1997

Runoff Quality Responses to Cattle-Gazing Strategy and Grassed Buffer Zone Length

Digital Object Identifier: https://doi.org/10.13023/kwrri.rr.201

Dwayne R. Edwards
University of Kentucky, dwayne.edwards@uky.edu

Brian T. Larsen
University of Kentucky

Teng T. Lim
University of Kentucky

Repository Citation

Edwards, Dwayne R.; Larsen, Brian T.; and Lim, Teng T., "Runoff Quality Responses to Cattle-Gazing Strategy and Grassed Buffer Zone Length" (1997). *KWRRI Research Reports*. 7.
https://uknowledge.uky.edu/kwrri_reports/7

Research Report No. 201

Runoff Quality Responses to Cattle-Grazing Strategy and Grassed Buffer Zone Length

by

Dwayne R. Edwards
Principal Investigator

Brian T. Larsen
Co-Principal Investigators

Teng T. Lim
Graduate Assistant

Project Number: 95-03
Agreement No.: 14-08-00D1-G2021
Period of Project: July 1995 to June 1996

University of Kentucky
Kentucky Water Resources Research Institute
Lexington, KY 40506-0107

The work on which this report is based was supported in part by the Department of the Interior, Washington, D.C. as authorized by the Water Resources Research Act as amended in 1996 by P.L. 104-147

1997

Research Report No. 201

Runoff Quality Repsonses to Cattle-Grazing Strategy and Grassed Buffer Zone Length

By

Dwayne R. Edwards
Principal Investigator

Brian T. Larsen
Co-Principal Investigator

Teng. T. Lim
Graduate Assistant

Kentucky Water Resources Research Institute
University of Kentucky
Lexington, KY

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Kentucky Water Resources Research Institute. The contents of this publication do not necessarily reflect the views and policies of the Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

ABSTRACT

Grazed pastures represent a source of potential 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 simulated grazed pasture is influenced by grazing duration (4-12 weeks), grazing strategy (no grazing, conventional grazing and rotational grazing), and by the use of grassed buffer strips (ranging in length from 0 to 18.3 m) installed down-slope of simulated pasture. 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 to 30.5 m long) were constructed and established in Kentucky 31 "tall" 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. Runoff samples were collected and analyzed according to standard methods for nitrogen (N), phosphorus (P), total suspended solids (TSS), and fecal coliform (FC). Runoff concentrations and transport of N and P from the plots used to simulate conventional and rotational grazing were low and, in many cases, not different from those measured for ungrazed plots. Runoff FC concentrations were greater for the simulated grazed plots than for the control plots, but there was no difference in concentrations between the simulated conventional and rotational grazing treatments. The buffer strips were very effective in removing TKN, PO4-P, TSS and FC in incoming runoff from manured plots. Concentrations of all these parameters were indistinguishable from background levels after crossing a buffer length of 6.1 m. This finding is attributed largely to very high infiltration in the plots used to assess the buffer strips.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Beef cattle production is an essential component of Kentucky's agricultural economy. In excess of one million cattle are marketed annually, worth 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 nutrients and solids loadings to surface waters. Cattle manure contains appreciable concentrations of nitrogen (N) and phosphorus (P) (0.6 and 0.2%, respectively; ASAE, 1991) as well as numerous microbes, all of which can be transported into downstream waters during runoff-producing rainfall events (e.g., Khaleel et al., 1980).

The major concern regarding runoff losses of nutrients is accelerated eutrophication. The causes and effects of eutrophication are generally well known (e.g., Sharpley et al., 1994). The degree to which runoff from grazed pasture promotes eutrophication, however, is not clear. Indeed, whether nutrient losses from grazed pastures are in significant greater than "background" losses and what variables affect those losses are apparently not well understood. Gary et al. (1985) sampled a stream flowing through a grazed pasture in Colorado and found that while ammonia N (NH_3-N) concentrations increased during grazing, concentrations of NO_3-N did not. Stream flow samples were not analyzed for P. It might be significant that stream flow in this study was generally sampled without regard for flow conditions; as a result, the stream flow samples were more representative of base flow conditions than of storm flow conditions. Grazed pastures can generally affect stream flow only quality during runoff-producing rainfall; these results might therefore be more closely related to direct deposition of manure into the stream than to the contribution of grazed pasture to stream flow quality. Doran et al. (1981) measured chemical quality of storm runoff from grazed pasture in Nebraska and reported that concentrations of N, P, total organic carbon (TOC) and chemical oxygen demand (COD) were higher from an ungrazed control plot than from the grazed pasture. That finding, however, might be more reflective of the difficulty in obtaining "background" data than of the role of grazing with regard to runoff quality, since it seems unlikely that runoff quality would be improved by the presence of fresh manure on the soil surface. Milne (1976) concluded that grazing cattle had a "negligible" impact on chemical quality of a Montana stream. Similar to a previously cited study, however, the samples were collected on a fixed schedule, rather than with emphasis on collection during runoff events. Available information therefore indicates no consensus on the effect of grazing on nutrient losses, which might be due to water sampling protocols, scale, sampling duration, or a combination of these and other factors.

The major concern with regard to runoff transport of bacteria and viruses from grazed pasture is obviously human health impacts. Available studies on the subject by no means address all aspects of the issue, but they are generally more consistent in their conclusions regarding grazing effects than studies on nutrient transport. Milne (1976) found that the cattle operation mentioned in the previous paragraph significantly increased stream bacteria concentrations, with similar findings reported by Burt (1976), Gary et al. (1983), Doran and Linn (1979), Doran et al. (1981) and Jawson et al. (1982).

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 Tiedmann et al. (1987, 1988), however, suggest that rotational grazing might have the opposite effect with regard to stream flow fecal coliform concentrations. Grassed filter strips are another measure with the potential for reducing pollutant losses from grazed pastures. Grassed filter strips are nothing more than grassed areas, down-slope of pollutant sources (row-cropped field, feed lot, etc.), that purify incoming runoff. Mechanisms of pollutant removal include deposition of solids and adsorbed pollutants, pollutant adsorption to vegetation and soil surfaces, and infiltration of soluble pollutants. () and () have judged infiltration to be the most important removal mechanisms for grassed pollutant sources, because the proportion of soluble pollutants is high relative to that for bare or row-cropped pollutant sources. Grassed filter strips are known to remove significant proportions (up to 90% or more) of incoming pollutants in runoff from cropland (), feed lots () and pastures amended with animal manures (Chaubey et al., 1994, 1995; Srivastava et al., 1996). Larsen et al. (1994) concluded that filter strip lengths as short as 0.6 m can have a "dramatic" effect on fecal coliform concentrations in runoff from grazed pasture, but little other work has been done to investigate the application of filter strips to grazed pasture.

The objectives of this study were to:

1. Measure concentrations and mass transport of nitrogen (N), phosphorus (P), carbon (C), solids, and fecal coliforms (FC) in runoff from simulated grazed pasture areas as a function of grazing strategy and time since initiation of grazing.
2. Determine the relationship between grassed buffer zone length and effectiveness in reducing runoff transport of the above parameters.

RESEARCH PROCEDURES

General

The study was performed using plots constructed on a Maury silt loam (fine, mixed, mesic Typic Paleudalf) soil at the Maine Chance University of Kentucky Agricultural Experiment Station. Dimensions of the plots used for the first objective were 2.4 by 6.1 m, and dimensions for those used in the second objective were 2.4 by 30.5 m (long axes oriented up- and down-slope). Plots were graded to a uniform 3% slope along the major axis and cross-leveled across the minor axis. The vegetation for all plots was “tall” fescue, maintained at a height of between 10-15 cm by mowing with a commercial mower and string trimmer. Each plot was bordered with galvanized iron (10 cm above and below ground surface) to isolate runoff. Soil samples were collected from each plot and analyzed by the University of Kentucky Regulatory Services Laboratory for nutrient content and other characteristics according to standard methods. The results of the soil sample analyses are given in Table 1.

Table 1. Research site soil properties.

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

[1] Mean of 30 samples.

[2] Standard deviation

A gutter was constructed and installed across the lower end of each of the shorter (6.1 m long) plots to concentrate runoff for measurement and sampling. These gutters were constructed of sheet metal and have a 5% slope to ensure "self-cleaning". Runoff from the gutter enters a 5-cm inside diameter (inside diameter; ID) length of polyvinyl chloride (PVC) pipe and empties approximately 45 cm above the bottom of a sump. Each sump is lined with 30-cm ID Automated Drainage Systems (ADS) pipe; the sump bottoms consist of 30-cm ID ADS end caps. Runoff is sampled as it exits the PVC pipe and before contacting the interior of the sump. Unsampled runoff leaves the sump through 10-cm holes in the sump bottoms and exits the research site through the site drainage system. The runoff gutter system for the longer (30.5 m long) plots is similar, but the gutters are constructed of wood and are installed on 6.1-m intervals along the major plot axes. The gutters for the long plots have covers that are normally in place to allow the runoff to travel unimpeded across the gutters. The gutters are removed only when a runoff sample is to be collected. Schematic drawings of the plots are given in Figs. 1 and 2.

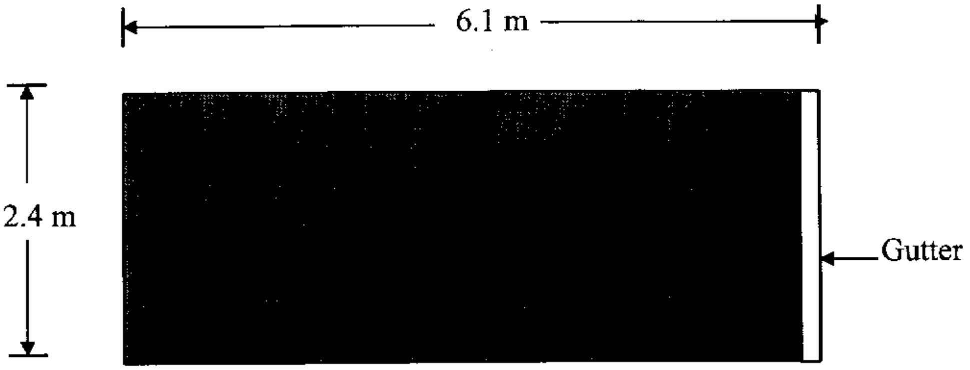

Figure 1. Schematic of plots used for objective 1

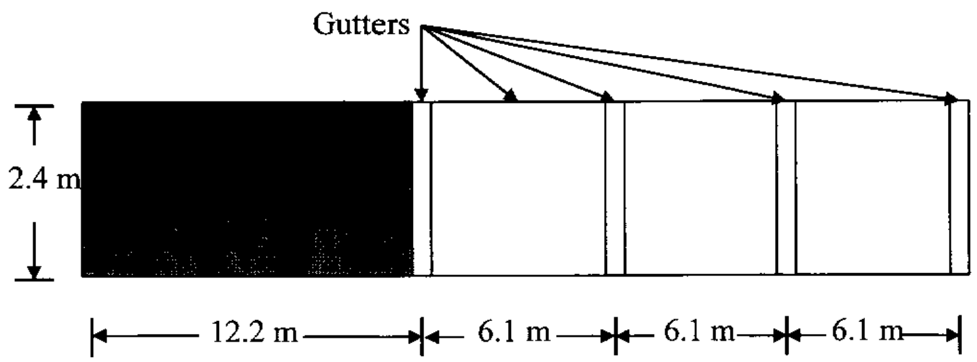

Figure 2. Schematic of plots used in objective 2.

Runoff was generated from the application of simulated rainfall. 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 design is similar in some respects to that developed at the National Soil Erosion Research Laboratory (Niebling et al., 1981) and modified by Edwards et al. (1992). The current design, however, uses a different nozzle (WSQ 30, Spraying Systems, Inc.), which alleviates the need for mechanisms to oscillate the nozzles. Simulated rainfall intensity is governed by the frequency at which the solenoid-actuated valves are opened to allow water to pass through the nozzles. The frequency of actuation is, in turn, controlled by a programmable logic controller that is interfaced with a notebook computer. The current simulators are very portable (each can be carried by four persons) and capable of rapid set-up and take-down. Each simulator can be operated independently (simultaneously providing water to separate 6.1 m-long plots at separate simulated rainfall intensities), or they can be used in series to provide rainfall to the longer plots (as was done in the second objective).

Runoff samples were collected by inserting a virgin polyethylene container (either 1 or 4 L volume) underneath the stream of runoff exiting the gutter through the PVC pipe for a period of 60 s or until the container was filled, whichever came first. The time required to collect the sample was measured with a digital stopwatch with a precision of 0.01 s. The frequency of runoff sample collection described in following sections. The rate of runoff associated with a particular runoff sample was calculated as the volume of the runoff sample divided by the time required to collect the sample. All runoff samples collected as part of this project were analyzed according to standard methods of analysis (Greenberg et al., 1992).

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), total P (TP), total suspended solids (TSS), chemical oxygen demand (COD), pH and FC. Filtration (necessary for NO_3-N, NH_3-N, and PO_4-P analyses) and pH measurements were performed in the field as soon as possible following sample collection. Technicians of the Biosystems and Agricultural Engineering Department Chemistry Laboratory performed all chemical, physical and microbiological analyses.

The data for a particular plot having runoff sampled on a particular day consisted of a set (5-7 values, depending on the sampling frequency) of runoff rates and corresponding times relative to the beginning of runoff. For each value of runoff rate, there was an associated set of values of analysis parameter concentrations. These data were reduced to runoff volume, mass transport of each parameter and flow-weighted mean concentration of each parameter. Runoff volume was calculated by numerically integrating flow rate with respect to time. 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.

Objective 1

The effects of grazing strategy and grazing duration on nutrient concentrations and transport in runoff was assessed using a factorial experimental design with three simulated grazing strategies and three levels of grazing duration. Each treatment was replicated three times. The grazing strategies included a control (ungrazed situation), a continuously grazed situation (3.7 animal units (AU)/ha), and a rotationally grazed situation (14.8 AU/ha for 7 days, ungrazed for 21 days). The grazing strategies were simulated only in terms of manure deposition, as described later. There were no attempts to replicate hoof traffic on the plots, and no cattle urine was added to the plots. A total of nine plots were used for this objective, corresponding to three replications of the three simulated grazing strategies. The grazing duration treatments 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 following initiation of simulated grazing.

The conventional grazing strategy was simulated by weekly application, beginning the first week of July 1996, of 1.4 kg manure/plot (calculated from standard manure production rates published by ASAE, 1991) to each plot. The manure was obtained from beef cattle fed a fescue diet. The 1.4 kg of manure was formed as a single deposit having a diameter of approximately 25 cm. The locations of the deposits were the same for all plots receiving manure. The locations were selected randomly with the exception that one deposit was never placed atop another. The location and schedule of manure deposition is given in Fig. 3. Samples of the manure were collected during each application and analyzed by the University of Kentucky Regulatory Services Laboratory for nutrient content and other characteristics. The results of the manure analyses are given in Table 2.

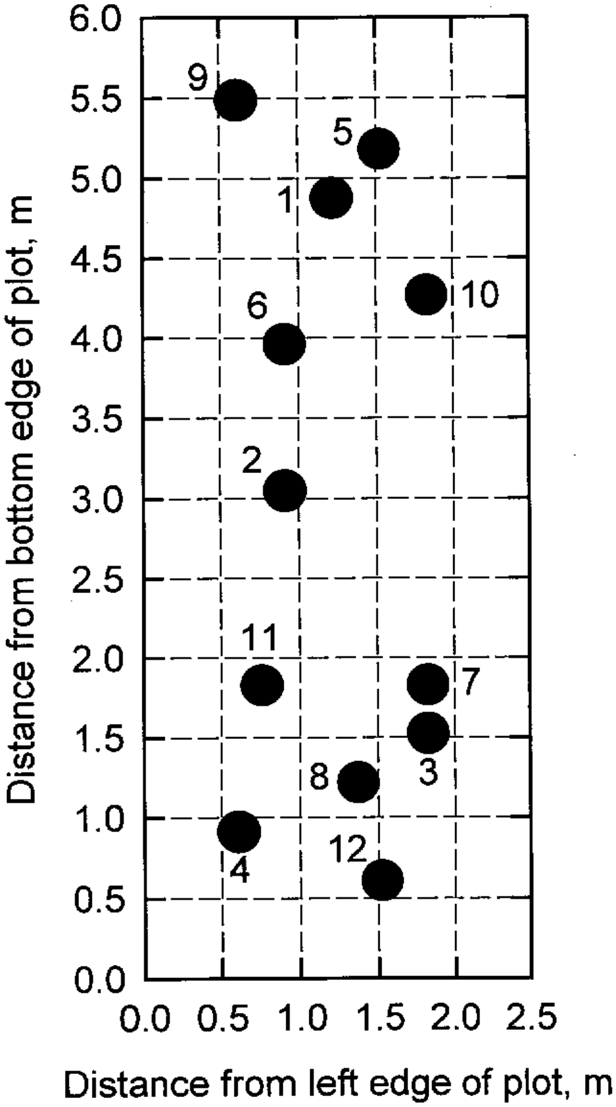

Fig. 3. Placement of manure within simulated grazed plots. Filled circles indicate manure deposits; the nearest number near a filled circle indicates the experimental week on which the manure was deposited.

Table 2. Properties of cattle manure.

Parameter	Mean[1]	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 applying 5.6 kg manure/plot as 4 1.4-kg deposits once each four weeks. The locations of the manure deposits were the same as for the simulated conventional grazing strategy. The only difference in the simulated conventional and rotational grazing strategies was, then, the timing of application of manure deposits, since the amounts deposited and the locations of those deposits were the same as for the simulated conventional grazing strategy.

At 4, 8 and 12 weeks following the beginning of manure deposition, simulated rainfall was applied to all nine plots. The simulated rainfall intensity was 50 mm/hr, maintained until 0.5 hr runoff had occurred from each plot. Total rainfall duration therefore generally differed between plots, but runoff duration was constant. Runoff was sampled (approximately 1 L sample size) at 2, 4, 6, 8, 16, 24 and 30 min after the beginning of runoff. The time required to collect each sample was recorded to enable calculation of runoff rates. The runoff samples were then prepared and analyzed as described previously. The effects of the experimental variables (grazing strategy and grazing duration) on concentrations and mass transport of analysis parameters were determined through analysis of variance (ANOVA).

Objective 2

This objective was accomplished in September, 1996 using three of the longer (30.5 m) plots described previously. The upper 12.2 m of each plot served as a simulated grazed area, as indicated in Fig. 2, while the remaining 18.3 m served as a buffer strip. In contrast to the random application of manure in Objective 1, the manure (total of 13.6 kg/plot) was applied only to the lower 1 m of the 12.2 m-long simulated grazed area. The rationale for this approach was that our data from the first objective suggested that incoming N and P concentrations might be insufficient to enable an accurate assessment of buffer strip performance if the manure were randomly applied within the simulated grazed area. Applying the manure only to the bottom of the simulated grazed area would promote measurable incoming pollutant concentrations and cause the data on buffer strip performance to be conservative, reflective of a near-worst case scenario.

Simulated rainfall was applied to each entire plot at 100 mm/hr until 1 hr of runoff had occurred. The relatively high simulated rainfall intensity was selected after a practice experiment indicated a very high infiltration capacity of the plots. Runoff samples were collected at 0, 6.1, 12.2 and 18.3 m down-slope of the simulated grazed area two minutes following the beginning of runoff and at 10-minute intervals thereafter. The samples were prepared and analyzed as described earlier for Objective 1. For this objective, then, the treatment variable was buffer strip length (with levels of 0, 6.1, 12.2 and 18.3 m) with three replications of each variable.

RESULTS AND DISCUSSION

Objective 1

Table 3 lists mean runoff concentrations of the analysis parameters. In general, concentrations of analysis parameters were significantly (p<0.10) affected by both grazing treatment and grazing duration. The exception was PO_4-P, which was significantly affected only by grazing duration (the data for PO_4-P concentrations in Table 3 are averaged across grazing treatments). In the cases of NO_3-N (p=0.01) and NH_4-N (p<0.001), the interaction between grazing treatment and duration was also significant.

The results with regard to soluble nutrients are similar to findings from other studies, in that concentrations are generally similar to background levels (i.e., concentrations measured for the control plots). There is also no consistent correlation between mean concentrations and either grazing treatment or duration. For example PO_4-P concentrations increased with grazing duration and did not depend on grazing treatment, while NO_3-N concentrations decreased with grazing duration and were highest for the CG grazing treatment. Except for the atypically high NH_3-N concentrations on the control plots at 12 weeks after initiation of grazing, there would be no effect of either grazing treatment or duration on runoff NH_3-N concentrations. In contrast, runoff concentrations of FC were significantly greater for the manure-treated plots than for the control plots, typically differing by two orders of magnitude. The concentration findings thus corroborate those reported previously, in that grazing effects on runoff quality were more evident in terms of microbiological water quality parameters than in chemical or physical parameters.

Table 3. Flow-weighted mean runoff concentrations of analysis parameters.

Parameter/ Grazing Treatment[1]	Grazing Duration		
	4 Weeks	8 Weeks	12 Weeks
	mg/L		
NO_3-N[2]			
X	0.55	0.42	0.15
CG	0.66	0.41	0.28
RG	0.39	0.33	0.27
NH_3-N[2]			
X	0.30	0.51	2.03
CG	0.36	0.53	0.39
RG	0.22	0.62	0.39
TKN[2]			
X	1.44	1.87	1.80
CG	1.77	2.24	2.10
RG	2.16	3.99	2.56
PO_4-P[3]	0.36	0.84	0.95
	cfu/100 mL		
FC[4]			
X	7.8×10^0	3.9×10^2	1.1×10^3
CG	3.6×10^3	1.1×10^4	3.4×10^5
RG	1.2×10^5	1.1×10^5	4.4×10^5

[1] X is control (no grazing), CG is conventional grazing and RG is rotational grazing.

[2] Arithmetic mean of three samples.

[3] Arithmetic mean of nine samples (averaged across grazing treatments).

[4] Geometric mean of three samples.

Runoff mass transport of nutrients is given in Table 4. One of the most noteworthy findings was that mass transport was quite low, usually only a few g/ha. Analysis of variance indicated differences due to both grazing treatment and duration, as was the case for concentrations. It is also apparent from Table 4 that mass transport was highest for the rotational grazing treatment, and that values of mass transport were higher for the longer grazing durations. These results, however, are attributed entirely to plot-to-plot differences in runoff. Table 4 also reports values of Soil Conservation Service (1972) curve number parameter (CN), separated according to grazing treatment and duration. The value of CN is a measure of the soil's propensity to contribute runoff. Higher values indicate greater runoff, all other factors being equal. Values of CN were also found during ANOVA to be dependent on both grazing treatment and duration. As indicated in Table 4, CN values were generally greater for the rotationally grazed plots and higher for the longest duration than others. This finding mirrors the mass transport results. Since concentrations generally demonstrated no clear association with grazing treatment or duration, and since mass transport is the product of concentration and runoff, the mass transport results must necessarily be strongly associated with the runoff results.

It is reasonable to ask now why the values of CN varied according to grazing treatment and duration. Differences in CN, in other words to runoff characteristics, are attributed to inherent spatial variability in soil hydraulic properties and soil moisture. The plots used and assigned to the various treatments were selected randomly, so no bias in that regard was present. It is also unlikely that the manure itself significantly affected the hydraulic properties. Only a few percent of plot area would have been covered by manure, even at the end of the experiment. Also, as shown in Table 4, there is again no clear relationship between CN and grazing treatment or duration, except that the rotationally grazed plots generally had higher CN values.

Table 4. Mean[1] mass transport and runoff curve numbers.

Parameter/ Grazing Treatment[2]	Grazing Duration		
	4 Weeks	8 Weeks	12 Weeks
CN			
X	40.6	52.9	56.6
CG	31.7	39.8	78.5
RG	74.2	62.5	77.8
	------------------------	g/ha	----------------------------
NO_3-N			
X	5.8	5.3	4.4
CG	10.2	4.3	29.1
RG	19.0	12.6	29.7
NH_3-N			
X	3.1	7.4	61.3
CG	5.8	5.7	42.6
RG	10.6	22.2	34.1
TKN			
X	15.3	23.6	61.4
CG	28.6	30.5	230.9
RG	105.7	147.2	256.0
PO_4-P			
X	4.0	10.5	22.1
CG	6.2	9.4	114.4
RG	18.1	45.5	124.1

---

[1] Arithmetic mean of three samples.

[2] X is control (no grazing), CG is conventional grazing and RG is rotational grazing.

RESULTS AND DISCUSSION

Objective 1

Table 3 lists mean runoff concentrations of the analysis parameters. In general, concentrations of analysis parameters were significantly ($p<0.10$) affected by both grazing treatment and grazing duration. The exception was PO_4-P, which was significantly affected only by grazing duration (the data for PO_4-P concentrations in Table 3 are averaged across grazing treatments). In the cases of NO_3-N ($p=0.01$) and NH_4-N ($p<0.001$), the interaction between grazing treatment and duration was also significant.

The results with regard to soluble nutrients are similar to findings from other studies, in that concentrations are generally similar to background levels (i.e., concentrations measured for the control plots). There is also no consistent correlation between mean concentrations and either grazing treatment or duration. For example PO_4-P concentrations increased with grazing duration and did not depend on grazing treatment, while NO_3-N concentrations decreased with grazing duration and were highest for the CG grazing treatment. Except for the atypically high NH_3-N concentrations on the control plots at 12 weeks after initiation of grazing, there would be no effect of either grazing treatment or duration on runoff NH_3-N concentrations. In contrast, runoff concentrations of FC were significantly greater for the manure-treated plots than for the control plots, typically differing by two orders of magnitude. The concentration findings thus corroborate those reported previously, in that grazing effects on runoff quality were more evident in terms of microbiological water quality parameters than in chemical or physical parameters.

Table 3. Flow-weighted mean runoff concentrations of analysis parameters.

Parameter/ Grazing Treatment[1]	Grazing Duration		
	4 Weeks	8 Weeks	12 Weeks
	mg/L		
NO_3-N[2]			
X	0.55	0.42	0.15
CG	0.66	0.41	0.28
RG	0.39	0.33	0.27
NH_3-N[2]			
X	0.30	0.51	2.03
CG	0.36	0.53	0.39
RG	0.22	0.62	0.39
TKN[2]			
X	1.44	1.87	1.80
CG	1.77	2.24	2.10
RG	2.16	3.99	2.56
PO_4-P[3]	0.36	0.84	0.95
	cfu/100 mL		
FC[4]			
X	7.8×10^0	3.9×10^2	1.1×10^3
CG	3.6×10^3	1.1×10^4	3.4×10^5
RG	1.2×10^5	1.1×10^5	4.4×10^5

[1] X is control (no grazing), CG is conventional grazing and RG is rotational grazing.

[2] Arithmetic mean of three samples.

[3] Arithmetic mean of nine samples (averaged across grazing treatments).

[4] Geometric mean of three samples.

Runoff mass transport of nutrients is given in Table 4. One of the most noteworthy findings was that mass transport was quite low, usually only a few g/ha. Analysis of variance indicated differences due to both grazing treatment and duration, as was the case for concentrations. It is also apparent from Table 4 that mass transport was highest for the rotational grazing treatment, and that values of mass transport were higher for the longer grazing durations. These results, however, are attributed entirely to plot-to-plot differences in runoff. Table 4 also reports values of Soil Conservation Service (1972) curve number parameter (CN), separated according to grazing treatment and duration. The value of CN is a measure of the soil's propensity to contribute runoff. Higher values indicate greater runoff, all other factors being equal. Values of CN were also found during ANOVA to be dependent on both grazing treatment and duration. As indicated in Table 4, CN values were generally greater for the rotationally grazed plots and higher for the longest duration than others. This finding mirrors the mass transport results. Since concentrations generally demonstrated no clear association with grazing treatment or duration, and since mass transport is the product of concentration and runoff, the mass transport results must necessarily be strongly associated with the runoff results.

It is reasonable to ask now why the values of CN varied according to grazing treatment and duration. Differences in CN, in other words to runoff characteristics, are attributed to inherent spatial variability in soil hydraulic properties and soil moisture. The plots used and assigned to the various treatments were selected randomly, so no bias in that regard was present. It is also unlikely that the manure itself significantly affected the hydraulic properties. Only a few percent of plot area would have been covered by manure, even at the end of the experiment. Also, as shown in Table 4, there is again no clear relationship between CN and grazing treatment or duration, except that the rotationally grazed plots generally had higher CN values.

Table 4. Mean[1] mass transport and runoff curve numbers.

Parameter/ Grazing Treatment[2]	Grazing Duration		
	4 Weeks	8 Weeks	12 Weeks
CN			
X	40.6	52.9	56.6
CG	31.7	39.8	78.5
RG	74.2	62.5	77.8
	---------- g/ha ----------		
NO_3-N			
X	5.8	5.3	4.4
CG	10.2	4.3	29.1
RG	19.0	12.6	29.7
NH_3-N			
X	3.1	7.4	61.3
CG	5.8	5.7	42.6
RG	10.6	22.2	34.1
TKN			
X	15.3	23.6	61.4
CG	28.6	30.5	230.9
RG	105.7	147.2	256.0
PO_4-P			
X	4.0	10.5	22.1
CG	6.2	9.4	114.4
RG	18.1	45.5	124.1

[1] Arithmetic mean of three samples.

[2] X is control (no grazing), CG is conventional grazing and RG is rotational grazing.

We therefore conclude that nutrient transport was not appreciably affected by grazing treatment or duration. Rather, in the absence of a treatment variable effect on runoff concentrations, the mass transport results were dominated by runoff amounts.

Objective 2.

The buffer strips had no effect on concentrations or transport of NO_3-N or NH_3-N. Mean runoff concentrations of NO3-N and NH3-N were 0.20 and 0.65 mg/L with standard deviations of 0.09 and 0.23 mg/L, respectively. Mean runoff transport of NO_3-N and NH_3-N was 178 and 621 mg with standard deviations of 119 and 339 mg, respectively. The buffer strips had a very significant effect ($p<0.001$), however, on concentrations of TKN, PO_4-P, TSS and FC in runoff. The buffer strips reduced (approximately 70 to100%) the concentration of each of these parameters and removed high proportions (approximately 70-80% for TKN, PO_4-P and TSS) of the incoming mass. The effects of the buffers on TKN, PO_4-P and TSS runoff concentrations are shown in Figs. 4-6, while the effects on transport are given in Figs. 7-9. The effects of the buffer strips on runoff FC concentrations are not depicted, because no FC was detected in runoff for buffer strips of 6.1 m and greater, even though the geometric mean incoming FC concentration was 1.85×10^5 cfu/100 mL.

It should be noted that Figs. 4-6 indicate somewhat elevated concentrations of TKN, PO^4-P and TSS entering the buffer strips; i.e., leaving the manure-treated portion of the plot. As pointed out earlier, the application of the manure to the manure-treated portions of the plots was specifically intended to promote relatively high runoff concentrations of manure concentrations entering the buffer strip. The reason, as stated previously, was to ensure that the results would enable an assessment of those buffer strips' effectiveness with regard to removing cattle manure

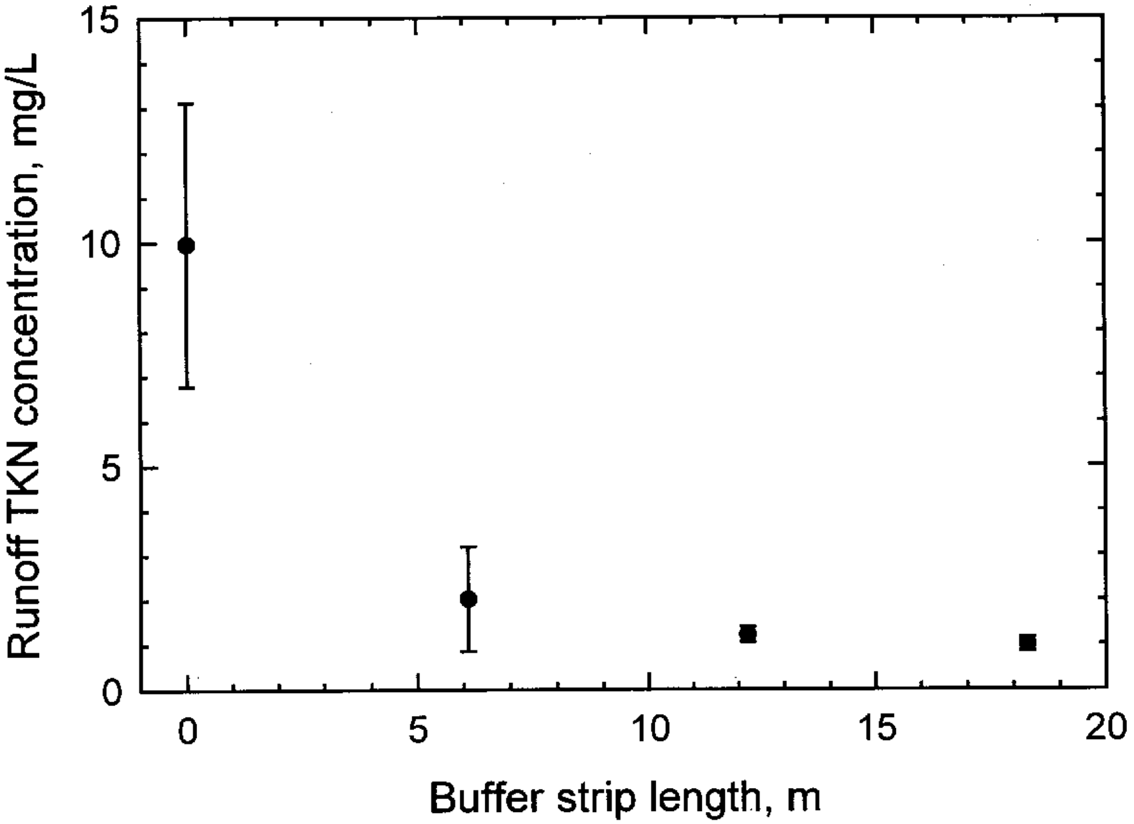

Figure 4. Mean runoff total Kjeldahl nitrogen concentration as a function of buffer strip length.

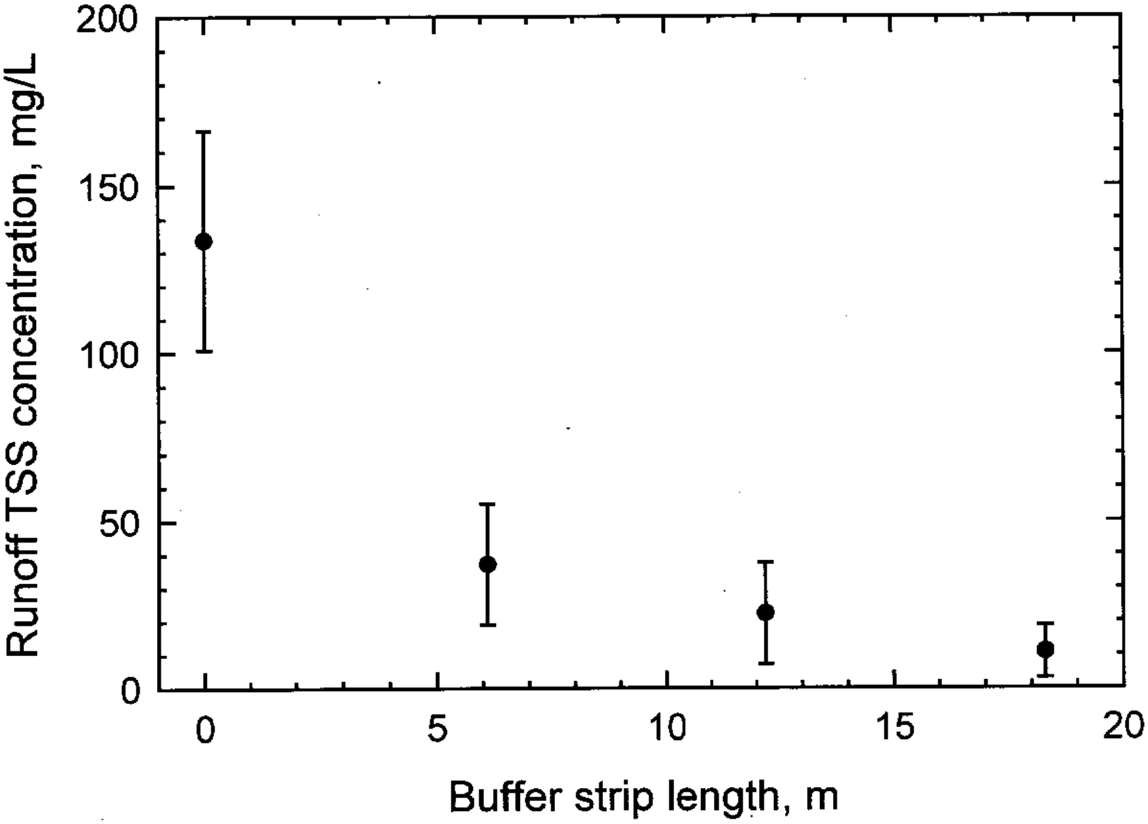

Figure 5. Mean runoff ortho-phosphorus concentration as a function of buffer strip length.

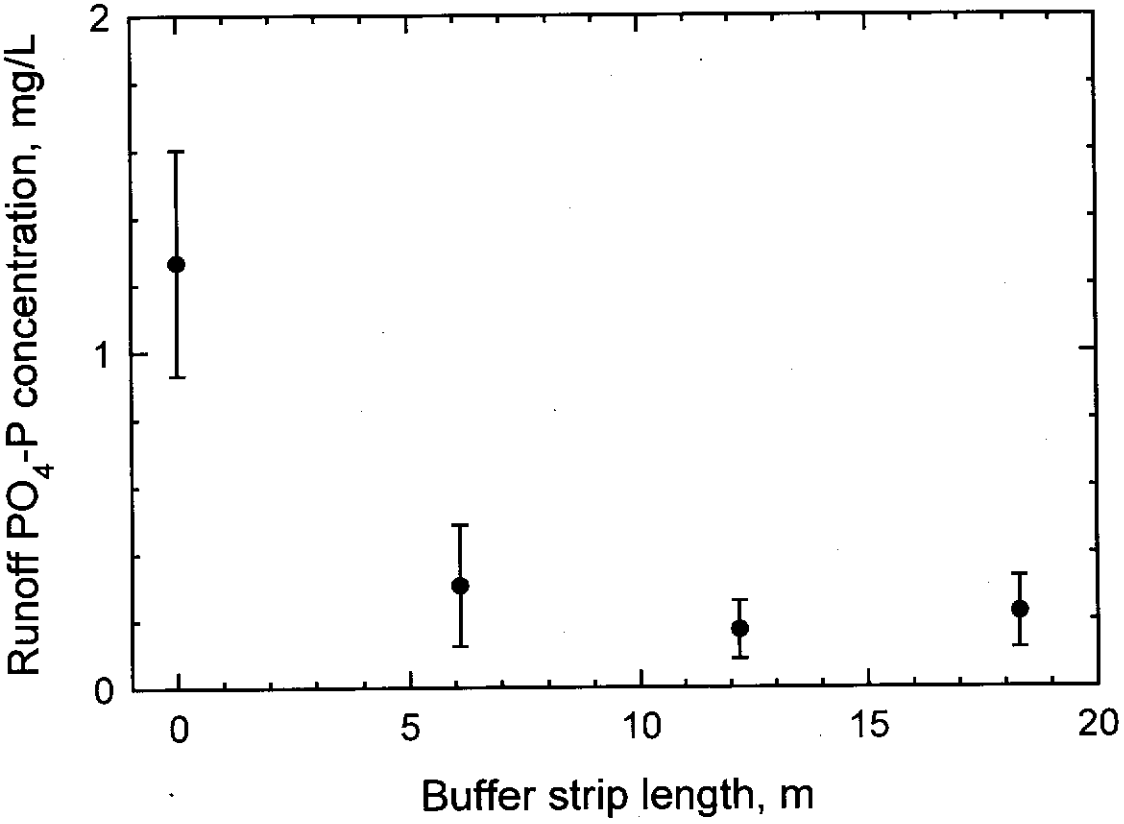

Figure 6. Mean runoff total suspended solids as a function of buffer strip length.

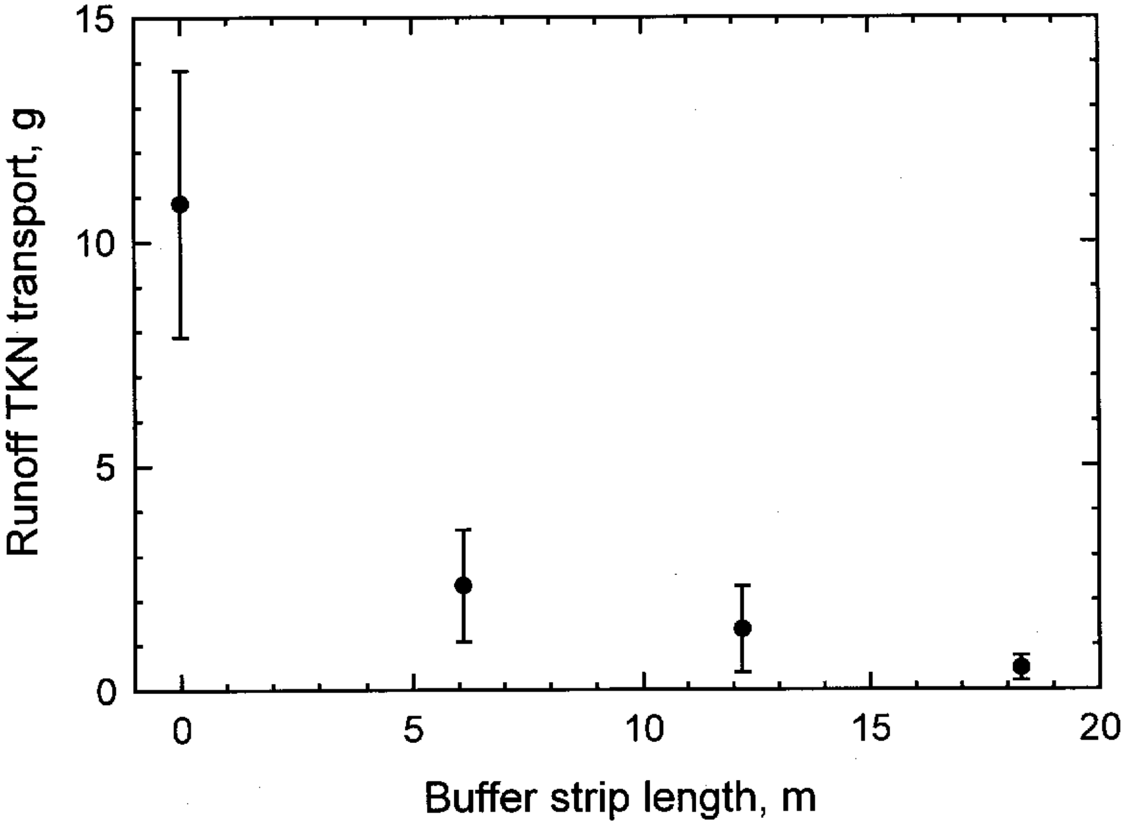

Figure 7. Mean runoff total Kjeldahl nitrogen transport as a function of buffer strip length.

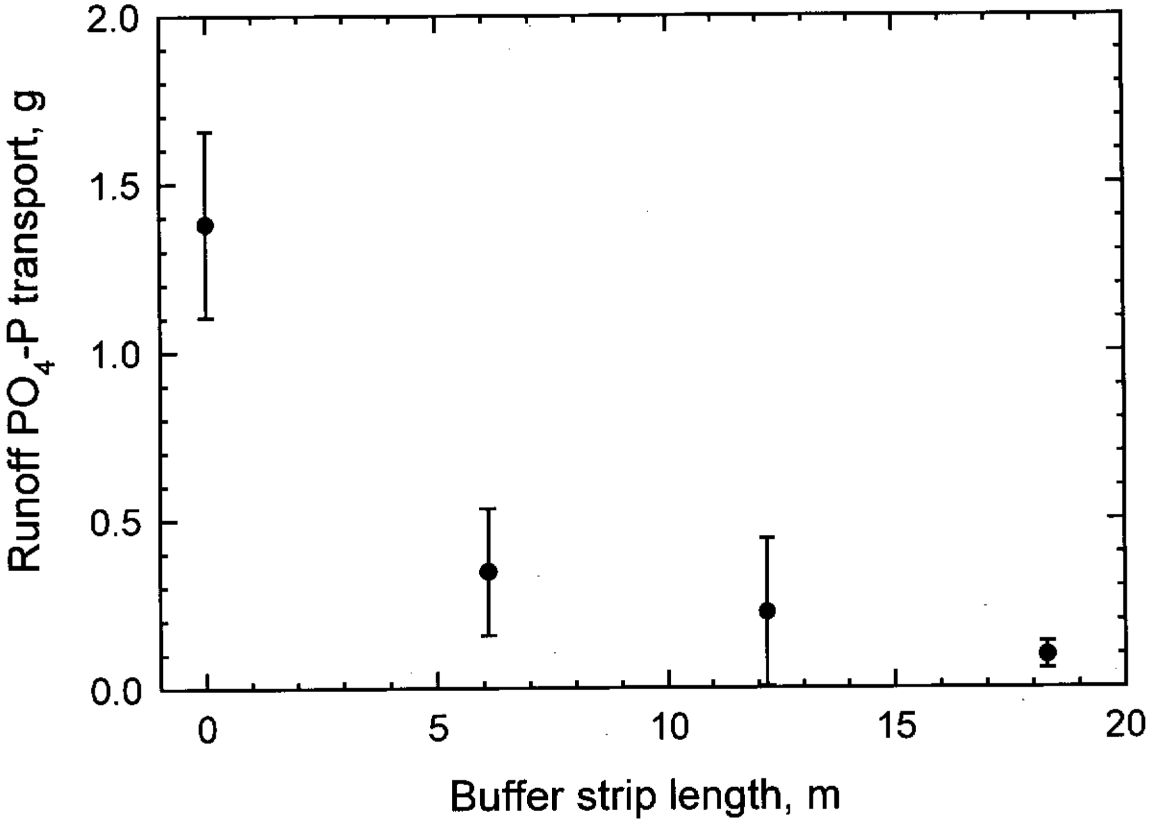

Figure 8. Mean runoff ortho-phosphorus transport as a function of buffer strip length.

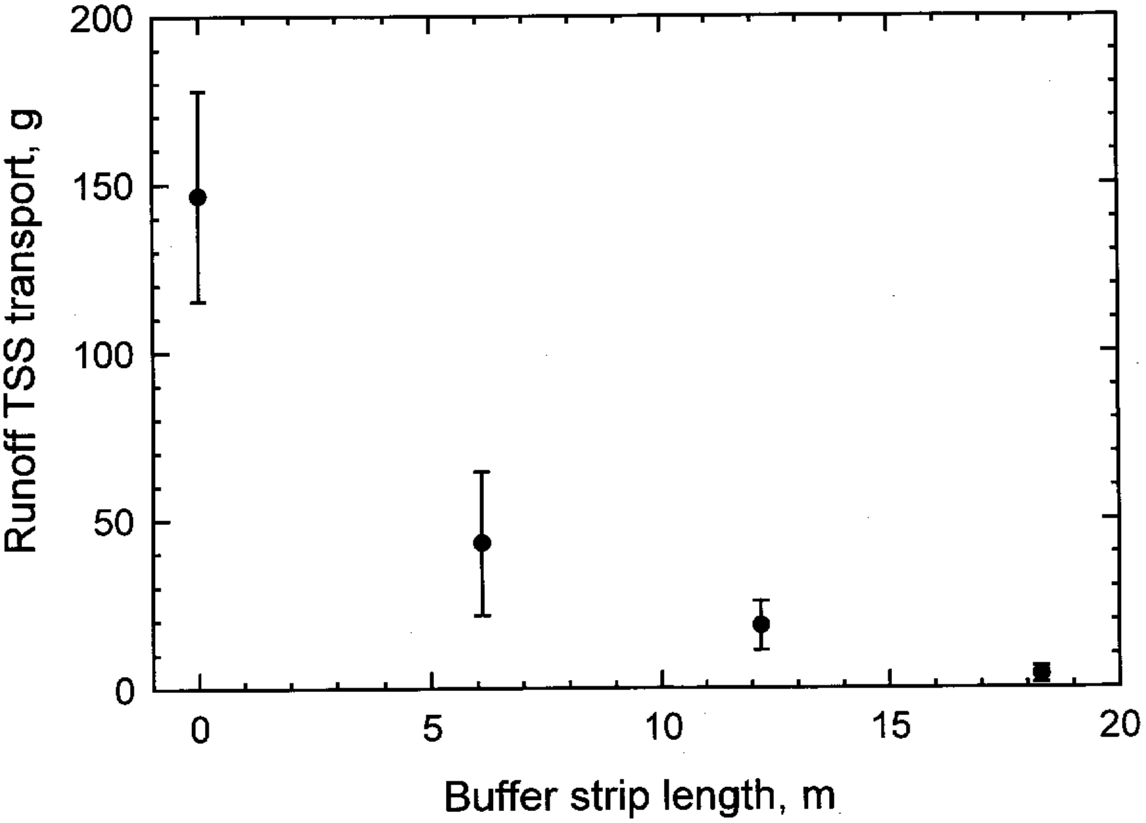

Figure 9. Mean runoff total suspended solids transport as a function of buffer strip length.

constituents from incoming runoff. The reason was not to replicate concentrations that might be reasonably expected in runoff from a grazed pasture. The results of the first objective of this study are better suited to the question of reasonably-expected concentrations, and Table 3 shows that they are much lower than those given in Figs. 4-6.

Only the first 6.1 m of the buffer strips were responsible for the improvements in runoff quality that were observed. Means separation indicated that incoming concentrations and transport of TKN, PO4-P, TSS were significantly greater than those measured at buffer strip lengths of 6.1 and greater, but that there was no significant change in concentration or transport beyond a buffer strip length of 6.1 m.

The buffer strips performed better than expected, especially with regard to removal of bacteria in incoming runoff. One of the reasons for the good performance is most likely related to the infiltration capacity of the buffer strips. The proportion of simulated rainfall that infiltrated the plots was quite high, averaging 3.3%. In the introductory section of this report, it was noted that infiltration can be one of the most important factors in determining buffer strip performance for grassed pollutant source areas (e.g., pasture). Overcash et al. (1981) and Edwards et al. (1996) have clearly demonstrated how a relatively high proportion of infiltrating rainfall translates directly into relatively high purification of incoming runoff. While buffer strips on less permeable soils might not perform as well as those of this study, the data of this report indicate that buffer strips can perform quite well, even with regard to bacteria removal, on soils with high infiltration rates. Another reason for the good performance of the buffer strips is likely the length of the strips relative to the characteristics of the pollutant source area. A longer or more runoff-prone (e.g., cropland) pollutant source area would have generated more runoff, and buffer strip performance decreases with incoming amount of runoff (Overcash et al., 1981; Edwards et al., 1996).

SUMMARY AND CONCLUSIONS

This study assessed the effects of cattle grazing strategy (control, conventional grazing and rotational grazing) and grazing duration on runoff quality with respect to N, P and FC. The study also evaluated the performance of grassed buffer strips in improving the quality of runoff from areas having cattle manure applied. The grazed pasture was simulated by plots established in Kentucky 31 "tall" fescue and having beef cattle manure applied. The runoff was caused by application of simulated rainfall.

Runoff N and P concentrations demonstrated no consistent dependence on either grazing strategy or grazing duration and were not substantially different from those measured for the control plots. Runoff concentrations of FC for the simulated grazed plots were higher 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 may not be significantly greater than for background conditions of similar soils and vegetation. The findings corroborate earlier findings in that runoff quality in terms of bacteria content might be more difficult to address than in terms of nutrient content.

The buffer strips performed well in removing incoming nutrients, solids and FC. The good performance of the buffer strips is attributed to high infiltration rates of the experimental plots and to the fact that the buffer strips were not dominated by high incoming runoff. It is likely that the buffer strips could have been shortened substantially without seriously diminishing buffer strip performance, in view of the infiltration characteristics of the plots. The findings indicate that if reductions in nutrient, solids and bacteria transport in runoff from grazed pasture are desired (assuming they are significantly greater than background levels), then buffer strips can be effective in helping meet this goal. The performance of a buffer strip would depend on several factors (e.g., soil, incoming runoff amount, and incoming concentrations), but it is possible to achieve very high proportions of pollutant removal with this relatively low-cost and low-maintenance practice.

REFERENCES

ASAE. 1991. Standards 1991, 38th ed. ASAE, St. Joseph, MI.

Burt, J.P. 1976. Bacteriological impacts of nonpoint sources on recreation lakes. Paper No. 76-2082. ASAE, St. Joseph, MI.

Chaubey, I., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. and D.J. Nichols. 1994. Effectiveness of vegetative filter strips in retaining surface-applied swine manure constituents. *Trans. ASAE* 37(3):845-850.

Chaubey, I., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. and D.J. Nichols. 1995. Effectiveness of vegetative filter strips in controlling losses of surface-applied poultry litter constituents. *Trans. ASAE* 38(6):1687-1692.

Doran, J.W. and D.M. Linn. 1979. Bacteriological quality of runoff water from pastureland. *App. Environ. Microbiol.* 37(5):985-991.

Doran, J.W., J.S. Schepers and N.P. Swanson. 1981. Chemical and bacteriological quality of pasture runoff. *J. Soil and Water Conser.* 36(3):166-171.

Gary, H.L., S.R. Johnson and S.L. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado front range stream. *J. Soil and Water Conserv.* 38(2):124-128.

Greenberg, A.E., L.S. Clesceri and A.D. Dalton (ed). 1992. *Standard methods for the examination of water and wastewater*. 18th ed. American Public Health Assoc., Washington, D.C.

Khaleel, R., K.R. Reddy and M.R. Overcash. 1980. Transport of potential pollutants in runoff water from land areas receiving animal wastes: A review. *Water Res.* 14:421-426.

Edwards, D.R., T.C. Daniel and P.A. Moore, Jr. 1996. Vegetative filter strip design for grassed areas treated with animal manures. *Appl. Eng. Agric.* 12(1):31-38.

Edwards, D.R., L.D. Norton, T.C. Daniel, J.T. Walker, D.L. Ferguson and G.A. Dwyer. 1992. Performance of a rainfall simulator. *Ark. Farm Res.* 41(2):13-14.

Jawson, M.D., L.F. Elliott, K.E. Saxton and D.H. Fortier. 1982. The effect of cattle grazing on indicator bacteria in runoff from a Pacific Northwest watershed. *J. Environ. Qual.* 11(4):621-627.

Larsen, R.E., J.R. Miner, J.C. Buckhouse and J.A. Moore. 1994. Water quality benefits of having cattle manure deposited away from streams. *Bioresource Technol.* 48:113-118.

Milne, C.M. 1976. Effect of a livestock wintering operation on a western mountain stream. *Trans. ASAE* 19:749-752.

National Agricultural Statistics Service and Kentucky Department of Agriculture. 1994. 1993-94 Kentucky Agricultural Statistics. Kentucky Agricultural Statistics Service, Louisville, KY.

Niebling, W.H., G.R. Foster, R.A Nattermann, J.D. Nowlin and P.V. Holbert. 1981. Laboratory and field testing of a programmable plot-sized rainfall simulator. Proc. Symp. on Erosion and Sediment Transport Measurement, Florence, Italy. Int. Assoc. Hydrologic Sci. Pub. No. 133.

Overcash, M.R., S.C. Bingham and P.W. Westerman. 1981. Predicting runoff pollutant reduction in buffer zones adjacent to land treatment sites. *Trans. ASAE* 24(2):430-435.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel and K.R. Reddy. 1994. Managing agricultural phosphorus for the protection of surface waters: Issues and opinions. *J. Environ. Qual.* 23(3):437-451.

Soil Conservation Service. 1972. National engineering handbook. Section 4, Hydrology. U.S. Dept. of Agric., Washington, D.C.

Srivastava, P., D.R. Edwards, T.C. Daniel, P.A. Moore, Jr. and T.A. Costello. 1996. Performance of vegetative filter strips with varying pollutant source and filter strip lengths. *Trans. ASAE* 39(6):2231-2239.

Tiedemann, A.R., D.A. Higgins, T.M. Quigley, H.R. Sanderson and C.C. Bohn. 1988. Bacterial water quality responses to four grazing strategies – comparisons with Oregon standards. *J. Environ. Qual.* 17(3):492-498.

Tiedemann, A.R., D.A. Higgins, T.M. Quigley, H.R. Sanderson and D.B. Marx. 1987. Responses of fecal coliform in streamwater to four grazing strategies. *J. Range Manag.* 40(4):322-329.