Riparian Grazing Impacts on Streambank Erosion and Phosphorus Loss Via Surface Runoff

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correlations, in some cases, were found between stocking rate and other variables including SBD, SS, and TP losses indicating that the use of low stocking rates could reduce contributions of SS, TP, and soil compaction from riparian SAs. However, the results from this study revealed that even the lowest stocking rates did not significantly reduce the SS and TP loss, indicating that even lower stocking rates would be needed to accomplish significant reductions. It is also possible that some of the other pasture and stream corridor characteristics, such as the ratio of stream length to pasture width, forage composition and its distribution, location and distribution of trees, climatic variables, and streambank steepness, may have impacts on riparian area use, by affecting cattle behavior and distribution throughout the pasture and the stream channel, regardless of stocking rates. Thus in this study, the potential positive effects of improved pasture management on water quality could be masked by the aforementioned spatial and temporal factors. In conclusion, these study results imply that streambank access paths to the stream channel and loafing areas along the streamside should be avoided or minimized to reduce the disturbance associated with the livestock. This can be achieved by fencing the near-stream riparian area and providing specific areas for cattle to cross or drink water or by providing off-stream water sources. In addition, field observation suggested that scattered single trees (usually not more than 1 or 2 trees per 100 m stream length) that grow on the streamside areas of the pastures may need to be removed to eliminate the formation of loafing areas, which, in turn, will decrease the chance of TP loss in runoff to pasture streams. Finally, grazing intensities should be decreased or, for the best, completely avoided in the near-channel riparian SAs to mitigate the impacts of animal trampling on soil compaction and forage growth.

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as silt loams (Table 1). The highest mean SBDs were found in the access paths, where most of the stream crossing and drinking activities took place (Table 2). On a regional basis, the Central region had significantly higher SBDs in all the SAs compared with Southeast and Northeast regions. This is probably due to the higher clay content found in the Central region riparian soils. Access paths also had the lowest SM and highest surface runoff across the regions. This response could be the result of higher surface soil compaction by cattle treading and the resulting bare soil surface with high slope gradients (Table 2). The lowest runoff volumes (highest infiltration) were found in the control area soils where SBD was lowest and vegetative cover highest as a result of less soil compaction by grazing cattle (Table 2).

A number of other studies have also reported SS and P losses from grazed pasture lands. McKergow *et al.* (2003) reported average sediment loads of 114 kg/ha/yr and TP export that ranged from 200 to 600 g/ha/yr from a small grazed catchment (6 km^2) in Western Australia. Gillingham and Thorrold (2000) reported TP losses of 110-1,670 g/ha/yr from grazed pasture lands in New Zealand. Similarly, Lambert *et al.* (1985) reported 1,500 g/ha/yr TP losses from a rotationally grazed pasture. TP concentrations in surface runoff ranging from 0.67 to 1.35 mg/l were reported by Barnett *et al.* (2004). None of these studies identified specific sources of the sediment or P. In order to implement proper land use management practices that will reduce sediment and nutrient movement from grazed pastures, it is essential to pinpoint the CSAs in the watershed that contribute most of the pollutants. This one-time event-based study was conducted to specifically quantify the magnitude of the SS and TP contributions from cattle access paths and loafing SAs.

Based on the results of this study, access paths were the major contributors of SS loads to the stream due to higher soil compaction and a lack of vegetation ground cover resulting from intensive livestock treading (Table 2). Control areas that accounted for 97.3% of the total SAs provided the least sediment loss per unit area because of the lower impact of livestock, but provided higher total amounts of SS loss than the loafing areas because of their large contributing area (Table 3). In some cases, significant relationships were found between stocking rates and SS losses in surface runoff suggesting that lower stocking rates could reduce sediment loads from riparian areas.

Mean TP concentrations were also significantly higher from access paths that corresponded well with the high SS concentrations from these areas indicating that most of the P movement took place in the particulate form attached to sediment in runoff. Both access paths and control areas were the major contributors of the TP loads (Table 3). Although access paths accounted for only 1.5% of the total SAs, the TP and SS contributions from these areas were very high (Table 3) suggesting that reducing their numbers on these sites could significantly reduce sediment and TP contributions to streams. There were also significant correlations between stocking rates and TP loss from the access paths in the Central region. When combining CSA's contribution, data showed that access paths and loafing areas contributed 72% of SS and 55% of the TP whereas their combined area contribution was only 2.7% of the total SAs (Table 3). This result indicated that both access paths and loafing areas were the major SAs of SS and TP losses to streams and their management needs special attention.

It is important to note that the average TP loss (0.428 kg/km; Table 3) from these SAs of the nine grazed pastures, within the 15-m wide strip in a simulated rainfall event, was much lower than the TP loss (93.6 kg/km/yr) recorded by the streambank erosion study conducted on the same pastures of this study (Tufekcioglu, 2006). However, spatial and temporal implications of the current surface runoff study enhance the understanding of the contribution of the various SAs to total TP loss to surface water.

Overall, the results of this study suggest that, in some cases, lower stocking rates in combination with the given regional soil characteristics have the potential to reduce soil compaction, SS, and TP losses, but the role of dissolved P export needs to be addressed further. However, the lowest stocking rates used in the pastures of this study may not be sufficient to mitigate the impact of the livestock on the riparian SAs, partially, due to the inherent characteristics (drinking and shading) of these areas that attract cattle. This suggests that even lower stocking rates should be used, especially for pastures with high clay soil content, in order to reduce the impact of livestock on the riparian SAs.

SUMMARY AND CONCLUSIONS

The streambank cattle access paths and loafing areas (CSAs) along the 15-m wide strips on both sides of the channel contributed 72% of the total SS and 55% of the total TP to streams, although they accounted for only 2.7% of the total SAs. Control areas contributed 28% of the total SS and 45% of the total TP to streams, even though they made up 97.3% of the total targeted SAs. These differences in contributions were mostly due to the effects of cattle on the vegetation and soil characteristics of the SAs. Significant losses. For all three regions, the mean SS loss from the access areas (236 kg/km or 79 kg/ha) in the 15-m wide strips on both sides of stream was significantly higher than from both the control (99 kg/km or 33 kg/ha; $p = 0.0168$) and loafing areas (20 kg/km or 7 kg/ha; $p < 0.0001$) (Table 3). Total sediment losses between loafing and control areas were also significantly different ($p < 0.0005$). Significantly positive correlations between stocking rates and SS losses were found for the control ($R^2 = 0.98$; $p = 0.0954$) and for the loafing areas ($R^2 = 0.99$; $p = 0.053$) in the Southeast region.

Total Phosphorus Concentrations and Losses from the 15-m Wide Strips

From all three regions, significant differences in mean TP concentrations were found between the access paths (10.5 mg/l) and both loafing (3.9 mg/l; $p < 0.0001$) and control areas (1.0 mg/l; $p < 0.0001$). Loafing and control areas' concentrations were also significantly different ($p = 0.0004$). The ANCOVA model showed that slope alone did not affect the TP losses from the SAs ($p = 0.1092$). However, the SA type ($p = 0.0425$), and the effect of interaction between slope and SA type ($p = 0.0920$) did affect the TP losses. The mean TP loss was significantly lower in the loafing areas (25 g/km or 8 g/ha) than in either the control areas (192 g/km or 64 g/ha; $p < 0.0001$) or access paths (211 g/km or 70 g/ha; $p < 0.0001$) (Table 3). Significantly positive correlations between stocking rates and TP loss were found for the access paths in the Central region ($R^2 = 0.99$; $p = 0.0897$).

DISCUSSION

Gburek and Sharpley (1998) suggested that to control P export from a watershed, areas that potentially have high soil-P content and surface runoff (CSAs) should be targeted for conservation practices. The establishment of conservation practices in these areas can minimize P loads to streams. These areas are generally within 60 m of the stream (Sharpley *et al.*, 1999; Gburek *et al.*, 2000), and although they account for approximately 10% of the total watershed area, they contribute approximately 90% of the annual algal-available P export during large storms (Pionke *et al.*, 1997). Another study by Diebel *et al.* (2009) found that by targeting the areas that produce the highest 10% of sediment and P in a watershed, P loads to the stream can be reduced by 20%. In contrast, if the bottom 10% of the areas that produce these pollutants is targeted, only 1% of the loads will be reduced. In this study, within the 30-m wide, 1-km long strip located on both sides of the stream (approximately 3 ha), the loafing, access paths, and control areas accounted for 1.2, 1.5, and 97.3%, of the total area, respectively, across all the grazing treatments (Table 3). This suggests that cattle intensively use approximately only 3% of the 15-m wide riparian strip located on both sides of the stream to either cross or drink water from the stream (access paths), or to huddle together in certain areas along the streambank (loafing areas) that provide shade. According to field observations in this study, it appears that the numbers and frequency of access paths and loafing areas along the 15-m wide strips are related not only to stocking rates but also to the steepness of the streambanks (the steeper the banks the less cattle tend to use them), the presence of trees directly along the channel that provide shade, and the width of the entire riparian pasture that is subject to grazing impacts. The fact that only one significant relationship was found between stocking rates and CSA contributions (in access paths from the Central region) also affirms the accuracy of this field observation.

Grazing can reduce infiltration and change ground cover and plant species composition by increasing soil compaction, which can result in increased surface runoff and erosion that contribute to changes in watershed hydrology and ultimately stream morphology (Agouridis *et al.*, 2005). A study conducted by Bear *et al.* (2012) found that reducing the stocking rate and altering the distribution of cattle will reduce the risk of nutrient loss to surface runoff from riparian areas of grazed pastures. Among grazing practices, continuous grazing often has the greatest potential to increase SBD because of the inherently high stocking rates and the length of time that the livestock have access to the soil (Chanasyk and Naeth, 1995; Clary, 1995). Similarly, a recent study by Tufekcioglu *et al.* (2012) found a significant relationship between stocking rate and soil compaction on the riparian areas of 13 grazed pastures in southern Iowa. Additionally, Daniel *et al.* (2002) indicated that stocking rates had less effect on silt-loam than on clay-loam pasture soils, but that grazing treatments regardless of stocking rates had greater SBD to a depth of 5 cm than those of ungrazed soils. Texture plays an important role in the rate of compaction by livestock. As expected, in this study, significant correlations were found between the stocking rate and SBD in the access paths of the Central and Southeast regions, where soil textures range from loam to clay-loam compared with the soils of the Northeast region that are more frequently classified

TABLE 2. Slope, Soil Bulk Density (SBD), Soil Moisture (SM), Simulated Rainfall Runoff, and Vegetation Type and Heights for Simulated Rainfall Plots in the Riparian Grazing Sites.

Region	Source Area	Slope (%)	SBD (g/cm^3)	SM (%)	Runoff (l/0.5 m^2)	Vegetation* (cm)
Central	Access	22	1.95	11	11	Bare^9
Central	Loafing	12	1.58	18	5	Bare^2, grass^1 (10)
Central	Control	24	1.60	14	6	Grass^4 (10, 20, 10, 18), legume^2 (3, 2)
N-E	Access	20	1.61	20	11	Bare^9
N-E	Loafing	10	1.41	30	11	Bare^3
N-E	Control	14	1.38	21	7	Grass^5 (4, 3, 3, 10, 10), legume^1 (2)
S-E	Access	15	1.72	16	12	Bare^9
S-E	Loafing	15	1.50	19	9	Bare^2, legume^1 (4)
S-E	Control	11	1.36	25	5	Grass^6 (20, 4, 4, 7, 10, 15)
Average	Access	19 (a)†	1.76 (a)	16 (b)	11 (a)	N/A
Average	Loafing	12 (b)	1.50 (b)	22 (a)	8 (b)	N/A
Average	Control	16 (b)	1.45 (b)	20 (a)	6 (c)	N/A

Notes: Recorded values for slope, SBD (soil bulk density), soil moisture (SM), and runoff are the average of nine values for streambank access paths, six for control, and three for loafing areas based on the number of simulations conducted in each source area in each region. N/A, not applicable.

*The superscript number shows the number of rainfall simulation plots per given vegetation type and the values inside the parentheses are the height (cm) of the vegetation for each individual plot.

†Different letters inside the parentheses indicate significant differences ($p < 0.10$) among source areas (access, loafing, and control) for slope, SBD, SM, and Runoff.

The mean SS loss was significantly higher from the access paths (280 g/0.5 m^2) than from either the loafing areas (124 g/0.5 m^2; $p = 0.0009$) or control areas (2 g/0.5 m^2; $p < 0.0001$). The difference in SS loss between loafing and control areas was also significant ($p = 0.0023$). As with the SS loss, access paths had significantly higher mean TP losses (241 mg/0.5 m^2) than either the loafing (84 mg/0.5 m^2; $p = 0.0002$) or control areas (3 mg/0.5 m^2; $p < 0.0001$). The difference in TP loss between control and loafing areas was also significant ($p < 0.0001$).

Source Area Contribution

Average access paths, loafing, and control areas accounted for 1.2, 1.5, and 97.3%, respectively, of the total area in the 15-m wide strips on both sides of the streams (Table 3). A significant correlation between stocking rates and SA contributions across the regions was only found for the access paths in the Central region ($R^2 = 0.99$; $p = 0.0333$). The field survey showed that the number of access paths within the 15-m wide strips on both sides of the stream were approximately three times greater than the number of loafing areas across the regions (Table 3).

Suspended Sediment Concentrations and Losses from the 15-m Wide Strips

Across all three regions, access paths had significantly higher mean runoff sediment concentrations (12.4 g/l) than either the loafing areas (5.2 g/l; $p = 0.0005$) or the control areas (0.5 g/l; $p < 0.0001$). Loafing and control areas' concentrations were also significantly different ($p = 0.0223$). The ANCOVA model showed that slope alone did not affect the SS losses from the SAs ($p = 0.1500$). However, the SA types (access path, loafing, and control areas) ($p = 0.0986$), and the effect of interaction between slope and SA type ($p = 0.0690$) did affect the SS

TABLE 3. The Area Contribution of the Source Areas (SAs) Within 15-m Wide Strips Located on Both Sides of the Stream Reaches Across the Regions and Their Suspended Sediment (SS) and Total Phosphorus (TP) Inputs to Stream.

Source Areas	Numbers of SAs (no.)*	Area Contribution (m^2/km)	SS (kg/km)	Significant Difference	TP (g/km)	Significant Difference
Access	17	455 (1.5)†	236 (66)	a	211 (49)	a
Loafing	6	345 (1.2)	20 (6)	c	25 (6)	b
Control	N/A	28,833 (97.3)	99 (28)	b	192 (45)	a
Access and loafing	23	800 (2.7)	256 (72)		236 (55)	

*Numbers of SAs within 15-m wide strip on both sides of stream are given as per kilometer of stream length. N/A, not applicable.

†Numbers inside the parentheses show the result as a percentage of the total. Different letters indicate significant difference ($p < 0.10$) among source areas for SS and TP losses.

concentrations were then multiplied by the total volume of 30 min of runoff to calculate how much SS and TP were contributed from the 0.5-m^2 plots. Contributions from the 0.5-m^2 plots for each SA within the site were multiplied by the areas of the total access paths and total loafing and control areas for each reach to quantify the total loads from each individual SA and treatment type. Also, as the control (riparian areas with grass cover) areas were not expected to contribute SS and TP from runoff from their whole 15-m wide areas, a 30% sediment delivery ratio (USDA-NRCS, 1998) was used to estimate the amounts of total SS and TP actually contributed to the stream channel from these areas. This ratio was not applied to either the access path's or loafing area's contributions because both of these SAs were bare and had direct connections to the streams.

Data Analysis

The impacts of stocking rates on sediment and P movement from the SAs were examined using the Statistical Analyses System (SAS Institute, 1999). Linear mixed effects model including SAs (access paths, loafing, and control areas) and nine different stocking rates were used to compare the SS and TP contributions using the analysis of variance and comparing LSmeans among SAs. A Generalized Randomized Complete Block Design (GRCBD) was used where the three regions and nine sites were the blocking variables and SAs were the treatments. To address the confounding effect of slope on SS and TP losses, the analysis of covariance (ANCOVA) model included SA, site, and region as blocking variables, slope as a continuous covariate, and also the interaction between slope and SA was used. So the factors were slope, SA, and their interaction. The interaction between SA and sites was included as a random effect to take into account the multiple observations per site. Some response variables were log-transformed to meet normality assumptions of these models. Using the MIXED procedure in the GRCBD analysis, data from all three regions and each variable were pooled to look at differences among the access paths, loafing, and control areas' SS and TP contributions. The same analysis was also applied to SBD, SM, slope, and runoff volume. By using the Pearson correlation analysis, relationships between the stocking rates and specific variables (SS, TP, and SBD) were only analyzed within region because of potential differences in soil characteristics (soil-P and texture) between regions (Table 1). Data were analyzed by calculating the averages for each SA type within each pasture site. Observations from the same site are not independent so Pearson's coefficient would not be valid without taking this average. Soil moisture, slope, runoff volume, and vegetation characteristics of the SAs were used as descriptive statistics to help explain the results of this study. In this study, all differences reported were significant at 10% ($p < 0.10$).

RESULTS

Soil Bulk Density and Soil Moisture

Mean SBD of the access paths (1.76 g/cm^3) across all three regions was significantly greater than in both the loafing areas (1.50 g/cm^3; $p < 0.0001$) and in the control areas (1.45 g/cm^3; $p < 0.0001$) (Table 2). In the Central ($R^2 = 0.98$; $p = 0.1068$) and Southeast region ($R^2 = 0.99$; $p = 0.0464$), significant positive correlations were found between the stocking rates and bulk densities for the access paths. The Central region had significantly higher mean bulk densities in all SAs (1.73 g/cm^3) than in both the Southeast (1.52 g/cm^3; $p = 0.0002$) and Northeast regions (1.46 g/cm^3; $p < 0.0001$). Mean SM was significantly lower in the access paths (16%) than in both the loafing (22%; $p = 0.0052$) and control areas (20%; $p = 0.0222$) across the regions (Table 2). Regionally, the Central region had significantly lower mean SM (14.2%) across all SAs than either the Southeast (20.6%; $p = 0.0041$) or Northeast region (23.4%; $p = 0.0001$).

Runoff Volume, Slope Gradient, Vegetation, Suspended Sediment, and Total Phosphorus Losses Based on the Plot Scale (0.5 m^2)

Mean runoff volume from the 0.5-m^2 SA plots was significantly greater from the access paths (11 l/0.5 m^2) than from both the loafing (8 l/0.5 m^2; $p = 0.0266$) and control area plots (6 l/0.5 m^2; $p = 0.0001$) (Table 2). Mean runoff from the loafing areas was also significantly higher than from the control areas ($p = 0.0724$). The mean slope gradients measured for access paths, loafing, and control area plots were 19, 16, and 12%, respectively (Table 2). The slope of the access paths across all three regions was significantly greater than that of either the loafing ($p = 0.0189$) or in the control areas ($p = 0.0530$). Vegetation on both access paths and loafing areas was sparse, with bare soil being predominant in these areas (Table 2). It is important to notice that the slope and vegetation features of the SAs are the major descriptive characteristics that differentiate them from each other.

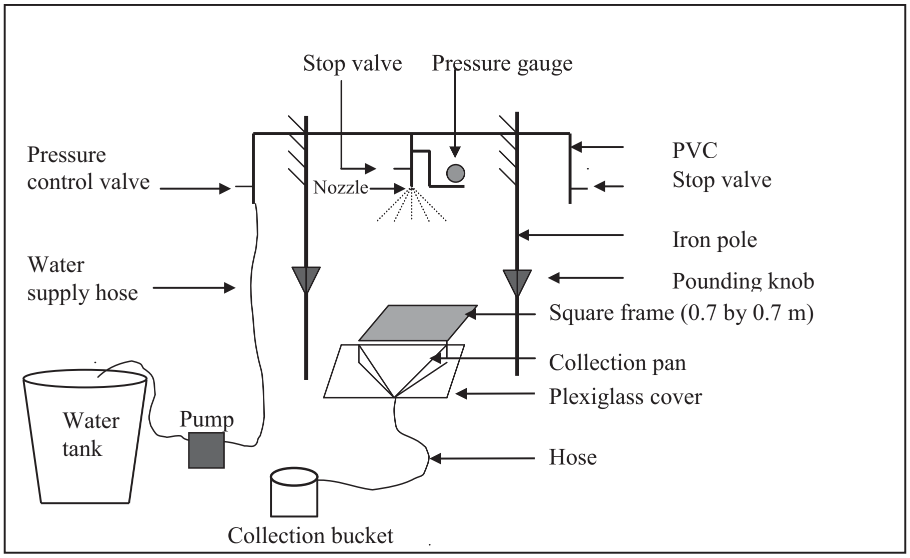

FIGURE 3. Schematics of Rainfall Simulation Setup. A portable 1.27-cm 30W single nozzle was placed 1.7 m above the soil surface. It was attached to PVC pipe and suspended. A nozzle pressure of 48.3 kPa was produced with a gasoline-powered pump to produce a mean rainfall intensity of 7 cm/half-hour on a 0.5-m^2 plot.

pretests showed that steady-state runoff from most of the plots was achieved within 30 min. A square steel frame 0.7 m on a side with 0.5 m^2 area was pounded into the ground, and fitted with a runoff collection pan. The runoff collection pan was located at the lowest edge of the plot to assure that water would flow from the plot to the collection pan. A plexiglass shield was placed on top of the collection pan to ensure that simulated rainfall was not falling directly into the bucket, which was located outside of the plot below the collection pan. The volume of runoff water was determined at the end of each of three 10-min periods (0-10, 10-20, and 20-30) using a graduated cylinder. Three subsamples of approximately 500 ml were taken from each period's runoff volume for laboratory analysis after thorough agitation of the solution. Water samples (total of 486) from the simulated events were analyzed for SS and TP. A 0.43-μm filter was used to separate the water samples for TP and to estimate SS. After the TP samples were digested with potassium persulfate, the extracted P was estimated colorimetrically with the molybdenum ascorbic blue method (Murphy and Riley, 1962).

Soil Bulk Density and Moisture Measurement

Before rainfall was applied to a plot, three 3-cm diameter and 7.5-cm deep soil cores were collected from around the rainfall simulation plot for SBD determinations. For antecedent soil moisture (SM) assessment, a total of three soil cores (3-cm diameter) were collected from the 0-5 cm depth to determine antecedent soil moisture prior to the simulated rainfall event for each plot (Naeth *et al.*, 1990). The bulk density and soil moisture samples were weighed after drying for 1 day at 105°C (Blake and Hartge, 1986).

Differences in antecedent soil moisture conditions were expected between regions of the state. Although the study was conducted during July and August, the driest time of the year, and all tests on a site were completed in 1 day, there was enough time between moving from one region to the next that natural rainfall did occur on some sites in the Northeast and Southeast regions before all the simulations could be completed.

Soil-P and soil texture data for the treatment sites were determined in another study conducted (Table 1) by Zaimes *et al.* (2008a). These data were used in this study to help explain the regional differences of some of the variables. Most importantly, inferences from these datasets were used to decide how the statistical analysis for this study should be done when investigating the relationship between stocking rate and other variables including SBD, SS, and TP losses.

Suspended Sediment and Total Phosphorus Losses from Stream Reaches

Because the treatment pasture sites had different stream reach lengths, the results that were extrapolated to each pasture reach were adjusted to a 1-km stream reach to facilitate comparisons between the treatments. For each treatment pasture site, the mean TP and SS concentrations were calculated for the access paths and loafing and control areas. These

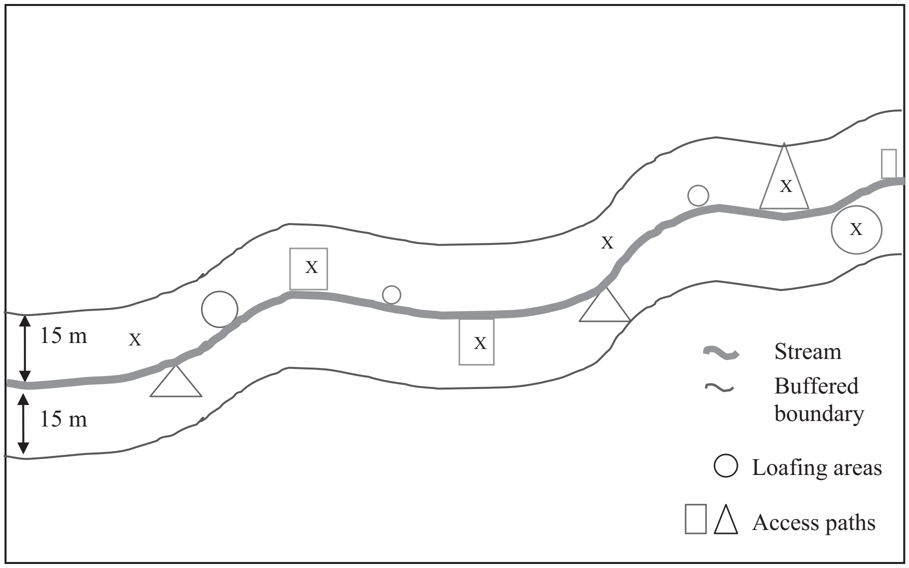

FIGURE 2. Schematics of Riparian Source Areas on a Pasture Stream Reach. Within a 15-m wide strip, located on both stream sides, all access paths and loafing areas (both critical source areas) were identified by their basic shapes of circle, rectangle, or triangle. The rest of the areas within the 15-m wide strip areas were considered the control area. Areas outside of the 15-m strips represent the rest of the pasture that could provide potentially low concentrations of sediment and P to the stream. As for the illustration, locations where the rainfall simulations were conducted are marked with the "X" in the pasture stream reach above (3 rainfall simulations were conducted on the cattle access paths, 2 on the control area, and 1 on the loafing area).

and control areas) within the 15-m wide strips. Areas of the SAs were compared to develop ratios of each of the three SAs within the 15-m wide strip on both sides of each stream reach. Stream reach lengths and pasture sizes were also calculated using GIS tools.

Simulated Runoff and Water Sampling

A total of 54 rainfall simulations were conducted during July and August, 2005, on a subset of access paths and loafing and control areas in the riparian grazing pasture sites. Through these simulations, the contributions of TP and SS to streams from surface runoff for each SA were quantified. Within each pasture site, a total of six rainfall simulations were conducted on three access paths, two control areas, and on one loafing area. This design was selected because of time and variability (in the SAs) concerns. All six rainfall simulations on one site were conducted during the same day to assure similar antecedent soil moisture values from each SA. We decided to conduct only one loafing area rainfall simulation per site because one treatment pasture site only had one loafing area within the 15-m wide strip. Additionally, our SA survey for all the sites showed that there was an average of three times as many access paths as loafing areas within the 15-m wide strip of each site. The access paths were also more variable in slope and shape than the loafing areas. Because of time constraints (completing only six simulations per day was feasible), we conducted only two control area simulations per site. Rainfall simulation plots within SAs were randomly selected from available SAs within each site by using the Statistical Analyses System program (SAS Institute, 1999). Just prior to starting each rainfall simulation, the slopes were determined by measuring the vertical and horizontal distances between the highest and lowest point of the plot. Vegetation types and heights were also identified and quantified for each rainfall plot.

In order to simulate rainfall, a portable 1.27-cm 30W single-nozzle (Tossell *et al.*, 1987) was placed 1.7 m above the soil surface (Figure 3). It was suspended from two iron stakes connected by a PVC (polyvinyl chloride) pipe (Tossell *et al.*, 1987; Nolan *et al.*, 1997; Quilbe *et al.*, 2005). A nozzle pressure of 48.3 kPa was produced with a gasoline-powered pump to produce a mean rainfall intensity of 7 cm/30 min on a 0.5-m^2 plot. Under natural conditions, this rainfall intensity (7 cm/half-hour) can occur with a return period of 100 years (Huff and Angel, 1992). We selected this high rainfall intensity to identify the potential differences in sediment and TP contribution to streams from the SAs under high impact conditions. Local tap water was used in the simulator, and P concentrations, which ranged from 0.06 to 0.32 mg/l, were measured prior to each application and subtracted from the runoff P-value. Thirty minutes of simulated rainfall were applied because

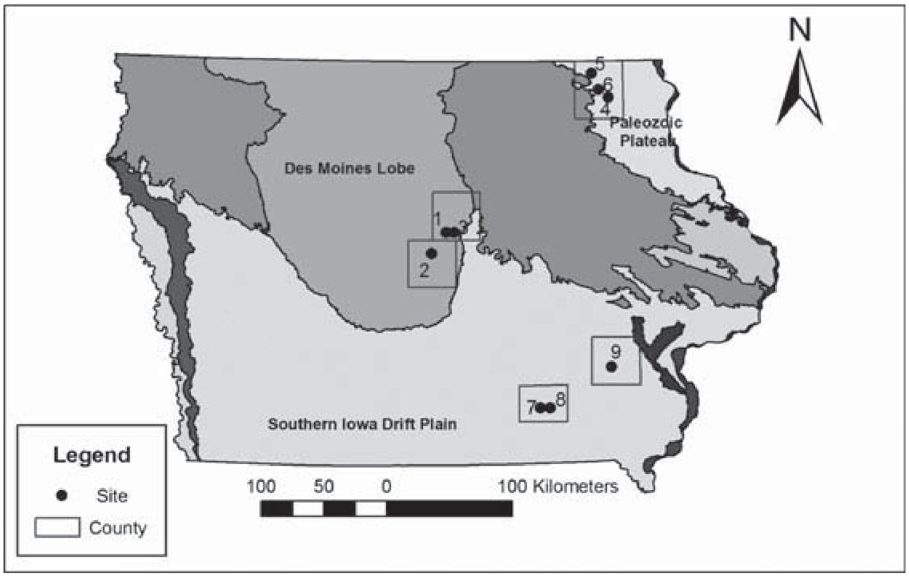

FIGURE 1. The Location of the Nine Riparian Grazed Pasture Sites in Three Different Physiographic Regions of Iowa. Numbers indicate "pasture (site) Id." Sites 1 and 3 were in Hardin County, whereas Site 2 was in Story County. Sites 4, 5, and 6 were in Winneshiek County. Sites 7 and 8 were in Wapello County, whereas Site 9 was in Washington County.

TABLE 1. General Characteristics of the Nine Riparian Grazing Sites Across the Three Regions of Iowa.

Pasture Id; Region*	Stocking Rate (cow-day/ha/m)	Pasture Size (ha)	Stream Length (m)	Bank Height† (m)	Soil-P Content‡ (mg/kg)	Soil Texture‡
Site 1; C	0.55	49	437	1.9	676	Loam, silt clay loam
Site 2; C	0.27	10	1,054	2.0	577	Loam, silt clay loam
Site 3; C	0.44	20	678	2.3	624	Silt clay loam
Site 4; NE	0.46	24	632	2.4	833	Silt loam
Site 5; NE	0.93	45	318	1.2	702	Silt loam
Site 6; NE	0.25	73	783	2.0	735	Silt loam
Site 7; SE	0.85	12	315	1.4	530	Loam, silt loam
Site 8; SE	1.15	16	686	2.0	608	Loam, silt loam
Site 9; SE	0.23	121	1,067	1.7	507	Silt loam

Notes: The mean soil-P content (759 mg/kg) from the Northeast region was significantly higher than both the Central region's soil-P content (628 mg/kg; $p < 0.0001$) and Southeast region's soil-P content (552 mg/kg; $p < 0.0001$). Differences in soil-P content were also significant between the Central and Southeast region ($p = 0.0266$). The Mixed procedure in SAS was used to analyze the data and the model included regions and soil-p content. Total number of observations used in the analysis was 270. Also, there were some differences in terms of soil textural unit among the regions.
*C, Central; NE, Northeast; SE, Southeast.
†Zaimes *et al.* (2008b).
‡Zaimes *et al.* (2008a); soil-P values from the surface riparian soils are at the depth of 0-5 cm.

area (SA), for stream sediment and TP that included, cattle streambank access paths as well as loafing and control areas (Figure 2). Hereafter, the "cattle streambank access paths" will be identified as "access paths." Within the 15-m wide strip, access paths and loafing areas were specifically identified as "critical source areas" (CSAs), because of their greater potential as major contributors of sediment and P to streams. Access paths were defined as ramps that cattle use to enter and cross the stream channel or drink water. Loafing areas were defined as streamside congregating areas where shading is provided by trees. The remaining vegetated areas within the 15-m wide strip, where there is low impact associated with cattle grazing, were considered as the control areas. A field survey was conducted along the pasture reaches to identify and quantify the total areas of cattle CSAs within the 15-m wide strip. CSAs were delineated as squares, rectangles, or circles during the field survey (Figure 2). By using basic area calculations for a square, rectangle, or circle, the area of each CSA was calculated. Geographic Information Systems (GISs) were used to calculate the total SAs of the riparian areas (combined access paths, loafing, contributor of the two. Still in some cases, watersheds with a higher percentage of grazed pastures have been found to contribute more P to streams than watersheds with greater percentages of other agricultural land uses (Downing and Kopaska, 2001).

In grazed pastures, surface runoff is the major pathway of sediment and P movement from critical source areas (CSAs) that include streambank access paths and loafing areas, because their soils are more compacted by cattle than the soils throughout the rest of the pasture (Sharpley *et al.*, 2000; McDowell and Srinivasan, 2009). The loss of P in surface runoff occurs in both particulate (sediment-bound) and dissolved forms. The movement of dissolved P in runoff involves many interacting factors in the soil-water environment, such as desorption, dissolution, extraction of P from vegetation, and fertilizer and manure inputs (Daniel *et al.*, 1994). However, in most cases, the major form of total P loss is the particulate form of P (Vaithiyanathan and Correll, 1992), a long-term P source for aquatic biota (Sharpley *et al.*, 1994).

Best Management Practices should focus on reducing the contributions of P from CSAs, where high soil-P coincides with high hydrological activity (surface runoff) that may lead to the contribution of greater amounts of P during a few major storms (Sharpley *et al.*, 1994). In addition, these areas have a very high potential to contribute sediment and P to stream water because they are immediately adjacent to the stream channel (Sharpley *et al.*, 2003). Indeed, Zaimes *et al.* (2008a, 2009) suggested that cattle streambank access paths and loafing areas within riparian zones require special attention because they can be major sources of sediment and P as well as manure and urine to streams. Still no study has documented the impacts of these areas on aquatic ecosystems in grazing pasture systems of the midwestern United States.

The objectives of this study were (1) to identify relationships between cattle stocking rate and rainfall plot variables including soil bulk density (SBD), suspended sediment (SS) loss, and total phosphorus (TP) loss within each region; and (2) to compare the differences in SBD, SS, and TP losses among cattle streambank access paths, and loafing and control areas (vegetated lengths of streambanks that cattle graze but do not use for loafing or to directly access the stream channel), under different stocking rates in three different physiographic regions of Iowa. The null hypotheses were (1) there is no relationship among rainfall plot variables and stocking rate, and (2) there are no differences in SBD, and SS and TP contribution to streams among cattle streambank access paths, loafing, and control areas under different stocking rates in the three major physiographic regions of Iowa.

METHODS

Study Locations and Treatments

This study was conducted in grazed riparian areas of three major physiographic regions in Iowa: the Des Moines Lobe in Central Iowa, the Southern Iowa Drift Plain in Southern Iowa, and the Paleozoic Plateau in Northeast Iowa (Figure 1). The Southern and Northeast regions with integrated drainage networks are the two oldest landscapes in Iowa (Prior, 1991), and were chosen because their riparian areas are dominated by cattle grazing. The Central area of the state is the youngest and most recently glaciated landscape of Iowa, with a poorly developed natural drainage system and areas of flat terrain, ridges, and prairie pothole wetlands (Prior, 1991). Row-crop agriculture dominates this landscape with cattle grazing usually restricted to narrow portions of riparian areas. Three riparian grazing pasture sites were identified in each region and were classified by their stocking rates per hectare and per stream length (cow-day/ha/m/yr). Cow-day per hectare and per stream length (cow-day/ha/m) was calculated as the product of the number of cow-calf pairs and the number of days they grazed on the pasture over a year divided by the area of the grazed pasture and the length of stream running through the pasture:

$$\text{Cow-day per hectare and per stream length} = \text{Cow-day (number of cow-calf} \times \text{day stocked)/(pasture area} \times \text{stream length)}$$

The Central region had stocking rates of 0.55, 0.27, and 0.44; the Northeast region 0.46, 0.93, and 0.25; and the Southeast region 0.85, 1.15, and 0.23 cow-day/ha/m/yr (Table 1). Pasture size and stream length for all the sites ranged from 10 to 121 ha, and from 315 to 1,067 m, respectively (Table 1). The streams draining all of the study sites are second or third order (Strahler, 1957), perennial, wadeable, deeply incised with average bank heights ranging from 1.2 to 2.5 m, and with the same riparian pasture treatment along both sides of the stream (Table 1) (Zaimes *et al.*, 2008b).

Identification and Area Measurement of the Critical Source Areas

In this study, a 15-m wide (horizontal distance from the streambank edge) strip on both sides of the stream was identified as the potential riparian source

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RIPARIAN GRAZING IMPACTS ON STREAMBANK EROSION AND PHOSPHORUS LOSS VIA SURFACE RUNOFF[1]

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ABSTRACT: Surface runoff is one of the major pathways of sediment and phosphorus (P) transport to surface waters. Rainfall simulations were conducted on nine grazed pasture sites with different stocking rates in three different Iowa (United States) regions. The purpose of the simulations was to determine the impacts of cattle grazing on the amounts of sediment and P in surface runoff within a 15-m wide strip on both sides of the stream from different source areas (SAs). These riparian SAs included stream-side loafing areas, cattle streambank access paths to the stream, and the other vegetated areas adjacent to the streambanks. The runoff samples collected during the simulations were analyzed for suspended sediment (SS) and total phosphorus (TP). Soil bulk density and antecedent soil moisture samples were collected around the rainfall simulation plots to identify differences in compaction, infiltration, and surface runoff among the SAs. SS and TP losses from access paths and loafing areas within the 15-m wide strips accounted for up to 72 and 55% of the total losses, respectively, even though they accounted for only 2.7% of the total area within the 15-m wide strips. This suggests that access paths and loafing areas require special attention to mitigate the impacts of cattle on stream water pollution. Significant correlations were found between stocking rates and both SS and TP losses suggesting that low stocking rates can reduce sediment and P export to streams from the SAs.

(KEY TERMS: pasture management; rainfall simulation; riparian area management; sediment transport; surface water.)

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INTRODUCTION

Sediment is the most common nonpoint source pollutant in agricultural watersheds (USEPA, 1996) and phosphorus (P) has been identified as a major limiting nutrient for eutrophication of many lakes and streams (Correll, 1998). Intensive agricultural land uses, such as row-crop cultivation and pasture grazing, are major contributors of sediment and P to aquatic ecosystems (Schultz *et al.*, 2004). Typically row-crop cultivation is considered the most important

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