JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
VOL. 33, NO. 2 AMERICAN WATER RESOURCES ASSOCIATION APRIL 1997

FECAL COLIFORM AND STREPTOCOCCUS CONCENTRATIONS IN RUNOFF FROM GRAZED PASTURES IN NORTHWEST ARKANSAS[1]

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ABSTRACT: Agricultural practices such as cattle grazing and animal manure application can contribute to relatively high runoff concentrations of fecal coliform (FC) and fecal streptococcus (FS). Available information, however, is inconsistent with respect to the effects of such practices as well as to measures that can discriminate among candidate sources of FC and FS. The objective of this study was to assess the effects of grazing, time of year, and runoff amounts on FC and FS concentrations and to evaluate whether FC/FS concentration ratios are consistent with earlier values reported as characteristic of animal sources. Runoff from four Northwest Arkansas fields was sampled and analyzed for fecal coliform (FC) and fecal streptococcus (FS) for nearly three years (1991-1994). Each field was grazed and fertilized, with two fields receiving inorganic fertilizer and two receiving animal manure. Runoff amount had no effect on runoff concentrations of FC or FS. There were no consistent relationships between the presence of cattle and FC and FS runoff concentrations. Both FC and FS concentrations were affected by the season during which the runoff occurred. Higher concentrations were observed during warmer months. Runoff FC concentrations exceeded the primary contact standard of 200 cfu/100 mL during at least 89 percent of all runoff events and the secondary contact standard of 1000 cfu/100 mL during at least 70 percent of the events. Ratios of FC to FS concentrations varied widely (from near zero to more than 100), confirming earlier findings that FC/FS ratios are not a reliable indicator of the source of FC and FS.
(KEY TERMS: cattle; runoff; manure; water quality; fecal coliform; fecal streptococcus.)

INTRODUCTION

Chemical and microbiological water quality impacts of agricultural practices such as cattle grazing and animal manure application have been extensively studied over the past two decades. Potential pollutants such as nutrients and sediment have certainly deserved the attention they have historically received. Microbiological quality indicators and their interpretations, however, are increasingly important for identifying rational management strategies that protect environmental quality without creating unnecessary challenges to efficient, economical animal production.

Animal manures can contain numerous pathogens (e.g., Azevedo and Stout, 1974; Ellis and McCalla, 1976) that are potentially harmful to humans. The potential impacts of poor microbiological quality are relatively immediate and personal in comparison to the longer-term impacts generally associated with poor chemical (e.g., nitrogen and phosphorus) quality.

Microbiological water quality is typically assessed using fecal coliform (FC) and, less commonly, fecal streptococcus (FS) analyses. Fecal coliforms are enteric to warm-blooded animals, and their presence in water is generally taken as indicating fecal pollution. Common FC standards for waters designated for primary and secondary contact usage are 200 and 1000 colony forming units (cfu)/100 mL, respectively (e.g., Arkansas Department of Pollution Control and Ecology, 1992). Fecal streptococcus is predominately an enteric organism but is not as reliable an indicator of fecal pollution as FC, because there are non-enteric FS species native to insects, soil, and vegetation (Geldreich, 1976; Hunt *et al.*, 1979; Kibbey *et al.*, 1978). Geldreich *et al.* (1968) proposed using the ratio of FC

[1]Paper No. 96098 of the *Journal of the American Water Resources Association* (formerly *Water Resources Bulletin*). **Discussions are open until October 1, 1997.**
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to FS concentrations (FC/FS) to help determine the source of fecal water pollution provided certain sampling conditions were present (Geldreich, 1967, 1970; Greenberg *et al.*, 1985). The availability of such a tool for identifying pollution sources would aid immensely in determining where effort should be focused to best control fecal pollution. Use of FC/FS values is not currently recommended, however, due to variable die-off rates among FS species as well as other factors (Greenberg *et al.*, 1992).

Many studies have assessed microbiological quality impacts of agricultural practices such as cattle grazing and manure application. Reviews of such studies have been reported by Crane *et al.* (1983), Bohn and Buckhouse (1985), and Baxter-Potter and Gilliland (1988), among others. The task of relating microbiological water quality to grazing and/or manure application has been singularly challenging. Manure (mechanically-applied or deposited by livestock) is typically considered a nonpoint source pollutant. The occurrence and degree of microbiological pollution is thus inseparably linked to temporally- and spatially-variable hydrologic factors such as rainfall and runoff (except when manures are directly deposited into waters).

The microbiological dynamics that are operative in the interim between manure deposition and transport by runoff further cloud relationships between manure and microbiological water quality. The quantity of microbiological pollutants present and available for runoff transport is a complex function of interacting variables such as temperature, timing and rate of manure deposition, soil conditions (especially moisture), sunlight, pH, toxic substances, competitive organisms, and organic matter (Gerba *et al.*, 1975). Most enteric organisms persist a short time outside their hose. Reddy *et al.* (1981) modeled die-off of microbiological indicator organisms as a first-order process that depends on several related variables such as those listed previously. Zhai *et al.* (1995) demonstrated that the first-order mortality model fit well for the initial weeks following manure deposition. Regrowth of FC, however, has been observed in studies reported by Cuthbert *et al.* (1950), Crane *et al.* (1980), Howell *et al.* (1996) and Van Donsel *et al.* (1967). As a result of the difficulties and uncertainties in mathematically relating microbiological water quality to grazing and/or manure application, the majority of information on the topic is empirical and frequently contains apparent contradictions.

Manure from grazing cattle can increase FC and FS concentrations in runoff from grazed pastures. Runoff from simulated rainfall applied to cattle droppings contained FC concentrations of 4.0×10^4 cfu/100 mL 30 d following deposition (Thelin and Gifford, 1983) and 4.2×10^3 cfu/100 mL 100 d following deposition (Kress and Gifford, 1984). Doran and Linn (1979) and Doran *et al.* (1981) analyzed runoff from grazed and ungrazed pasture fields in Nebraska for FC and FS, finding that mean FC concentrations were 5-10 times greater in runoff from the grazed (average of 1.1×10^5 cfu/100 mL) than from the ungrazed field (average of 1.3×10^4 cfu/100 mL). Runoff FC concentrations were less during snowmelt runoff than during rainfall runoff. Mean runoff FS concentration, however, was greater for the control field than for the grazed field. Ratios of FC to FS concentrations were judged useful in differentiating between domestic animal manure and wildlife manure pollution.

In a similar study, Jawson *et al.* (1982) monitored runoff from grazed and ungrazed fields. These researchers found higher FC concentrations in grazed field runoff, with the differences in FC concentrations between grazed and ungrazed field runoff increasing with time into the experiment. Runoff concentrations of FC during the three-year study averaged from 2.6×10^2 to 1.5×10^3 cfu/mL for the grazed field and from 4.0×10^0 to 4.7×10^2 cfu/100 mL for the ungrazed field. Runoff concentrations of total coliforms (TC) and FS, however, did not appear to differ between the two fields. Runoff concentrations of TC, FC, and FS increased each spring after warm weather for both fields, even when cattle had been absent for a considerable time from the grazed field. The FC/FS concentration ratio was not considered useful in distinguishing between domestic and wildlife sources of pollution, possibly because of the relative persistence of FS in comparison to FC.

The relationship between grazing and microbiological quality is less clear for stream samples that are collected without consideration of runoff events (i.e., grab samples). Stephenson and Street (1978) found that FC concentrations in grab samples from Idaho stream sites were directly related to cattle grazing, increased in response to rainfall runoff, and were in excess of 2.0×10^3 cfu/100 mL. The highest FC concentrations were observed in the summer, during intermittent stream flow. Tiedemann *et al.* (1988) showed that FC concentrations in Oregon streams were related to grazing strategy, with mean concentrations above 1.0×10^3 cfu/100 mL for some grazed fields. The researchers did not find a conclusive relationship between cattle presence and FC concentrations, but found relationships between stream FC concentrations and water temperature or flow rate. The FC/FS ratio appeared useful in discriminating between domestic and wildlife sources of fecal pollution. Skinner *et al.* (1974) monitored streams in Wyoming draining areas of diverse land use and found that maximum FC concentrations occurred in July/August. There was little difference between grazed and other land uses in terms of FC concentrations, and the FC/FS ratio did not appear useful in determining sources of fecal pollution. Gary *et al.* (1983) found that FC concentrations in a Colorado stream responded to cattle grazing only at a relatively high stocking rate (150 cattle on 160 ha). Observed FC concentrations were relatively low, averaging from only 6.0 x 10^0 to 1.8 x 10^2 cfu/100 mL for all fields and study periods.

The apparently contradictory conclusions reached in these studies suggest that the impacts of grazing/manure application on microbiological water quality are not clearly understood. Similarly inconsistent conclusions exist regarding the usefulness of the FC/FS ratio as a tool to help identify microbiological pollution sources and thus to reduce pollution from these sources. There are also several unanswered practical questions related to the issue of microbiological water quality, including the magnitude of "background" concentrations of microbiological parameters and the appropriateness of current microbiological water quality standards.

The earlier-cited studies of Doran and Linn (1979), Doran *et al.* (1981) and Jawson *et al.* (1982) indicated that storm runoff from ungrazed pasture can exceed both primary and secondary contact standards. Background concentrations in streams can also exceed primary contact standards, as reported by Hollon *et al.* (1982) for an ungrazed area in Tennessee and Blevins *et al.* (1995) for agricultural watersheds in central and western Kentucky. Niemi and Niemi (1991) also reported that streams draining pristine areas in Finland sometimes did not meet microbiological quality standards for good swimming water. The question of background FC concentrations is further complicated by evidence of multiplication and growth of enteric bacteria (e.g., Hendricks and Morrison, 1967; Howell *et al.*, 1996). Thus, regardless of their values and influential variables, it appears that even background concentrations of FC can exceed standards for both primary and secondary contact.

This study was initiated to collect and analyze data that can help to resolve some of the general questions that have been raised regarding microbiological water quality impacts of grazing/manure application. The specific objectives of the study were to determine the effects of (a) cattle presence, (b) time of year and (c) storm runoff amount on runoff concentrations of FC and FS. A secondary objective of the work was to determine whether observed FC/FS ratios were consistent with previously-suggested values indicative of non-human microbiological pollution. The information from this study extends the data base on microbiological water quality impacts of cattle grazing and can thus improve our understanding of how microbiological water quality parameters are related to influential variables and processes. This study did not address runoff FC and FS contributions from wildlife. While such contributions undoubtedly occurred, they were considered part of "background" FC and FS contributions.

METHODS AND MATERIALS

Runoff from two pairs of fields was monitored and sampled from September 1991 to April 1994. The fields are identified as RA, RB, WA and WB. Fields RA and RB were owned by one individual, and fields WA and WB were owned by another. The field identifiers denote ownership (owner "R" or owner "W") and order in which instruments were installed ("A" is first and "B" is second). Fields RA and RB were adjacent, while fields WA and WB were separated by approximately 300 m. Selected characteristics of the monitored fields are given in Table 1. All fields are located in northwestern Arkansas (36°00′N, 94°25′W) and

TABLE 1. Selected Characteristics of the Monitored Fields.

Field	Area (ha)	Soil Texture[1]	Curve Number[2]	Average Slope	Slope Length (m)	Erodibility[3] (Mg/ha/year)
RA	1.23	Silt Loam	74	0.03	182	0.99
RB	0.57	Sandy Loam	61	0.02	188	0.54
WA	1.46	Loam	79	0.04	257	0.54
WB	1.06	Sandy/Gravelly Loam	64	0.04	239	0.49

[1]Harper *et al.*, 1969.
[2]Soil Conservation Service, 1986.
[3]Soil Conservation Service, 1983.

have a mean elevation of approximately 360 m. The mean annual rainfall and mean daily temperature for Fayetteville, Arkansas, the nearest location (approximately 35 km east) for which detailed climatological data are available, are 1065 mm and 14.6°C, respectively. The predominant cover for all fields was "tall" fescue (*Festuca arundinacea* Schreb.).

All fields were fertilized during the project. Fields RB and WA received ammonium-nitrate (NH_4NO_3), while fields RA and WB received poultry manure and poultry litter, respectively. The treatment schedule and application rates for selected fertilizer constituents are given in Table 2. All fields were also grazed by dairy cattle during the study period. Grazing densities varied throughout the project as indicated in Table 3.

TABLE 2. Fertilizer Application Schedule.

Field	Date	Application Rate (kg/ha) N	P
RA[1]	03/15/92	332	119
	07/13/93	451	209
RB[2]	03/23/92	67	0
	08/14/92	67	0
	04/22/93	116	0
	07/14/93	136	0
WA[2]	03/23/92	138	0
	04/13/93	102	0
	07/20/93	102	0
	03/24/94	101	0
WB[3]	03/23/92	218	62
	08/13/92	144	59
	04/13/93	158	43
	07/20/93	194	71
	03/29/94	186	71

[1]Fertilized with poultry manure.
[2]Fertilized with ammonium nitrate.
[3]Fertilized with poultry litter.

Instrumentation to measure and sample runoff was installed at the outlet of each field. Runoff was channeled into type "H" flumes (Agricultural Research Service, 1979). Flume depths were 30.5 cm for fields RB and WB and 45.7 cm for fields RA and WA. Stilling wells were constructed and attached to the outsides of the flumes, and an electronic pressure transducer was placed inside each stilling well to measure the water height inside the flume. Pressure transducer output was measured and recorded at five-minute intervals by data loggers. The data logger initiated runoff sampling by an automated sampler upon a water depth of 2.5 cm in the flume floor. Sampling (1 L samples collected at five to ten-minute intervals in polyethylene containers) continued until flume water depth dropped below 2.5 cm or all (24) sample bottles were filled. Samples were collected from a trough (approximately 4 cm wide by 8 cm deep) installed just below the flume outlet. Rainfall was measured and recorded at five-minute intervals by tipping bucket rain gauges. One gauge was used for each pair of fields (RA/RB and WA/WB). All instruments were battery-powered and operated continuously except for scheduled maintenance.

TABLE 3. Grazing Schedule.

Month/Year	Field RA/RB (animal units/ha)	WA	WB
8/91-1/92	2.0	0.3	0.3
2/92-3/92	2.0	0.0	1.0
4/92-6/92	0.0	0.0	1.0
7/92-9/92	0.0	0.0	1.7
9/92-12/92	1.5	1.1	1.1
1/93-4/93	1.5	0.0	1.5
5/93	0.0	0.0	1.5
6/93	0.0	0.0	0.9
7/93	0.0	0.0	0.0
8/93-10/93	1.4	1.0	0.0
11/93-1/94	1.4	0.5	0.5
2/94-3/94	0.0	0.5	0.5
4/94	0.0	0.0	1.0

Runoff samples were collected as soon as possible (< 24 h) following each runoff event and transported to the Arkansas Water Resources Center Water Quality Laboratory for FC and FS analysis. All FC and FS analyses were conducted by the membrane filtration method (Greenberg *et al.*, 1992) within 24 hours of sample delivery. The automated sampler collection bottles were sanitized by thorough washing and acid soaking between storm events. Analyses of rinsate from the sanitized bottles indicated that the sanitation technique was effective in removing all FC and FS. Data from the FS and FC analyses were used with the observed runoff rates to compute flow-weighted concentrations of these bacterial parameters for all storm events sampled. Storm event FC/FS ratios were computed based on flow-weighted mean runoff concentrations of FC and FS.

The effect of runoff depth on runoff FC and FS concentrations was assessed by regressing the natural logarithms of the respective flow-weighted concentrations against runoff depth. The effects of grazing cattle were determined by first grouping the observed FC and FS according to whether the associated runoff event occurred when cattle were present or absent. Means of the natural logarithms of concentrations were then calculated and compared using the standard t-test. The effects of time of year on FC and FS concentrations were evaluated by first grouping the observations according to the "season" in which they occurred. Four three-month seasons were used: January through March, April through June, July through September, and October through December. One-way analysis of variance (ANOVA) was performed using natural logarithms of FC and FS concentrations to test the significance of season as an explanatory treatment. The studentized Newman-Keuls method was used to separate means whenever ANOVA indicated a significant season effect.

RESULTS AND DISCUSSION

Fecal coliform and FS concentrations are given in Figures 1-4, in which grazed and non-grazed periods and fertilizer application dates are indicated. Selected statistics for FC, FS, and FC/FS are given in Table 4. Mean FC and FS concentrations were generally greater than values reported in the previously-mentioned investigations. While numerous factors might have played a role in mean concentration differences, it is noteworthy that this study site was further south than the cited studies. Mean air temperatures were presumably higher during this study than the others, and it was pointed out that some researchers have linked higher temperature to high concentrations of indicator bacteria in water. Howell *et al.* (1996) reported considerably greater regrowth of FC deposited in sediments at 35°C than at 4°C. Temperature differences might thus have promoted the FC and FS concentration differences in this study compared to others.

Runoff concentrations of FC and FS were not significantly affected by event runoff depth. Runoff depth also had no significant impact on the FC/FS ratio. This finding appears to be inconsistent with earlier work that found a relationship between flow rate and FC concentrations. Those studies, however, involved streams rather than field runoff, and the difference is important. Fecal coliform and FS concentrations in streams during base flow should logically be relatively low, because of the filtration and the travel time that water supporting flow has presumably experienced. In contrast, the runoff that partially supports stream storm flow is generally associated with less filtration and shorter travel times, both of which are factors that promote relatively high

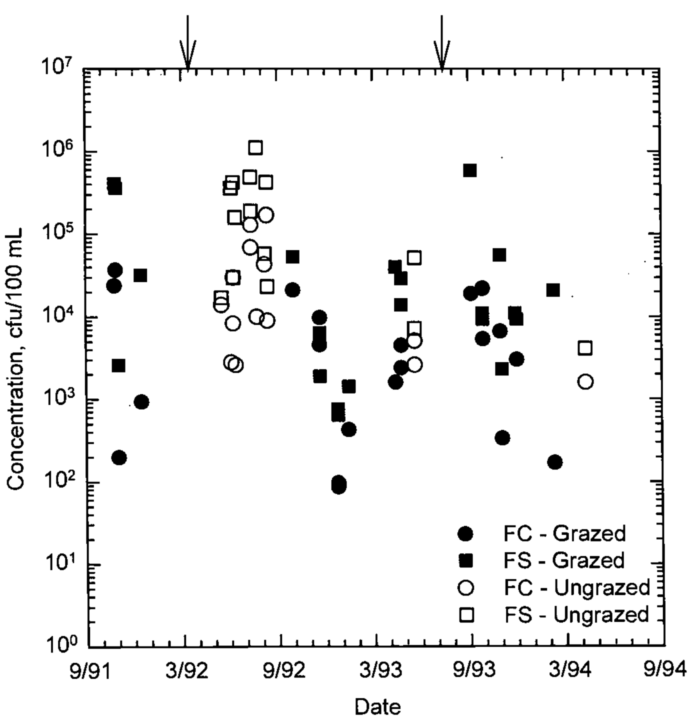

Figure 1. Fecal Coliform (FC) and Fecal Streptococcus (FS) Concentrations in Runoff from Field RA. The arrows at the top of the figure indicate poultry manure application.

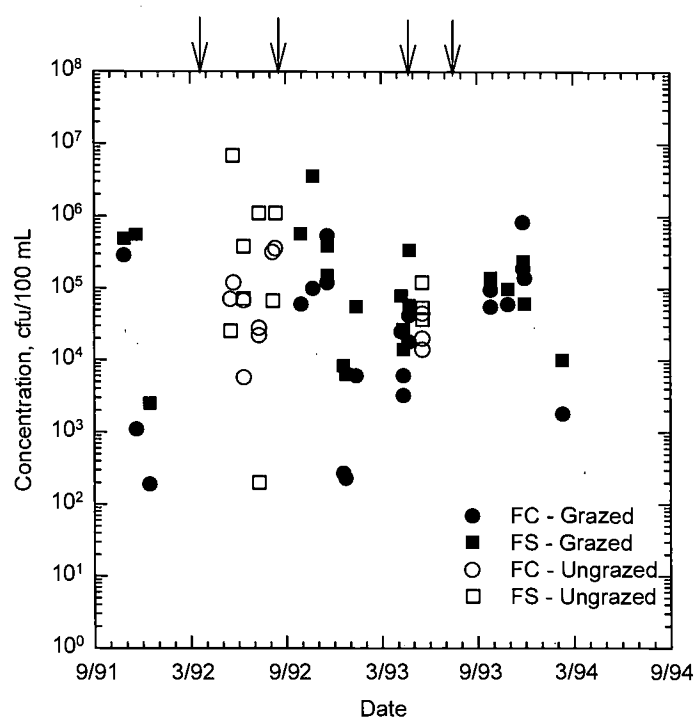

Figure 2. Fecal Coliform (FC) and Fecal Streptococcus (FS) Concentrations in Runoff from Field RB. The arrows at the top of the figure indicate inorganic fertilizer application.

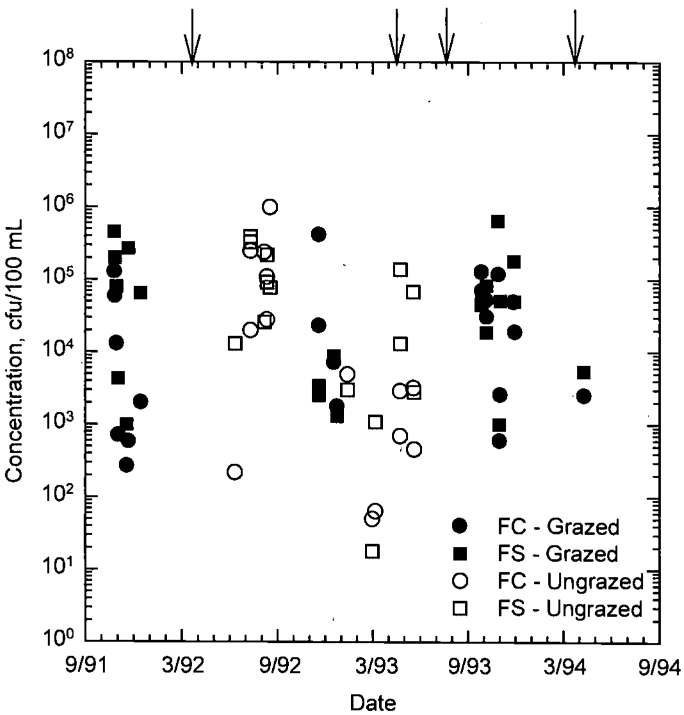

Figure 3. Fecal Coliform (FC) and Fecal Streptococcus (FS) Concentrations in Runoff from Field WA. The arrows at the top of the figure indicate inorganic fertilizer application.

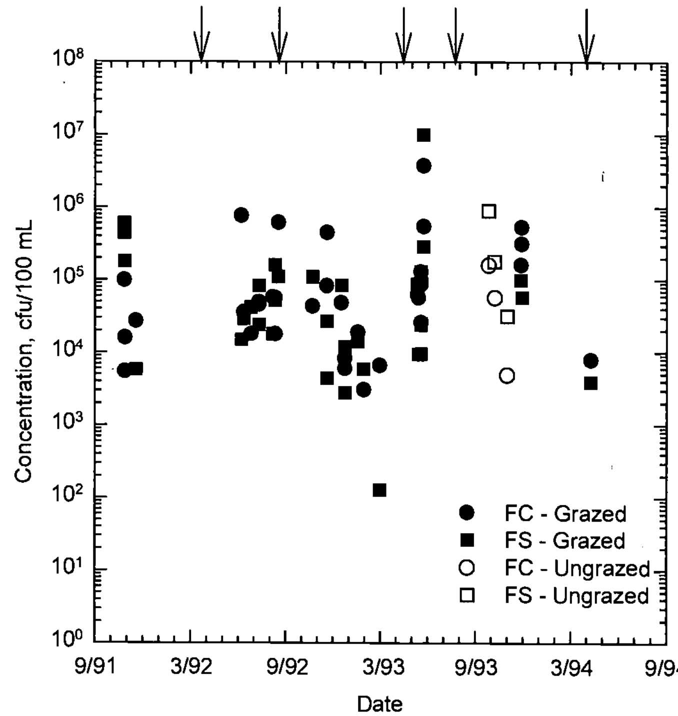

Figure 4. Fecal Coliform (FC) and Fecal Streptococcus (FS) Concentrations in Runoff from Field WB. The arrows at the top of the figure indicate poultry litter application.

TABLE 4. Selected Statistics for FC, FS, and FC/FS.

Parameter	Field			
	RA	RB	WA	WB
FC (cfu/100 mL)				
Mean*	3.7×10^3 b**	2.7×10^4 a	8.7×10^3 b	5.5×10^4 a
Maximum	1.7×10^5	8.4×10^5	9.9×10^5	3.7×10^6
Minimum	8.7×10^1	1.9×10^2	5.0×10^1	3.0×10^3
FS (cfu/100 mL)				
Mean	2.9×10^4 b	1.1×10^5 a	2.3×10^4 b	4.2×10^4 b
Maximum	1.1×10^6	6.8×10^6	6.5×10^5	1.0×10^7
Minimum	6.4×10^2	2.5×10^3	1.8×10^1	1.3×10^2
FC/FS				
Mean	0.39	0.71	4.94	7.32
Maximum	2.42	140.00	123.53	102.27
Minimum	0.01	0.20	0.00	0.03

*Geometric mean.
**Within-row means followed by the same letter are not significantly ($p < 0.05$) different.

concentrations of FC and FS. In the case of fields where outflow depends solely on runoff, the issue of base flow versus storm flow is moot. The results of this study thus do not contradict those of earlier studies, they simply suggest that significant FC and FS concentrations are an inherent characteristic of runoff under the study conditions, and that those concentrations are related less to runoff amounts than simply to the occurrence of runoff.

There were significant between-field differences in mean runoff FC and FS concentrations as indicated in Table 4. Unfortunately, it is easier to eliminate factors that might have caused the differences than to identify the responsible factor(s). Animal manure application alone is not responsible for FC and FS concentration differences, because field RB, which was amended with only inorganic fertilizer, was in the highest groupings for both FC and FS concentrations. The maximum runoff FC and FS concentrations observed for field WB occurred one day following application of poultry litter (Figure 3), but there were generally no consistent relationships between manure application and runoff FC and FS concentrations. Differences in grazing practices are also not the sole factor responsible for FC and FS runoff concentration differences. Indeed, Figures 1-4 suggest that the presence of grazing cattle made little if any difference in runoff FC and FS concentrations, as discussed later. For example, field RB had significantly ($p < 0.05$) greater mean runoff FC and FS concentrations than field RA, even though both fields were contained within one fenced area and were therefore identical in terms of grazing practices.

Fecal coliform and FS runoff concentrations varied significantly between seasons for all fields except RB (Table 5). Except for field RB, the months of January through March were always in the lowest grouping of mean runoff FC and FS concentrations while the months of July through September were among the highest. These findings are consistent with those reported by Jawson *et al.* (1982), Skinner *et al.* (1974), Stephenson and Street (1978) and Tiedemann *et al.* (1988), who also noted higher FC and FS concentrations during warmer seasons.

Relationships between grazing and FC and FS runoff concentrations were inconsistent. There were significant differences between mean FC and FS runoff concentrations during grazed and ungrazed periods only for field RA. The presence of grazing cattle had no measurable impact on either FC or FS concentrations for the remaining three fields. Interestingly, the mean runoff FC concentration for Field RA during grazed periods (2.3×10^3 cfu/100 mL) was significantly ($p < 0.05$) lower than during ungrazed periods (1.3×10^4 cfu/100 mL). Mean runoff FS concentrations were similarly lower during grazed periods (1.4×10^4 cfu/100 mL) than during ungrazed periods (8.5×10^5 cfu/100 mL). Table 3, however, indicates that the ungrazed periods on Field RA generally corresponded with warmer months. The grazing treatment effect might thus actually be a reflection of the season effect.

Ratios of FC to FS concentrations were generally less than 1. Median FC/FS concentration ratios were 0.22, 0.13, 0.30, and 1.24 for fields RA, RB, WA, and WB, respectively. In a few cases (7 percent of the total observed events), however, FC:FS concentration ratios were greater than 6. It is very unlikely than sources of human origin were responsible for the elevated FC/FS concentration ratios. Thus, the data from this study indicate that the FC/FS concentration ratio alone is not a reliable indicator of the source of the coliforms and streptococci in runoff.

Relative to standards for primary contact (200 cfu/100 mL) and secondary contact (1000 cfu/100 mL), runoff quality with respect to FC concentrations was consistently poor. Figures 5-8 indicate that FC runoff concentrations failed to meet the primary contact standard in from 89 (field RA) to almost 100 percent (field WB) of all observed runoff events. The secondary contact standard of 1000 cfu/100 mL was exceeded in from 70 percent (field RA) to almost 100 percent (field WB) of all runoff events. It appears unreasonable to expect that under the conditions of

TABLE 5. Seasonal Mean* Fecal Coliform and Fecal Streptococcus Concentrations

Field	Winter	Spring	Summer	Fall
	Season** (cfu/100 mL)			
RA				
FC	4.9×10^2 b	4.8×10^3 a	2.8×10^4 a***	9.3×10^2 b
FS	4.9×10^3 b	4.9×10^4 ab	1.1×10^5 a	1.0×10^4 ab
WA				
FC	4.5×10^2c	9.2×10^2 c	9.5×10^4 a	8.3×10^3 b
FS	7.5×10^2 b	2.1×10^4 a	8.4×10^4 a	2.5×10^4 a
WB				
FC	7.3×10^3 b	1.2×10^5 a	7.2×10^4 a	4.4×10^4 a
FS	2.5×10^3 b	5.9×10^4 a	9.3×10^4 a	4.4×10^4 a

*Geometric mean.
**Winter is January through March, Spring/Summer is July through September, and Fall is October through December.
***Within-row means followed by the same letter are not significantly ($p > 0.05$) different.

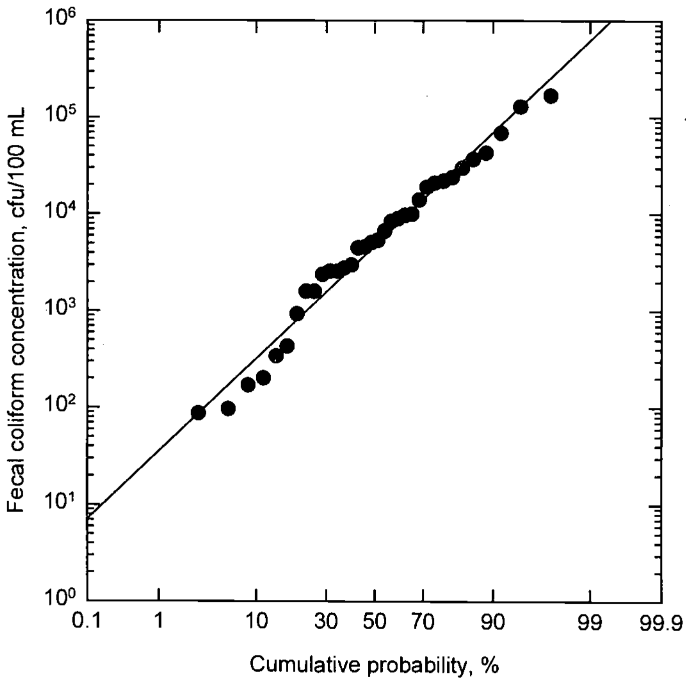

Figure 5. Probability Distribution of Fecal Coliform (FC) Concentrations in Runoff from Field RA.

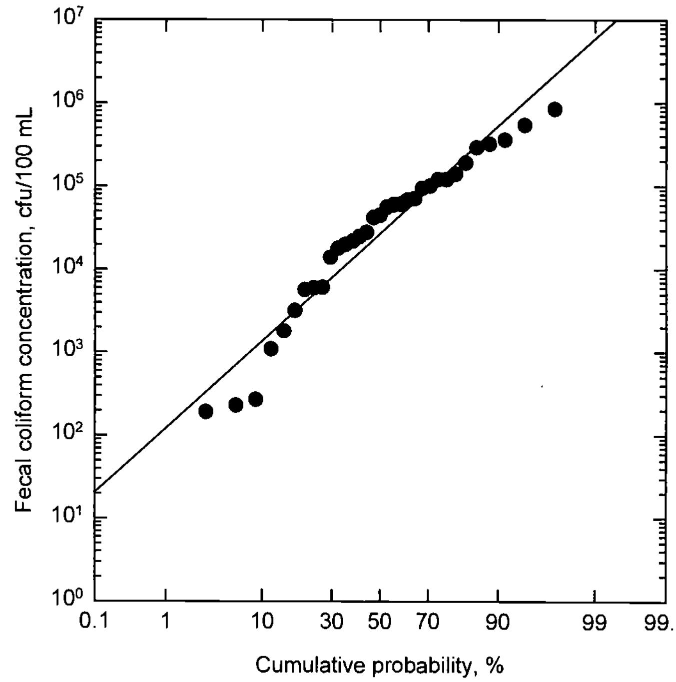

Figure 6. Probability Distribution of Fecal Coliform (FC) Concentrations in Runoff from field RB.

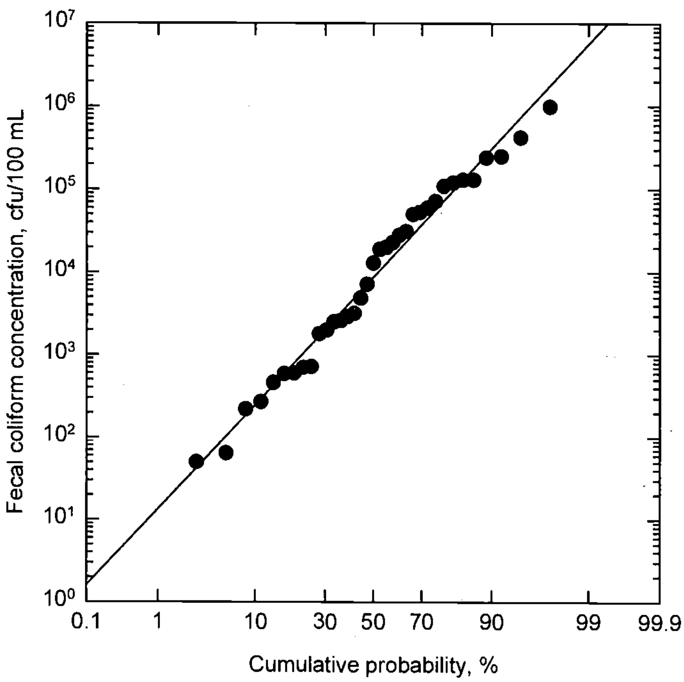

Figure 7. Probability Distribution of Fecal Coliform (FC) Concentrations in Runoff from Field WA.

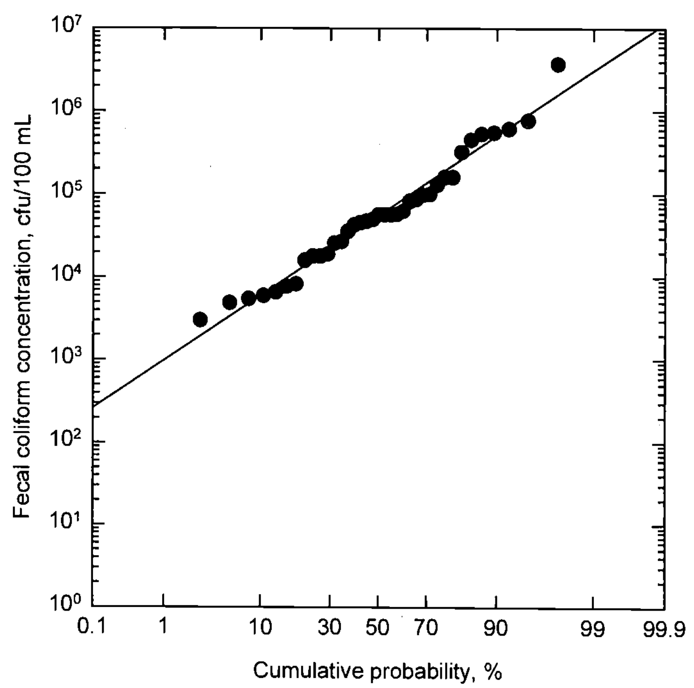

Figure 8. Probability Distribution of Fecal Coliform (FC) Concentrations in Runoff from Field WB.

this study, runoff will consistently meet primary (or even secondary) contact standards in terms of FC concentrations. This does not indicate, however, that the intended uses of the receiving waters will necessarily be impaired due to high FC concentrations. Even assuming that the receiving waters (i.e., streams) have FC concentrations as high as the contributing runoff, and assuming further that nonpoint source pollution (i.e., FC in runoff) is the cause of the high FC concentrations, then these high concentrations will generally be associated only with rainfall-runoff events. On the basis of earlier-cited studies, the high FC concentrations should thus be transient, and FC concentrations should decrease with the recession of storm flow. If the intended uses of the receiving waters are primary and secondary contact, then it is relevant to ask whether these uses are practical during periods of high FC concentrations – in other words, during storm flow. If activities such as swimming and boating are not practical during high stream flows, then it is logical to question the appropriateness of applying standards to nonpoint pollution sources that are better suited to point pollution sources.

SUMMARY

Nearly three years' runoff from four Northwest Arkansas pasture fields was sampled and analyzed for fecal coliform (FC) and fecal streptococcus (FS). The fields were grazed and fertilized during the study, with two fields receiving animal manure and the other two receiving inorganic fertilizer.

The quality of runoff was consistently poor in terms of FC concentrations. Runoff FC concentrations exceeded the primary contact standard of 200 cfu/100 mL during at least 89 percent of all runoff events, and the secondary contact standard of 1000 cfu/100 mL was exceeded during at least 70 percent of the events.

In general, FC and FS concentrations were not directly related to either treatment with animal manure or presence of grazing cattle. The lack of an animal manure treatment effect might be related to the interval between application and runoff. Maximum FC and FS concentrations for one field (WB) were measured for runoff that occurred one day following poultry litter application, but the interval between manure application and runoff was otherwise (sometimes appreciably) greater than one day. Die-off of unprotected (against sunlight, dessication, etc.) FC and FS in the interval between application and runoff might have contributed to the finding of no consistently notable differences in FC and FS concentrations in runoff occurring prior to and following application. The lack of consistent grazing effects on runoff FC and FS concentrations could have been due in part to buffering of runoff as it traveled from manure deposits to the field outlets. Another possible reason for this result is that the ungrazed periods might have been too short for runoff concentrations of FC and FS originating from cattle manure to reach background conditions; this explanation would be consistent with the earlier-cited work of Thelin and Gifford (1983) and Kress and Gifford (1984).

On the other hand, both FC and FS concentrations were significantly affected by the season during which the runoff occurred, with higher concentrations observed during the warmer months. This finding supports results reported by Jawson *et al.* (1982), Skinner *et al.* (1984) and Tiedemann *et al.* (1988) and might be evidence of FC and FS regrowth during warm conditions in environments that are relatively protected from sunlight and desiccation (e.g., the interior of manure deposits).

Ratios of FC to FS concentrations varied widely, ranging from almost zero to more than 100. These data confirm earlier findings that FC/FS ratios are not a reliable indicator of the source of FC and FS in the runoff. The lack of consistent FC/FS ratios might be due to different die-off rates coupled with variable intervals between manure deposition/application and runoff, as other researchers have suggested.

ACKNOWLEDGMENTS

The investigation reported in this article is part of a project of the Kentucky Agricultural Experiment Station (RIS 95-05-095) and is published with the approval of the Director of the Station as a contribution to Regional Research Project S-249. Further support for this investigation was provided by the Arkansas Soil and Water Conservation Commission, the U.S. Environmental Protection Agency, and the U.S. Department of the Interior, Geological Survey, through the Arkansas Water Resources Center.

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