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STREAMBANK SOIL AND PHOSPHORUS LOSSES UNDER DIFFERENT RIPARIAN LAND-USES IN IOWA[1]

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ABSTRACT: Phosphorus and sediment are major nonpoint source pollutants that degrade water quality. Streambank erosion can contribute a significant percentage of the phosphorus and sediment load in streams. Riparian land-uses can heavily influence streambank erosion. The objective of this study was to compare streambank erosion along reaches of row-cropped fields, continuous, rotational and intensive rotational grazed pastures, pastures where cattle were fenced out of the stream, grass filters and riparian forest buffers, in three physiographic regions of Iowa. Streambank erosion was measured by surveying the extent of severely eroding banks within each riparian land-use reach and randomly establishing pin plots on subsets of those eroding banks. Based on these measurements, streambank erosion rate, erosion activity, maximum pin plot erosion rate, percentage of streambank length with severely eroding banks, and soil and phosphorus losses per unit length of stream reach were compared among the riparian land-uses. Riparian forest buffers had the lowest streambank erosion rate (15-46 mm/year) and contributed the least soil (5-18 tonne/km/year) and phosphorus (2-6 kg/km/year) to stream channels. Riparian forest buffers were followed by grass filters (erosion rates 41-106 mm/year, soil losses 22-47 tonne/km/year, phosphorus losses 9-14 kg/km/year) and pastures where cattle were fenced out of the stream (erosion rates 22-58 mm/year, soil losses 6-61 tonne/km/year, phosphorus losses 3-34 kg/km/year). The streambank erosion rates for the continuous, rotational, and intensive rotational pastures were 101-171, 104-122, and 94-170 mm/year, respectively. The soil losses for the continuous, rotational, and intensive rotational pastures were 197-264, 94-266, and 124-153 tonne/km/year, respectively, while the phosphorus losses were 71-123, 37-122, and 66 kg/km/year, respectively. The only significant differences for these pasture practices were found among the percentage of severely eroding bank lengths with intensive rotational grazed pastures having the least compared to the continuous and rotational grazed pastures. Row-cropped fields had the highest streambank erosion rates (239 mm/year) and soil losses (304 tonne/km/year) and very high phosphorus losses (108 kg/km/year).

(KEY TERMS: riparian areas; streambank erosion; soil and phosphorus losses; best management practices; grazing practices; nonpoint source pollution.)

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INTRODUCTION

Phosphorus has been identified as the limiting nutrient for eutrophication of many surface waters (Daniel *et al.*, 1998), while sediment is the number one water quality problem in the United States (U.S.) (Simon and Darby, 1999). Because phosphorus is typically transported with sediment (David and Gentry, 2000), reducing sediment delivery to streams can reduce both of these pollutants.

Streambank erosion has been suggested as a major contributor of sediment to streams. Sekely *et al.* (2002) estimated that streambank erosion in a Minnesota stream 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 streams. In other regions of the U.S. (Simon *et al.*, 1996) and other countries (Kronvang *et al.*, 1997), the contribution was estimated to be up to 80-90%. Very few studies have estimated streambank erosion contributions to stream total phosphorus load (Sekely *et al.*, 2002). In Minnesota, Sekely *et al.* (2002) estimated that only 7-10% of the total phosphorus in the stream was from streambank erosion, while in Illinois, Roseboom (1987) estimated it to be more than 55%. In Denmark, Kronvang *et al.* (1997) estimated streambank erosion to contribute more than 90% of the stream total phosphorus load.

Decreased streambank stability in many cases is the result of reduced vegetation cover that decreases root length and mass in the soil (Dunaway *et al.*, 1994). Livestock overgrazing is one land-use practice that can dramatically impact vegetation cover. Belsky *et al.* (1999) reported many studies that have shown livestock grazing reducing streambank stability in the western U.S. Rotational and intensive rotational grazing are slowly replacing traditional continuous grazing in Iowa because they maintain more vegetative cover providing better utilization of pasture forages, increased profitability and are generally considered more environmentally friendly (USDA-NRCS, 1997a). In the rotational and intensive rotational grazing, the pastures are divided in small sections (paddocks) and livestock are moved from one paddock to the next providing short intensive grazing pressure in a paddock followed by long periods of rest and recovery. The result is more complete utilization of the available forage, with time for that forage to regrow and maintain healthy and strong root systems. While many studies on the influence of intensive rotational and rotational grazing on stream ecosystems have been conducted in the western U.S, very few have been conducted in the Midwest (Lyons *et al.*, 2000). The objective of this study was to compare streambank erosion along reaches with different riparian land-uses, with a specific focus on grazing practices. For this comparison, six different streambank erosion variables were used: (1) erosion rate, (2) erosion activity, (3) maximum pin plot erosion rate, (4) percentage of severely eroding bank length, (5) soil, and (6) phosphorus loss per unit of stream length. Based on the potential intensity of the land-use on the riparian vegetation and streambanks, we hypothesized that the streambank erosion would be as follows: row-cropped fields > continuous pastures > rotational pastures > intensive rotational pastures > pastures where cattle were fenced out of the stream > grass filters > riparian forest buffers. This study complemented earlier research conducted by the authors (Zaimes *et al.*, 2004, 2006) that examined only three different land-uses, riparian forest buffers, continuous pastures, and row-cropped fields, along one single stream in central Iowa.

STUDY AREA

Iowa's natural vegetation has been altered more than any other state in the U.S. In the last 150 years, 99.9% of the tall-grass prairies were plowed, 95% of the wetlands were drained, and 70% of the forests were cut (Whitney, 1994). In their place, more than 90% of the land is now in annual row-crops and grazed pastures (Burkart *et al.*, 1994).

Stream reaches selected for this study were located in northeast and southeast Iowa because these are two major livestock grazing regions in Iowa. The Iowan Surface and the Paleozoic Plateau are the major landforms in northeast Iowa (Prior, 1991). The Paleozoic Plateau has narrow valleys in sedimentary rock with almost no glacial deposits, and because of the shallow limestone near the surface, there are numerous caves, springs, and sinkholes. The Iowan Surface is dominated by gently rolling terrain created by material loosened and moved by many weathering events caused by conditions during the last glaciation. The Southern Iowa Drift Plains landform, in southeast Iowa has many gullies, creeks, and rivers, with steeply rolling hills and valleys (Prior, 1991). Streambank erosion has deepened channels into glacial material deposited 500,000 years ago while a mantle of loess covers the slopes and hills. In addition, stream reaches in central Iowa were also used with one of these in the *Bear Creek National Restoration Demonstration Watershed* where a previous study had been conducted (Zaimes *et al.*, 2004, 2006). Central Iowa lies on the Des Moines Lobe landform that has subtly rolling terrain with some broad curved bands or ridges, knobby hills, and irregular ponds and wetlands resulting from the most recent glaciation in Iowa (Prior, 1991).

Riparian Land-Uses

The riparian land-uses of interest were annual row-cropped fields (RC), continuous (CP), rotational (RP), intensive rotational (IP) grazed pastures, pastures where the cattle were fenced out of the stream (FP), grass filters (GF), and riparian forest buffers (RF). Besides riparian land-use, the major criteria for selecting study reaches were as follows: (1) having lengths >300 m with the same land-use on both streambanks, (2) located along first- to third-order streams (Strahler, 1957), (3) channels in the widening stage (Stage III) of the channel evolution model (Schumm *et al.*, 1984), and (4) owned by private farmers. The focus was on low-order streams because they are in closest contact with their adjacent hillslopes, and therefore can contribute a significant portion of the sediment to larger streams. Low-order streams contribute 30-50% of the sediment to the Illinois River (Johnson, 2003). Working on private farms allowed evaluation of actual land-use management as practiced by farmers in the different regions. It was also felt that working with private farmers would make it easier to convince other farmers to change their practices by demonstrating results on neighboring farms.

Over a six-month period, more than 70 landowners and 120 reaches were visited, to eventually select 30 study reaches. It was not possible to find suitable reaches for all the riparian land-uses in every region. The riparian land-uses and the number of reaches of each riparian land-use in each region are presented in Table 1. The slopes of the stream channels for all reaches were less than 2%. In the northeast and southeast region, the watershed area above each reach was <52 km^2 while in the central region the area was <78 km^2. The hillslopes above all of the riparian areas were dominated by agricultural row-crop fields with some pastures and homesteads and occasional small pockets of forests.

Suitable reaches with RC adjacent to the streambanks were found only in the central region. Corn (*Zea mays* L.) and soybean(s) [*Glycine max* (L.) Merr.] were the annual row-crops, grown in alternating years. These reaches typically had a narrow strip (<4 m) of grasses and/or annual weeds along the streambanks, although many of the row-crops were grown right up to the streambank edge.

All pastures of this study were grazed by beef cattle and were dominated by vegetation consisting of cool-season grasses and forbs such as Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Schreb.), reed canary grass (*Phalaris arundinacea* L.), smooth bromegrass (*Bromus inermis* L.), orchardgrass (*Dactylis glomerata* L.), white clover (*Trifolium repens* L.), and red clover (*Trifolium pratense* L.). Each landowner started and ended grazing on different dates for all pasture practices, which led to different numbers of total grazing days. The CP were not divided into paddocks, and the cattle had full access to the stream during the entire grazing period. In the northeast and central region, grazing started in early May and ended in early November. In the southeast one of the CP reaches followed similar dates, while in the other two the cattle remained on the pastures throughout the year. Supplemental feeds (like hay) were supplied to cattle that grazed year-around. The grazing period for the IP and RP also ran from early May to early November in all regions. In the RP, the pastures were divided into two to three paddocks. Each paddock was grazed 15-30 days and rested for 30 days. In the IP, the pastures were divided into more than six paddocks and each paddock was grazed 1-7 days and rested for 30-45 days. Because the RP and IP practices have only recently been adopted by farmers with beef cattle in Iowa, study reaches were selected only if they had been converted from continuously grazed or row-crop agriculture for more than three years.

In the FP reaches, cattle had no access to the channel for at least three years. While this is a practice that might have great potential for decreasing streambank erosion, many cattle farmers in Iowa are reluctant to adopt it because the stream is the main water source for the cattle and because of the extensive and costly fence maintenance that may be required after flashy floods, which often occur in low-order streams of Iowa.

The selected GF reaches were vegetated by introduced cool-season grasses (USDA-NRCS, 1997c). The RF reaches were vegetated by zones of trees, shrubs, and warm season grasses (USDA-NRCS, 1997b). In one case, an existing natural forest along the streamside was used in lieu of a designed riparian forest buffer. Reaches for both of these land-uses were selected only if they had been established for at least five years. These two land-uses are the major conservation practices in riparian areas of Iowa and much of the Midwest.

METHODS

Rainfall Data

Rainfall data were used from the National Oceanic and Atmospheric Administration (NOAA) weather

TABLE 1. General Characteristics of the Riparian Land-Use Reaches in This Study (2001-2004).

Riparian Land-Use	Reach#	Series[1]	Average Bank Height (m)	Width/Depth	Soil Texture[1]	Stocking Rate (AUM)	Precipitation (cm) Year 1[2]	Year 2[2]	Year 3[2]	Year 1-3
Central										
Row-cropped fields	2	Spillville-Coland complex	1.7	3.3	Clay loam, Loam	N/A	74	75	87	241
Continuous pastures	2	Coland, Colo, Spillville-Coland complex	1.7	2.7	Silt loam, Clay loam, Loam	16.3-23.5	74-91	63-75	79-87	241-246
Rotational pastures	2	Coland, Coland-Terrill complex	1.5	2.1	Clay loam	15.0-33.9	91	75	79	246
Grass filters	2	Spillville, Spillville-Coland complex	1.7	2.5	Clay loam, Loam	N/A	74	75	87	241
Riparian forest buffers	2[3]	Coland, Hanlon-Spillville and Spillville-Coland complexes	1.5	3.8	Clay loam, Loam	N/A	74	75	87	241
Northeast										
Continuous pastures	3	Dorchester, Radford, Otter-Ossian complex	1.5	3.6	Silt loam	15.6-22.5	62-92	52-64	106-107	233-250
Intensive rotational pastures	3	Dorchester, Dorchester-Chaeseburge-Viney and Dorchester-Chaeseburge complexes	1.2	3.6	Silt loam	9.6-19.5	92-134	52-59	95-108	242-300
Cattle fenced out of streams	2	Radford, Spillville	1.4	2.3	Silt loam	N/A	91-92	52-55	104-106	249-250
Riparian forest buffers	2	Colo-Otter-Ossian complex, Spillville	1.0	2.3	Silt loam, Loam	N/A	91-92	52-55	104-106	249-250
Southeast										
Continuous pastures	3	Nodaway, Nodaway-Cantril complex	1.8	1.4	Silt loam, Loam	15.4-22.6	56-86	54-64	74-86	185-235
Rotational pastures	2	Nodaway	1.9	2.0	Silt loam	12.9-29.3	76-86	59-64	81-86	216-235
Intensive rotational pastures	2	Nodaway, Nodaway-Cantril complex	2.1	1.5	Silt loam, Loam	7.6-12.7	86-93	54-78	74-100	215-271
Cattle fenced out of stream	1	Nodaway	1.9	1.4	Silt loam	N/A	86	78	100	271
Grass filters	2	Amana, Nodaway	1.8	2.1	Silt loam	N/A	76-86	55-59	74-81	215-216

Notes: AUM, animal unit month; N/A, not applicable.
[1]Soil Survey Geographic (SSURGO) (2004).
[2]Year 1: August 2001-2002; Year 2: August 2002-2003; Year 3: August 2003-2004.
[3]In this region, a natural forest along the stream was used as a riparian forest buffer reach.

station closest to each study reach (NOAA, 2002-2004a, 2002-2004b). Yearly rainfall data were correlated to yearly streambank erosion. For this study, precipitation was the best available variable to correlate to streambank erosion because discharge data were not available for any of the low-order streams. The flashiness of most first- to third-order streams in Iowa allows good seasonal correlation between precipitation and discharge, especially in spring and early summer.

Erosion Pins

Steel rods, called erosion pins, were inserted perpendicularly into the streambank (Wolman, 1959). Hooke (1979) recommended that one-third of the pin should remain buried so as not to get lost during a major erosion event. In addition, pins should not exceed 800 mm in length, to minimize interference with streambank erosion processes. A length of 762 mm was used in this study because erosion rates of up to 500 mm per erosion event had been witnessed in similar size streams (Zaimes *et al.*, 2004). A diameter of 6.4 mm was selected because it was small enough to cause minimum disturbance to the banks but large enough to not bend under most high discharge events (Lawler, 1993).

Erosion pins are well suited for measuring bank erosion rates for short-time scales and when high resolution is needed (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). Each erosion pin plot included two horizontal rows of five pins each. Pins within these rows were placed 1 m apart for a total length of 4 m. The streambank heights of the pin plots across all reaches varied from 1.6 to 2.2 m. To consistently place the pins in similar bank positions among the streambanks, the horizontal rows were placed at 1/3 and 2/3 of the height of the bank. Erosion pin plots with similar dimensions have been found to not influence streambank erosion processes (Lawler, 1993).

Severely eroding streambanks were the only ones selected for pin plot placement because these banks are the major source of sediment in streams (Beeson and Doyle, 1995). These banks are bare with slumps, vegetative overhang and/or exposed tree roots (USDA-NRCS, 1998). A preliminary field survey was conducted along each study reach, to identify all severely eroding banks and to record their locations on recent aerial photographs (scale 1:24,000). A random numbers table was then used to select five of those severely eroding banks in each reach to establish pin plots.

At installation, approximately 50 mm of the erosion pins were left exposed. Exposed pin lengths were measured once in the spring, summer, and fall of each year from August 2001 to August 2004. During the winter season, most pin plots could not be measured because they were frequently covered with snow and ice. The large numbers of measured pins (1,500 total), on 30 study reaches, with many frequent measurements over a three-year period resulted in a larger number of observations than found in most other studies that have used this method (Lawler, 1993).

Erosion pin measurements provided three of the six different variables used in this study to compare streambank erosion among riparian land-uses. These variables were streambank erosion rate, erosion activity, and maximum pin plot erosion rate. To estimate *erosion rate*, the previous measurement of the exposed erosion pin length was subtracted from the most recent one. When the difference was positive, the exposed pin measurement represented erosion; if it was negative then the pin measurement represented deposition. In contrast, *erosion activity* was the absolute value of the subtraction between the previous and the most recent pin measurement. Couper and Maddock (2001) suggested recording the *change* (absolute value) of erosion pin measurements, regardless of whether they represent erosion or deposition because they measure how active (unstable) the streambank is. The streambank erosion rate and activity for a given erosion pin plot were estimated by averaging the erosion rate and activity, respectively, of all the pins in the plot. The average streambank erosion rate and activity for a riparian land-use was estimated by averaging the erosion pin rate and activity, respectively, of all the plots in the specific riparian land-use for the entire measuring period. To estimate the *maximum pin plot erosion rate*, the erosion rate of the pin plot with the highest erosion rate within each riparian land-use in each region was used (Couper and Maddock, 2001). When a pin was completely lost during an erosion event, an erosion value of 600 mm was assumed (Zaimes *et al.*, 2006).

Severely Eroding Bank Survey

In August 2002, a second more detailed field survey of all the severely eroding banks was conducted. During this survey, the total length and average height for all severely eroding banks within each reach were measured. The height was estimated to the nearest 10 cm with a scaled height pole and measured at several points along the eroding streambank to calculate an average. With these measurements, the total length of severely eroding banks was estimated for each reach. By dividing the total length of the severely eroding banks for each reach by the total bank length for the reach (sum of the length on both sides of the channel), the *percentage of severely eroding bank length* (fourth variable) was estimated (USDA-NRCS, 1998). The percentage was used for comparison among riparian land-uses because each riparian land-use had a different stream reach length. In addition, the sum of the product of the average height and length for each severely eroding bank was used to estimate the severely eroding bank area within each reach. Total severely eroding area for each riparian land-use was determined as the sum of severely eroding bank areas within each reach of the land-use.

Streambank Soil and Phosphorus Losses

The product of streambank erosion rate, streambank soil bulk density, and severely eroding bank area for each riparian land-use was used to estimate its total soil loss from the streambanks. Streambank erosion rate was the average rate of all the pin plots in the riparian land-use. By multiplying the total soil loss by the average streambank soil phosphorus concentration in each riparian land-use, total phosphorus loss from streambanks was estimated. Streambank *soil and phosphorus loss per unit of stream length* (fifth and sixth variable, respectively) were estimated by dividing the streambank soil and phosphorus loss for each riparian land-use by its total stream reach length. This was necessary because each riparian land-use had a different total stream reach length. The bulk density and phosphorus concentrations estimates used were from a complimentary study the authors conducted (Zaimes *et al.*, 2008) that has not yet been published. In this complementary study, bulk density and phosphorus concentrations were estimated by collecting soil samples from severely eroding banks in each reach.

Data Analysis

The analysis of covariance in the Statistical Analysis System (SAS) was used to examine impacts of riparian land-use on streambank erosion rate and activity for each year and for all three years (SAS Institute, 1999). The sample size was the number of pin plots in each riparian land-use. Rainfall was used as a covariate in the above model because even in the same region, some riparian land-use reaches received different amounts of rainfall. Analysis of variance in SAS was used to compare percentage of severely eroding bank lengths and the model included regions and riparian land-uses. Difference were considered significant when the p-values <0.10. The p-value is the probability of how much evidence we have against the null hypothesis (Kuehl, 1999).

RESULTS AND DISCUSSION

Streambanks are never completely stable, and natural processes, including streambank eorison, channel migration, succession of riparian vegetation, are always occurring. However, in Iowa and the rest of the Midwest, agricultural land-use alterations to the riparian and hillslope areas of many watersheds have triggered changes in bank stability that have led to accelerated erosion that is considered unnatural. This study investigated the impact of different riparian land-uses on accelerated streambank erosion.

Erosion Pins

Over the entire three-year period, average erosion rates among land-uses ranked as follows: in the central region, RC > CP > GF > RP > RF; in the northeast region, CP > IP > FP > RF; in the southeast region, RP > CP > IP > FP > GF (Table 2). Average erosion activities among land-uses in all three regions ranked in the same orders as erosion rates except in the southeast region where the CP and RP activities were the same (Table 3). As expected, erosion activities for all riparian land-uses were higher than the respective erosion rates. The differences among the riparian land-uses based on the above rankings were not always significant. Specifically, in the southeast region there were no significant differences in erosion rate or activity among any of the riparian land-uses (Tables 2 and 3).

In the central region, the banks along RC had significantly higher annual and three-year average erosion rates and activities than those along the RF, GF, and RP banks (Tables 2 and 3). The three-year average erosion rates and activities for the CP banks were significantly higher than those of the RF banks. The CP banks also had significantly higher erosion rates and/or activities than the RF banks during the last two years of the study, and the GF and RP banks in Year 3. The differences we saw in this region were expected, although even more significant differences among the land-uses were expected. In the northeast region, the CP and IP banks had significantly higher three-year average erosion rates and/or activities than the RF and FP banks (Tables 2 and 3). In Year 1, RF and FP banks had net deposition, while the

TABLE 2. Streambank Erosion Rates Under Different Riparian Land-Uses in Three Iowa Regions.[1]

Riparian Land-Use	Streambank Erosion Rates[2] Year 1[3] (mm)	SD[4]	Year 2[3] (Mm)	SD[4]	Year 3[3] (Mm)	SD[4]	Sum Year 1-3 (mm)	SD[4]	Average Year 1-3 (mm/year)	SD[4]
Central										
Row-cropped fields	225 (74)	a	223 (59)	a	271 (37)	ab	717 (137)	a	239 (46)	a
Continuous pastures	79 (71)	a	128 (64)	ab	298 (40)	a	499 (133)	ab	166 (44)	ab
Rotational pastures	70 (73)	a	54 (75)	b	198 (44)	bc	313 (135)	bc	104 (45)	bc
Grass filters	87 (74)	a	66 (59)	b	168 (37)	c	319 (137)	bc	106 (46)	bc
Riparian forest buffers	54 (74)	a	4 (59)	b	83 (37)	c	139 (137)	c	46 (46)	c
Northeast										
Continuous pastures	151 (63)	a	184 (48)	b	137 (45)	b	512 (109)	a	171 (36)	a
Intensive rotational pastures	114 (65)	ab	98 (53)	ab	313 (39)	a	511 (130)	a	170 (43)	a
Cattle fenced out of streams	–25 (73)[5]	b	51 (65)	ab	24 (47)	c	67 (137)	b	22 (46)	b
Riparian forest buffers	–10 (73)[5]	ab	36 (65)	a	1 (47)	c	45 (137)	b	15 (46)	b
Southeast										
Continuous pastures	127 (61)	a	23 (50)	a	182 (40)	a	302 (125)	a	101 (42)	a
Rotational pastures	166 (72)	a	16 (59)	a	199 (39)	a	366 (136)	a	122 (45)	a
Intensive rotational pastures	59 (72)	a	55 (62)	a	169 (37)	a	281 (134)	a	94 (45)	a
Cattle fenced out of stream	42 (102)	a	–6 (102)	a	95 (55)	a	173 (209)	a	58 (70)	a
Grass filters	37 (72)	a	12 (61)	a	109 (46)	a	123 (143)	a	41 (48)	a

[1]The mean rainfall that each riparian land-use reach received was used as a covariate to estimate streambank erosion rate. In parentheses is the standard error.
[2]To estimate *erosion rate*, the previous measurement of the exposed erosion pin length was subtracted from the most recent measurement. When the difference was positive, the exposed pin measurement represented erosion; if it was negative the pin measurement represented deposition. Streambank erosion rate was the average rate of all the pin plots in the riparian land-use of a region.
[3]Year 1: August 2001-2002; Year 2: August 2002-2003; Year 3: August 2003-2004.
[4]SD, significant differences. In this column the different letters indicate significant differences (p-value <0.10) among riparian land uses.
[5]Negative numbers indicate deposition.

TABLE 3. Streambank Erosion Activities Under Different Riparian Land-Uses in Three Iowa Regions.[1]

Riparian Land-Use	Streambank Erosion Activities[2] Year 1[3] (mm)	SD[4]	Year 2[3] (Mm)	SD[4]	Year 3[3] (Mm)	SD[4]	Sum Year 1-3 mm	SD[4]	Average Year 1-3 (mm/year)	SD[4]
Central										
Row-cropped fields	307 (65)	a	298 (59)	a	322 (49)	a	906 (138)	a	302 (46)	a
Continuous pastures	137 (62)	ab	235 (64)	a	336 (52)	a	698 (135)	ab	233 (45)	ab
Rotational pastures	102 (64)	b	137 (74)	ab	252 (58)	ab	491 (137)	bc	164 (46)	bc
Grass filters	165 (65)	b	157 (59)	ab	224 (49)	ab	526 (138)	bc	175 (45)	bc
Riparian forest buffers	107 (65)	b	63 (59)	b	135 (49)	b	285 (138)	c	95 (46)	c
Northeast										
Continuous pastures	182 (55)	a	237 (48)	a	248 (60)	a	679 (110)	a	226 (37)	a
Intensive rotational pastures	141 (65)	a	156 (53)	ab	381 (51)	b	703 (132)	a	234 (44)	a
Cattle fenced out of streams	48 (64)	a	92 (65)	ab	125 (62)	c	295 (139)	b	98 (46)	b
Riparian forest buffers	56 (64)	a	73 (65)	b	105 (62)	c	265 (139)	b	88 (46)	b
Southeast										
Continuous pastures	212 (53)	a	117 (49)	a	247 (52)	a	539 (126)	a	180 (42)	a
Rotational pastures	223 (63)	a	86 (59)	a	250 (52)	a	541 (137)	a	180 (46)	a
Intensive rotational pastures	115 (63)	a	119 (61)	a	265 (49)	a	505 (136)	a	168 (45)	a
Cattle fenced out of stream	102 (90)	a	105 (102)	a	210 (72)	a	459 (211)	a	153 (70)	a
Grass filters	155 (63)	a	82 (61)	a	136 (60)	a	342 (144)	a	114 (48)	a

[1]The mean rainfall that each riparian land-use reach received was used as a covariate to estimate streambank erosion rate. In parentheses is the standard error.
[2]To estimate *erosion activity*, the absolute value of the subtraction between the previous and the most recent measurement of the exposed erosion pin length was used. Streambank erosion activity was the average activity of all the pin plots in the riparian land-use of a region.
[3]Year 1: August 2001-2002; Year 2: August 2002-2003; Year 3: August 2003-2004.
[4]SD, significant differences. In this column the different letters indicate significant differences (p-value <0.10) among riparian land uses.

banks of CP and IP had low erosion rates. Because of this, the FP banks had significantly lower erosion rates than the CP banks. Deposition was probably experienced because of frequent freeze-thaw activities during the winter period and the low streamflows that were not able to remove the deposited material that fell from the top to the bottom of the streambanks during that year. In Year 2 all land-uses experienced erosion, even though precipitation total amounts were lower than in Year 1. During Year 2, the erosion rates and activities on the CP banks were significantly higher than those on the RF and FP banks. In Year 3, CP and IP banks had significantly higher erosion rates and activities than the RF and FP banks. In this year IP banks also had significantly higher erosion rates and activities than the CP banks. This was something we did not expect, although we must note that over the three-year period CP and IP had very similar erosion rates and activities.

Both erosion rate and activity were used to compare among riparian land-uses because they each provide a different perspective on streambank erosion. Erosion rate, measures only the erosional soil bank loss. Pins at the bottom of the bank that have experienced deposition have negative erosion rates. As a result, it can provide a better measure of how much soil was lost to the channel from the streambank. Erosion activity usually results in a larger value because it includes both erosional soil bank loss and depositional soil bank gain. It measures any soil that has moved along the streambank such as soil eroded from the top of the streambank that was deposited at the bottom of the streambank. Some of the depositional soil may only be held temporarily until a large enough discharge event scours it away from the streambank. As a result, erosion activity might measure the loss of the soil twice and overestimate the actual soil lost from the streambank. However, if bank stability is the main interest, erosion activity is probably a better indicator. This is particularly true during dry years, when many streambanks experience primarily deposition of eroded materials (Couper and Maddock, 2001).

Over the three-year period, certain riparian land-uses had higher erosion activities than erosion rates. Specifically, in the central region, the erosion activities of the RF banks were approximately two times greater than erosion rates, while in the northeast region erosion activity for the RF banks was approximately six times greater than erosion rate while erosion activity of the FP banks were approximately 4.5 times greater than erosion rates. Finally, in the southeast region, the erosion activities of GF and FP banks were approximately three times greater than the erosion rates. For all other riparian land-uses in all regions the erosion activities were approximately 1.5 times greater than the erosion rates. The larger differences between erosion activities and erosion rates on the RF, GF, and FP streambanks show that more deposition was occurring on their streambanks. This suggests that RF, GF, and FP streambanks might be stabilizing faster than those in the other riparian land-uses, especially if plants are able to colonize the depositional material at the bottom of the banks. The banks of RF, GF, and FP are transitioning faster from the widening phase (Stage III) to the stabilizing phase (Stage IV) of the channel evolution model (Schumm *et al.*, 1984) because of fewer disturbances and plant establishment.

The maximum pin plot erosion rate ranked as follows: in the central region, RC > GF > CP > RP > RF; in the northeast region, CP > IP > RF > GF; and in the southeast region, FP > CP > RP > IP > GF. The maximum pin plot erosion rates did not follow the same order as the erosion rates and activities. In this study these extremes were as much as 3.5 times greater than the mean erosion rates for certain riparian land-uses in the central region, as much 5.3 times greater in the southeast region and as much as 9.5 times greater in the northeast region (Tables 2 and 4). Using only the mean erosion rates can greatly underestimate how much a specific streambank can potentially retreat after a significant erosion event. Interestingly, the highest extremes between the maximum pin plot rates and the average erosion rate were found in land-uses that excluded livestock from the channels. Banks of the RF (3.5 times) and GF (3.0 times) in the central region, banks of RF (9.5 times) and FP (4.2 times) in the northeast region, and banks of FP (5.2 times) in the southeast region had the largest differences between mean erosion rates and the maximum pin plot erosion rates. This might indicate that most banks along the RF, GF, and FP are stabilizing but that they have a few outside bend banks that are still highly erosive. Streambank erosion is a natural process and streams should be expected to have some banks that are highly erosive.

In most cases erosion rates and activities were lower, although not always significantly different, on banks of RF, GF, and FP than on those along crop fields or pastures. The RF, GF, and FP had perennial plant communities along their banks and no livestock pressure. In many cases, erosion rates and activities were between two and five times lower. The RC banks had the highest erosion rates and activities followed by the various grazing practices. Grazing practices that allowed direct access to the stream channel were not significantly different from each other regardless of the amount of rest that was allowed for plant regrowth in the paddocks. Bank healing seems

TABLE 4. Streambank Maximum Pin Plot Erosion Rates Under Different Riparian Land-Uses in Three Iowa Regions.[1]

	Streambank Maximum Pin Plot Erosion Rate[2]				
Riparian Land-Use	**Year 1[3] (mm)**	**Year 2[3] (mm)**	**Year 3[3] (mm)**	**Sum Year 1-3 (mm)**	**Average Year 1-3 (mm/year)**
Central					
Row-cropped fields	551	569	586	1246	415
Continuous pastures	309	300	442	865	288
Rotational pastures	184	345	319	639	213
Grass filters	195	417	450	954	318
Riparian forest buffers	70	53	406	479	160
Northeast					
Continuous pastures	461	514	512	1487	496
Intensive rotational pastures	883	367	511	1386	462
Cattle fenced out of streams	36	51	292	285	95
Riparian forest buffers	178	10	276	423	141
Southeast					
Continuous pastures	387	96	497	834	278
Rotational pastures	387	57	347	735	245
Intensive rotational pastures	272	206	372	683	228
Cattle fenced out of stream	249	313	348	910	303
Grass filters	128	16	147	171	57

[1]The mean rainfall that each riparian land-use reach received was used as a covariate to estimate streambank erosion rate.
[2]*Maximum pin plot erosion rate* is the erosion rate of the pin plot with the highest erosion rate within each riparian land-use in each region.
[3]Year 1: August 2001-2002; Year 2: August 2002-2003; Year 3: August 2003-2004.

to require more time than regrowth of the forage in the paddocks.

Severely Eroding Bank Survey

Lyons *et al.* (2000) found that 1-66% of the streambank lengths of streams surveyed in Wisconsin were severely eroding, similar to the 10-54% found in this study. The lowest percentage (10%) was found along RF reaches in northeast Iowa while the highest (54%) was found along the CP and RP reaches in the southeast (Table 5). In many cases riparian land-use practices that had perennial vegetation and excluded livestock (RF, GF, and FP) had significantly lower percentages than the riparian agricultural land-uses (RC, CP, RP, and IP) (Table 5). Among the grazing riparian land-uses the only significant difference was found in the southeast, where IP was lower than the other two grazing practices. In Wisconsin, Lyons *et al.* (2000) found significantly higher percentages of severely eroding banks in CP reaches than in those of IP, GF, and RF. In southwestern Wisconsin, Simonson *et al.* (1994) suggested that streams of high quality should have less than 20% of their streambank lengths severely eroding. In this study, severely eroding streambank lengths along RF, GF, and FP in all regions were always below this percentage. In contrast, the CP, RP, IP, and RC had 25% or more of their streambank lengths severely eroding across all regions.

The percentage of severely eroding bank lengths showed more significant differences among riparian land-uses (Table 5) than the erosion rate or activity (Tables 2 and 3). As the erosion pins were placed on severely eroding banks, high erosion rates and activities were expected. The data from this study suggest that the percentage of severely eroding bank lengths provides a better indicator of the impacts of the adjacent riparian areas.

Soil and Phosphorus Losses

Total soil and phosphorus losses among riparian land-uses were strongly correlated to the lengths of severely eroding streambanks (Table 5). Once again, RF, GF, and FP streambanks had the lowest losses regardless of region. For these land-uses, soil and phosphorus losses were in the range of 2-48 times and 2-62 times less, respectively than the agricultural land-uses (RC, CP, RP, and IP). Among the grazing practices, IP streambanks had the lowest losses with no consistent differences between CP and RP streambanks.

Streambanks along RC in the central region had the highest soil losses with 304 tonne/km/year (Table 5). Across all regions, streambank soil losses along CP ranged from 197 to 264 tonne/km/year, while those along RP ranged from 94 to 266 tonne/km/year, and those along IP ranged from 124 to 153 tonne/km/year. Streambanks along FP and GF

TABLE 5. Soil and Total Phosphorus Losses From Streambank Erosion Under Different Riparian Land-Uses in Three Iowa Regions.[1]

Riparian Land-Use	Stream Reach Length	Severely Eroding Streambank			Bulk Density[2] (tonne/m^3)	Streambank Soil Loss[3]		Streambank Soil Phosphorus Concentrations[2] (kg/tonne)	Streambank Phosphorus Loss[4]	
	Total (km)	Length %	SD[5]	Area (m^2)		Total (tonne/year)	Unit length (tonne/km/year)		Total (kg/year)	Unit Length (kg/km/year)
Central										
Row-cropped fields	1.6	44 (6)	a	1657	1.23	487	304	354	172	108
Continuous pastures	1.7	39 (6)	ab	1999	1.35	448	264	349	156	92
Rotational pastures	1.3	25 (6)	b	899	1.31	122	94	398	49	37
Grass filters	1.6	16 (6)	bc	615	1.16	76	47	303	23	14
Riparian forest buffers	1.4	14 (6)	bc	430	1.24	25	18	350	9	6
Northeast										
Continuous pastures	1.6	38 (5)	a	1935	1.15	381	238	518	197	123
Intensive rotational pastures	1.5	27 (5)	a	1125	1.20	230	153	432	99	66
Cattle fenced out of streams	0.8	11 (6)	b	203	1.16	5	6	464	2	3
Riparian forest buffers	0.8	10 (6)	b	244	1.10	4	5	479	2	2
Southeast										
Continuous pastures	1.8	54 (5)	a	2661	1.32	355	197	360	128	71
Rotational pastures	1.5	54 (6)	a	2403	1.36	399	266	459	183	122
Intensive rotational pastures	0.7	32 (6)	b	371	1.28	87	124	531	46	66
Cattle fenced out of stream	0.3	16 (6)	bc	239	1.32	18	61	555	10	34
Grass filters	0.7	16 (6)	c	289	1.29	15	22	406	6	9

[1]The mean rainfall that each riparian land-use reach received was used as a covariate to estimate streambank erosion rate. In parentheses is the standard error.
[2]Data from Zaimes *et al.*, 2008.
[3]The product of streambank erosion rate, bulk density, and severely eroding bank area for each riparian land-use within a region was used to estimate its *total soil loss* from the streambanks. Streambank erosion rate was the average rate of all the pin plots in the riparian land-use of a region. Streambank s*oil loss per unit of stream length* was estimated by dividing the streambank phosphorus loss for each riparian land-use by its total stream reach length within a region.
[4]The product of streambank erosion rate, bulk density, severely eroding bank area, and average soil phosphorus concentration for each riparian land-use within a region, was used to estimate its *total phosphorus loss* from the streambanks. Streambank erosion rate was the average rate of all the pin plots in the riparian land-use of a region. Streambank *phosphorus loss per unit of stream length* was estimated by dividing the streambank soil loss for each riparian land-use by its total stream reach length within a region.
[5]SD, significant differences. In this column the different letters indicate significant differences (p-value <0.10) among riparian land uses.

had soil loses that ranged from 6 to 61 tonne/km/year and 22-47 tonne/km/year respectively, while those along RF had losses ranging 5-18 tonne/km/year. In Vermont, DeWolfe *et al.* (2004) found similar soil losses (10-663 tonne/km/year) from streams with similar watershed areas to this study.

Total phosphorus concentration differences in streambank soils among riparian land-uses (Table 5) were not significant (Zaimes *et al.*, 2008). Total phosphorus losses from streambanks along RC in central Iowa were 108 kg/km/year. Across all regions total phosphorus losses along CP ranged from 71 to 123 kg/km/year, while along RP losses ranged from 37 to 122 kg/km/year, and along IP losses were 66 kg/km/year. Banks along FP, GF, and RF had the smallest phosphorus losses ranging from 3 to 34, 9-14, and 2-6 kg/km/year, respectively. Large phosphorus losses per unit length from banks along pastures with full livestock access to the stream and row-cropped fields indicate that streambank erosion can be a significant contributor to the stream water phosphorus load. Similar streambank phosphorus losses (10-840 kg/km/year) from streams with similar watershed areas to this study were found in Vermont (DeWolfe *et al.*, 2004).

Streambank Erosion and Riparian Land-Uses

Based on the responses of the six variables (Tables 2, 3, 4, and 5) used in this study, RF was the land-use that stabilized streambanks and minimized soil and total phosphorus losses the most. These responses are especially encouraging because most of the RF had only recently been established following the abandonment of past riparian management practices such as RC and CP. The GF riparian land-use followed but was not as efficient. This could have been because the GF were even younger than the RF in some cases. In addition, tree root systems probably provide more protection to streambanks than grass roots along the deeply incised channels with nearly vertical banks that were found along our study reaches. There has been a lot of debate about the role of roots in bank stabilization, with some indicating tree roots as more effective (Gregory *et al.*, 1991), while others suggest grass roots are more effective (Lyons *et al.*, 2000). Recent studies indicate that trees stabilize streambanks better because of the greater quantity of larger diameter roots (Wynn *et al.*, 2004; Wynn and Mostaghimi, 2006). In general, when selecting riparian vegetation for streambank stability, it is very important to not only consider the hydrologic channel processes but also the mechanical and ecological processes that control streambank stability (Simon and Collison, 2002).

Regardless of whether it is trees or grasses, perennial plant communities with vigorous root systems increase streambank stability. Vegetation is an integral part of the riparian landscape, and the amount of streambank vegetation, especially in low-order streams, is important because of the stabilizing support the roots can provide (Thorne and Tovey, 1981). However, when bank height exceeds the rooting depth of the vegetation other stream stabilization techniques might be necessary.

In FP reaches, streambank stability was greater than in the other grazing systems that allowed full cattle access to the stream. Cattle are attracted to riparian areas and tend to spend a lot of time in and around the stream (Trimble and Mendel, 1995). Improvements in streambank stability in FP reaches have also been found in other studies (Laubel *et al.*, 2003), but this practice is not socially and economically acceptable to many farmers in Iowa. Where off-stream water is provided as an alternative to fencing, streambank erosion has been dramatically reduced (Sheffield *et al.*, 1997), and in some cases cattle weight gains have even been seen (Porath *et al.*, 2002). In Iowa, off-stream water without fencing would not be as effective as it is in some other states because many pastures are confined to the narrow riparian corridors along low-order streams.

There were mixed results when comparing RP and IP to CP. In most cases CP had the greatest negative impact on streambanks. There were indications, although mostly nonsignificant, that IP had less impact on streambanks than either RP or CP. The differences in individual farmer interpretation of each of these practices and the fact that some of the RP and IP systems had been established for no longer than three years may have contributed to the inconsistencies that were found in this study. Work by Lyons *et al.* (2000) suggested that IP can improve streambank stability and decrease soil losses. Decreased erosion and increased stability could be attributed to the shorter time cattle spend in the stream and the adjacent riparian areas thereby reducing streambank disturbance. Bank stabilization could probably increase more if the number of paddocks along the stream decreased and the number of paddocks in the uplands increased. This would decrease the time that cattle spent in the riparian areas. Even with decreased numbers of paddocks there may not be enough rest to allow plants to get reestablished on heavily disturbed streambanks. So in many cases, the keys to successful recovery of streambank stability in pastures will include decreasing animal stocking rates, controlling the timing of grazing in the riparian paddocks, especially under wet conditions and when the least damage to the plants can be done (Clary and Kinney, 2002), or by eliminating cattle from the streambanks completely until plants are re-established.

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