PHOSPHORUS, SEDIMENT, AND *E. coli* LOADS IN UNFENCED STREAMS OF THE GEORGIA PIEDMONT, USA

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Abstract. Contamination of unfenced streams with phosphorus, sediments, and pathogenic bacteria from cattle activity may be affected by the availability of shade and alternative water sources. The objectives of this study were to evaluate water quality in two streams draining tall fescue/ bermudagrass pastures with different shade distributions, and to quantify the effects of alternative water sources on stream water quality. Loads of DRP, TP, and TSS were measured during storm flow, and loads of DRP, TP, TSS, and *E.coli* were measured every 14 d during base flow in two streams located in the Piedmont region of Georgia. Our results showed that grazing cattle in pastures with unfenced streams contributed significant loads of DRP, TP, TSS, and E. coli to surface waters ($p<0.01$). Although storm flow was similar in both streams, loads of DRP, TP, and TSS were larger ($p< 0.08$) in the pasture with the smaller amount of non-riparian shade. Water trough availability significantly decreased ($p< 0.08$) base flow loads of TSS and *E. coli* in both streams. Our results indicate that possible BMPs to reduce P, sediment, and *E. coli* contamination from beef-cattle-grazed pastures may be to develop or encourage non-riparian shade and to provide cattle with an alternative water supply away from the stream.

INTRODUCTION

Cattle grazing pastures with unfenced streams may lead to stream contamination with P, sediments, and pathogenic bacteria (Sauer et al., 1999, Line et al., 2000). Direct deposition of P and pathogens into streams may be particularly important in endophyte-infected tall fescue pastures, where animals have been reported to seek shade and water to alleviate the effect of fescue toxicosis. Ergot alkaloids produced by the endophyte in tall fescue have been shown to induce vascular constriction and therefore cause hyperthermia in cattle (Hoveland, 2003). As a result, cattle commonly seek shade or stand in bodies of water to aid in heat dissipation, especially during tall fescue seed production, which occurs during late spring in Georgia. Consequently, the amount and location of shade in tall fescue pastures may play significant roles in determining the amount of contamination in streams. Also, the availability of water troughs may draw cattle away from streams, decreasing contamination. The objectives of this study were to evaluate the water quality of two streams flowing through tall fescue pastures with different shade distribution, and to evaluate the effect of water troughs on stream water quality.

METHODS

The streams used in this study flowed through two pastures located at the Central Research and Education Center of the University of Georgia (Eatonton, GA; Latitude 33°24’ N, Longitude 83°29’ W, elevation 150 m). Portable samplers (ISCO model 6700; ISCO, Lincoln, NE) were installed where the stream entered and exited each pasture (Fig 1). Pressure transducers were used to monitor the level of the stream and calculate flow discharge. Stormflow samples were taken by the ISCO samplers, while baseflow samples were taken manually every 14 d at the same locations where stormflow samples were collected. For the purpose of this paper, the pasture between water quality sampling stations G5 and G6 will be referred to as pasture G5G6, and the pasture between water quality sampling stations G8 and G9 will be referred to as pasture G8G9. The pasture area in G5G6 was 3.32 ha greater than that of G8G9, but the watershed areas were similar (17.9 ha in G5G6 and 18.0 ha in G8G9). The two predominant forages in the pastures were endophyte-infected (Neotyphodium coenophialum Morgan-Jones and Gams) Kentucky 31 tall fescue and common bermudagrass. The soils are classified as Iredell sandy loam (Fine, montmorillonitic, thermic, Typic Hapudalfs); Mecklenburg sandy loam and sandy clay loam (Fine, mixed thermic Ultic Hapludalfs); and Chewacla silty clay (Fine-loamy, mixed, active, thermic Fluvaquentic Dystrudepts) (Perkins et al., 1987).

To delineate the extent of tree shade in each pasture, the circumference of the crown of each tree was surveyed after leaf-out with a submeter Trimble Model TSC1 GPS unit (Trimble, Sunnyvale, CA). Subsequently, a 6-m buffer around the edge of the crown was created in ArcView GIS 3.2 using the Spatial Analyst (Environmental Systems Research Institute, Inc., Redlands, CA) and the Xtoolsmh extensions (Oregon Department of Forestry, Salem, OR).

Both pastures were stocked with 20 cow/calf (Angus and Angus-Hereford cross) pairs. Single strand, electric cross fences were installed before the project began, and were used to rotationally graze cattle on either side of the riparian area; however, cattle were allowed access to the entire riparian area throughout the duration of the study.

Two water troughs with water meters were installed in each pasture before the project began, and water meter readings were taken periodically during the study. The average distance from the water troughs to the stream was 91 m in G5G6 and 81 m in G8G9 (Fig. 1). Monitoring of water quality took place with and without water troughs available. When water troughs were not available, an electric fence around the troughs prevented cattle access to them. At the onset of the project (Mar. 2001), the intention was to evaluate water quality for one year with water troughs available, then close the water troughs in Mar., 2002 and evaluate water quality without water troughs for one additional year. Due to drought in 2002, however, the discharge of the streams dwindled to the point cattle could no longer drink sufficient amounts of water from the stream, thus the troughs were opened on 3 June, 2002. The troughs remained opened until 23 Dec., 2002, when sufficient flow in the streams allowed the troughs to be closed again until July 2003. The total number of storm flow events analyzed when water troughs were available was 14 in G5G6 and 22 in G8G9; the number of storm flow events analyzed when water troughs were not available was 24 in G5G6 and 18 in G8G9. The number of base flow samples taken while water troughs were available were 12 in G5G6 and 17 in G8G9; the number of base flow samples taken when water troughs were not available was 21 in G5G6 and 25 in G8G9

Storm water samples were analyzed for total suspended solids (TSS), dissolved reactive P (DRP), and total P. Base flow samples were further analyzed for *Escherichia coli* (E. coli) using the Colilert (Idexx Laboratories Inc, Westbrook, ME) enzyme substrate method (Clesceri et al., 1998).

Due to the nature of this study and the distribution of the data, parametric statistical procedures were not applicable; therefore, the analysis was carried out with non-parametric methods. PROC UNIVARIATE (SAS Institute, Inc, 1999) was used on a per pasture basis to determine the median as well as the signed-rank statistic, which was used to determine if the median loads of DRP, TP, and TSS, as well as flow contributed by each pasture during storm events and base flow were significantly different from zero. PROC UNIVARIATE was also used to determine if one pasture contributed a greater load than the other. The Kruskal-Wallis statistic under PROC NPAR1WAY (SAS Institute, Inc., 1999) was used to determine if the condition of the water troughs (open or closed) had an effect on the loads contributed from the pastures to their streams during storm events and base flow.

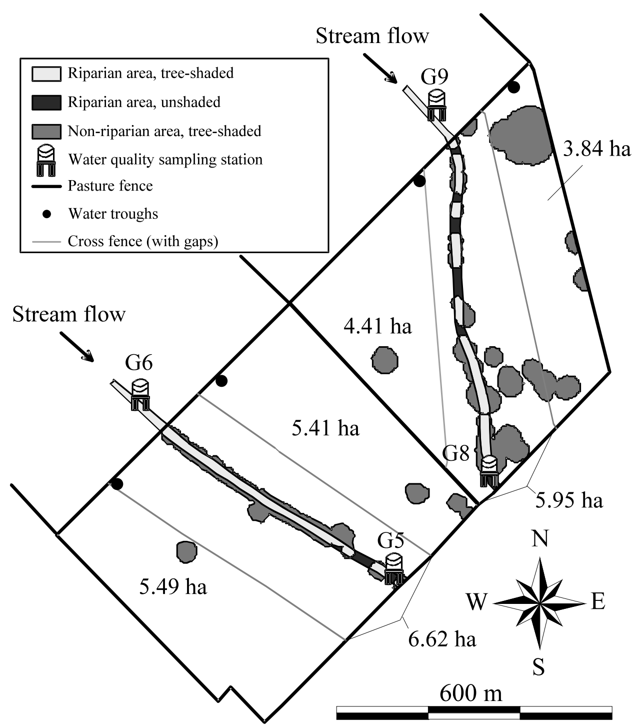

Fig. 1. Map of pastures showing streams and shade.

RESULTS AND DISCUSSION

The pastures varied not only in the amount, but the distribution of tree-shade (Table 1). In both pastures, the majority of the shade available to cattle was in non-riparian areas, but pasture G8G9 had over twice the amount of total shade of pasture G5G6 and almost three times the amount of non-riparian shade.

Table 1. Tree-shaded area, riparian area, and total area of pastures used in the study.

Area description	Pasture	
	G5G6	G8G9
Non-riparian shade (m^2)	6,425	18,523
Riparian shade (m^2)	4,212	5,010
Total shade (m^2)	10,637	23,553
Riparian area (m^2)	4,961	6,406
Pasture area (ha)	17.52	14.20

Analysis of median loads and median flow-weighted concentrations for storm flow in both streams (Table 2) showed that the pastures were contributing significantly ($p<0.01$) to the nutrient and sediment content as well as to the discharge of the streams.

Table 2. Median storm flow loads and flow-weighted concentrations of dissolved reactive P (DRP), total P (TP), and total suspended solids (TSS); and median base flow loads

Variable	Pasture		Difference	
	G5G6	G8G9	G5G6 – G8G9	
	– Stormflow loads- -			p>|s|
DRP (kg $storm^{-1}$)	0.075	0.102	0.042	0.024
TP (kg $storm^{-1}$)	1.94	0.99	0.57	0.019
TSS (kg $storm^{-1}$)	2121	311	786	0.031
Flow (m^3 $storm^{-1}$)	2175	2131	-170	0.712
	- Stormflow concentrations -			
DRP (mg L^{-1})	0.050	0.036	0.026	0.037
TP (mg L^{-1})	0.64	0.42	0.23	0.047
TSS (mg L^{-1})	507	218	58	0.076
	-- Median baseflow loads --			p>|s|
DRP (g d^{-1})	2.91	2.77	2.87	0.07
TP (g d^{-1})	98.2	104.8	-3.3	0.84
TSS (kg d^{-1})	16.6	37.4	-12.4	0.04
E.coli (CFU d^{-1}) x 10^9	1.4	2.5	-2.5	0.01
Flow (m^3 d^{-1})	641	622	97	0.94

During the monitoring period, 29 kg of DRP, 242 kg of TP, and 237 Mg of TSS were lost in 240,000 m^3 of storm flow discharge from pasture G5G6. Pasture G8G9 contributed a total of 15 kg of DRP, 69 kg of TP, and 51 Mg TSS in 200,000 m^3 of flow during the same period. These totals show that over the monitoring period, pasture G5G6 contributed more nutrients and suspended solids in storm flow than G8G9. If the median TSS load per storm event is divided by the pasture area, the median rate of TSS loss per storm event was 121 kg ha^{-1} in G5G6 and 22 kg ha^{-1} in G8G9.

The median differences between G5G6 and G8G9 in storm flow loads of DRP, TP, and TSS as well as the median differences in flow-weighted concentration of DRP and TP were significantly ($p<0.05$) different from zero (Table 2). The median difference in the flow weighted concentration of TSS was significantly different from zero at p= 0.08. These results confirm that G5G6 contributed more nutrient enrichment and sediment addition to surface water than G8G9 during storm flow.

Because storm flow was similar in both streams (Table 2), the greater nutrient and sediment inputs in G5G6 were apparently due to different cattle behavior in each pasture. In an analysis of separate data collected in this study we found that in May, June, and July, cattle spent 9 % of the day in the riparian area of G5G6, as opposed to 5 % in the riparian area of G8G9 (Byers, 2004). We also found that in May, June, and July, cattle in G8G9 spent 22 % of the day in non-riparian shade whereas cattle in G5G6 spent only 10 % of the day in non-riparian shade. Pasture G8G9 had almost three times more non-riparian shade than pasture G5G6 (Table 1), which would explain the observed differences in cattle behavior. Thus, the larger loads of DRP, TP, and TSS in G5G6 than in G8G9 were probably caused by cattle spending more time in the riparian area and less time in non-riparian shade in G5G6. These results suggest that providing or encouraging non-riparian shade away from the stream may be a best management practice (BMP) to reduce P and TSS loads from grazed tall fescue pastures during storm flow.

Both pastures contributed significantly ($p<0.01$) to base flow loads of DRP, TP, TSS, and E.coli in their respective streams (Table 2). The median differences in daily base flow loads of DRP, TSS, and E. coli between the two pastures (G5G6-G8G9) were different from zero ($p=0.07$), indicating that the unfenced pastures were not contributing similar loads of contaminants to their respective streams. The load of DRP was larger in G5G6 than in G8G9, in agreement with storm flow results. The loads of TSS and E.coli, however, were larger in G8G9 than in G5G6, in contrast with results observed for storm flow. The reason for this larger load of TSS and E.coli in G8G9 may have been that the stream in G8G9 had a large pool where cattle liked to stand for extended periods of time. Cattle defecation and trampling in this pool would lead to increased loads of E.coli and sediments in base flow. The stream in G5G6 did not have such a large pool where several cattle could stand simultaneously in the stream.

The results obtained for storm flow water quality may lead to the conclusion that one way to discourage cattle use of the riparian area would be to remove trees from the riparian zone. We are not, however, advocating this conclusion. Tree-shaded areas provide many crucial services in maintaining a healthy aquatic ecosystem (Bjorkland et al., 2001).

Table 3. Median storm flow and base flow loads of DRP, TP, and TSS, and median base flow loads of *E.coli.*

		Water Trough		Kruskal-
Pasture	Variable	Yes	No	Wallis
		- kg storm^{-1} -		p> chi^2
G5G6	DRP	0.13	0.07	0.19
	TP	0.50	7.40	0.55
	TSS	181	2276	0.29
G8G9	DRP	0.03	0.12	0.59
	TP	0.47	2.25	0.15
	TSS	216	1235	0.13
		--Baseflow loads --		
G5G6	DRP (g d^{-1})	1.48	9.87	<0.01
	TP (g d^{-1})	62.2	144.1	<0.01
	TSS (kg d^{-1})	1.8	34.3	<0.01
	E.coli (CFU d^{-1}) x 10^9	0.19	3.73	<0.01
G8G9	DRP (g d^{-1})	0.86	3.38	0.23
	TP (g d^{-1})	176.7	96.1	0.49
	TSS (kg d^{-1})	21.2	59.0	0.06
	E.coli (CFU d^{-1}) x 10^9	1.15	7.689	0.08

When water troughs were available in G8G9, the median storm flow loads of TP and TSS were decreased (p= 0.15) by 79 and 82 %, respectively, when compared to loads without water troughs (Table 3). Water trough availability did not have a major effect on storm flow loads in pasture G5G6.

When water troughs were available in G5G6, the median base flow loads of DRP, TP, TSS, and E.coli were decreased (p<0.01) by 85, 57, 95, and 95 %, respectively, when compared to the loads observed without water troughs (Table 3). It should be pointed out, however, that stream flow was also 51 % smaller when the water troughs were available, which would tend to reduce loads. But, because the proportional decreases observed in most loads were larger than the proportional decrease observed in flow, it can be concluded that the availability of water troughs decreased the direct input of contaminants into the stream in G5G6. This conclusion is supported by separate data collected in this study, which showed that providing water troughs decreased the amount of time cattle spent in the riparian area of G5G6 by 40 to 96 %, depending on time of the year (Byers, 2004).

When water troughs were available in G8G9, the median base flow loads of TSS and E.coli were decreased (p=0.08) by 64 and 85 % respectively, when compared to loads without water troughs (Table 3). In the case of G8G9, there were no differences in stream flow between periods with and without water troughs, so the decrease in load can be directly attributed to a decrease in contaminant input into the stream. It should be noted that in the accompanying study on cattle behavior, we did not observe a decrease in the amount of time spent by cattle in the riparian area of G8G9 when water troughs were available (Byers et al., 2004). These results suggest that although time spent by cattle in the riparian area of G8G9 did not decrease when water troughs were available, direct inputs of contaminants into the stream did decrease. The reason for this is that the availability of water troughs would have made it less necessary for cattle to get into the stream to drink water. In the accompanying study, we estimated that when water troughs were available in G8G9, the proportion of water drunk from the stream decreased from 100 % (without troughs) to 31 % (Byers et al., 2004).

In general, our results agree with those of Sheffield et al. (1997), who found that installing a water trough resulted in a 96 % reduction in TSS load, a 97 % reduction in TP load, and a 51 % reduction in fecal coliform load. In contrast, Line et al. (2000) found that installing a water trough increased the TP load by 12 % and did not affect the TSS load.

One factor that may have decreased the expected effect of water troughs in our study is that the average daily temperature-humidity index (THI; National Oceanic and Atmospheric Administration, 1976) during March through July, which is when cattle spent most time in riparian areas, was significantly (p< 0.01) larger when the troughs were available (79) than when they were not available (73). Bicudo et al. (2003) found a sharp increase in water consumption at THI>75. Thus, a larger THI when the troughs were available could have forced the cattle to spend more time directly in the water, thereby increasing contamination and reducing the impact of having an alternative water source away from the stream.

SUMMARY AND CONCLUSIONS

Our results show that grazing cattle in pastures with unfenced streams contributed significant ($p<0.01$) loads of DRP, TP, and TSS to surface waters during storm flow, as well as significant loads of DRP, TP, TSS, and E. coli during base flow. The contaminant loads contributed from the pastures appeared to be a function of shade distribution and water trough availability. In pasture G5G6, with a lower amount of non-riparian shade, storm flow loads of DRP, TP, and TSS were larger ($p<0.05$) than in pasture G8G9, which had abundant non-riparian shade. The larger storm flow loads in G5G6 appeared to be a direct response to cattle spending more time in the riparian area of G5G6. The availability of water troughs decreased ($p<0.08$) base flow loads of TSS and E.coli in both pastures. The results of this study indicate that potential BMPs to reduce P, sediment, and E.coli contamination from beef cattle-grazed pastures may be to build or encourage non-riparian shade and to provide cattle with alternative water sources away from the stream.

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