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Gully and Stream Bank Erosion in Three Pastures with Different Management in Southeast Iowa

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Gully and stream banks can be major sources of sediment and nutrients to surface waters, both major water quality problems in the United States. Sediment may also carry phosphorus to surface waters, the primary limiting nutrient causing eutrophication. Overgrazing can induce gully and stream bank erosion by reducing vegetation cover that weakens bank soil resistance to stream water flow. This study examines stream and gully bank erosion adjacent to continuous (CP), rotational (RP) and intensive rotational (IP) pastures, grazed by beef cattle in southeast Iowa. Stream and gully bank erosion were measured by: a) surveying the extent of the severely eroding bank areas of the stream reaches running through the pasture management site and the gullies intersecting the specific stream reach and b) randomly establishing pin plots on subsets of the surveyed eroding stream and gully banks. Soil loss for the gullies and stream banks for each site were estimated as the product of the mean bank erosion rate, bulk density and the total severely eroding bank area. Total phosphorus (TP) losses from the gully and stream banks were estimated by multiplying the total soil loss by the TP concentration of the gully and stream bank soils. Soil samples were collected from the gully banks and bed, stream banks, loafing areas and surface riparian areas to estimate TP soil concentrations. The high TP concentrations of the loafing area soils compared to the other sampled locations and their proximity to the stream indicated that these areas could be significant sources of both sediment and TP to surface waters. The gully bank soil and TP losses ranked as follows: CP (207 Mg km^{-1} of soil; 70 kg km^{-1} of TP) > RP (89 Mg km^{-1} of soil; 40 kg km^{-1} of TP) > IP (28 Mg km^{-1} of soil; 12 kg km^{-1} of TP). The stream banks had a different ranking for soil losses: RP (323 Mg km^{-1} of soil) > CP (282 Mg km^{-1} of soil) > IP (170 Mg km^{-1} of soil) and TP losses: RP (129 kg km^{-1} of TP) > IP (86 kg km^{-1} of TP) > CP (83 kg km^{-1} of TP). It was expected that moving from CP, the traditional pasture management practice in Iowa, to RP and IP would reduce stream and gully bank erosion but this was not always the case. Assuming that the only sources of soil and TP losses in each site were stream and gully banks, then stream banks would contribute 76%, 85% and 86% of the total soil loss and 73%, 84% and 87% of the TP from the CP, RP and IP, respectively. These results indicate that stream banks were a more substantial source of sediment and TP in these streams than gully banks.

INDEX DESCRIPTORS: gully bank soil losses-gully bank phosphorus losses-loafing areas-riparian pasture management-soil phosphorus-stream bank soil losses-stream bank phosphorus losses.

Sediment is the number one water quality problem in the United States (Simon and Darby 1999) with gullies and streams being major contributors. In agricultural landscapes, gullies can be a major sediment pathway because they are landforms that can increase the connectivity of the landscape (Poesen et al. 2003). Gullies can contribute up to 94% of total stream sediment load (Poesen et al. 2003). In Iowa watersheds, studies have found gully erosion contributions from 20% (Piest and Bowie 1974) to 34% (Thomas et al. 2004) of the total sediment yield in a stream. Stream bank erosion can also contribute up to 80–90% of the total stream sediment load (Simon et al. 1996; Kronvang et al. 1997). In the Midwest, Sekely et al. (2002) estimated that stream bank erosion in a Minnesota watershed contributed 30–45% of the sediment load to streams while Odgaard (1984) and Schilling and Wolter (2000) estimated a higher contribution of 45–50% in several Iowa watersheds.

Sediments carry nutrients, particularly phosphorus, which has been identified as the primary limiting nutrient causing eutrophication of many surface waters (Daniel et al. 1998). Very few studies have estimated stream bank and gully erosion contributions to the stream total phosphorus (TP) load (Sekely et al. 2002). In Minnesota, Sekely et al. (2002) estimated that only 7–10% of the TP in the stream load was from stream bank erosion, while in Illinois, Roseboom (1987) estimated it was 55%. In Denmark, Kronvang et al. (1997) estimated stream bank erosion to contribute more than 90% of the stream TP load. In watersheds in Oklahoma intensive gully remediation decreased the sediment load to surface waters by six times and the nutrient loss by half (Sharpley et al. 1996).

Gully and stream bank erosion can be induced by changes in vegetation cover brought about by human activities or by the introduction of cattle (Schumm 1999). In Iowa more than 90% of the vegetation cover is primarily in annual row-crop agriculture

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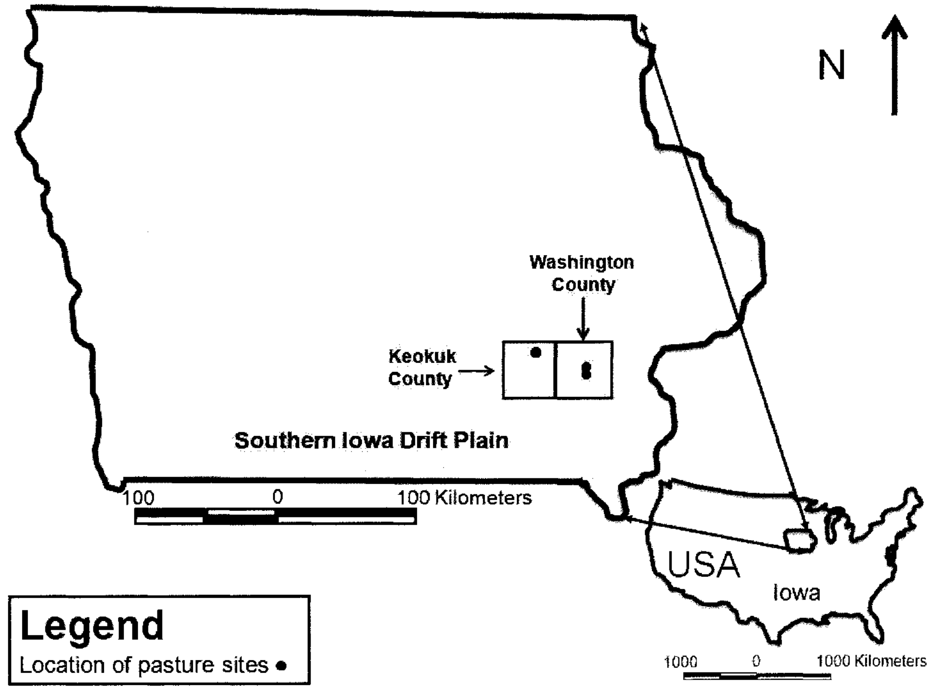

Fig. 1. The approximate location of the three riparian pasture management sites. Two of the sites were in Washington County, Iowa while the other one in Keokuk County, Iowa. All sites were in the Southern Iowa Drift Plains landform that is showed in the figure with gray.

and grass pastures (Burkart et al. 1994). This is a substantial change in a landscape that 150 years ago was dominated by tall-grass prairies with many wetlands, and some savannas and forests. These changes have heavily impacted the hydrology of the landscape resulting in the development of gullies and the modification of its stream's morphology (Anderson 2000).

The objective of this study was to investigate soil and TP losses from stream reaches and the intersecting gullies adjacent to continuous (CP), rotational (RP) and intensive rotational (IP) riparian pastures. In the past, most Iowa riparian pastures grazed by beef cattle were managed as CP, where the cattle have full access to the entire pasture and stream reach. Today, many farmers in Iowa are adopting RP and IP management that divide the pasture into smaller sections (paddocks), instead of having just one large section. The Natural Resource Conservation Service (NRCS) is recommending these pasture management practices because they better utilize pasture forages, increasing profitability (USDA-NRCS 1997). There are also indications that these practices may be more environmentally friendly than CP because of potential decreases in erosional soil losses (USDA-NRCS 1997). These changes in beef cattle grazed pastures of Iowa make it important to investigate if the establishment of these new pasture management practices will have an impact on stream bank and gully erosion.

METHODS

Study Area

The study was conducted in Keokuk and Washington counties of southeast Iowa (Fig. 1), a major cattle grazing region of the state. This region lies in the Southern Iowa Drift Plain landform that has many gullies, creeks, and rivers, with steeply rolling hills and valleys (Prior 1991). Stream bank erosion has deepened channels into glacial material deposited 500,000 yrs ago while a mantle of loess still covers the hills.

Riparian Land-uses

The study sites (Fig. 1) consisted of deeply incised, third order stream reaches (Strahler 1957), with perennial flow and the same riparian land-use on both sides of the stream. The sites were established on private farms to better evaluate the impacts of actual grazing practices of Iowa farmers. In addition, it would be easier to convince other local farmers to change their management practice by demonstrating the results on their neighbor's farm.

The general characteristics of the three riparian pasture sites grazed by beef cattle can be seen in Table 1. In the CP site the cattle had full access to the stream and pasture and the cattle grazed year-round with supplemental feed provided during the winter. This management had been on this site for more than 50 yrs. The selected RP and IP sites had been established for at least 4 yrs, before the study started. In RP, the pasture was divided into three paddocks while in the IP, the pasture was divided into six paddocks.

Survey of Severely Eroding Banks

A survey of all the severely eroding stream and gully banks was conducted with the same operator to minimize bias. The surveyed gullies intersected the stream reach running through the pasture site. Gullies are channels that have been recently formed that are relatively deep with usually ephemeral, but sometimes intermittent flow (Brooks et al. 2003). Severely eroding stream and gully banks were defined as bare with slumps, vegetative overhang and exposed tree roots (USDA-NRCS 1998). Emphasis was given to

Table 1. General characteristics of the three riparian pasture management sites.

Riparian pasture site	Soil series[a]	Soil texture[a]	Stocking rate (cow-calf ha^{-1})	Grazing period[b]
Continuous (CP)	Nodaway	Silt loam	1.2	year around
Rotational (RP)	Nodaway	Silt loam	1.2	~ middle of April to middle of October
Intensive rotational (IP)	Nodaway	Silt loam	0.7	~ end of March to middle of October

[a]SSURGO 2004
[b]Actual dates differ from year to year because of the yearly variation in weather conditions

severely eroding banks because these tend to have the greatest potential for erosion compared to the moderate and slightly eroding banks that are more vegetated (Beeson and Doyle 1995). During this survey, the total length and average height for all severely eroding banks within each stream reach and along all intersecting gullies were measured. The height was measured with a scaled height pole at several points along each eroding bank to calculate an average. The sum of the product of the average height and length for each severely eroding bank was the severely eroding bank area within each riparian pasture site. The severely eroding bank area was estimated separately for the gully and stream banks of each riparian pasture site.

Erosion Rates

Erosion pins are commonly used to measure erosion rates for short-time-scales when high resolution is required (Lawler 1993). Resolution can be as high as 5 mm (Simon et al. 1999). Accuracy, in this study, was increased even more because all pin measurements were collected by one operator (Couper et al. 2002). The erosion pins are steel rods, 762 mm in length and 6.4 mm in diameter, that are inserted perpendicularly into the bank face (Fig. 2). The specific length and diameter of the pins was selected based on past erosion events (Zaimes et al. 2006) and to minimize interferences with bank erosion processes (Lawler 1993). The initial exposed pin length was 50 mm. Erosion pins were placed only on severely eroding stream and gully banks (Fig. 2).

One classic gully from each of the pasture management sites was selected for erosion pin placement. Classic gullies have channel depths ranging from 0.5–30 m deep that common farm equipment cannot ameliorate (SSSA 2001). In our study reaches the gully depths did not exceed 2.5 m. Each classic gully had three erosion pin plots that were selected randomly; after all severely eroding gully banks had been identified. Each erosion pin plot had a network of five pins inserted half-way down the bank and approximately 1 m apart in the horizontal direction. Pins were not placed in the gully bed because of the potential danger of cattle stepping on them. As a result the estimates of soil loss from gullies could underestimate the total soil losses from gullies that are downcutting or overestimate the total soil losses from gullies that are aggrading.

Five randomly selected erosion pin plots were also placed on severely eroding stream banks in each stream reach of the pasture management sites. These erosion pin plots included two horizontal rows of five pins each (Fig. 2). Pins within these rows were placed 1 m apart. To consistently place the pins in similar vertical positions among the stream banks, the horizontal rows were placed at 1/3 and 2/3 of the height of the bank. More erosion pins were used in the stream reaches because of the substantially taller banks compared to the gullies.

The pins were measured five times (initially measured when first installed in the bank) and erosion rates were estimated for four periods: i) Summer 2003 (SU 03), 13 April–12 August 2003; ii) Fall 2003 (FA 03), 13 August–15 November 2003; iii) Spring 2004 (SP 04), 16 November 2003–3 May 2004; and iv) Summer 2004 (SU 04), 4 May 2004–17 August 2004. The pins were not measured during the winter because they were not easily

Fig. 2. The placement of erosion pins on a stream bank. The streams bank pin plots had two horizontal rows of pins, placed 1/3 of the bank height apart. The gully bank pin plots had only one horizontal row of pins, placed in the middle of the bank. The horizontal row of the plots had five erosion pins, placed 1 m apart.

accessible and/or covered with snow. To estimate the erosion rate of a pin, the most recent measurement was subtracted from the previous measurement. If the difference was positive the exposed pin had bank erosion, but if the difference was negative the pin had bank deposition. The mean bank erosion rate for each plot was estimated by averaging the rate of erosion or deposition from all pins in the plot.

Soil Measurements

Soil samples were collected once from each riparian pasture management site to measure: (1) TP and (2) bulk density. The soil series for all three sites was Nodaway (fine-silty, mixed, nonacid, mesic Mollic Udifluvents) (SSURGO 2004). For TP, soil cores were collected adjacent to three of the five stream bank erosion pin plots and from all the gully bank erosion pin plots. Two soil cores were collected every 0.5 m from the top to the bottom of the bank. From each depth the two soil cores were consolidated into one composite sample. The dimensions of the soil samples were 5 × 3 cm (length × diameter). The number of TP soil samples collected from each bank depended on its height. In addition, two 5 × 3 cm (length × diameter) soil samples for TP were collected from the gully bed below the pin plots. For bulk density, two more soil samples were collected at the same time and same depths that soil TP samples were collected but only from the stream and gully banks. The dimensions of these soils samples were 7.5 × 3 cm (length × diameter).

Phosphorus and other nutrients can accumulate in the soil from the extensive presence of cattle, in areas close to shade, water sources, and supplement feeders (Matthews et al. 1994). So two 5 × 3 cm (length × diameter) soil samples for TP analysis were also collected from two randomly selected cattle loafing areas in each pasture management site. Finally, TP soil samples were also collected from the surface soils of the riparian areas of the pasture management sites. The samples were collected from the riparian areas on both sides of the stream at distances of 3, 6, 10, 15 and 20 m from the bank and perpendicular to the stream channel at each of the three stream bank erosion pin plots. At each sampling distance, three 5 × 3 cm (depth × circular diameter) soil cores were collected and consolidated into one composite sample. These soil samples provided an estimate of the TP concentration of the surface riparian pasture soils.

The soil samples collected for TP analysis were air dried for 48 hr and then sieved through a 2 mm screen. Total phosphorus was estimated by digesting 0.14–0.16 g of soil with a sodium hypobromide solution and identifying the extracted phosphorus colorimetrically by a modified molybdenum blue reaction (Dick and Tabatabai 1977). The bulk density soil samples were weighed after being dried for 1 day at 105 °C.

Soil and Phosphorus Losses

Soil losses for the gullies and stream banks, for each pasture management site, were estimated as the product of the respective mean bank erosion rate for the entire period, bulk density and total severely eroding gully and stream bank area. Total phosphorus losses from the gullies and stream banks were estimated by multiplying the total soil loss by the TP concentration of the gully and stream banks, respectively. Gully bank soil and TP losses per unit length of gully were estimated by dividing the total soil and TP losses, by the total length of all the gullies that intersected the stream reach of each pasture management site. Similarly, stream bank soil and TP losses per unit length of stream were estimated by dividing the total soil and TP losses, by the total stream reach length of each site. This was required in order to compare losses among the different pasture management sites because the gullies and stream reaches had different lengths.

Data Analysis

An ANOVA was used to examine the impact of riparian pasture management practice (independent variable) on stream bank and gully bank erosion rates (dependent variable), for every season and for the entire period (independent variables) using SAS software (SAS Institute 1999). A similar ANOVA was used for TP concentrations and bulk densities (dependent variables). Differences were considered significant at the 10% (p-value$<$0.10) because this was an observational study. The p-value is the probability of how much evidence there is against the null hypothesis (Kuehl 1999).

RESULTS

Survey of Severely Eroding Banks

The gully lengths per unit stream length of the IP were the longest while the RP the shortest, although all three pasture sites had similar number of gullies per unit stream length (Table 2). The severely eroding gully bank area per unit stream length had a different ranking with RP having the largest and IP the smallest. For the stream bank severely eroding areas per unit stream length, the CP had the largest and the IP the smallest (Table 2). Stream banks had substantially larger severely eroding bank areas than the gullies in each pasture management site (Table 2).

Erosion Rates

The gully erosion rate in the CP for the entire period was about twice as large as the rates in the RP (p=0.06) and IP (p=0.05) (Table 3). The gully in the CP also had a significantly higher erosion rate than the gully in the RP in SP 04 (p=0.07) and SU 04 (p=0.05). The gully in the RP had a significantly higher erosion rate than the CP (p=0.04) and IP (p$<$0.01) in SU 03. The seasonal gully erosion rates ranked as: a) CP - SP 04 $>$ SU 04 $>$ SU 03 $>$ FA 03; b) RP - SU 03 $>$ SP 04 $>$ SU 04 $>$ FA 03; and c) IP - SP 04 $>$ SU 04 $>$ SU 03 = FA 03; with many significant differences. Specifically, the CP gully bank erosion rate in SP 04 was significantly higher than in FA 03 (p$<$0.01), SU 03 (p$<$0.01) and SU 04 (p$<$0.05). The CP gully bank erosion rate in SU 04 was also significantly higher than in FA 03 (p=0.01) and SU 03 (p=0.06). In the RP, the gully bank erosion rate was significantly higher in SU 03 than in FA 03 (p$<$0.01), SU 04 (p=0.03) and SP 04 (p=0.09). In the IP, SP 04 had a significantly higher gully bank erosion rate than in FA 03 (p$<$0.01), SU 03 (p=0.01) and SU 04 (p$<$0.1). The IP also had a significantly higher gully bank erosion rate in SU 04 than in FA 03 (p=0.08). In addition, the large difference between the maximum and minimum erosion pin rate of all pins within a pasture management site indicates the high variability of gully bank erosion (Table 4).

The stream bank erosion rates for the three pasture management sites had only one significant difference; the RP was significantly higher than the CP in FA 03 (p=0.06) (Table 3). This was because the CP stream banks during this period had deposition while those in the RP had erosion. The stream bank seasonal erosion rate rankings for CP, RP and IP were the same for all three sites and as follows: SP 04 $>$

Table 2. The total numbers, lengths and severely eroding bank areas of the gullies and streams for the three riparian pasture management sites. To compare the variables among the riparian management sites, most of them are adjusted to a per unit stream length (1 km).

Riparian pasture site		Number (#) Total	Lengths (m) Total	Severely eroding bank area (m^2) Total	Number ($\# km^{-1}$) per unit stream length	Length ($m\ km^{-1}$) per unit stream length	Severely eroding bank area ($m^2\ km^{-1}$) per unit stream length
Continuous (CP)	Gully[a]	5	366	254	6.0	438	304
	Stream[b]	1	835	1294	NA[c]	NA[c]	1550
Rotational (RP)	Gully[a]	6	686	388	5.6	643	364
	Stream[b]	1	1067	1153	NA[c]	NA[c]	1080
Intensive rotational (IP)	Gully[a]	3	403	80	6.7	989	179
	Stream[b]	1	448	335	NA[c]	NA[c]	748

[a]The variables refer to all the gullies intersecting their respective stream reach in their pasture management site.
[b]Each riparian pasture management site had only 1 stream reach.
[c]NA=not applicable, because the variables cannot be standardized to the 1 km stream reach length.

SU 04 > SU 03 > FA 03. For both the CP and IP the erosion rate in FA 03 and SU 03 was significantly lower than the rate in SP 04 and SU 04 (all, $p<0.02$). For the RP the erosion rate in SP 04 was significantly higher than the other three seasons ($p<0.01$). In addition, in the RP the stream bank erosion rate in SU 04 was also significantly higher than in FA 03 ($p<0.01$). Stream banks also experienced high erosion variability within a pasture site since maximum and minimum erosion pin rate differences of the individual pins within a pasture site were large (Table 4).

Differences over the entire period between gully and stream bank erosion rates were only significant for the CP, where the gully banks had a higher rate than the stream banks ($p=0.03$). For the RP the stream bank erosion rate was significantly higher than the gully rate in SP 04 ($p=0.06$) while in SU 03 the gully rate was significantly higher ($p<0.01$).

Soil Measurements

From all the soil sampling locations, only the cattle loafing areas in the IP had significantly higher soil TP concentrations than loafing areas in the CP and RP ($p<0.01$) (Table 5). Comparing soil TP concentrations among the sampling locations within a pasture management site, only the loafing areas had significantly higher concentrations than the other locations (Table 5). Specifically in the IP, the cattle loafing areas had significantly higher TP concentration than all the other sampling locations ($p<0.01$). In the RP, cattle loafing area's soil TP concentrations were significantly higher than those in the stream ($p=0.04$) and gully ($p=0.06$) banks. Similarly, soil TP concentrations in CP cattle loafing areas were significantly higher than those in the gully bed ($p=0.09$) and stream ($p=0.03$) and gully ($p=0.05$) banks.

Comparing the bulk densities of the gully banks, the CP (1.22 g cm^{-3}) was higher than those of the RP (1.17 g cm^{-3}) and IP (1.15 g cm^{-3}), although differences were not statistically significant. The stream bank bulk densities ranked differently and as follows: IP (1.42 g cm^{-3}) > CP (1.39 g cm^{-3}) > RP (1.29 g cm^{-3}); differences were also not significant.

Soil and Phosphorus Losses

The gully banks in the CP had the largest soil and TP losses per unit gully length while RP followed and IP had the smallest losses (Table 6). The stream banks had a different ranking. The RP had the largest soil and TP losses per unit stream length (Table 6). The CP followed in soil losses while the IP followed in TP losses. For the entire stream reach in the CP, RP and IP the stream banks always lost more soil and TP, than the gully banks (Table 6).

Table 3. Average gully and stream bank erosion rates for the three riparian pasture management sites. The SE is shown in parentheses.

Riparian pasture site	Summer 2003 (SU 03) 03/14/03–08/12/03 Gully	Summer 2003 Stream	Fall 2003 (FA 03) 8/13/03–11/15/03 Gully	Fall 2003 Stream	Spring 2004 (SP 04) 11/16/03–05/03/04 Gully	Spring 2004 Stream	Summer 2004 (SU 04) 05/04/04–08/17/04 Gully	Summer 2004 Stream	Total 3/14/03–08/17/04 Gully	Total Stream
	Bank erosion (mm)									
Continuous (CP)	26 (15)	4 (12)	10 (12)	−8 (11)	130 (35)	72 (27)	79 (23)	60 (13)	245 (45)	128 (26)
Rotational (RP)	71 (15)	5 (12)	13 (12)	22 (11)	37 (35)	112 (27)	14 (23)	76 (13)	135 (45)	215 (26)
Intensive rotational (IP)	3 (15)	10 (12)	3 (12)	1 (11)	85 (35)	120 (27)	30 (23)	45 (13)	121 (44)	176 (26)

Table 4. The maximum and minimum gully and stream bank erosion pin rate of all the pins within each of the three riparian pasture management sites.

Riparian pasture site		Summer 2003 (SU 03) 03/14/03–08/12/03		Fall 2003 (FA 03) 8/13/03–11/15/03		Spring 2004 (SP 04) 11/16/03–05/03/04		Summer 2004 (SU 04) 05/04/04–08/17/04		Total 3/14/03–08/17/04	
		Gully	Stream	Gully	Stream	Gully	Stream	Gully	Stream	Gully	Stream
		Bank erosion									
		mm									
Continuous (CP)	MAX	85	98	47	72	459	581	421	434	518	568
	MIN	−6	−87	−11	−128	−12	−75	2	−62	110	−143
Rotational (RP)	MAX	212	254	33	107	220	400	117	269	343	554
	MIN	−58	−158	−57	−114	−109	−64	−84	−25	−135	78
Int. rotational (IP)	MAX	72	165	13	171	182	692	230	395	288	729
	MIN	−24	−197	−31	−212	−3	−175	−23	−142	15	157

DISCUSSION

Accelerated gully (Webb and Hereford 2001) and stream bank erosion (Belsky et al. 1999) has been attributed to overgrazing. Finding pasture management practices to replace CP, that stabilize stream and gully banks, will be necessary to minimize sediment and TP nonpoint source pollution. This dataset can provide an indicator of the potential impact of these three pasture management practices on stream and gully bank erosion although extrapolations should be done cautiously since we did not have replicated sites. Future studies should have three replications of each pasture management practice within the region to be able to extrapolate the results for the entire region.

Over the entire period, the CP gully had a significantly higher erosion rate than those in the RP and IP, while for stream banks the RP had a higher rate than those in the CP and IP, although differences were not significant. Comparing gully and stream bank erosion rates over the entire period, within each pasture management practice, the differences were only significant in the CP. Specifically, the gully erosion recession rate in the CP was 100 mm more than the stream bank rate. For the RP and IP, the stream bank erosion rate was higher than the gully bank erosion rate, over the entire period, although differences were not significant. As expected, erosion rates had seasonal differences with SP 04 most frequently having the highest rate. During spring and early summer when most rainfall in Iowa occurs, the landscape has minimal to no vegetation cover because the annual row-crops that dominate are still young. This leads to a greater portion of rainfall becoming overland flow, reaching the gullies and streams rapidly and causing high gully and stream flows. In contrast, in the fall the rainfall is less than in the spring and early summer and the annual crops are fully grown, providing more vegetation cover, and reducing overland flow. In this study, FA 03 had the lowest erosion rates for all three pasture management sites.

Both gully and stream banks experienced high variability in erosion rates within a pasture site and even within a pin plot. Depending on the location of the pin on the bank, during certain periods, some pins had extremely high erosion rates while other pins had deposition. During the winter months freeze -thaw action loosens the bank material that starts eroding from the top portions of the bank and gets deposited on the lower portions. Most of this deposited material typically gets eroded with the first high flow event of spring. In addition, along the length of the bank, stream flow has different erosion impacts. Outside bends experience higher turbulence and velocities than inside bends or straight reaches. Even on an outside bend the stream flow does not erode the bank uniformly. Because the stream reaches in this study had taller banks than the gullies they also, almost always, had higher erosion rate variability (maximum minus minimum erosion pin rate) than the gullies (except for the erosion rate variability for the entire period of the gully in the RP) (Table 4). The variability of bank erosion is well documented (Lawler, 1993) and in order to capture this variability you place more than one pin along a stream bank and on taller banks you have more than one row of pins.

Soil TP concentrations of the loafing areas were significantly higher than those in the other sampled locations. This is not surprising since cattle congregate in these areas and increase feces deposition that subsequently increases surficial soil TP concentrations (Matthews et al. 1994). Typically, feces contain significantly higher TP concentrations than the soil. Cattle loafing areas, thus, should be a major concern for sediment and TP contributions especially when they are located adjacent to stream or gully banks where they are highly

Table 5. Total phosphorus concentrations of the gully banks and bed, loafing areas, surface riparian areas and stream banks of three riparian pasture management sites. The SE is shown in parentheses.

Riparian pasture site	Gully bank	Gully bed	Loafing areas	Riparian	Stream bank
	mg kg^{-1}				
Continuous (CP)	337 (124)	386 (136)	764 (167)	515 (122)	296 (124)
Rotational (RP)	448 (125)	547 (137)	854 (167)	505 (122)	400 (124)
Intensive rotational (IP)	471 (136)	583 (125)	1827 (167)	547 (122)	504 (123)

Table 6. Gully and stream bank erosion soil and TP losses for the three riparian pasture management sites.

	Gully Losses				Stream Bank Losses			
	per unit gully length		entire stream reach		per unit stream length		entire stream reach	
	Soil	TP	Soil	TP	Soil	TP	Soil	TP
Riparian pasture site	Mg km^{-1}	kg km^{-1}	Mg	kg	Mg km^{-1}	kg km^{-1}	Mg	kg
Continuous (CP)	207	70	76	26	323	129	235	70
Rotational (RP)	89	40	61	27	282	83	345	138
Intensive rotational (IP)	28	12	11	5	170	86	76	38

susceptible to overland flow and erosion reaching directly into the channels.

Gully soil erosion losses per unit gully length were 2.3 and 7.4 times higher in the CP than those in the RP and IP, respectively. Total phosphorus losses per unit gully length from the CP were 1.8 and 5.8 times larger than those in the RP and IP, respectively. These numbers may indicate the impact of continual cattle access in riparian pastures and their gullies (e.g. CP) and suggest that moving to RP and IP could potentially decrease soil and TP losses from gully erosion. The stream bank losses among the three pasture management sites had a different ranking than the gullies and smaller differences. The stream bank soil losses per unit stream length in RP were 1.1 and 1.9 times larger than those in the CP and IP. For TP, the RP losses per unit stream length were 1.6 and 1.5 times larger than those in the CP and IP, respectively. Another interesting result was that although the CP had larger soil losses per unit stream length than the IP, the IP had slightly larger TP losses than the CP. This difference was because of the higher soil TP concentration in the soils of the IP compared to the CP (Table 5). These stream bank results were not as expected. A possible explanation could be the lingering impacts on the RP and IP from past management practices. The RP and IP had been established only during the last four years since the study started. In other words, some impacts on riparian areas may still reflect the previous management practices and might hinder the erosion assessment of the current management practices.

In all pastures, soil and TP losses from stream bank erosion were always substantially larger than those from gully bank. The greater losses were primarily a result of the larger severely eroding bank areas of the streams compared to the banks of the gullies that were intersecting the respective stream reach (Table 2). We must note that soil and TP losses from gullies could be under or over estimated because we did not measure losses from the beds of the gullies although losses from the stream bed were also not estimated. Typically gully beds are more frequently eroding that stream beds. If we assume that the only sources of soil loss in each pasture management site were stream and gully banks, then gully banks contributed only 24%, 15% and 14% of the total soil loss from the CP, RP and IP, respectively, while the rest originated from stream banks. Similarly, if we assume that the only sources of TP losses were stream and gully banks, the contributions of gully banks to the TP losses would only be 27%, 16% and 13% from the CP, RP and IP, respectively. These results indicate that stream bank erosion is a larger contributor of soil and TP losses in these reaches. In addition, based on the percentages, among the three pasture practices, gully contributions from the CP were the largest, providing approximately 1/4 of the sediment and TP load to a stream.

Overall, stream and gully banks can contribute significant amounts of sediment and TP to the stream. In these reaches, stream bank erosion was a more substantial contributor due to its larger severely eroding areas. In order to reduce nonpoint sediment and TP reaching streams from pastures, actions need to be taken to stabilize stream and gully banks. One of the actions that have been recommended is moving from CP to RP and IP. In this study, there were some indications that this could potentially work, although more significant differences were expected. Potential reasons for not seeing more differences were the relatively recent conversion of the sites to these new practices and that other management practices might also be required to stabilize the stream and gully banks (e.g. reducing stocking rates, complete exclusion of the cattle from the stream and gully banks). Overall, this study indicates that RP and IP should be further studied as they show promise of reducing inputs of non-point source sediment and TP from pastures.

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