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Phosphorus, Sediment, and *Escherichia coli* Loads in Unfenced Streams of the Georgia Piedmont, USA

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ABSTRACT

Contamination of unfenced streams with P, sediments, and pathogenic bacteria from cattle (*Bos taurus*) 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 (*Festuca arundinacea* Schreb.)–common bermudagrass (*Cynodon dactylon* L.) pastures with different shade distribution, and to quantify the effects of alternative water sources on stream water quality. For 3 yr, loads of dissolved reactive phosphorus (DRP), total phosphorus (TP), and total suspended solids (TSS) were measured during storm flow, and loads of DRP, TP, TSS, and *Escherichia coli* were measured every 14 d during base flow. We also used GPS collars to determine amount of time cattle spent in riparian areas. Our results showed that cattle-grazed pastures with unfenced streams contributed significant loads of DRP, TP, TSS, and *E. coli* to surface waters ($p <$ 0.01). Time spent by cattle in riparian areas as well as storm flow loads of DRP, TP, and TSS were larger ($p < 0.08$) in the pasture with the smaller amount of nonriparian shade. Water trough availability decreased base flow loads of TSS and *E. coli* in both streams, and decreased time cattle spent in riparian areas in the pasture with the smaller amount of nonriparian shade ($p < 0.08$). Our results indicate that possible BMPs to reduce contamination from cattle-grazed pastures would be to develop or encourage nonriparian shade and to provide cattle with alternative water sources away from the stream.

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). Phosphorus is the limiting factor for many aquatic plants growing in fresh water. Thus, an increase in P availability in streams can lead to eutrophication, which may kill fish and other aquatic life (Correll, 1998). Sedimentation in surface waters may interfere with proper gill function in aquatic animals as well as embed pebbles in the streambed, which eliminates hiding and spawning places for aquatic fauna (Wood and Armitage, 1997). Pathogenic intestinal organisms from feces deposited in surface water may lead to health problems and possible death in humans as well as other animals drinking from contaminated waterways (USEPA, 2002).

Phosphorus delivery to surface waters can occur via surface runoff and occasionally via subsurface flow. Phosphorus can also enter streams in grazed pastures through direct defecation of cattle into streams. Line et al. (2000) determined that an unfenced stream flowing through a 14.9-ha pasture grazed by 60 dairy cows had a mean weekly load of 50 kg of total P (TP).

In terms of volume, suspended sediment is the largest contaminant in surface waters (Cooper, 1993). Sediment from the stream channel is caused by sloughing of stream bank material or by streambed degradation and resuspension of sediment into the water column. Both processes occur naturally, but can be worsened by livestock activity (Myers and Swanson, 1996; Clary, 1999).

Pathogenic bacteria present in animal manure can be important stream contaminants in grazed pastures. The most common fecal indicator bacteria discussed in the literature are total coliforms, fecal anaerobes, fecal coliforms, and fecal enterococci, but the USEPA has recommended the use of *Escherichia coli* as the preferred fecal indicator bacteria for fresh water because it is a much more effective predictor of gastrointestinal illness than other fecal indicator bacteria (USEPA, 1986).

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 stream contamination by cattle, but information on this subject is lacking. Information is also lacking on the amount of time that cattle spend in riparian areas of Southern Piedmont, tall fescue pastures. Global positioning system (GPS) collars mounted on cattle have been used in cattle behavior studies (Bailey, 1999; Turner et al., 2000; Ganskopp et al., 2000; Bicudo et al., 2003) and should be useful to track use of riparian areas by cattle in the Southern Piedmont.

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Abbreviations: BMP, best management practice; DRP, dissolved reactive phosphorus; GPS, global positioning system; THI, temperature–humidity index; TP, total phosphorus; TSS, total suspended solids; UTM, universal transverse mercator.

Fencing entire reaches of stream riparian areas has been proposed as a way to reduce P, sediment, and pathogen loads in streams. The high cost of fencing, however, prevents many livestock producers from implementing this practice (Line et al., 2000). An alternative to fencing may be installing water troughs away from the stream. The presence of an alternative water source for cattle reduced by 51% the amount of time cattle spent in the stream (Sheffield et al., 1997). Because cattle were not spending as much time in the stream, the flow-weighted concentration of total suspended solids (TSS) decreased from 132 to 14 mg L^{-1}, an 89% reduction; and TP decreased from 0.203 to 0.072 mg L^{-1}, a 65% reduction. In contrast, Line et al. (2000) concluded that water troughs alone did not significantly decrease the mean weekly discharge of TSS from cattle-grazed pastures. Clearly, additional work is needed to evaluate the effect of water troughs on stream water quality.

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 effects of alternative water sources on stream water quality. A secondary, supporting objective was to determine the amount of time spent by cattle in the riparian areas of these pastures.

MATERIALS AND METHODS

Site Description

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; 33°24′ N lat; 83°29′ W long; elev. 150 m). Portable samplers (ISCO model 6700; ISCO, Lincoln, NE) were installed where the stream entered and exited each pasture (Fig. 1). For the purpose of this article, the pasture between water quality sampling stations G5 and G6 will be referred to as pasture G5G6, and the pasture between 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; Fig. 1). The streams in both pastures had been unfenced for >10 yr and had been dredged in 1994 to improve pasture drainage. The average slope of the stream was 0.4% in G5G6 and 0.6% in G8G9. The average slope perpendicular to the stream was 4.5% in G5G6 and 3.1% in G8G9. The stream length was approximately 397 m in G5G6 and 506 m 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).

Shade and Riparian Area Survey

The riparian area in pastures G5G6 and G8G9 were not easily identifiable because tall fescue had encroached to the edge of the water; thereby masking a clear vegetation change. Therefore, to delineate the riparian area, the banks of the two streams were surveyed using a submeter Leica 342 GPS unit (Leica Geosystems AG, Switzerland), and a 12-m buffer area centered on the stream was created in ArcView GIS 3.2 (Environmental Systems Research Institute, Redlands, CA). To delineate the extent of the tree shade, the crown circumference of each tree was surveyed with a submeter Trimble Model TSC1 GPS unit (Trimble, Sunnyvale, CA) after leaf-out, and 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, Redlands, CA) and the Xtoolsmh extensions (Oregon Department of Forestry, Salem, OR). The submeter Trimble Model TSC1 GPS was also used to delineate pasture, stream, and cross fences as well as determine the position of the water troughs in the two pastures. From this survey it was determined that 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 nonriparian areas, although the amounts of shade varied greatly between pastures. Pasture G8G9 had over twice the amount of total shade of pasture G5G6 and almost three times the amount of nonriparian shade.

Pasture Management

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. Water meters were read weekly or biweekly during 36 measurement periods between May 2001 and August 2003, and readings were used to determine daily water consumption per cow–calf pair. Water meters

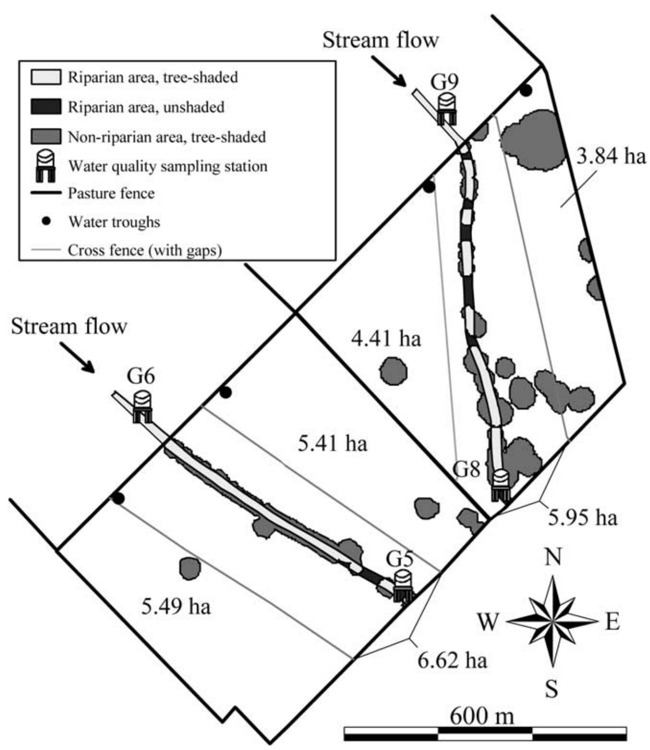

Fig. 1. Map of pastures G5G6 and G8G9 showing tree-shaded areas, riparian areas, fences, watering troughs, and water quality sampling stations. Riparian areas are defined as 12-m buffers centered on the stream. Tree-shade is defined as the circumference of the crown plus a 6-m buffer extending from the outer edge of the crown.

were also installed in troughs located in two pastures upstream of the ones used in the study, where the streams were fenced to prevent cattle access. These pastures were of similar area as those in the study (16.3 ha upstream of G5G6 and 16.9 ha upstream of G8G9) and were also stocked with 20 cow–calf pairs. For each measurement period, the amount of water consumed by cattle in the study pastures (where cattle had access to the streams) was subtracted from the amount of water consumed in the upstream pastures (where cattle did not have access to the streams) to obtain an estimate of the amount of water that cattle drank from the stream when water troughs were available. All of these differences were evaluated by a *t* test to determine if they were significantly different from zero. The average distance from the water troughs to the stream was 91 m in G5G6 and 81 m in G8G9 (Fig. 1).

Water Quality Monitoring

Monitoring of water quality during storm events took place with and without water troughs available (Fig. 2). When water troughs were not available, an electric fence around the troughs prevented cattle access to them. At the onset of the project (March 2001), the intention was to evaluate water quality for 1 yr with water troughs available, then close the water troughs in March 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 August 2003.

To remain conservative in the analysis, the data from the storm events and base flow samplings that took place with open troughs between 3 June and 23 Dec. 2002 were not used in this study (Fig. 2), as it was feared that cattle may have defecated at high rates near the riparian area during the previous time when the troughs were closed, thus loading the area heavily with contaminants.

The total number of storm flow events analyzed when water troughs were available was 14 in G5G6 and 22 in G8G9 (Fig. 2); 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 was 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 Flow and Base Flow Water Quality: Sampling and Equipment

When monitoring water quality during storm events, it was important to take multiple discrete water samples at several points throughout the event as the concentration in each sample is commonly a function of discharge and time since the storm event began. Therefore, to ensure multiple discrete samples across the entire hydrograph of discharge, a DRUCK, PDCR 1230 pressure transducer (Druck, New Fairfield, CT) was installed vertically in the stream through a PVC pipe attached to a t-post. The pressure transducer was connected to a Campbell Scientific CR510 datalogger (Campbell Scientific, Logan, UT), which at predetermined stream heights would trigger the ISCO sampler to take a 500-mL water sample. The datalogger recorded the date, time, and stream height every 15 min, and every time a sample was taken. A 12-V deep-cycle marine battery provided electricity for the system, and was recharged by a Solarex 60-W solar panel (Solarex, Frederick, MD). Following a storm event, water samples were retrieved and taken to the laboratory for analysis. To measure base flow concentrations, grab samples were taken every 14 d at the same locations and depths where storm flow samples were collected.

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

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

Storm Flow and Base Flow Water Quality: Laboratory Analysis

A 250-mL aliquot of each water sample was filtered trough a preweighed, acid-washed, 0.45-μm Supor-450 polyethersulfone filter (Pall Life Sciences, Ann Arbor, MI), and the filter was dried at 106°C for 24 h and reweighed to determine TSS. The filtrate was analyzed for dissolved reactive P (DRP) by the molybdate-blue procedure (Murphy and Riley, 1962). An unfiltered sample was analyzed for TP by the same procedure, following Kjeldahl digestion (USEPA, 1979). Base flow samples were further analyzed for *E. coli* using the Colilert (Idexx Laboratories, Westbrook, ME) enzyme substrate method (Clesceri et al., 1998).

Storm Flow Water Quality: Data Processing

To determine the volume of discharge (m^3 s^{-1}) that moved past each water quality station during a storm event, a rating curve was developed to calculate flow at any given stream height. To construct the rating curve, the cross-sectional area of each stream was surveyed at 10-cm increments with a Model 300 Level (Berger Instruments, Braintree, MA) so that the hydraulic radius at each stream height could be calculated. Stream velocity can be estimated using Manning's Equation; however, the roughness coefficient (Manning's N) is a parameter difficult to estimate because it is affected by bank vegetation, rocks, and streambed structure. Because Manning's Equation is very sensitive to this parameter, it became pertinent that Manning's N be calculated as accurately as possible at each water quality station. Therefore, a 750-Area Velocity Module (ISCO, Lincoln, NE) was installed in the stream adjacent to the pressure transducer and attached to an extra ISCO sampler to measure velocity. Stream velocity data were then used together with hydraulic radius and slope to estimate

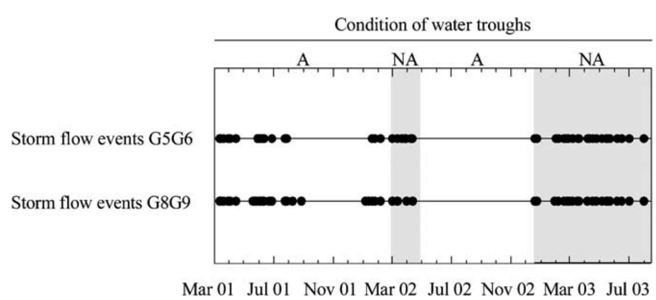

Fig. 2. Storm events (indicated by circles) and condition of water troughs (A, available; NA, not available) in pastures G5G6 and G8G9 from 1 Mar. 2001 to 15 Aug. 2003.

Manning's N for each station. Once Manning's N was determined, individual discharge rating curves for each water quality station were created using FlowMaster (Haestad Methods, Waterbury, CT).

Using the rating curves, the discharge for each station was calculated on a 15-min basis from 12 Mar. 2001 to 15 Aug. 2003. Each storm event was identified and the discharge for each storm flow water sample was integrated with respect to time in Mathcad 8.0 (Mathsoft Engineering & Education, Cambridge, MA) from the beginning of the event to the time each sample was taken. This provided the cumulative discharge (L storm^{-1}) at the time each sample was taken. The concentration (mg L^{-1}) of contaminants in the discrete samples was then integrated in Mathcad with respect to cumulative discharge to calculate the load (kg) of contaminant per storm flow event at each station. To calculate the load contributed by each pasture, the load at the upstream station was subtracted from the load at the downstream station (G5 − G6 and G8 − G9). Flow-weighted concentrations for stream flow generated in each pasture were calculated by dividing an event load of contaminant by the event volume of discharge.

Base Flow Water Quality: Data Processing

During base flow, the flow rate should not vary significantly during the day; therefore the flow rate at the time each grab sample was taken was expressed on a daily basis and then multiplied by the concentration of contaminant in the grab sample to obtain a daily load. Flow rates were calculated with the rating curves described above. Daily loads contributed by each pasture were calculated by subtracting the upstream load from the downstream load (G5 − G6 and G8 − G9).

Global Positioning System Collars

Model GPS2200LR Livestock GPS Collars (Lotek Wireless, Newmarket, ON, Canada) were used to monitor cattle location in the pastures. Because the collars were programmed to take a location fix every 5 min and the memory could hold about 5000 data points, each collection period was limited to approximately 17 d.

To test the accuracy of the collars, a benchmark was established adjacent to the pastures by georeferencing it with respect to a U.S. Geological Service benchmark. Two GPS Collars were placed on the benchmark for 2 wk, after which the data from the collars were differentially corrected using data from a U.S. Coastguard reference station in Macon, GA. Once differentially corrected, 95% of the data points taken by the collars were accurate to within 3 m of the established benchmark.

In May, June, July, and August 2001, three cows from each pasture were randomly selected and fitted with GPS collars, after which they were returned to their respective pastures and allowed to resume normal grazing behavior. Water troughs were available in both pastures during these measurement periods (Fig. 2). Also, in March and December 2002, GPS collars were mounted on cows in each pasture so that their behavior could be monitored for 8 d with available water troughs, followed by 8 d without water troughs. A similar study with a reversal of trough availability was performed in July 2003, in which cattle behavior was monitored for 8 d without water troughs, followed by 8 d with water troughs.

At the end of each monitoring period, collars were removed and the data downloaded using Lotek's proprietary software. Also a proprietary software (N4) from Lotek was used with data from a U.S. Coastguard reference station in Macon, GA, to differentially correct the collar data. Once corrected, the data were reprojected to universal transverse mercator (UTM) coordinates using CorpCon version 5.11 (U.S. Army Corps of Engineers, Topographic Engineering Center, Alexandria, VA) and were imported as event themes into ArcView GIS 3.2 (Fig. 2).

Statistical Analysis: Water Quality Data

Due to the nature of this study and the distribution of the data, parametric statistical procedures were not applicable; therefore, the analysis was performed with nonparametric methods. PROC UNIVARIATE (SAS Institute, 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 on the difference in loads between pastures to determine if one pasture contributed a greater load than the other (i.e., if the median of the differences in loads was different from zero according to the signed-rank statistic). The Kruskal–Wallis statistic under PROC NPAR1WAY (SAS Institute, 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.

Statistical Analysis: Global Positioning System Collar Data

ArcView GIS was used to identify and export tables of attributes (date, cow number, time, and temperature) of the points gathered from each collar that intersected with total riparian area, tree-shaded riparian area, or tree-shaded nonriparian area layers. The tables were then imported into Excel (Microsoft, Redmond, WA) and the attributes were sorted, averaged, and analyzed for several key trends. To determine the amount of time cattle spent in the riparian area and nonriparian shade as a function of month of the year, the data from cow collars used in pastures G5 and G8 were sorted by month and pasture, averaged, the standard error determined, and plotted in SigmaPlot Version 8.0 (SPSS, Chicago, IL). PROC MIXED in SAS (SAS Institute, 1999) was used to quantify monthly differences in the cattle usage of the riparian area. To determine the effect of water trough availability on the amount of time cattle spent in the riparian area and in nonriparian shade, data obtained during periods when the condition of the troughs changed (available or not available) over the monitoring period were divided into two groups based on trough status: available or not available. PROC MIXED (SAS Institute, 1999) was then used to determine if water trough availability was a significant factor in affecting percentage of the day cattle spent in the riparian area or in nonriparian shade.

RESULTS AND DISCUSSION

Storm Flow Water Quality

Analysis of median loads (Fig. 3) 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. 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

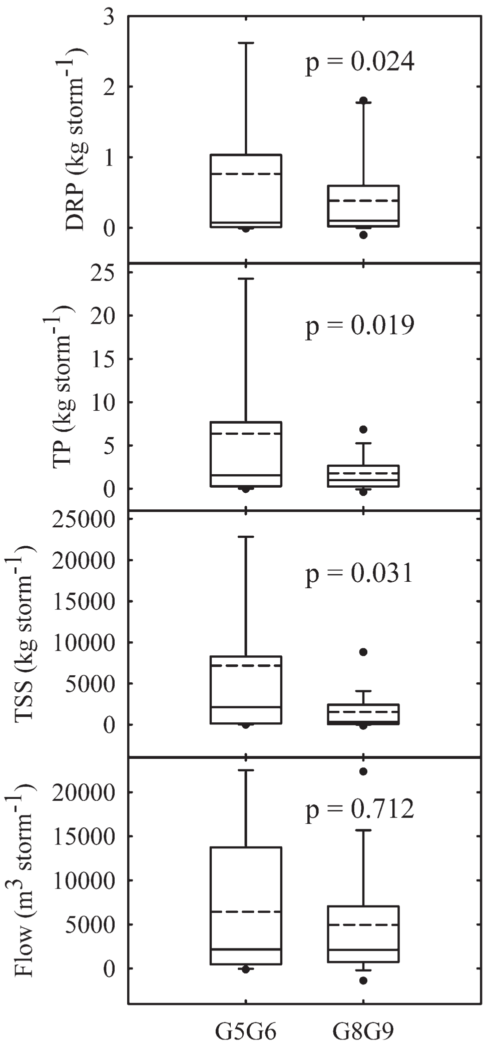

Fig. 3. Boxplots of storm flow and storm flow loads of DRP, TP, and TSS in G5G6 and G8G9 (means indicated by dashed lines; *p* indicates probability of type I error for signed-rank statistic to test whether median of load differences between pastures is significantly different from zero).

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 be 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 (Fig. 3) as well as the median differences in flow-weighted concentrations of DRP and TP (Table 2) were significantly different from zero at $p = 0.05$. The median difference in the flow-weighted concentration of TSS was significantly different 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 (Fig. 3), the greater nutrient and sediment inputs in G5G6 were apparently due to different cattle behavior in each pasture. Data collected with GPS collars indicated that in May, June, and July 2001 cattle spent more time in the riparian area of G5G6 than in the riparian area of G8G9 (Fig. 4). In both pastures, most of the time spent in the riparian area was in the shade (average of 93% in G5G6 and 83% in G8G9). We also found that in May, June, July, and August 2001, the amount of time spent in nonriparian shade was greater in G8G9 than in G5G6 (Fig. 4). Pasture G8G9 had almost three times more nonriparian 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 (Fig. 3) were probably caused by cattle spending more time in the riparian area (mostly in the shade) and less time in nonriparian shade. These results suggest that providing or encouraging nonriparian 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. Research in this area is lacking because previous research on shade effect has concentrated on improving forage use and weight gain performance (McIvan and Shoop, 1971; Buffington et al., 1983; Blackshaw and Blackshaw, 1994). Thus, further research should be conducted to evaluate nonriparian shade as a potential BMP to reduce stream contamination by cattle.

Table 2. Median storm flow flow-weighted concentrations of DRP, TP, and TSS; and median base flow loads in unfenced streams draining two cattle-grazed pastures during 2001–2003 [*p* indicates probability of type I error for signed-rank statistic (|*s*|) to test whether medians of load or concentration differences between pastures is significantly different from zero].

	Pasture		Difference	
Variable†	G5G6	G8G9	G5G6 − G8G9	
	Median storm flow concentrations			$p > \|s\|$
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 base flow loads			
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}	1.4×10^9	2.5×10^9	-2.5×10^9	0.01
Flow, m^3 d^{-1}	641	622	97	0.94

† DRP, dissolved reactive phosphorus; TP, total phosphorus; TSS, total suspended solids.

Base Flow Water Quality

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 pool where cattle stood for extended periods of time. Cattle defecation and trampling in this pool would lead to increased loads of

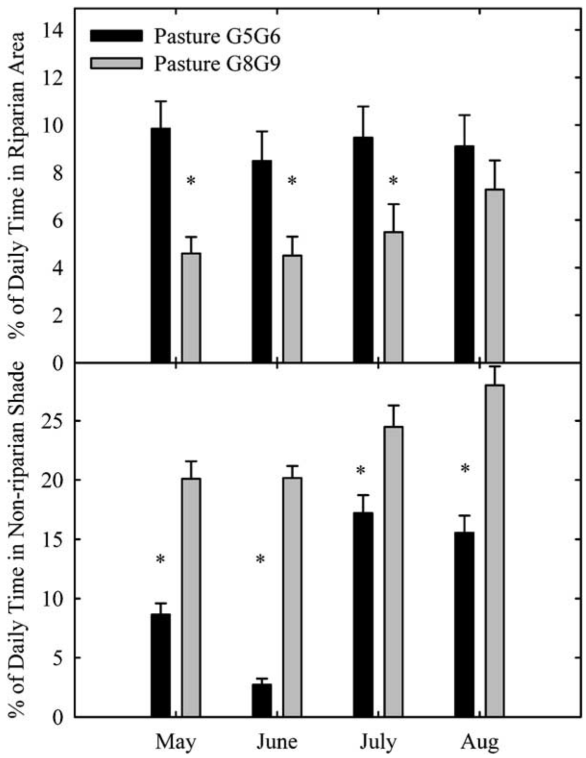

Fig. 4. Percentage of daily time spent by cattle in the riparian area and in nonriparian shade of pastures G5G6 and G8G9 in 2001 (bars are standard errors; asterisks indicate significant differences between pastures at $p = 0.05$).

E. coli and sediments in base flow. The stream in G5G6 did not have such a pool. This observation suggests that it may be worthwhile to evaluate whether the elimination of stream pools may lead to a reduction of stream water contamination by cattle.

Effect of Water Trough on Storm Flow Water Quality

In both streams, median storm flow loads of DRP, TP, and TSS were not different ($p = 0.10$) between periods with and without water troughs (Table 3). Because storm flow is likely to receive contributions of DRP, TP, and TSS through surface runoff from areas near the stream, these results suggest that the availability of water troughs did not decrease deposition of feces in these areas.

Table 3. Median storm flow loads of DRP, TP, and TSS in unfenced streams draining two cattle-grazed pastures during periods with and without water troughs available.

Pasture	Variable†	Water trough Yes	Water trough No	Kruskal–Wallis
		kg storm^{-1}		
		Median storm flow loads		$p >$ 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

† DRP, dissolved reactive phosphorus; TP, total phosphorus; TSS, total suspended solids.

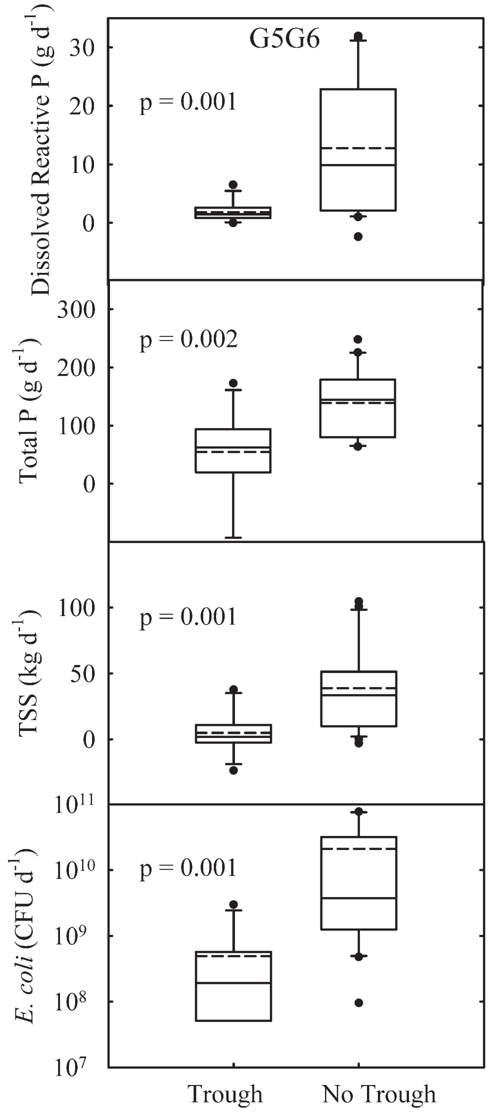

Fig. 5. Effect of water trough availability on base flow loads of DRP, TP, TSS, and *E. coli* in pasture G5G6 (means indicated by dashed lines; *p* indicates probability of a larger chi^2 for testing differences between loads with and without water trough with the Kruskal-Wallis test).

Effect of Water Troughs on Base Flow Water Quality

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 with the loads observed without water troughs (Fig. 5). It should be pointed out that stream flow was 51% smaller when the water troughs were available, which would tend to reduce loads. But, because the proportional decreases observed in DRP, TSS, and *E. coli* loads were much 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 data collected with GPS collars, which showed that providing water troughs decreased the amount of time cattle spent in the riparian

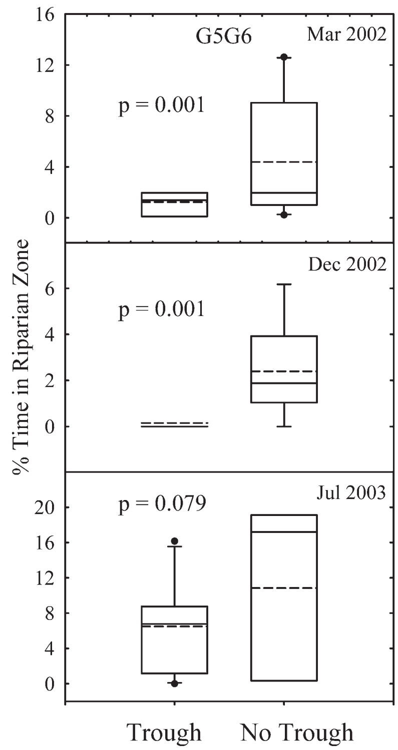

Fig. 6. Effect of water trough availability on the percentage of daily time spent by cattle in the riparian area of pasture G5G6 (means indicated by dashed lines; *p* indicates probability of type I error for testing differences between means).

area of G5G6 by 40 to 96%, depending on time of the year (Fig. 6). These results agree with those of Godwin and Miner (1996) who found that when a water trough was provided, cows spent 75% less time within 4.5 m of an Oregon stream. The smaller amount of time spent in the riparian area of G5G6 probably resulted in a smaller amount of time spent directly in the stream, which led to a reduction in base flow loads. Data from the water meters installed in the troughs indicated that when water troughs were available in G5G6, the proportion of water drunk from the stream decreased from 100% (without troughs) to 25%, suggesting less time spent in the stream.

When water troughs were available in G8G9, the median base flow load of TSS decreased by 64% (from 59 to 21 kg d^{-1}; $p = 0.06$) and the median base flow load of *E. coli* decreased by 85% (from 7.68×10^9 to 1.15×10^9 CFU d^{-1}; $p = 0.08$) when compared to loads without water troughs. In the case of G8G9, there were no differences in stream flow between periods with and without water troughs (data not shown), so the decrease in load can be directly attributed to a decrease in contaminant input into the stream. It should be noted that data collected with GPS collars did not show a significant decrease ($p = 0.20$) in the amount of time spent by cattle in the riparian area of G8G9 when water troughs were available (data not shown). 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 TSS and *E. coli* into the stream did decrease. A possible reason for this result is that the availability of water troughs would have made it less necessary for cattle to get into the stream to drink water, thereby reducing direct input of contaminants. Data collected with water meters installed in the troughs indicated that when water troughs were available in G8G9, the proportion of water drunk from the stream decreased from 100% (without troughs) to 31%.

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 coliforms 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 than when they were not available (79 vs. 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.

CONCLUSIONS

Our results show that cattle-grazed 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 ($p < 0.01$) 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, which had a smaller amount of nonriparian shade, storm flow loads of DRP, TP, and TSS were larger ($p < 0.05$) than in pasture G8G9, which had abundant nonriparian shade. The larger storm flow loads in G5G6 appeared to be a direct response to cattle spending more time in the riparian area as shown by GPS collar data. The availability of water troughs decreased ($p < 0.08$) base flow loads of TSS and *E. coli* in both pastures, but did not affect storm flow loads. The results of this study indicate that potential BMPs to reduce P, sediment, and *E. coli* contamination from beef cattle–grazed pastures would be to build or encourage nonriparian shade and to provide cattle with alternative water sources away from the stream. Further work on the effect of increasing nonriparian shade should be performed to confirm these results. Also, further work should be performed to study the impact of water trough availability in an experimental setup in which similar pastures with and without water troughs are evaluated simultaneously. This would avoid confounding results by changes in THI, as observed in our study.

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