Runoff Nutrient and Fecal Coliform Content from Cattle Manure Application to Fescue Plots

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Summary

This study assessed effects of cattle-grazing strategy (control, conventional, and rotational grazing) and grazing duration on runoff quality with respect to nitrogen, phosphorus, and fecal coliform and impacts of runoff depth and timing of sample collection on these variables. The grazed pasture was simulated by plots established in KY 31 fescue and having beef cattle manure applied. Runoff was caused by application of simulated rainfall.

Runoff nitrogen and phosphorus concentrations demonstrated no consistent dependence on either grazing strategy or grazing duration and were not substantially different from those measured for control plots. Runoff concentrations of fecal coliform for manure-treated plots were initially higher than from control plots but did not differ for the second and third simulated rainfall events. Runoff fecal coliform concentrations from manure-treated plots 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 may not be greater than for background conditions for similar soils, vegetation, and manure application rates as those used in this study. This study did not examine effects of hoof traffic or urine addition. While those variables may be expected to influence both the amount and quality of runoff (e.g., through increased depression storage, higher solids and adsorbed nutrient concentrations, and increased ammonia nitrogen and/or nitrate nitrogen concentrations), additional work will be required to isolate those variables' effects from those of manure alone.

Introduction

Beef cattle production is an essential component of Kentucky's agricultural economy. In excess of 1 million cattle are marketed annually, worth over $750 million to Kentucky cattle producers. Similar to other agricultural enterprises, however, cattle production has potential to contribute nutrient and bacteria loadings to surface waters. Cattle manure contains appreciable amounts of nitrogen (.6%) and phosphorus (.2%), bacteria, and viruses, which can be transported into receiving waters during runoff-producing rainfall events.

A major concern regarding runoff losses of nutrients is accelerated eutrophication. The causes and effects of eutrophication are generally well known. The degree to which runoff from grazed pasture promotes eutrophication is not clear. Indeed, whether nutrient losses from grazed pastures are significantly greater than "background" losses and how these losses are affected by soil, weather, stocking density, and other variables are not well defined.

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, used to enhance cattle production, has been suggested for improving quality of runoff from pasture. Some studies, however, suggest that rotational grazing may have the opposite effect with regard to stream flow fecal coliform concentrations. The effects of rotational grazing on runoff quality has not been extensively studied, even though the practice is increasingly recommended as beneficial from a production standpoint.

The objective of this study was to measure and relate concentrations and mass transport of nitrogen, phosphorus, and fecal coliform in runoff from fescue plots receiving cattle manure applied to simulated grazing strategies and durations. Additional analyses of data were performed to assess how runoff concentrations are related to runoff depth and timing of runoff sample collection.

Procedures

The study was performed using nine plots constructed on a Maury silt loam (fine, mixed, mesic Typic Paleudalf) soil at the Maine Chance Agricultural Experiment Station. Plots were graded to a uniform 3% slope along the major axis and cross-leveled along the minor axis. Plot dimensions were 8 by 20 ft, with the long axes oriented up and downslope. Plots used for the experiment were randomly selected from 30 plots arranged as three rows of 10 plots each. Plots had within-row separation distances of 2.5 ft and between-row separation distances of 10 ft. Vegetation for all plots was KY 31 fescue (*Festuca arundinacea* Schreb.), maintained at a height of 3 to 5 inches by mowing with a commercial mower and string trimmer. Vegetation was established by seeding (approximately 350 lb/acre) the previous summer with straw mulch. One year elapsed between seeding and the time of the experiment; full vegetative cover had been established with no observable differences between plots. Each plot was bordered with galvanized iron (4 inches above and below ground surface) to isolate runoff.

Soil samples were collected from each plot one month prior to manure application to plots. Five soil samples were collected per plot and composited. The composite soil samples were analyzed by the University of Kentucky Regulatory Services Laboratory for nutrient content and other characteristics according to standard methods (Table 1). No amendments were applied to plots between soil sampling and manure application.

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% slope to increase gutter velocities and prevent sedimentation in gutters. Discharge from gutter entered a 2-inch internal diameter (i.d.) length of polyvinyl chloride (PVC) pipe and emptied approximately 18 inches above the bottom of a sump. Each sump was lined with 12-inch i.d. corrugated plastic tubing and 12-inch i.d. end cap. Runoff was sampled as it exited the PVC pipe and

Table 1. Research site soil properties.

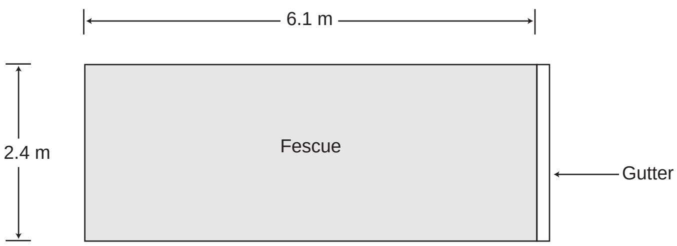
Variable	Mean[a]	SD[b]
pH	**5.5**	**.3**
	ppm	
Total nitrogen	1,865	164
Phosphorus	92	10
Potassium	226	40
Calcium	1,113	123
Magnesium	142	27
Zinc	1.7	.3
Organic matter	31,000	3,200

[a]N = 30.

[b]Standard deviation.

before reaching the interior of the sump. Unsampled runoff discharged through a 4-inch diameter hole in the sump bottom and exited the research site through an adjacent drainage system. This drainage system conveyed only plot runoff, not subsurface flows beneath plots. A plot schematic is given as Figure 1.

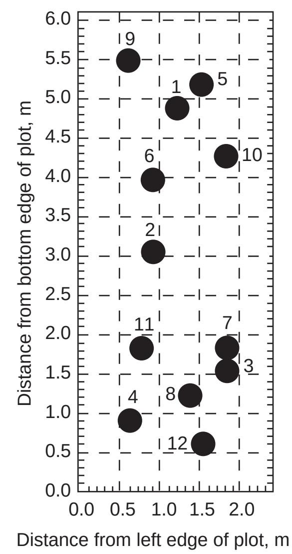
Figure 1. Plot schematic (not to scale).



Manure was applied to plots to simulate effects of grazing strategy and duration on nutrient concentrations and transport in runoff through a factorial experimental design (three simulated grazing strategies, three grazing durations, and three replications). Treatments and replications were randomly assigned to nine plots used in the study. Three grazing strategies were simulated: ungrazed (control), continuously grazed (1.7 animal units (AU)/ac, where AU is defined as a 1,000-lb animal), and rotationally grazed (6.7 AU/ac for 7 days, ungrazed for 21 days). The stocking densities used in this study were selected to be comparable to, but slightly lower than, initial densities recommended for well-managed pastures in Kentucky (2.25-3.5 AU/ac). The grazing strategies were simulated only in terms of manure deposition, with no attempt to replicate hoof traffic or cattle urine addition to the plots. Grazing duration treatments were four, eight, and 12 weeks. Effects of grazing duration were assessed by multiple applications of simulated rainfall to nine plots at four, eight, 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 3.1 lb fresh manure per plot (calculated from standard manure production rates). Manure was obtained from confined beef cattle fed a fescue diet in an unrelated study. The 3.1 lb of manure was formed as a single deposit having a diameter of approximately 10 inches. Each deposit covered an area of approximately .54 ft^2. Locations of deposits were the same for all plots receiving manure, and locations were randomly selected with exception that one deposit was never placed atop another (Figure 2). Proportion of total plot area covered by manure deposits increased linearly from .3% after the first week's manure application to 4% after the twelfth week's application. One manure sample was collected during each of twelve applications and analyzed by University of Kentucky's Regulatory Services Laboratory for water and nutrient content (Table 2).

Figure 2. Placement of manure within simulated grazed plots. 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.



Except for manure application, all plots received identical management during the study. All plots were mowed similarly (height, date) and equally exposed to natural rainfall and wildlife. Mower wheels and blade did not disturb manure deposits.

Rotational grazing strategy was simulated by applying 12.3 lb manure/plot as four 3.1-lb, 10-inch diameter deposits once each four weeks beginning on the fourth week of July1996. Locations of manure deposits were the same as the simulated conventional grazing strategy. The only difference between the simulated conventional and rotational grazing strategies was timing of manure deposit application.

Five rainfall simulators, each capable of applying from 0 to 4.7 inches/hour simulated rainfall to plots, were constructed as a part of this project. At four, eight, and 12 weeks following the beginning of manure deposition (July 28, August 23, and September 18), simulated rainfall was applied to each of nine plots on the same day. The plots received a total of 9.4 inches (238 mm) natural rainfall in intervals between manure application and simulated rainfall (Table 3). Simulated rainfall intensity was a constant 2 inches/hour, maintained until a .5-hour duration of runoff had occurred from each plot. A constant runoff duration

Table 2. Properties of cattle manure.

Variable	Mean[a], ppm	SD[b]
Moisture	814,800	23,200
Total nitrogen	22,500	3,600
Phosphorus	5,840	1,890
Potassium	3,400	1,640
Copper	36	21
Zinc	114	41

[a]N = 12.

[b]Standard deviation.

was chosen in preference to a constant rainfall duration to control for plot-to-plot variation in previous soil moisture. Rainfall applied prior to runoff (R_R, mm) was calculated as the product of rainfall intensity and duration of rainfall prior to runoff (measured with stopwatch). Total rainfall applied (R_T, mm) was calculated as the sum of R_R and one inch (the additional rainfall applied during the .5 hour of runoff). Total rainfall duration differed between plots, but runoff duration was constant. Runoff was sampled at 2, 4, 6, 8, 16, 24 and 30 minutes 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 seconds or until container was filled, whichever came first. Times required to collect the samples were measured with a digital stopwatch to enable computation of runoff rates. Due to low runoff rates observed during the study, time required to collect a sample was generally greater than 20 seconds, with a minimum of 6.0 seconds.

Table 3. Natural rainfall between July 1 and September 18, 1996[a].

Day	July	Aug	Sept	Day	July	Aug	Sept
		mm				mm	
1	T[b]	T	.5	17	1.3	13.2	3.8
2	T	T	0	18	2.3	0	0
3	25.4	0	.3	19	1.3	0	- - -
4	0	0	.5	20	24.9	0	- - -
5	0	0	.3	21	T	0	- - -
6	0	0	0	22	T	0	- - -
7	T	0	1.3	23	0	0	- - -
8	4.3	20.6	0	24	0	5.6	- - -
9	0	0	.3	25	0	0	- - -
10	0	0	0	26	0	0	- - -
11	0	2.5	0	27	0	1.3	- - -
12	0	3.3	2.5	28	2.5	0	- - -
13	8.9	0	0	29	.3	0	- - -
14	4.6	0	0	30	13.0	0	- - -
15	22.6	0	.3	31	20.6	0	- - -
				Total	131.8	58.4	47.8

[a]National Climate Data Center.

[b]Trace.

All runoff samples were analyzed for total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), ortho-phosphate (PO_4-P), and fecal coliform (FC). Filtration (.45 mm pore diameter, necessary for NO_3-N and PO_4-P analyses) was performed in the field following sample collection.

Daily plot runoff data consisted of seven values for runoff rates and corresponding times relative to 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 mean concentration of each chemical and biological variable. Runoff volume (Q, mm) was calculated by numerically integrating flow rate with respect to time. Plot Curve Number (CN) was determined by calculating S from the relationship:

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

And converting S to curve number from:

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

Mass transport was calculated by summing products of concentration and associated incremental runoff volumes. Flow-weighted mean concentration was calculated by dividing mass transport by total runoff volume. Effects of experimental variables (grazing strategy and grazing duration) on rainfall prior to runoff, total rainfall, runoff, curve number, flow-weighted concentrations, and mass transport of chemical/biological variables were determined through analysis of variance (ANOVA) conducted at $P = .05$ significance level.

Further analysis of results was conducted to determine how concentration results varied with runoff volume and time since beginning of runoff. Flow-weighted mean concentrations were regressed against runoff to determine whether there were linear relationships between concentrations and runoff volume. A regression line slope different ($P < .05$) from zero was an indication of a significant relationship between variables. In addition, relative concentrations (C_R) were calculated for all plots and sampling times as ratio of concentration of a variable at a sampling time to 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 variable's corresponding sets of C_R values. Significant F-statistic values ($P < .05$) were evidence of changes in relative concentrations during runoff.

Results and Discussion

Means and standard deviations of rainfall prior to runoff (R_R), total rainfall (R_T), runoff (Q), and curve number (CN) are given in Table 4. In general, there was high plot-to-plot variability in hydrologic variables measured during the experiment, as seen by relatively large differences in means of variables. High variability in hydrologic variables for runoff studies involving grassed plots is not uncommon and appears to increase with increasing soil dryness.

Means, standard deviations, and results of means separation for runoff concentrations of chemical and biological parameters are given in Table 5. In general, the results with regard to soluble nutrients are similar to findings from other studies involving grazing, in that neither grazing treatment nor grazing duration made any consistent differences in terms of the measured concentrations of nutrients in runoff; i.e., addition of the manure did not cause the runoff concentrations to consistently differ from background concentrations.

Runoff concentrations of fecal coliform for manure-treated plots were usually two orders of magnitude or more greater than for control plots, but concentration differences were generally not significant. The only within-grazing-duration differences among means occurred during the first simulated rainfall event, with manure-treated plots exhibiting higher runoff fecal coliform concentrations than the control plots. Lack of subsequent within-duration treatment differences may have been due to cumulative effects of animal (rodents, birds, etc.) activity on the control plots, since plots were not protected against presence of natural sources of fecal coliform.

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 manure and runoff that contacts manure deposits after originating from further upslope may be assumed to have high concentrations of nutrients and fecal coliform relative to runoff from control plots. However, nearly all manure deposits were located at least one meter from the runoff sampling gutter; water contacting those deposits would have been susceptible to filtration over that flow distance (Figure 2). A model has been developed to describe performance of vegetative filter strips assuming that only infiltration of soluble pollutants was responsible for filtration. This model is given by:

$$C_X = C_B + (C_O - C_B)e^{(1/1-D)\ln(1/1+k)} \tag{3}$$

Table 4. Statistics of applied rainfall, runoff, and curve numbers.

Variable/grazing treatment	Grazing Duration[a], weeks					
	4	SD[b]	**8**	SD	**12**	SD
	mm					
Rainfall prior to runoff						
Control	**71.1[de]**	12.3	**38.9[e]**	14.1	**29.5[e]**	7.7
Conventional	**133.8[d]**	76.8	**81.1[de]**	39.8	**21.2**	5.9
Rotational	**16.8[e]**	9.4	**30.9**	11.0	**20.9[e]**	6.6
Total rainfall						
Control	**96.5[de]**	12.3	**64.3[e]**	14.1	**67.6[e]**	7.7
Conventional	**159.2[d]**	76.8	**106.5[de]**	39.8	**46.6[e]**	5.9
Rotational	**42.2[e]**	9.4	**56.3[e]**	11.0	**46.3[e]**	6.6
Runoff						
Control	**1.15[f]**	.34	**1.35[ef]**	.67	**3.72[def]**	1.81
Conventional	**1.65[ef]**	1.43	**1.16[f]**	.98	**11.33[d]**	5.99
Rotational	**5.20[def]**	.67	**3.86[def]**	2.42	**10.61[de]**	6.77
	dimensionless					
Curve number						
Control	**40.6[fg]**	4.4	**52.9[def]**	7.6	**56.6[def]**	5.5
Conventional	**31.7[g]**	13.3	**39.8[fg]**	14.2	**78.5[d]**	10.0
Rotational	**74.2[de]**	7.1	**62.5[def]**	10.9	**77.8[de]**	11.2

[a]Arithmetic means, N = 3.

[b]Standard deviation.

[d,e,f,g]For a given variable, means within row or column followed by same letter are not different (P > .05).

where C_X is concentration (mg/L) of pollutant exiting filter strip, C_O is concentration (mg/L) of pollutant entering filter strip, C_B is background concentration (mg/L), D is ratio of infiltration to runoff, and K is ratio of filter strip length to manure-treated length. The situation of this study is analogous to the above developed model, if recognized that each manure deposit constitutes a discrete pollutant source and that concentrations measured in plot runoff reflect a flow-weighted integration of concentrations associated with discrete deposits. Equation (3) predicts that concentrations exiting the filter strip (analogous to plot in this study) decrease with increasing infiltration. Infiltration in this study was generally high, which would promote high filtration of soluble pollutants (Table 4). Equation (3) also predicts that concentrations will decrease with increasing filter strip length; as noted earlier, the minimum “filter strip length” was 3.25 ft for all but one manure deposit with half the deposits located 10 ft or more from the plot edges. We conclude that the combination of high infiltration capacity and adequate filtration lengths played a significant role in finding no impact of manure application on runoff quality.

Flow-weighted mean concentrations of analysis variables were regressed against associated runoff (Q) to determine whether runoff was a significant source of variation in the data. Runoff significantly affected flow-weighted mean concentrations of nitrate nitrogen, ortho-phosphate and fecal coliform; nitrate nitrogen concentrations decreased with increasing runoff; ortho-phosphate and fecal coliform experienced the opposite effect (Figures 3, 4, 5). The lowest groupings of nitrate nitrogen concentrations were generally associated with the 12-week grazing duration (Table 5), corresponding to the generally highest groupings of runoff (Table 4). The differences in nitrate nitrogen concentrations indicated in Table 5 are likely related in part to differences in runoff. Since there were no differences among treatment mean concentrations for ortho-phosphate, the mean values reported in Table 5 appear not to have been confounded by runoff, even though two of the highest three mean ortho-phosphate concentrations were associated with the two highest mean runoff values (Tables 4 and 5). The effects of runoff values on mean fecal coliform concentrations reported in Table 5 are not easily identified, and it appears that runoff effects did not dominate treatment effects.

Except in the case of nitrate nitrogen, relative concentrations of chemical and biological variables exhibited dependence on time of sample collection. Figures 6 through 9 depict relationships between relative concentration and time for ammonia nitrogen, total nitrogen, ortho-phosphate, fecal coliform and time after initiation of runoff. 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 “flushing” of chemical and biological variables followed by dilution and/or decreasing availability for transport.

Noteworthy of findings was that mass transport was quite low, usually only a few grams/acre (Table 6). Analysis of variance indicated differences were due to both grazing treatment and duration, similar to concentration data. Mass transport was highest for the rotational grazing treatment and values of mass transport were higher for longer grazing durations. These results, however, are attributed entirely to plot-to-plot differences in runoff. We therefore conclude that nutrient transport was not appreciably affected by grazing treatment or duration in this experiment. Rather, in the absence of consistent treatment variable effects on runoff concentrations, the mass transport results were dominated by runoff amounts.

One study on a stream flowing through a grazed pasture in Colorado noted that suspended solids concentrations were low (usually < 10 mg/L), ammonia N (NH_3-N) concentrations (.14 to .42 mg/L range) increased during grazed periods, and nitrate N (NO_3-N) concentrations trended higher when cattle were present but were not different during any of the grazing periods. The chemical quality of Nebraska storm runoff from grazed pasture was measured when cattle were present and runoff concentrations of chemical constituents were 1.1 to 1.8 times greater than when no cattle were present. However, the runoff concentrations from an ungrazed control plot were higher (two to eight times) than from the grazed pasture of NO_3-N, total Kjeldahl N (TKN), soluble P, total organic carbon (TOC), chloride, total organic carbon, and chemical oxygen demand (COD). That finding may reflect hydrologic plot differences. A sampled flow from five stations along a Montana stream during the runoff (snowmelt) period and irregularly during the non-runoff period indicated that wintering cattle had a “negligible” impact on the chemical quality of the stream.

The major concern with regard to runoff transport of bacteria and viruses from grazed pasture is human health impacts. Published research by no means addresses all aspects of the issue, but these studies are generally more consistent in their conclusions regarding grazing effects than studies on nutrient transport. In the Colorado study, researchers 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. The 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. A cattle-wintering operation in the west caused “very marked” increases in stream bacteria concentrations, with total coliform concentrations downstream of the cattle sometimes more than three times greater than those upstream of the cattle. A Pacific Northwest researcher sampled streams draining a 21.5-ha grazed field and a .9-ha ungrazed field during rainfall and snowmelt runoff. 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.

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, and it can be difficult to control for the 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

Figure 3. Relationship between flow-weighted mean runoff nitrate nitrogen (NO_3-N) concentration and runoff depth (Q).

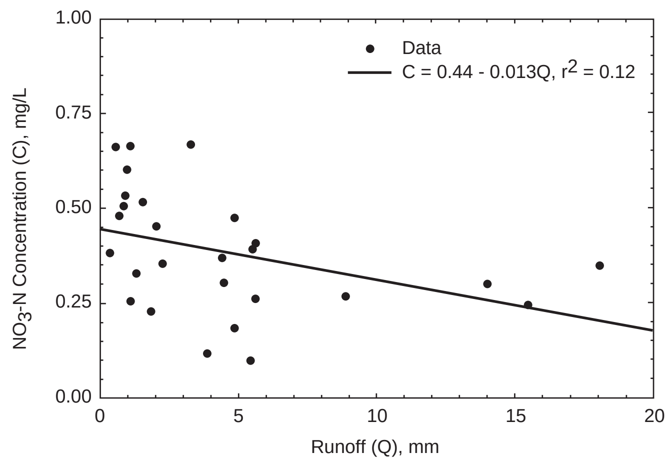


Figure 4. Relationship between flow-weighted mean runoff orthophosphorus (PO_4-P) concentration and runoff depth (Q).

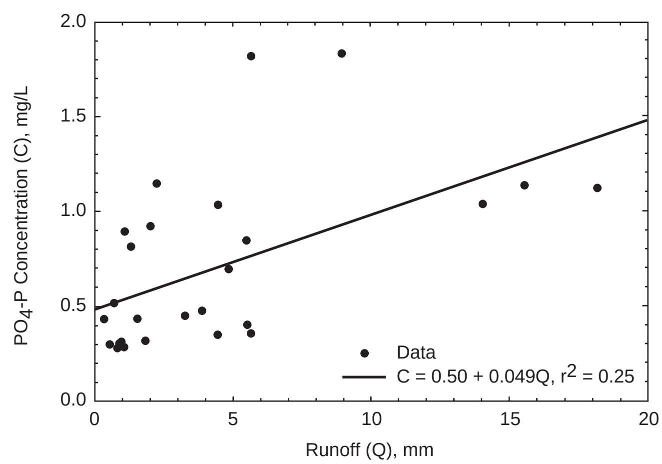
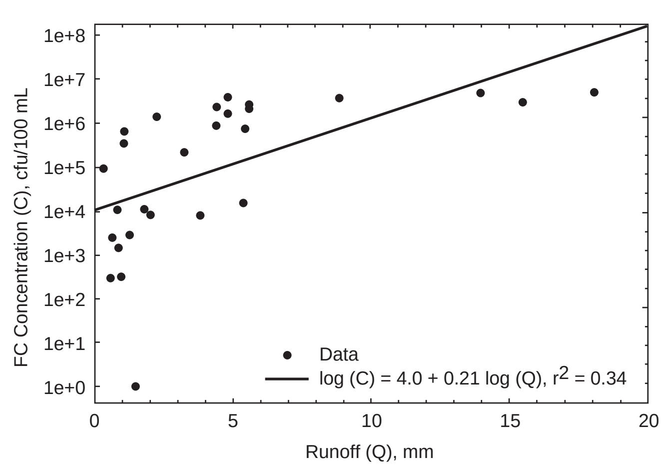


Figure 5. Relationship between flow-weighted mean runoff fecal coliform (FC) concentration and runoff depth (Q).



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.

The presence of different means-grouping letters in Table 5 indicates that there were differences among treatment means, but there was no consistent association between treatments and concentrations. In the case of ortho-phosphate (PO_4-P), there were no significant differences among means attributable to either grazing treatment or grazing duration. The mean runoff total nitrogen (TKN) concentration for the rotational grazing treatment at eight weeks grazing duration was significantly higher than all other total nitrogen concentrations, but there were no differences among the eight remaining mean concentrations. There were no significant differences among within-grazing-duration concentrations for ammonia nitrogen (NH_3-N) runoff concentrations and only one difference among within-grazing-treatment concentrations. The same is generally true of nitrate nitrogen (NO_3-N) concentrations, with only two inconsistent within-grazing-duration treatment mean differences and two within-grazing-treatment mean differences.

The detection of differences in within-grazing-treatment means was expected in view of differences in prior natural rainfall on the simulated rainfall dates. For example, 1.5 inches of rainfall occurred two days prior to the September 18 simulated rainfall (Table 3), causing several variables' means to differ significantly between the July 28 and September 18 simulated rainfall events (e.g., rainfall prior to runoff and runoff for the conventional grazing treatment). However, means separation indicated that there are differences in within-grazing-duration means. For example, mean rainfall prior to runoff and runoff (R_R and Q) values for the rotational grazing treatment were lower and higher, respectively, than corresponding mean values for the control and conventional grazing treatments for the four-week grazing duration. The differences in within-grazing-duration means are more likely an artifact of the assignment of treatments to plots rather than a reflection of differences in compaction and cover (since maintenance procedures were identical for each plot) or an indication that the presence of the manure somehow affected the hydrologic variables (especially since the area covered by the manure was less than 1.5% of the total plot area at the time of the first simulated rainfall). It is also noteworthy that within-grazing-treatment differences among means occurred only for the first simulated rainfall event, which followed a week of no natural rainfall, and vanished after the first simulated rainfall event (Table 4).

Table 5. Statistics of runoff concentrations.

Variable /grazing treatment	Grazing Duration[a], weeks					
	4	SD[b]	**8**	SD	**12**	SD
	mg/L					
Nitrate nitrogen						
Control	**.55[cd]**	.05	**.42[de]**	.08	**.15[f]**	.07
Conventional	**.66[c]**	.0	**.41[de]**	.08	**.28[e]**	.03
Rotational	**.39[de]**	.02	**.33[ef]**	.12	**.27[e]**	.08
Ammonia nitrogen						
Control	**.30[de]**	.07	**.51[cde]**	.23	**.36[cde]**	.02
Conventional	**.36[cde]**	.05	**.53[cd]**	.14	**.39[cde]**	.04
Rotational	**.22[e]**	.03	**.62[c]**	.02	**.39[cde]**	.14
Total Kjeldahl nitrogen						
Control	**1.44[d]**	.10	**1.87[d]**	.40	**1.80[d]**	.11
Conventional	**1.77[d]**	.30	**2.24[d]**	1.13	**2.10[d]**	.24
Rotational	**2.16[d]**	.36	**3.99[c]**	.54	**2.56[d]**	.07
Ortho-phosphate						
Control	**.35[c]**	.08	**.76[c]**	.21	**.55[c]**	.27
Conventional	**.35[c]**	.09	**.63[c]**	.46	**1.07[c]**	.06
Rotational	**.37[c]**	.03	**1.14[c]**	.60	**1.22[c]**	.57
	Colony-forming units (CFU)/100 mL					
Fecal coliform[g]						
Control	**7.8×10^{0}[e]**	4.7×10^{1}	**3.9×10^{2}[de]**	2.0×10^{0}	**1.1×10^{3}[cde]**	1.4×10^{0}
Conventional	**3.6×10^{3}[cd]**	6.2×10^{1}	**1.1×10^{4}[cd]**	1.2×10^{1}	**3.4×10^{5}[c]**	1.5×10^{0}
Rotational	**1.2×10^{5}[cd]**	1.8×10^{0}	**1.1×10^{5}[cd]**	3.0×10^{0}	**4.4×10^{5}[c]**	1.2×10^{0}

[a]Arithmetic means, N = 3.

[b]Standard deviation.

[c,d,e,f]For a given variable, means within row or column followed by same letter are not different (P > .05).

[g]Geometric means, N = 3.

Table 6. Statistics of runoff mass transport.

Variable /grazing treatment	Grazing Duration[a], weeks					
	4	SD[b]	**8**	SD	**12**	SD
	g/ha					
Nitrate nitrogen						
Control	**5.8[c]**	1.4	**5.3[c]**	2.9	**4.4[c]**	.6
Conventional	**10.2[c]**	8.9	**4.3[c]**	3.1	**29.1[c]**	14.3
Rotational	**19.0[c]**	3.3	**12.6[c]**	9.5	**29.7[c]**	25.9
Ammonia nitrogen						
Control	**3.1**	.1	**7.4[e]**	6.5	**61.3[c]**	9.3
Conventional	**5.8[e]**	5.7	**5.7[e]**	4.4	**42.6[cd]**	24.4
Rotational	**10.6[de]**	1.5	**22.2[de]**	13.7	**34.1[cde]**	15.0
Total Kjeldahl nitrogen						
Control	**15.3[d]**	3.9	**23.6[cd]**	11.2	**61.4[cd]**	27.9
Conventional	**28.6[cd]**	28.3	**30.5[cd]**	37.5	**230.9[cd]**	135.7
Rotational	**105.7[cd]**	27.9	**147.2[cd]**	101.6	**256.0[c]**	168.9
Ortho-Phosphate						
Control	**4.0[e]**	2.0	**10.5[e]**	7.1	**22.1[cde]**	19.3
Conventional	**6.2[e]**	6.7	**9.4[e]**	12.9	**114.4[cd]**	63.3
Rotational	**18.16[cde]**	3.1	**45.5[cde]**	44.8	**124.1[c]**	81.8

[a]Arithmetic means, N = 3.

[b]Standard deviation.

[c,d,e,f]For a given variable, means within row or column followed by same letter are not different (P > .05).

Figure 6. Relationship between runoff ammonia nitrogen (NH_3-N) relative concentration and timing of sample collection. Bars represent +/- one standard deviation.

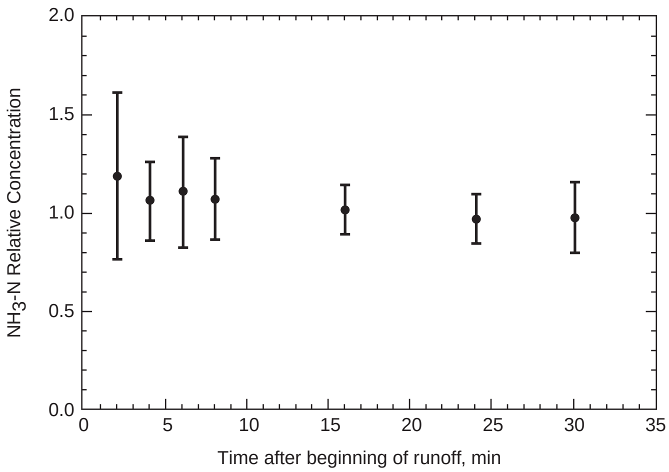


Figure 7. Relationship between runoff total Kjeldahl nitrogen (TKN) relative concentration and timing of sample collection. Bars represent +/- one standard deviation.

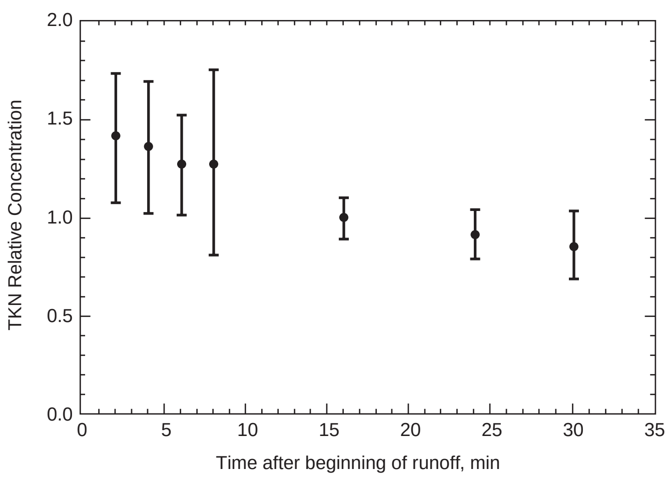


Figure 8. Relationship between runoff ortho-phosphorus (PO_4-P) relative concentration and timing of sample collection. Bars represent +/- one standard deviation.

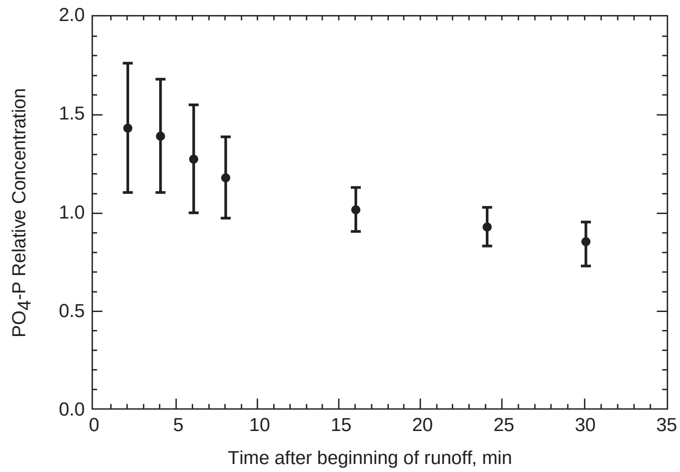
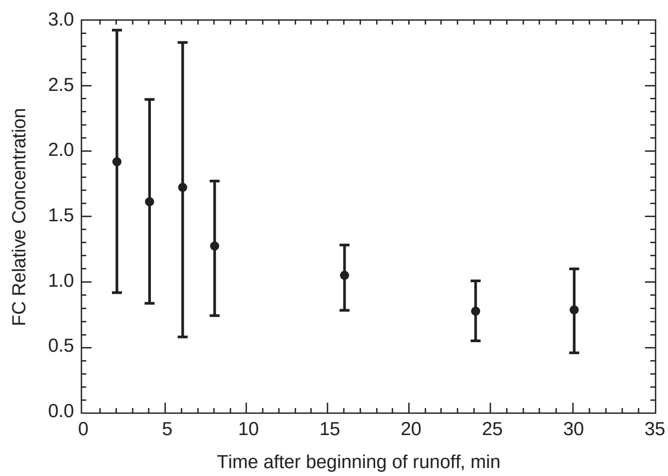


Figure 9. Relationship between runoff fecal coliform (FC) relative concentration and timing of sample collection. Bars represent +/- one standard deviation.



Vegetated Filter Strip Removal of Cattle Manure Constituents in Runoff

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Summary

This study assessed vegetated filter strip length effects on quality of runoff from cattle manure-treated plots. Cattle manure (60 lb nitrogen/acre) was applied to the upper 40 ft of grassed plots, while the lower 60 ft functioned as vegetated filter strip for runoff produced by simulated rainfall (4 inches/hour). Runoff samples were collected at vegetated filter strip lengths at 0, 20, 40, and 60 ft and analyzed for various manure constituents.

Vegetated filter strip removed significant fecal coliform, ortho-phosphate, total suspended solids, total solids, electrical conductivity, total nitrogen, and total phosphate from incoming runoff. No concentration reductions were observed for vegetated filter strip length of greater than 20 ft. The removal of fecal coliform was found to be 100% after a length of 20 ft, likely due to high plot infiltration. This is an encouraging finding, because similar studies found vegetated filter strips to be ineffective in removing fecal coliform. However, the vegetated filter strip in this study did not remove significant incoming nitrate nitrogen

and ammonia nitrogen, likely due to small amounts of mineral nitrogen in applied cattle manure. Although runoff ammonia concentration was not significantly affected by vegetated filter strip length, data suggested a decreasing trend with increasing vegetated filter strip length. Had more ammonia nitrogen been present in manure, a significant vegetated filter strip effect on runoff concentrations may have been noted.

Even though these findings are a necessary first step, they can not be directly translated to potential ecological benefits of vegetated filter strip implementation. Relating vegetated filter strip performance to ecological impacts would require detailed information on the stream, river, or lake of interest; chemical composition of water and sediments; quantity and quality of runoff from all sources; and response dynamics of the plants/animals of interest. An analysis of ecological impacts would be more site specific than an analysis of vegetated filter strip performance alone. Despite the challenges, such investigations should be undertaken, since the true focus of agricultural water quality research is ultimately environmental (human, animal, and plant) rather than "edge-of-field" reductions in concentration or transport.

Introduction

Concern regarding the environmental impact of grazing cattle manure entering streams, lakes, and other waters is common in areas having substantial animal production. Decomposition of organic matter can cause dissolved oxygen concentrations to drop below respiration requirements of fish. Excessive inputs of nitrogen and phosphorus may accelerate eutrophication of water bodies and promote growth of aquatic weeds and algae. Waters that receive pasture runoff can also contain high concentrations of indicator organisms, such as fecal coliform, that signal the possible presence of pathogenic microorganisms.

It is not clear whether grazing at recommended stocking densities has any significant effect on downstream waters. It is generally accepted that it is better for manure to be deposited farther away from waters as opposed to nearer (or even directly in). By direct implication, there is a water quality benefit associated with some intervening land area between manure and the water body of concern; i.e., a buffer zone.

Vegetated filter strips, also known as buffer strips, buffer zones, or filter strips, are vegetated regions that receive and purify runoff from upslope pollutant source areas. They are widely used and are increasingly viewed as a practical, low-cost management option for improving the quality of runoff from pollutant source areas. Researchers have demonstrated the effectiveness of vegetated filter strips for sediment removal in runoff from strip mines, nutrients and solids removal from feedlot and cropland runoff, and treatment of municipal wastewater. Some studies have shown that vegetated filter strips can remove 90%+ of incoming pollutants.

There is uncertainty with associating vegetated filter strip length to filtering performance, and there are several different strategies available to select the best vegetated filter strip length for a particular situation. One method is a ratio of manure-treated area to vegetated filter strip area of one-to-one required to reduce runoff concentrations of various poultry litter constituents to background levels. With a second method, vegetated filter strip length depends on soil, incoming pollutant concentrations, and pollution reduction goals. Some service agencies, as a third method, recommend standard vegetated filter strip lengths with some flexibility, depending on factors such as land slope. Since vegetated filter strips typically replace land otherwise used for crop or forage production, there is a desire to minimize filter areas. Appropriate procedures for determining optimal placement, dimensions, and orientation of buffer area must be developed for vegetated filter strip to be most effective and economical.

The objective of this study was to determine the effects of vegetated filter strip length on concentration and mass transport of nitrogen, phosphorus, solids, fecal coliform, and other variables in runoff from cattle manure-treated plots. Most previous studies have addressed uses of vegetated filter strip downslope from feedlots or row-cropped lands; however, this study addresses the effectiveness of vegetated filter strip downslope of simulated grazed areas.

Procedures

This experiment was conducted at Maine Chance Agriculture Experiment Station, where the soil is Maury silt loam (fine, mixed, mesic Typic Paleudalf). Earlier work at the site indicated the soil has high water intake capacity; runoff as a proportion of applied rainfall ranged only from 1 to 21% for a 2.5 inch/hour simulated rainfall event applied to grassed plots at the site. A good stand (100% cover with a mean height of approximately 4 inches) of KY 31 tall fescue (*Festuca arundinacea* Schreb.) had been established on all experimental plots. Plots were irrigated two to three times per week (if necessary) to promote vegetation growth and avoid summer dormancy. The vegetation height was maintained with a commercial lawn mower and trimmer for weekly cutting and trimming.

Three plots (100 x 8 ft, oriented with major axes up and downslope) were used for the experiment (Figure 1). The plots are level across the minor axes and have a constant 3% slope along the major axes. Rustproof metal borders (1.5 inches exposed height) were installed around the plots to isolate runoff. Wooden gutters were installed along the length of each plot distributed 20, 40, 60, 80, and 100 ft from the top, which separated the plots into five sections of equal areas. Easily removable watertight covers were installed on gutters so runoff would cross and continue downslope when covered. Each gutter was constructed to drain to one side of the plot where runoff samples could be collected. The gutter slope is sufficient to minimize deposition of solid materials.

The upper 40 ft of each plot was used to represent pasture and was treated with beef cattle manure, while the remainder of each plot acted as a vegetated filter strip (Figure 1). Manure application rate was 60 lb nitrogen/acre (gross application of 17.2 lb manure). This rate of manure application is equivalent to that produced from four 1,000-lb cattle (animal units)/acre for a seven-day period, which would represent a heavily grazed condition. The objective was to assess the effectiveness of vegetated strips' ability to filter cattle manure constituents, so ma-

Figure 1. Schematic (not to scale) of experimental plot.

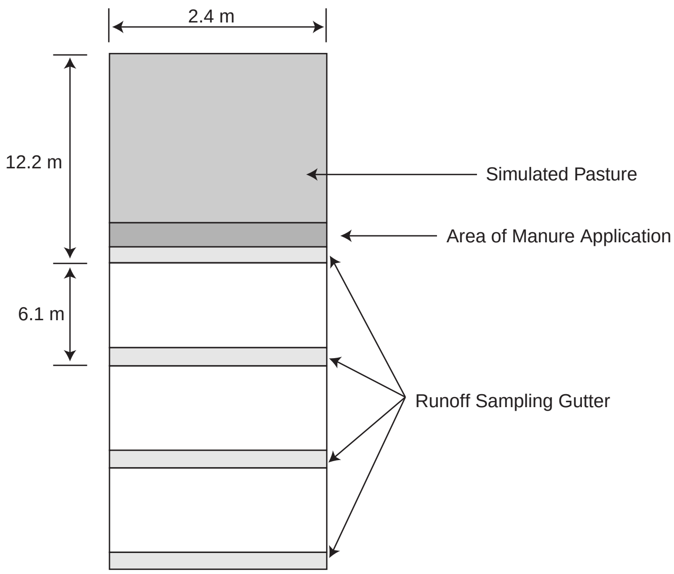

Table 1. Soil composition of rain simulation plots.

Variable	Plot 1[a]	Plot 2[a]	Plot 3[a]	Overall	CV[b]
PH	6.0	6.4	6.2	6.2	.04
Organic matter, %	3.22	2.96	3.56	3.24	.09
		mg/kg			
Phosphorus	86.7	99.7	93.0	93.1	.07
Potassium	381.5	353.4	337.4	357.4	.06
Calcium	1209	1560	1405	1392	.13
Magnesium	265.6	321.9	325.9	304.5	.11
Zinc	2.10	1.53	2.11	1.91	.17
Total nitrogen	1999	1830	1973	1934	.05

[a]N = 5, dry matter basis.
[b]Coefficient of variance.

Table 2. Cattle manure composition.

Variable	Mean[a], mg/kg	CV[b]
Moisture	814800	.03
Total nitrogen	22500	.16
Phosphorus	5840	.03
Potassium	3400	.48
Copper	36	.58
Zinc	114	.36

[a]N = 12.
[b]Coefficient of variance.

Table 3. Municipal water composition.

Variable	Mean[a]	CV[b]
pH	**8.08**	**.00**
	mg/L	
Nitrate nitrogen	.0003	.57
Ammonia nitrogen	.0004	.75
Total nitrogen	.56	.26
Ortho-phosphorus	.0001	1.00
Total phosphorus	.0093	1.08
Total suspended solids	1.10	.27
Total solids	27.43	.18

[a]N = 3.
[b]Coefficient of variance.

nure was applied along the lower edge of the simulated pasture. Therefore, the manure application was structured to ensure high incoming concentrations of manure constituents to evaluate vegetated filter strip performance. Prior to manure application, approximately five soil samples (0-2 inches) were collected from each plot and analyzed (Table 1) for pH, organic matter, total nitrogen, calcium, zinc, etc. The cattle manure originated from confined beef cattle fed fescue hay in a separate experiment (Table 2).

Five calibrated rainfall simulators per plot were used to generate runoff. Rainfall intensity used for this experiment was 4 inches/hour, with municipal water as the source. This high rainfall intensity (corresponding return period of > 100 years) was used to enhance runoff occurrence because of high infiltration capacity at the site. Simulated rainfall was applied immediately after application of cattle manure. The combination of intense simulated rainfall, its proximity to manure application, and the method of manure application can be considered as representing a "near-worst-case" scenario and constituted a rigorous test of the vegetated filter strip.

Runoff samples were collected at 2, 4, 8, 18, 30, 45, and 60 minutes after the beginning of continuous runoff at vegetated filter strip lengths of 0, 20, 40, and 60 ft during runoff in three replications. At a given sampling time, a runoff sample was collected first from the lowermost gutters and then successively the next gutter, up the length of the experimental plots. A technician was stationed at each gutter and began collecting the sample from the particular gutter immediately following collection of the runoff sample from the next downslope gutter. Sample volumes were in the range of 1.2 to 2 L. Time required to collect each sample was recorded, so that runoff rates could be computed. Three municipal water samples were collected during the experiment and analyzed to determine background quality of the water source (Table 3).

Runoff samples were weighed immediately after collection to determine sample masses and volumes, and pH was measured at the site. Samples were refrigerated while awaiting further analyses for total nitrogen, ammonia nitrogen, nitrate nitrogen, ortho-phosphate, total phosphate, total suspended solids, total solids, electrical conductivity, and fecal coliform. Electrical conductivity was determined using a conductivity probe, ammonia nitrogen was determined colormetrically, and standard methods were used for the remaining analyses.

The concentration and runoff data were jointly used to calculate flow-weighted mean runoff concentrations, mass transport, and mass removal effectiveness of analysis parameters.

Mass removal effectiveness was calculated from:

$$E(x) = 100\left(\frac{M(0) - M(x)}{M(0)}\right) \quad (1)$$

where E is mass removal effectiveness (%), M is mass transport (grams), and x is vegetated filter strip length (meters). The term M(0) is mass entering the vegetated filter strip. The significance of vegetated filter strip effects was assessed using analysis of variance (ANOVA). In cases where concentration or mass transport was significantly affected by vegetated filter strip length, the data were fitted to the following first-order exponential decay models to calculate rate coefficients that can facilitate comparison to earlier studies:

$$C(x) = C_0 e^{-kx} \quad (2)$$

$$M(x) = M_0 e^{-kx} \quad (3)$$

In these equations, C is concentration (mg/L), M is mass transport (mg), x is vegetated filter strip length, and C_o, M_o, and k are coefficients (k is the rate coefficient). For data that are described perfectly by Equations (2) and (3), the coefficients C_o and M_o will be equal to the initial concentration and mass transport, respectively. The coefficients C_o, M_o, and k were determined through linear regression using the natural logarithms of both sides of Equation (2) and (3) (i.e., C_o and M_o were not constrained to be equal to the initial concentration and mass transport, respectively).

Results and Discussion

Total nitrogen, ortho-phosphate, total phosphate, fecal coliform, total suspended solids, total solids, and electrical conductivity were decreased ($P < .05$) in response to increasing vegetated filter strip length (Table 4). However, no reductions in concentrations occurred beyond a vegetated filter strip length of 20 ft. The first order model of Equation (2) explained a significant proportion of variation in the concentration data, particularly for total suspended solids and total nitrogen (coefficients of determination, .37 and .96, respectively). Fitted first-order models are demonstrated in Figure 2 for total nitrogen and ortho-phosphate.

Concentrations of nitrate nitrogen and ammonia nitrogen and pH were not affected ($P > .05$) by vegetated filter strip length. Mean runoff pH (7.89) was similar to the water used to simulate rainfall, and mean nitrate nitrogen (.20 mg/L) and ammonia nitrogen (.65 mg/L) concentrations in runoff were comparable to "background" concentrations measured in runoff from plots having no manure applied (data not shown). Therefore, manure added no significant nitrate or ammonia nitrogen to the soil, which was expected since manure was fresh, and there was little opportunity for mineralization to occur.

Virtually all phosphate in runoff was in the soluble orthophosphate form rather than associated with sediment; therefore, it is likely that infiltration and binding to soil was the primary removal mechanism for phosphate. The vegetated filter strip was effective in removing both suspended and total solids from runoff, but it appears that little dissolved solids were removed by the vegetated filter strip, indicated by similar electrical conductivity values. The dissolved solids in runoff may reflect background contributions from the soil rather than from manure. Performance of vegetated filter strips and fecal coliform concentrations was particularly encouraging. Incoming fecal coliform concentrations in runoff were as high as 2×10^7/100 mL, while none were detected after the runoff had traversed vegetated filter strip length of 20 ft. This was likely due to high infiltration within the plots. An average of 2.9 inches simulated rainfall was required to produce runoff from the plots, and runoff as a percentage of total simulated rainfall averaged only 1.8%.

Calculations of mass transport for the pollutants (Table 5) indicated that the vegetated filter strips removed significant proportions of incoming pollutants. The first-order model of Equation (3) explained much of mass transport data variation, with coefficients of determination ranging from .94 to .99, and is demonstrated in Figure 3 for total nitrogen and phosphorus. These findings reinforce recommendations regarding use of first-order models for designing vegetated filter strips to remove soluble pollutants in incoming runoff.

Except for total nitrogen, vegetated filter strip lengths greater than 20 ft had no effect on mass transport. Mass transport of nutrients was quite low (usually less than 2 g), even for this relatively severe scenario. This strongly suggests that nutrient losses from grazed pasture can be insignificant from an agronomic standpoint and that the vegetated filter strip will yield negligible return on investment in terms of retaining beneficial nutrients. The impetus for installing them might be more properly related to environmental quality rather than production considerations. Calculated values of mass removal effectiveness are given in Table 6. Except for total suspended solids, there were no improvements in overall effectiveness for vegetated filter strip lengths greater than 20 ft.

Table 4. Runoff concentrations of cattle manure constituents.

	Vegetative Filter Strip Length, ft[a]					
Parameter	0	20	40	60	k[b]	r[2, c]
Total nitrogen, mg/L	10.12[d]	2.04[e]	1.22[e]	1.00[e]	.12	.84
Ortho-phosphorus, mg/L	1.28[d]	.031[e]	.17[e]	.23[e]	.09	.69
Total phosphorus, mg/L	1.42[d]	.32[e]	.15[e]	.23[e]	.10	.68
Fecal coliform/100 mL	1.8×10^{6}[d]	.00[e]	.00[e]	.00[e]	.70	.60
Total suspended solids, mg/mL	133.74[d]	37.54[e]	22.44[e]	10.85[e]	.13	.96
Total solids, mg/mL	525.8[d]	367.2[e]	409.9[e]	396	NS[f]	
Electrical conductivity, µs/cm	611.9[d]	558.1[e]	556.1[e]	547.1[e]	NS[f]	

[a]N = 3.

[b]First-order rate coefficient for Equation (2), m^{-1}.

[c]Coefficient of determination.

[d, e]Superscripts in rows which differ at P < .05.

[f]Not significant, P < .05.

In practical applications, it is likely that the areas that contribute runoff and pollutants to the vegetated filter strip will have lengths of greater than 40 ft, as used in this study. In longer pollutant source lengths, incoming runoff can be expected to increase with length. Even though our earlier results suggest that concentrations might be unaffected by increasing source length, the increased runoff would lead to accompanying increases in pollutant masses entering the vegetated filter strip. The results of this study can not be used directly to assess the effects of longer pollution source lengths upon vegetated filter strip performance.

Table 5. Runoff mass of cattle manure constituents.

Variable	Vegetative Filter Strip Length, ft[a] 0	20	40	60	k[b]	r^{2}[c]
	mg					
Total nitrogen	11135[d]	2,443[e]	1039[e, f]	452.1[f]	.17	.98
Ortho-phosphorus	1408[d]	362.7[e]	161.5[e]	90.6[e]	.15	.96
Total phosphorus	1563[d]	382.3[e]	143.5[e]	92.1[e]	.16	.95
Total suspended solids	147945[d]	44273	15074	3798	.20	.99
Total solids	587986[d]	438164[d, e]	347445[d, e]	183969	.07	.94

[a]N = 3.
[b]First-order rate coefficient for Equation (2), m^{-1}.
[c]Coefficient of determination.
[d, e, f]Superscripts in rows which differ at $P < .05$.

Despite their potential for markedly improving the quality of incoming runoff, VFS performance is not consistent across all topography and pollutants. A recent study pointed out that performance of VFS in reducing nutrients is highly variable. Others concluded that VFS were not sufficient for reducing runoff FC concentrations to primary contact standards. Another pointed out that the VFS did not remove significant nitrate N (NO_3-N) or FC in a study involving swine manure. A third group has vividly demonstrated that the flow regime within the VFS is critically important to good performance, with VFS removing far less pollutants for concentrated flow than for diffuse flow. Although it is apparent that VFS are generally capable of contributing to runoff quality improvements, the forms of the improvements and the design parameters for optimal performance are difficult to define.

Table 6. Vegetative filter strip mass removal effectiveness[a].

Variable	Vegetative Filter Strip Length, ft[a,b] 20	40	60
Total nitrogen	78.0	89.5	95.3
Ortho-phosphorus	74.5	87.8	93.0
Total phosphorus	76.1	90.1	93.6
Total suspended solids	70.0[c]	89.5[d]	97.6[d]
Total solids	23.6	40.8	69.8

[a]Percentage removed compared to no vegetative filter strip.
[b]Mean of three replications.
[c, d]Superscripts in rows which differ at $P < .05$.

Figure 2. Observed and first-order predictions of total nitrogen (TKN) and ortho-phosphorus (PO_4-P) concentrations as functions of vegetated filter strip (VFS) length.

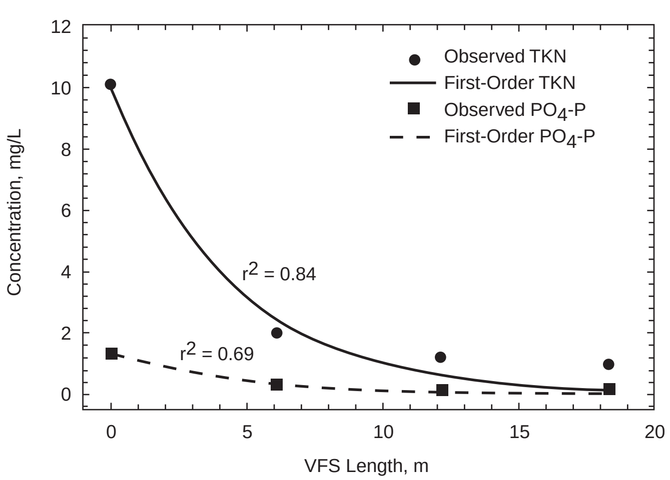

Figure 3. Observed and first-order predictions of total nitrogen (TKN) and total phosphorus (TP) mass transport as functions of vegetated filter strip (VFS) length.