the longer filters used in 1992. Fecal bacteria concentrations in runoff were greater in 1993 than 1992, but the runoff patterns in 1993 were similar to those we observed in 1992 (Figure 2).

Bacterial trapping efficiency appeared to be greater in 1993 than in 1992 even though the grass filters were shorter (Table 1). The erosion strip length was shorter in 1993 than in 1992, but dye tracing observations suggested that more of the filter surface area appeared to be used, presumably because moisture conditions were more uniform.

Table 1. Runoff, sediment, and bacterial trapping by grass filters during simulated rain.

Year	Filter Length	Runoff	Sediment	Fecal coliforms	Fecal streptococci
		% Trapped			
1992	9.0 m	89.3	99.1	74.0	29.4
		87.3	98.9	43.0	nd†
1993	4.5 m	86.3	97.2	95.0	91.9
		65.8	93.1	50.0	23.1

†nd = not determined

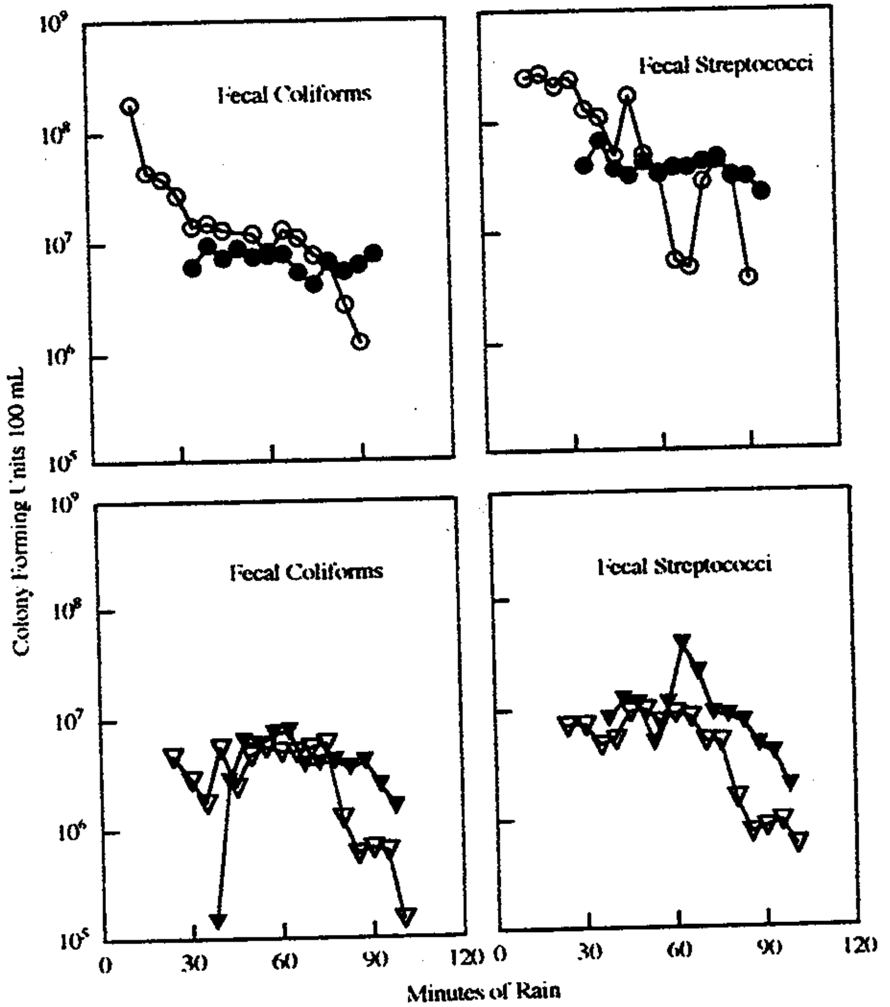

Figure 2. Fecal coliform and fecal streptococci concentrations in runoff from 18.3-m erosion strips (open symbols) and 4.5-m grass filters (closed symbols) in 1993. Each paired set of figures represents an individual plot.

Up to 95% of the fecal bacteria were trapped by the grass filters (Table 1), but their concentration in surface runoff was still high, well above the limit for primary contact water. The fecal bacteria concentrations in grass filter runoff again exceeded the concentrations in erosion strip runoff. This was not as noticeable as it was in 1992.

Crane et al. (1983) and Walker et al. (1990) suggested that grass filters alone were insufficient to reduce bacterial concentrations to meet water quality goals. Our research supports that conclusion. Most of the fecal bacteria in runoff can be held in relatively short grass filter strips by infiltration and sediment trapping. This is inconsequential since the standards for water quality (less than 1 fecal coliform/100 mL for drinking water and less than 200 fecal coliforms/100 mL for primary contact water) are based on bacterial concentration, not mass. It is unlikely that those standards will ever be met as long as the initial fecal bacteria concentration in runoff remains elevated.

At first glance it appears that grass filters have the opposite effect on water quality than intended, since we have consistently found that the concentration of fecal bacteria in grass filter runoff exceeds the concentration in erosion strip runoff. This implausible result can be explained two ways. First, the grass filters receive sediment from a much larger area than they represent themselves. The effect is to concentrated manure-laden sediment at the field/filter interface from which fecal bacteria are continually removed by the action of rain and flowing water. Second, the poultry litter is not itself a homogenous mixture of fecal bacteria; rather, it is a collection of large aggregates that are heterogeneously applied to the field. When these aggregates erode from the field and are trapped by the grass filters, they subsequently break up, releasing the bacteria held within.

1994 RAIN SIMULATIONS

Rain simulations were on-going in 1994 at the time of writing, so only preliminary information will be presented. In 1994 we began looking at *Salmonella* in runoff from poultry-manured fields as well as trying to relate sediment particle size to bacterial runoff. We also began looking at the effect of sequential rainfall on fecal bacteria concentrations in runoff. Runoff patterns in a representative plot are shown in Figure 3.

In 1994, one day prior to runoff studies, the erosion strips were rained on to create more uniform soil moisture conditions. This influenced fecal bacteria runoff in subsequent rain simulations because it apparently reduced the rate at which fecal bacteria concentrations declined as runoff continued. Litter may have been dispersed by the rain and caused fecal bacteria to be more uniformly distributed in soil. Some fecal bacteria growth may have also been stimulated, since the concentration of fecal bacteria in runoff in 1994 was only slightly less than it was the preceding year when 65% more poultry litter was applied (Figure 3).

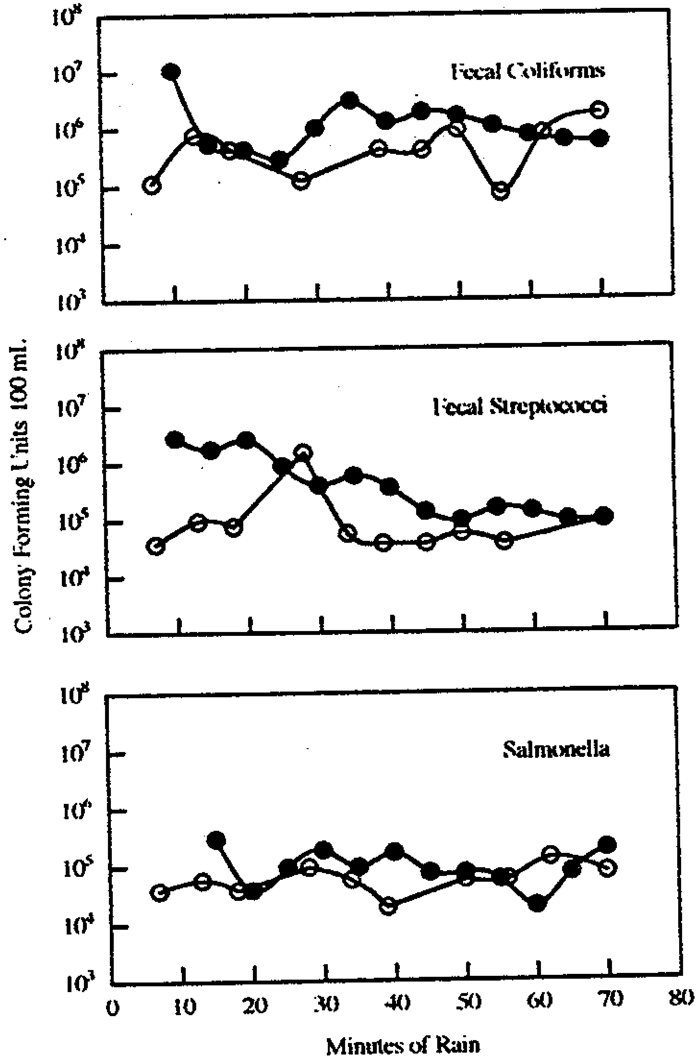

Figure 3. Fecal bacteria concentrations in runoff from 18.3-m erosion strips (open symbols) and 4.5-m grass filters (closed symbols) in 1994.

The patterns of fecal bacteria runoff we observed in previous years remained consistent. Fecal bacteria concentrations generally declined as runoff continued; the fecal bacteria concentration in grass filter runoff was typically greater than in erosion strip runoff; and fecal bacteria concentrations were in excess of 10^4/100 mL for the duration of runoff.

The binding of bacteria to soil is a relatively rapid process, so we would expect to see most of the bacteria particle bound. We wanted to see if fecal bacteria concentrations in runoff were associated with a particular sediment size fraction. To do this we used a pipette method for particle size analysis and removed aliquots from each sample period at 0-, 5-, and 75-min intervals. With this method, after 5 min, coarse particles, greater than 20 µm in diameter, will settle below a 10-cm sampling depth, and by 75 min, only particles smaller than 5 µm will remain in suspension.

As runoff continued, the effect of settling time on bacterial concentrations, particularly fecal coliforms, became more apparent (Figure 4). The greater the settling time, the lower the bacterial concentration. Aggregates greater than 5 µm in size become progressively more important to the concentration of fecal bacteria in surface runoff the longer that runoff continues.

The implications of this result in terms of grass filters are apparent. First, it shows that by trapping sediment, the grass filters trap the bulk of fecal bacteria. However, these bacteria are subject to detachment by the impact of rainfall and flowing water. This accounts for our observation that fecal bacteria concentrations are greater in grass filter runoff than erosion strip runoff. The field/filter interface acts as a bacterial reservoir.

Settling time had less effect on bacterial concentrations in runoff from the grass filters than it did for erosion plot runoff. This suggests that the sediment particles to which bacteria were bound were smaller and more uniform (Figure 5). The implications of this for bacterial trapping by grass filters are ominous since it indicates that the particles that are mobile in grass filters (clay-sized or slightly larger) are those least likely to be trapped.

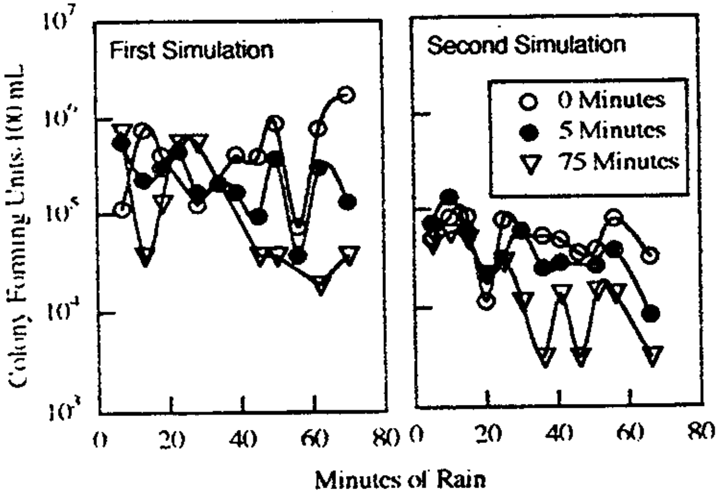

Figure 4. Effect of settling time on fecal coliform concentrations in surface runoff from poultry manured erosion strips collected from successive rain simulations in 1994. The second rain simulation occurred five days after the first simulation.

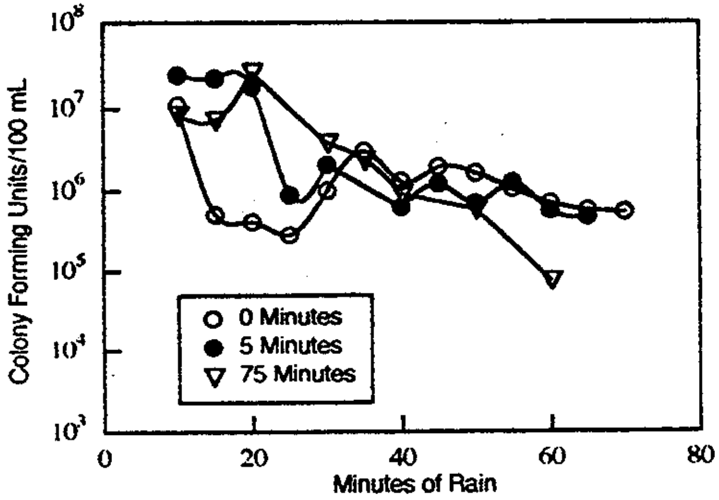

Figure 5. Effect of settling time on the fecal coliform concentration in surface runoff from 4.5-m grass filters following the first rain simulation.

Construction of grass filters with sufficient length to a) prevent any runoff from occurring and b) trap smaller than silt-sized particles would be impractical in agricultural settings. The fecal bacteria concentration in runoff will likely exceed water quality standards in those cases where surface application and even incorporation of poultry litter at rates of 10 Mg/ha or greater are followed shortly afterwards by rain.

The greatest runoff and constituent loss from surface-applied poultry litter occurs in the first runoff following application (Edwards and Daniel, 1993). When rain simulations were repeated on a plot, after a five-day interval, initial fecal bacteria concentrations in runoff were reduced approximately one order of magnitude. The effect of settling time was approximately the same (Figure 4). Clearly, the potential for fecal bacteria runoff at levels in excess of water quality standards was still present.

CONCLUSIONS

Grass filters have been used successfully to reduce soil erosion from agricultural fields and are a recommended practice for reducing concentrations of fecal constituents from point sources. Their use in minimizing the effects of fecal contamination by surface runoff from manured fields has been examined with mixed results. After three years of rainfall simulation studies, our results indicate that reducing surface runoff water to meet primary water contact standards of 200 fecal coliforms/100 mL using grass filters as the sole management practice will be an elusive goal. Even though fecal constituents are reduced up to 95%, the runoff still contains bacterial concentrations far in excess of existing primary water contact standards.

Our study used atypically intense rainfall to cause surface runoff. Depending on the length, slope, and management practices used on a manured field, grass filters as short as 4.5 m would probably trap runoff if it occurred. Consequently, grass filters should deter surface water contamination by fecal bacteria in runoff from manured fields on most occasions. It is unlikely that the grass filter length needed to ensure total compliance with primary contact water standards for surface runoff water will be practical. Runoff from poultry manured fields, if it occurs, will contribute to surface water contamination, particularly when manure application is followed by runoff-producing rainfall.

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