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RUNOFF NUTRIENT AND FECAL COLIFORM CONTENT FROM CATTLE MANURE APPLICATION TO FESCUE PLOTS[1]

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ABSTRACT: Grazed pastures represent a potential source of nonpoint pollution. In comparison to other nonpoint sources (e.g., row-cropped lands), relatively little information exists regarding possible magnitudes of pollution from grazed pasture; how that pollution is affected by weather, soil, management and other variables; and how the pollution can be minimized. The objective of this study was to assess how the quality of runoff from fescue plots is influenced by duration of cattle manure application (4-12 weeks) and manure application strategy (none, weekly application of 1.4 kg/plot, and monthly application at 5.6 kg/plot). Additional analyses were performed to relate runoff quality to the timing of sample collection. The study was conducted at the University of Kentucky Maine Chance Agricultural Experiment Station north of Lexington. Plots (2.4 m wide by 6.1 m long) were constructed and established in Kentucky 31 fescue (*Festuca arundinacea* Schreb.) to represent pasture. Grazing was simulated by application of beef cattle manure to the plots. Runoff was generated by applying simulated rainfall approximately 4, 8 and 12 weeks following initiation of manure application. Runoff samples were collected and analyzed according to standard methods for nitrogen (N), phosphorus (P) and fecal coliforms (FC). Runoff concentrations of N and P from manure-treated plots were low and generally not consistently different from control plot concentrations or related to manure application strategy. Runoff FC concentrations from manure-treated plots were higher than from control plot concentrations. Runoff concentrations of ammonia N, total Kjeldahl N, ortho-P and FC decreased approximately exponentially in response to increasing time of sample collection. These findings suggest that manure deposition on well-managed pasture at the rates used in this study might have a negligible impact on nutrient content of runoff.
(KEY TERMS: grazing; runoff; nutrients; fecal coliform.)

INTRODUCTION

Beef cattle production is an essential component of Kentucky's agricultural economy. More than one million cattle are marketed each year, with a worth of over $750,000,000 to Kentucky cattle producers (National Agricultural Statistics Service and Kentucky Department of Agriculture, 1994). Similar to other agricultural enterprises, however, cattle production has the potential to contribute to enhanced nutrient and bacteria loadings to surface waters. Cattle manure contains appreciable amounts of nitrogen (N) and phosphorus (P) (0.6 and 0.2 percent, respectively) (ASAE, 1991) as well as bacteria and viruses, all of which can be transported into receiving waters during runoff-producing rainfall events (e.g., Khaleel *et al.*, 1980). Runoff of nutrients, and especially P, can be important in the context of accelerated eutrophication, as described by Sharpley *et al.* (1994). The major concern regarding runoff of bacteria and viruses is human health impacts.

Under some conditions, the presence of cattle can influence hydrologic response and soil erosion. Owens *et al.* (1983b) linked cattle occupancy with increased runoff, but no effect on erosion was noted due to sufficient grass cover. Hofmann and Ries (1991) further explored the relationships among grazing, runoff, and erosion, finding that ground cover, as influenced by grazing, was the most influential factor in determining soil loss and hydrologic variables. McIvor *et al.* (1995) reported similar results for an experiment in Australia, suggesting that grazing was important in terms of its influence on cover and recommending a minimum of 40 percent ground cover. Costin (1980) drew similar conclusions based on a study involving sheep grazing in Australia, but noted high runoff and soil loss for cover of less than 70 percent. McColl and Gibson (1978a) measured runoff from New Zealand pastures grazed by sheep, finding that days since

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grazing explained a significant portion of runoff variation and associated grazing with decreased cover and infiltration. Mwendera *et al.* (1997) observed that erosion from plots in Ethiopia was influenced by both grazing pressure and slope, and noted that excessive erosion was possible under moderate grazing pressure for slopes above 5.8 percent.

Grazing can promote elevated concentrations in runoff and stream flows, but the results of studies of this nature are mixed. Gary *et al.* (1983) sampled a stream flowing through a grazed pasture in Colorado. Suspended solids concentrations were low (usually < 10 mg/L), reflective of sample collection during low flow conditions. Ammonia N (NH_3-N) concentrations ranged from 0.14 to 0.42 mg/L and increased significantly, relative to those observed during ungrazed periods during one of the four grazing periods investigated. The authors noted a trend toward higher nitrate N (NO_3-N) concentrations when cattle were present, but detected no significant differences during any of the grazing periods. Doran *et al.* (1981) measured chemical quality of storm runoff from grazed pasture in Nebraska and reported that when cattle were present, runoff concentrations of several chemical constituents (ammonium N, NO_3-N, soluble P, total P, total organic carbon, chemical oxygen demand, and chloride) were generally 1.1 to 1.8 times greater than when no cattle were present. However, these researchers also reported that runoff concentrations of these chemicals as well as total Kjeldahl N (TKN) were higher (2 to 8 times) from an ungrazed control plot than from the grazed pasture. McColl and Gibson (1978b) associated sheep grazing with substantial increases in runoff nutrient and organic matter concentrations for New Zealand pastures. Owens *et al.* (1983b) reported that N concentrations in runoff from grazed pastures tended to be higher than from ungrazed pastures, but that the runoff characteristics were similar and did not significantly degrade water quality. Milne (1976) sampled flow from five stations along a Montana stream adjacent to a cattle wintering operation and concluded that wintering cattle had a "negligible" impact on the chemical quality of the stream. Dixon *et al.* (1983) investigated nutrient losses from a cattle wintering operation in Idaho and found similarly low nutrient losses. Owens *et al.* (1983a) reached similar conclusions after analyzing runoff from a 26 ha unimproved pasture watershed and a 17.7 ha wooded watershed, finding that the presence of cattle had little effect on runoff quality for the pasture watershed. Chemical concentrations in runoff from the wooded watershed were reported as equal to or greater than those from the pasture watershed. These researchers (Owens *et al.*, 1991) later assessed quality of storm and base flows from watersheds having differing dominant land uses, finding negligible differences in chemical quality between water leaving unfertilized wooded areas and unfertilized pasture.

In contrast to the studies involving runoff and chemical quality impacts, most studies have linked grazing to elevated concentrations of microorganisms in runoff and stream flow. Gary *et al.* (1983) found that fecal coliform (FC) and fecal streptococcus (FS) concentrations increased significantly when 150 or more cattle were grazing in the 160 ha of pasture adjacent to the stream. In one year of their study, FC concentrations downstream of grazing cattle averaged 156 colony-forming units (CFU) per 100 mL, whereas FC concentrations upstream of grazing were 21 CFU/100 mL, with similar findings during the subsequent year. The cattle wintering operation studied by Milne (1976) caused "very marked" increases in stream bacteria concentrations, with total coliform concentrations downstream of the cattle sometimes more than three orders of magnitude greater than those upstream of the cattle. Jawson *et al.* (1982) sampled intermittent streams draining a 21.5 ha grazed field and a 0.9 ha ungrazed field during rainfall and snowmelt runoff. Samples collected during a three-year period were analyzed for total coliforms (TC), FC, and FS. While only small differences in TC and FS concentrations were detected between the grazed and ungrazed fields, FC concentrations were related to the recentness of grazing. Similar results were reported by Howell *et al.* (1995), who studied stream flows for two central Kentucky watersheds and found that stream concentrations of FC increased when cattle were present in the contributing watershed.

As can be inferred from the cited studies, general relationships between runoff pollution and grazing are unclear. As a result, the development of predictive tools is in its infancy, as evidenced by a scarcity of mathematical simulation models oriented toward grazing (Cooper *et al.*, 1992; Walker *et al.*, 1990). The identification of relationships might have been hindered by the scales, sampling protocols, grazing parameters, and/or other study characteristics. When conducting field-scale studies, for example, there are numerous challenges in identifying hydrologically-similar fields of comparable areas so that grazed fields can be compared directly to ungrazed fields. Differences in field characteristics can translate to differences in chemical and bacterial quality, as suggested by Doran *et al.* (1981), and it can be difficult to control for water quality differences that result from field differences. It is also possible that samples from studies involving more or less fixed-interval stream sampling are weighted in favor of base-flow conditions rather than storm runoff conditions. In this case, the results would normally be more reflective of the effects of direct cattle access to streams (e.g., manure deposited directly in the streams) than of the effects related to storm runoff from the grazed pastures themselves.

Very little work has been done to evaluate the factors that influence runoff of nutrients and bacteria or to develop and assess methods of reducing those losses. Rotational grazing, which has been used to enhance cattle production, has been suggested as a possible measure for improving quality of runoff from pasture. Studies reported by Tiedemann *et al.* (1987, 1988), however, suggest that rotational grazing might have the opposite effect with regard to stream flow fecal coliform concentrations. The effects of rotational grazing on runoff quality thus have not been extensively studied, even though the practice is increasingly recommended as beneficial from a production standpoint.

The objective of this study was to assess how the quality of runoff from fescue plots was influenced by duration of cattle manure application (4-12 weeks) and manure application strategy (none, weekly application of 1.4 kg/plot, and monthly application at 5.6 kg/plot). Additional analyses of the data were performed to assess how runoff concentrations are related to timing of runoff sample collection.

As will be discussed later, the two manure application strategies only partially simulated conventional and rotational grazing, and this in terms of the timing of manure application. Hoof traffic was not simulated, nor was urine applied to the plots. In addition, the two grazing strategies are considered to cause differences in vegetation quality, with rotational grazing leading to a healthier forage stand with a better-developed root system. These factors might contribute to noticeable differences in runoff quality and therefore deserve investigation. In the present study, however, the emphasis was on the effects (if any) of grazing strategy as reflected by the presence of manure deposits of relatively uniform ages as opposed to deposits of a range of ages. This approach thus represents an initial step toward assessing the full runoff quality effects of conventional vs. rotational grazing while extending the study of Kress and Gifford (1984) by examining more water quality parameters and using a larger scale.

PROCEDURES

Experimental Details

The study was performed using nine plots constructed on a Maury silt loam (fine, mixed, mesic Typic Paleudalf) soil at the University of Kentucky Maine Chance Agricultural Experiment Station. The plots were graded to a uniform 3 percent slope along the major axis and cross-leveled along the minor axis. Plots dimensions were 2.4 by 6.1 m with the long axes oriented upslope and downslope. The plots used for the experiment were randomly selected from 30 plots arranged as three rows of 10 plots each. The plots had within-row separation distances of 0.8 m and between-row separation distances of 3.1 m. The vegetation for all plots was Kentucky-31 fescue (*Festuca arundinacea* Schreb.), maintained at a height of between 8 -13 cm by mowing with a commercial mower and string trimmer (the trimmings were removed from the plots). The vegetation was established by seeding (approximately 350 kg/ha) the previous summer followed by straw mulching. Approximately one year had elapsed between seeding and the time of the experiment, during which time full vegetative cover had been established with no observable cover differences between plots. Each plot was bordered with galvanized iron (10 cm above and below ground surface) to isolate runoff.

Soil samples were collected from each plot approximately one month prior to manure application to the plots. Five soil samples were collected from each plot and mixed together to form one composite soil sample per plot. The composite soil samples were analyzed for nutrient content and other characteristics according to standard methods (Table 1). No amendments were applied to the plots between soil sampling and manure application.

TABLE 1. Research Site Soil Properties.

Parameter	Mean[1]	SD[2]
pH	5.5	0.3
Total N	1,865 mg/kg	164 mg/kg
P	92 mg/kg	10 mg/kg
K	226 mg/kg	40 mg/kg
Ca	1,113 mg/kg	123 mg/kg
Mg	142 mg/kg	27 mg/kg
Zn	1.7 mg/kg	0.3 mg/kg
Organic Matter	31,000 mg/kg	3,200 mg/kg

[1]Mean of 30 samples.
[2]Standard deviation.

A gutter was installed across the lower end of each plot to concentrate runoff for measurement and sampling. These gutters were constructed of sheet metal and had a 5 percent slope to increase gutter velocities and prevent sedimentation in the gutters. Discharge from the gutter entered a 5-cm i.d. length of polyvinyl chloride (PVC) pipe and emptied approximately 45 cm above the bottom of a sump. Runoff was sampled as it exited the PVC pipe and before reaching the interior of the sump. Unsampled runoff discharged through a hole in the sump bottom and exited the research site. A plot schematic is given as Figure 1.

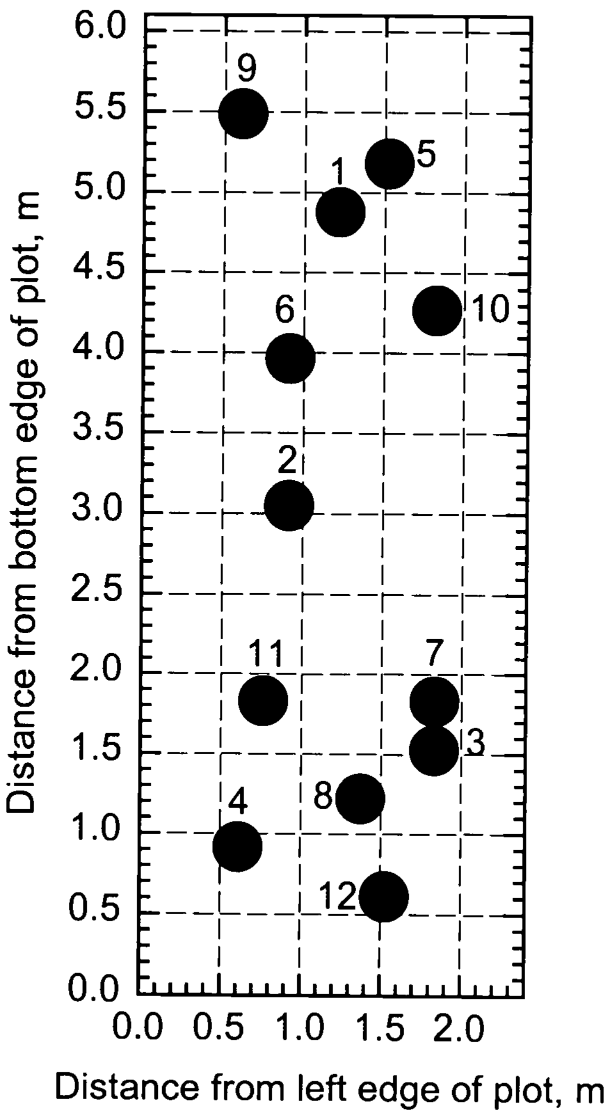

Figure 1. Plot Schematic and Placement of Manure. Filled circles indicate manure deposits; the number near a filled circle indicates the experimental week on which the manure was deposited after initiation of the experiment.

Manure Application

Manure was applied to the plots to simulate the effects of grazing duration and to partially simulate the effects of different grazing strategies on nutrient concentrations and transport in runoff through a factorial experimental design with three manure application strategies and three grazing durations. Each treatment combination was replicated three times. Treatments and replications were randomly assigned to the nine plots used in the study. Three grazing strategies were simulated: ungrazed (control), continuously grazed (3.7 animal units (AU)/ha) (an AU is defined as a 450 kg animal), and rotationally grazed (14.8 AU/ha for seven days, ungrazed for 21 days). The stocking density used in simulating continuous grazing was selected as slightly lower than initial densities recommended for well-managed pasture in Kentucky (5-8 AU/ha; Turner *et al.,* 1986). The stocking density for the rotational grazing strategy simulation reflects equal cattle and pasture area as simulated for the continuous grazing strategy, but with the cattle spending only one week in four (comparable to Henning and Lacefield, 1997) in a particular paddock. The grazing strategies were simulated only in terms of the timing of manure application, as described later. There were no attempts to replicate hoof traffic on the plots, and no cattle urine was added to the plots. The grazing duration treatment levels were 4, 8, and 12 weeks. The effects of grazing duration were assessed by multiple applications of simulated rainfall to the nine plots at 4, 8, and 12 weeks after the beginning of manure application.

Beginning the first week of July 1996, the conventional grazing strategy was simulated by weekly application of a 1.4 kg fresh (approximately 6 h since excretion) manure/plot (calculated from standard manure production rates published by ASAE, 1991). The manure was obtained from confined beef cattle that were fed a fescue diet in connection with an unrelated study. The 1.4 kg of manure was formed as a single deposit having a diameter of approximately 25 cm. Each deposit thus covered an area of approximately 0.05 m^2. The locations of the deposits were the same for all plots receiving manure, and locations were randomly selected with the exception that one deposit was never placed on top of another. The location and schedule of manure deposition are given in Figure 1. The proportion of total plot area covered by manure deposits increased linearly from 0.3 percent after the first week's manure application to 4 percent after the 12th week's application. One manure sample was collected during each of the 12 applications and analyzed water and nutrient content (Table 2).

Except for manure application, all plots received identical management during the study. All plots were mowed to the same height on the same day, all were equally exposed to natural rainfall, and all were equally exposed to wildlife. The mower was operated so that the wheels did not contact the manure deposits. The blade height was sufficient to prevent contact with the manure deposits, so that the deposits were undisturbed throughout the study.

TABLE 2. Properties of Cattle Manure.

Parameter	Mean[1] (mg/kg)	SD[2] (mg/kg)
H_2O	814,800	23,200
Total N	22,500	3,600
P	5,840	1,890
K	3,400	1,640
Cu	36	21
Zn	114	41

[1]Mean of 12 samples.
[2]Standard deviation.

The rotational grazing strategy was simulated by monthly application of 5.6 kg manure/plot beginning on the fourth week of July 1996. The manure was applied as four 1.4-kg, 25-cm diameter deposits as described earlier and in the same locations as were used in the simulated conventional grazing strategy. The only difference between the simulated conventional and rotational grazing strategies was the timing of application of manure deposits.

Runoff Sampling and Analysis

Five rainfall simulators, each capable of applying from 0-120 mm/hr simulated rainfall to one 2.4 by 6.1 m plot, were constructed as a part of this project. The simulator operates on the same principle as that described by Miller (1987) but provides greater areal coverage. The greater coverage is achieved by using a simulator consisting of two rows of four nozzles per row, with a 1.85 m separation distance between nozzles, as opposed to the single-nozzle simulator described by Miller (1987).

At approximately 4, 8, and 12 weeks following the beginning of manure deposition (July 28, August 23, and September 18), simulated rainfall was applied to each of the nine plots on the same day. The simulated rainfall intensity was a constant 50.8 mm/hr, maintained until a 0.5-h duration of runoff had occurred from each plot. This rainfall intensity was used because preliminary work indicated that the plots have a high intake capacity and were unlikely to consistently produce runoff at lower simulated rainfall intensities. Natural storms of the intensity and duration used in the study are reasonably uncommon; a 50.8 mm/hr storm with a duration of 1 hr, for example, has a return period of slightly more than 10 years for the Lexington area (Hershfield, 1961). A constant runoff duration was chosen in preference to a constant simulated rainfall duration to control for plot-to-plot variation in antecedent soil moisture.

The simulated rainfall applied prior to the beginning of runoff, R_R (mm), was calculated as the product of simulated rainfall intensity and the duration of simulated rainfall prior to the beginning of runoff (as measured with a stopwatch). The total simulated rainfall applied, R_T (mm), was calculated as the sum of R_R and 25.4 mm (the additional simulated rainfall applied during the 0.5 h of runoff). Total simulated rainfall duration therefore generally differed between plots, but runoff duration was constant. Approximately 1 L samples were collected 2, 4, 6, 8, 16, 24, and 30 min after the beginning of runoff. Runoff samples were collected by inserting a clean polyethylene container (1 L volume) underneath the stream of runoff exiting the gutter through the PVC pipe. Runoff entered the container for a period of 60 sec or until the container was filled, whichever came first. The times required to collect the samples were measured with a digital stopwatch with a precision of 0.01 sec to enable computation of runoff rates. Due to the generally low runoff rates observed during the study, the time required to collect a sample was in nearly all cases greater than 20 sec, with a minimum of 6 sec.

All runoff samples were analyzed for total Kjeldahl N (TKN), ammonia N (NH_3-N), nitrate N (NO_3-N), ortho-P (PO_4-P) and FC according to Greenberg *et al.* (1992). Filtration necessary for NO_3-N and PO_4-P analyses was performed in the field within one hour of sample collection.

The plots received a total of 238 mm natural rainfall (measured with a recording tipping bucket rain gage at the plot site) in the intervals between manure application and simulated rainfall, as indicated in Table 3. In no case was the natural rainfall sufficient to produce runoff, and there were no apparent effects of natural rainfall on the integrity of the manure deposits.

Data Analysis

The data for a particular plot having runoff sampled on a particular day consisted of a set of seven values of runoff rates and corresponding times relative to the beginning of runoff. For each calculated value of runoff rate, there was an associated set of values of chemical and biological parameter concentrations. These data were summed over the runoff duration to produce runoff volume, mass transport and flow-weighted concentration of each chemical and biological parameter. Runoff depth (Q, mm) was calculated by numerically integrating flow rate with

TABLE 3. Natural Rainfall Measured Between July 1 and September 18, 1996.[1]

Month	Day	Rainfall (mm)	Month	Day	Rainfall (mm)	Month	Day	Rainfall (mm)
July	1	T[2]	August	1	T	September	1	0.5
July	2	T[3]	August	2	T	September	2	0.0
July	3	25.4	August	3[3]	0.0	September	3	0.3
July	4	0.0	August	4	0.0	September	4	0.5
July	5	0.0	August	5	0.0	September	5	0.3
July	6	0.0	August	6	0.0	September	6[3]	0.0
July	7[3]	T	August	7	0.0	September	7	1.3
July	8	4.3	August	8	20.6	September	8	0.0
July	9	0.10	August	9	0.0	September	9	0.3
July	10	0.0	August	10[3]	0.0	September	10	0.0
July	11	0.0	August	11	2,5	September	11	0.0
July	12	0.0	August	12	3.3	September	12	2.5
July	13[3]	8.9	August	13	0.0	September	13[3]	0.0
July	14	4.6	August	14	0.0	September	14	0.0
July	15	22.6	August	15	0.0	September	15	0.3
July	16	0.0	August	16	11.9	September	16	38.1
July	17	1.3	August	17	13.2	September	17[3,4]	3.8
July	18	2.3	August	18[3]	0.0	September	18[5]	0.0
July	19[3]	1.3	August	19	0.0			
July	20	24.9	August	20	0.0	**Total**		**47.8**
July	21	T	August	21	0.0			
July	22	T	August	22[3,4]	0.0			
July	23	0.0	August	23[5]	0.0			
July	24	0.0	August	24	5.6			
July	25	0.0	August	25	0.0			
July	26	0.0	August	26	0.0			
July	27[3,4]	0.0	August	27	1.3			
July	28[5]	2.5	August	28	0.0			
July	29	0.3	August	29[3]	0.0			
July	30	13.0	August	30	0.0			
July	31	20.6	August	31	0.0			
Total		**131.8**	**Total**		**58.4**			

[1]National Climate Data Center, 1996a,b,c.
[2]Trace.
[3]1.4 kg manure/plot applied to continuous grazing plots.
[4]5.6 kg manure/plot applied to rotational grazing plots.
[5]Simulated rainfall applied.

respect to time. The plot Curve Number (CN) (SCS, 1972) was determined by calculating the soil water retention parameter S from the relationship (Haan and Edwards, 1988)

$$S = 5R_T + 10Q - 10\sqrt{Q^2 + 1.25R_TQ} \quad (1)$$

and converting S to CN from

$$CN = \frac{25,400}{S + 254} \quad (2)$$

where R_T is as previously defined. Mass transport was calculated by summing the products of concentration and associated incremental runoff volumes. Flow-weighted mean concentration was calculated by dividing mass transport by total runoff volume. The effects of the experimental variables (grazing strategy and grazing duration) on R_R, R_T, Q, CN, flow-weighted concentrations and mass transport of chemical and biological parameters were determined through analysis of variance (ANOVA) conducted at the $p = 0.05$ significance level. Untransformed data were used in all ANOVA procedures except in the case of FC, in which natural logarithms of the data were used because of the approximate log-normal distribution of the data.

Further analysis of the results was conducted to determine how the concentration results varied with regard to time since the beginning of runoff. Relative concentrations (C_R) were calculated for all plots and sampling times as the ratio of concentration of a particular parameter at a particular sampling time to the flow-weighted mean concentration. These relative concentrations were pooled over all treatments and replications, and ANOVA followed by means separation was performed on each analysis parameter's corresponding sets of C_R values. Significant ($p < 0.05$) F-statistics were taken as evidence of changes in relative concentrations during runoff.

RESULTS AND DISCUSSION

The ANOVA results for the main treatment effects are given in Tables 4 and 5 for all hydrologic, chemical and biological variables investigated. In the cases of four of the nine variables, the interaction between grazing treatment and duration was significant; the ANOVA results for those variables appear in Table 6.

Plot Hydrologic Variables

There was concern that the relatively short interval between establishment of the plots and the initiation of this experiment might influence the results, particularly with regard to hydrologic variables. Additional rainfall-runoff studies have been conducted on these plots in the succeeding years (Edwards *et al.*, 1999; Moss *et al.*, 1999), however, and the hydrologic response of the plots has been consistent.

All hydrologic variables were significantly affected by both grazing treatment and duration, and all but Q were affected by the interaction of grazing treatment and duration (Tables 4, 5, and 6). The rotational grazing plots generally demonstrated a greater tendency toward runoff, as indicated by lower values of R_R and R_T and higher values of Q and CN (Table 4). As Table 6 indicates, however, the grazing treatment effect was usually evident only for the four-week grazing duration following one week of no natural rainfall (Table 3), the sole exception being CN values. The detection of a significant grazing treatment effect on hydrologic variables is judged to most likely be an artifact of the assignment of treatments to plots since (a) maintenance procedures were identical for each plot and (b) the area covered by the manure was less than 1.5 percent of the total plot area at the time of the first simulated rainfall, equal to the manure-covered area for the conventional grazing plots.

TABLE 4. Grazing Treatment Effects on Concentrations.

Variable[1]	Grazing Treatment: Control	Conventional	Rotational
R_R (mm)	46.5 ab[2]	78.7 a	22.9 b
R_T (mm)	76.1 ab	104.1 a	48.3 b
Q (mm)	2.1 b	4.7 ab	6.6 a
CN	50.0 b	50.0 b	71.5 a
NO_3-N (mg/L)	0.37 ab	0.45 a	0.33 b
NH_3-N (mg/L)	0.39 a	0.43 a	0.41 a
TKN (mg/L)	1.70 b	2.04 b	2.90 a
PO_4-P (mg/L)	0.56 a	0.68 a	0.91 a
FC (cfu/100 mL)	1.5×10^3 b	2.4×10^5 a	1.8×10^6 a

[1]R_R is simulated rainfall prior to runoff, R_T is total simulated rainfall, Q is runoff, CN is curve number, NO_3-N is nitrate nitrogen. NH_3-N is ammonia nitrogen, TKN is total Kjeldahl nitrogen, PO_4-P is ortho-phosphorus and FC is fecal coliform.
2Within-row means followed by the same letter are not significantly different ($p = 0.05$).

TABLE 5. Grazing Duration Effects on Concentrations.

Variable[1]	Grazing Duration: 4 Weeks	8 Weeks	12 Weeks
R_R (mm)	73.9 a[2]	50.3 ab	23.9 b
R_T (mm)	99.3 a	75.7 ab	53.5 b
Q (mm)	2.7 b	2.1 b	8.6 a
CN	48.8 b	51.7 b	70.9 a
NO_3-N (mg/L)	0.54 a	0.39 b	0.23 c
NH_3-N (mg/L)	0.29 b	0.56 a	0.38 b
TKN (mg/L)	1.79 b	2.70 a	2.15 ab
PO_4-P (mg/L)	0.36 b	0.84 a	0.91 a
FC (cfu/100 mL)	1.5×10^4 b	7.9×10^4 ab	5.4×10^5 a

[1]R_R is simulated rainfall prior to runoff, R_T is total simulated rainfall, Q is runoff, CN is curve number, NO_3-N is nitrate nitrogen. NH_3-N is ammonia nitrogen, TKN is total Kjeldahl nitrogen, PO_4-P is ortho-phosphorus and FC is fecal coliform.
2Within-row means followed by the same letter are not significantly different ($p = 0.05$).

TABLE 6. Combined Grazing Treatment and Duration Effects.

Variable/ Grazing Treatment[1]	Grazing Duration[2] 4 Weeks	8 Weeks	12 Weeks
R_R (mm)			
Control	71.1[2] a1[23]	38.9 a1	29.5 a1
Conventional	133.8 a1	81.1 ab1	21.2 b1
Rotational	16.8 a2	30.9 a1	20.9 a1
R_T (mm)			
Control	96.5 a12	64.3 a1	67.6 a1
Conventional	159.2 a1	106.5 ab1	46.6 b1
Rotational	42,2 a2	56,3 a1	46.3 a1
CN			
Control	40.6 a2	52.9 a12	56.6 a2
Conventional	31.7 b2	39.8 b2	78.5 a1
Rotational	74.2 a1	62.5 a1	77.8 a1
NO_3-N (mg/L)			
Control	0.55 a1	0.42 a1	0.15 b1
Conventional	0.66 a1	0.41 b1	0.28 b1
Rotational	0.39 a2	0.33 a1	0.27 a1

[1] R_R is simulated rainfall prior to runoff, R_T is total simulated rainfall, Q is runoff, and CN is curve number.
[2] Arithmetic mean of three samples.
[3] For a given variable, within-row means followed by the same letter and within-column means followed by the same numeral are not significantly different ($p = 0.05$).

The detection of significant grazing duration effects (Table 5) was expected in view of differences in prior natural rainfall on the simulated rainfall dates (Table 3). For example, 38 mm of rainfall occurred two days prior to the September 18 simulated rainfall (Table 3), causing the means of several variables to differ significantly between the July 28 and September 18 simulated rainfall events (e.g., Q and CN, Table 5).

Chemical and Biological Parameter Concentrations

The results with regard to soluble nutrients are similar to findings from other studies involving grazing (e.g., Milne, 1976; Doran *et al.,* 1981), in that concentrations from the manure-treated plots were often indistinguishable from background levels (i.e., those from the control plots). For example, there were no grazing treatment effects on runoff concentrations of PO_4-P and NH_3-N, and no significant differences in runoff concentrations of NO_3-N and TKN between the conventionally grazed and control plots (Table 4). The only nutrient runoff differences attributable to grazing treatment involved NO_3-N, which was lowest for the rotational grazing treatment (but not different from the control treatment), and TKN, which was highest for the rotational grazing treatment (Table 4). The TKN differences are attributed to organic N differences, since there were no differences in NH_3-N concentrations. These findings can be linked to the freshness of the manure deposits on the rotational grazing plots relative to application of simulated rainfall. Fresh manure can be expected to be relatively low in NO_3-N and high in organic N with the situation reversing as nitrification occurs. However, there were no grazing treatment effects on runoff NO_3-N concentrations for the 8-week and 12-week grazing durations (Table 6). Concentrations of FC for the manure-treated plots were usually two orders of magnitude or more greater than for the control plots (Table 4), consistent with greater availability of FC for runoff transport from the manured plots.

Runoff concentrations of all N forms as well as PO_4-P and FC were significantly affected by grazing duration (Table 5). The data on runoff PO_4-P and FC concentrations indicate generally increasing availability of these parameters for runoff transport, which is explainable by the increasing amounts of manure present on the manured plots. The results with regard to N are more difficult to explain. The behavior of NO_3-N is consistent with NO_3-N removal from near the soil surface, due to plant uptake, natural and simulated rainfall, or both. The relatively high TKN and NH_3-N concentrations occurring during the 8-week grazing duration, however, appear unrelated to weather, manure application, or plant uptake.

As discussed earlier, the presence of manure (irrespective of grazing treatment) affected runoff concentrations of only NO_3-N and TKN, with effects on NO_3-N apparent during only the 4-week grazing duration. The lack of a consistent effect of manure application on runoff quality is probably linked to within-plot filtering. Both rainfall that runs off after impacting the manure and runoff that contacts the manure deposits after originating from further upslope may be assumed to have high concentrations of nutrients and FC relative to the runoff from the control plots. As indicated in Figure 1, however, nearly all manure deposits were located at least 1 m from the runoff sampling gutter; water contacting those deposits would thus have been susceptible to filtration over a flow distance of at least 1 m. Overcash *et al.* (1981) modeled performance of vegetative filter strips downslope of a pollutant source. The modeled situation is analogous to this study, with the manure deposits constituting the pollutant source, and the unmanured plot area down-slope of the deposits constituting the filter strip. The model assumed that only infiltration of soluble pollutants was responsible for filtration and predicts that concentrations exiting the filter strip decrease with increasing infiltration. As

Tables 4, 5, and 6 indicate, infiltration in this study was high, which would promote high filtration of soluble pollutants. The Overcash *et al.* (1981) model also predicts that concentrations will decrease with increasing filter strip length (as noted earlier, the minimum "filter strip length" was 1 m for all but one manure deposit with half the deposits located 3 m or more from the plot edges). It may be concluded that the combination of high infiltration capacity and adequate filtration lengths played a significant role in the findings with regard to runoff nutrient concentrations.

Analysis of variance indicated that, except in the case of NO_3-N, relative concentrations of chemical and biological parameters exhibited dependence on the time at which the sample was collected. Figures 2 through 5 depict relationships between relative concentration and time for NH_3-N, TKN, PO_4-P, and FC and time after initiation of runoff. In these figures, the highest relative concentrations are seen to be associated with the earliest sampling period with subsequent relative concentrations declining in approximately exponential fashion. The behavior of relative concentration values is consistent with an initial

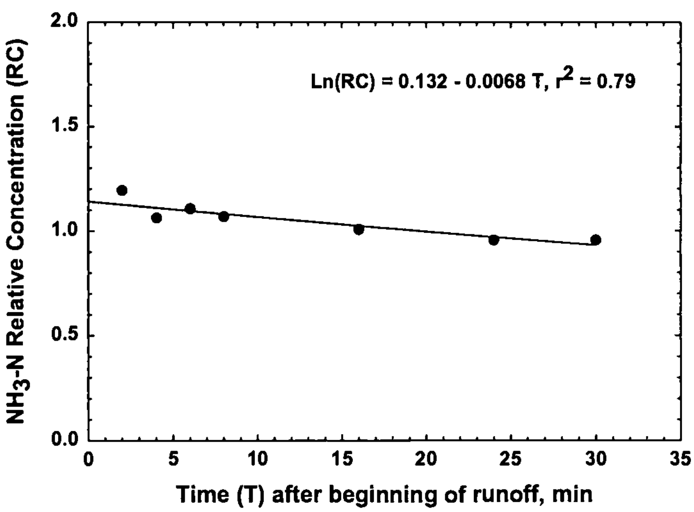

Figure 2. Relationship Between Runoff Ammonia Nitrogen (NH_3-N) Relative Concentration and Timing of Sample Collection. The filled circles represent means of data, and the line represents the fitted curve.

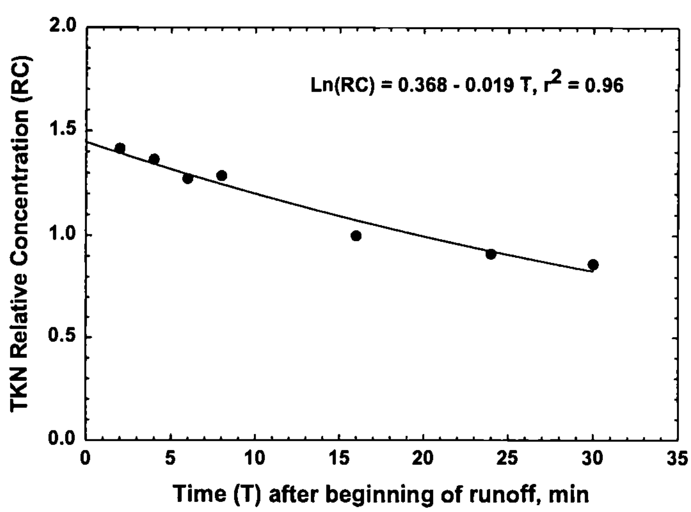

Figure 3. Relationship Between Runoff Total Kjeldahl Nitrogen (TKN) Relative Concentration and Timing of Sample Collection. The filled circles represent means of data, and the line represents the fitted curve.

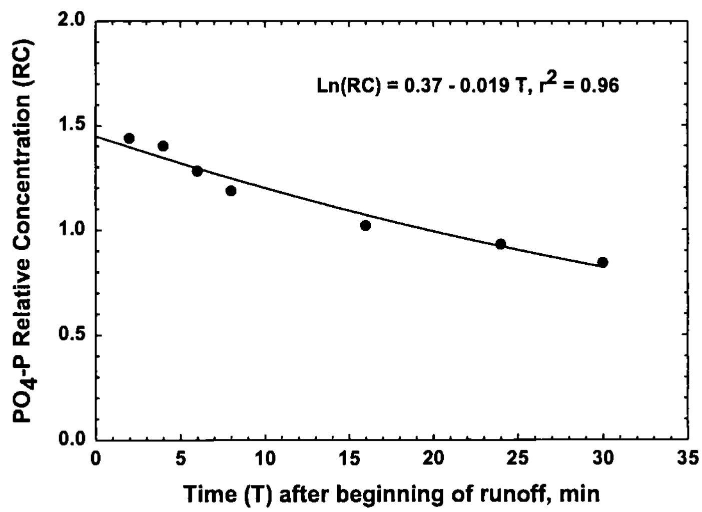

Figure 4. Relationship Between Runoff Ortho-Phosphorus (PO_4-P) Relative Concentration and Timing of Sample Collection. The filled circles represent means of data, and the line represents the fitted curve.

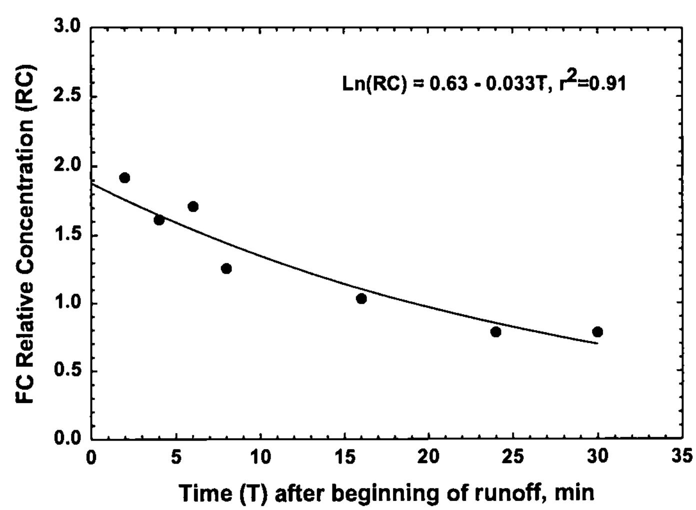

Figure 5. Relationship Between Runoff Fecal Coliform (FC) Relative Concentration and Timing of Sample Collection. The filled circles represent means of data, and the line represents the fitted curve.

"flushing" of the chemical and biological parameters followed by dilution and/or decreasing availability for transport of the parameters.

Chemical Parameter Mass Transport

The effects of grazing treatment and duration on runoff mass transport of nutrients is given in Tables 7 and 8, respectively. One of the most noteworthy findings was that mass transport was quite low, usually only a few g/ha. Analysis of variance detected that, with the exception of NH_3-N (which was affected only by grazing duration), mass transport was influenced by both grazing treatment and grazing duration, but not the interaction between the two variables. The effects of grazing treatment on mass transport closely reflect the effects on hydrologic variables and chemical concentrations as given in Table 4. Mass transport for the rotational grazing treatment was always in the highest mass transport grouping. In the case of PO_4-P, this follows directly from the rotational grazing plots' tendency toward higher runoff (Table 4). The influence of greater runoff from the rotational grazing plots is also evident in NO_3-N mass transport, where the lower concentrations were offset by the higher runoff (Table 4). The effects of grazing treatment on TKN transport reflect the combination of highest concentration and highest runoff from the rotational grazing plots (Table 4). Table 8 indicates that grazing duration influenced mass transport more through its effects on runoff than on concentrations. Mass transport for the 12-week grazing duration was always in the highest grouping due to the higher runoff measured at that duration (Table 4). Concentrations of NO_3-N, for example, were lowest at the 12-week grazing duration but combined with high runoff to produce the highest mass transport.

SUMMARY AND CONCLUSIONS

This study assessed the effects of cattle manure application strategy (control and partial simulation of conventional and rotational grazing) and duration on runoff quality with respect to N, P, and FC as well as the impacts of runoff depth and timing of sample collection on these parameters. The grazed pasture was simulated by plots established in Kentucky 31 fescue and having beef cattle manure applied. The runoff was caused by application of simulated rainfall.

Inorganic N and P concentrations demonstrated no consistent dependence on either grazing strategy or grazing duration and were usually not different from those measured for the control plots. Runoff concentrations of FC for the manure-treated plots were significantly greater than from control plots but did not depend on whether conventional or rotational grazing was being simulated. These findings suggest that when manure deposition within a grazed field is random, runoff transport of nutrients from the manure might not be significantly greater than for background conditions for similar soils, vegetation, and manure application rates as those used in this study. As discussed earlier, this study did not examine the effects of hoof traffic, urine addition, or vegetation differences due to conventional vs. rotational grazing. While those variables might be expected to influence both the amount and quality of runoff, additional work will be required to isolate the effects of those variables from those of the manure properties alone. It would also be helpful in future studies to include a subsurface water component to both clarify the dynamics of nutrient and microorganism transport and to better evaluate the contribution of subsurface transport to overall offsite losses of manure components.

TABLE 7. Grazing Treatment Effects on Transport.

	Grazing Treatment		
Variable[1]	Control (g/ha)	Conventional (g/ha)	Rotational (g/ha)
NO_3-N	5.2 b[2]	14.5 ab	20.4 a
NH_3-N	23.9 a	18.0 a	22.3 a
TKN	33.4 b	96.6 ab	169.7 a
PO_4-P	12.2 b	43.3 ab	62.6 a

[1]NO_3-N is nitrate nitrogen, NH_3-N is ammonia nitrogen, TKN is total Kjeldahl nitrogen, and PO_4-P is ortho-phosphorus.
[2]Within-row means followed by the same letter are not significantly different ($p = 0.05$).

TABLE 8. Grazing Duration Effects on Transport.

	Grazing Duration		
Variable[1]	4 Weeks (g/ha)	8 Weeks (g/ha)	12 Weeks (g/ha)
NO_3-N	11.7 ab[2]	7.4 b	21.1 a
NH_3-N	6.5 b	11.8 b	46.0 a
TKN	49.9 b	67.1 b	182.8 a
PO_4-P	9.4 b	21.8 b	86.9 a

[1]NO_3-N is nitrate nitrogen, NH_3-N is ammonia nitrogen, TKN is total Kjeldahl nitrogen, and PO_4-P is ortho-phosphorus.
[2]Within-row means followed by the same letter are not significantly different ($p = 0.05$).

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