Environmental Management (2012) 49:1009–1021
DOI 10.1007/s00267-012-9830-9

Assessing Riparian Conservation Land Management Practice Impacts on Gully Erosion in Iowa

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Received: 11 May 2010 / Accepted: 20 February 2012 / Published online: 15 March 2012

Abstract Well-established perennial vegetation in riparian areas of agricultural lands can stabilize the end points of gullies and reduce their overall erosion. The objective of this study was to investigate the impacts of riparian land management on gully erosion. A field survey documented the number of gullies and cattle access points in riparian forest buffers, grass filters, annual row-cropped fields, pastures in which the cattle were fenced out of the stream, and continuously, rotationally and intensive rotationally grazed pastures in three regions of Iowa. Gully lengths, depths and severely eroding bank areas were measured. Gullies exhibited few significant differences among riparian management practices. The most significant differences were exhibited between conservation and agricultural management practices, an indication that conservation practices could reduce gully erosion. Changes in pasture management from continuous to rotational or intensive rotational grazing showed no reductions in gully erosion. It is important to recognize that more significant differences among riparian management practices were not exhibited because the conservation and alternative grazing practices had recently been established. As gully formation is more impacted by upland than riparian management, gully stabilization might require additional upland conservation practices. The existence of numerous cattle access points in pastures where cattle have full access to the stream also indicates that these could be substantial sources of sediment for streams. Finally, the gully banks were less important sediment contributors to streams than the streambanks. The severely eroding bank areas in streams were six times greater than those in the gullies in the monitored reaches.

Keywords Agricultural land management practices · Conservation land management practices · Riparian areas · Gully erosion · Cattle access points · Streambank erosion

Introduction

Soil erosion, especially ephemeral and classic gully erosion, is a principal cause of land degradation worldwide (Valentin and others 2005). Poesen and others (2003) have defined gully erosion as "the erosion process whereby runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths." Land management practices that substantially alter the natural vegetation cover, initiate gully development and accelerate gully growth are cultivation, irrigation systems, overgrazing, log-hauling tracks, road building and urbanization (Chaplot and others 2005; Gomez and others 2003; Poesen and others 2003; Schumm 1999; Valentin and others 2005).

Prior to European settlement of the Americas, the Iowa landscape was dominated by tall-grass prairies with many pothole wetlands as well as some savannas and forests (Whitney 1994). Today, more than 90% of the landscape is used for annual row crops and cool-season grass pastures (Burkhart and others 1994). These changes have altered the hydrology of the landscape, resulting in the development of gullies and in increasing watershed drainage density

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(Andersen 2000). For example, land management changes increased the volume of a gully in Iowa by 9,200 m^3 from 1964 to 2000, corresponding to 320 Mg $year^{-1}$ of soil loss (Thomas and others 2004).

Gullies are a major pathway for sediment delivery to surface waters. Sediment is a major water quality problem of surface waters in the United States (Simon and Darby 1999). Gullies not only generate sediment from their own channel erosion, but also increase landscape connectivity by greatly enhancing sediment export from sheet and rill erosion from inter-gully areas (Poesen and others 2003; Stall 1985). A survey of 22 watersheds in Spain reported that the sediment yield of watersheds with numerous gullies was 92% greater than that of watersheds with no gullies (Poesen and others 2002). In most regions of the Midwestern United States, it is predicted that climate change will increase runoff, soil erosion (Nearing and others 2004; Rogovska and Cruse 2011) and consequently, gully erosion, indicating that measures need to be taken to reduce soil sediment losses.

Worldwide, gully contributions to total stream sediment loads can vary from 10 to 94% (Poesen and others 2003). Studies in Iowa watersheds have found gully contributions to stream sediment loads ranging from 20 to 34% (Piest and Bowie 1974; Thomas and others 2004). The variability of gully contributions can be attributed to the land management of the watersheds. In Coon Creek (Wisconsin, USA), the contribution of gullies to the creek sediment load changed from 18 to 36% during the years 1850–1990 because of land management changes (Trimble 1999). In the Piedmont region of the Southeastern United States, the expansion of agricultural activities from 1860 to 1920 increased the gully network, eventually ruining many agricultural fields (Trimble 2008). After the 1920s, erosion was reduced in this region because of the transition of former croplands to forests and pastures and the implementation of soil conservation practices.

Most riparian areas in Iowa have been managed as row-crop fields or continuously grazed pastures for many decades. However, today, conservation practices such as riparian forest buffers and grass filters are being established to mitigate non-point source pollution, including sediment of surface waters. These riparian land management practices are adopted by farmers in Iowa because of the economic benefits from the Conservation Reserve Program (USDA-FSA 2008). In addition, beef cattle farmers in Iowa are converting continuously grazed pastures to rotationally grazed or intensive rotationally grazed pastures because these practices better utilize pasture forage, thereby increasing profitability (USDA-NRCS 1997a). In some pastures, cattle are being completely fenced out of streams.

A previous study conducted by the authors found that riparian areas where conservation practices are established (e.g., riparian forest buffers, grass filters and pastures in which the cattle are fenced out of the stream) have significantly less streambank erosion than riparian areas with agricultural management practices (e.g., row-crop fields as well as continuously, rotationally and intensive rotationally grazed pastures) (Zaimes and others 2008). The stabilization of a stream channel and/or its riparian area also can stabilize the end point of a gully (Knight and others 2010). Most in-field gullies end in the stream channel or its riparian area. Stabilizing the end point of the gully can control down-cutting, widening and head-cutting (Schumm 1999).

The first objective of this study was to examine whether different riparian land management practices can stabilize pre-existing gullies and prevent the development of new ones by surveying all gullies on sites under different riparian land management practices. It was hypothesized that gully erosion would decrease in a spectrum as follows: row-crop fields > continuously grazed pastures > rotationally grazed pastures > intensive rotationally grazed pastures > pastures in which the cattle were fenced out of the stream > grass filters > riparian forest buffers. The rationale was that row-crop fields have no vegetation cover for much of the year and are the most susceptible to gully erosion. While pastures do have vegetation present throughout the year, cattle activities can increase compaction, reduce vegetation cover and destabilize banks, thus increasing gully erosion. In areas with paddocks (e.g., rotationally and intensive rotationally grazed pastures), cattle spend less time in and around gullies, which should decrease the above-mentioned negative impacts. The riparian conservation practices that include undisturbed perennial vegetation (e.g., pastures in which the cattle are fenced out of the stream, grass filters and riparian forest buffers) should have the lowest gully erosion activity. The second objective was to compare streambank (measured by Zaimes and others 2008) and gully erosion on these study sites in order to estimate their relative sediment contributions to streams.

Methods

Study Regions

The research was conducted on 30 privately owned farms in central, northeastern and southeastern Iowa (Fig. 1). Private farms were chosen to evaluate the impacts of actual land management practices of Iowa farmers. Demonstrating effective land management practices on a neighbor's farm makes it easier to convince other local farmers to change their practices.

The Iowan Surface and the Paleozoic Plateau are the major landforms in northeastern Iowa (Prior 1991). The

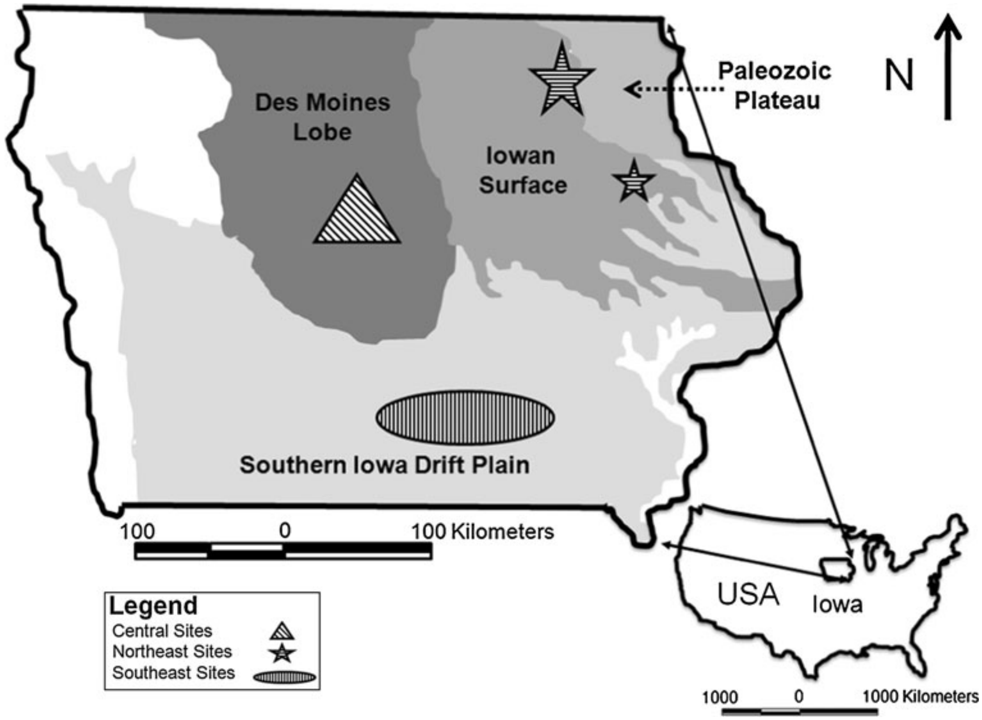

Fig. 1 The approximate locations of the study sites in the three regions of Iowa

Iowan Surface has gently rolling terrain created by material moved by strong weathering events under permafrost conditions during Iowa's last glaciation (12,000–14,000 ybp). The Paleozoic Plateau is the oldest landscape in Iowa, and it features deeply incised narrow valleys and almost no glacial deposits. The Des Moines Lobe landform in central Iowa has poorly developed natural drainage and flat terrain, with some broad ridges, small hills and closed prairie wetlands because it is the most recently glaciated landscape of Iowa (Prior 1991). The Southern Iowa Drift Plain in southeastern Iowa has a highly developed drainage network with steeply rolling hills and valleys developed from incision through a loess cap into the glacial material deposited 500,000 ybp (Prior 1991).

Selection of Study Sites

The 30 study sites (Table 1) were selected based on the following characteristics: (1) stream size, (2) stream order (3) riparian land management along both sides of the stream, (4) soils, (5) upstream watershed area, (6) watershed upland land management and (7) topography. The streams draining all of the study sites are 1st–3rd order (Strahler 1957), wadeable, and deeply incised, with perennial flows and the same riparian land management along both sides of the stream for a length of at least 300 m. While the soils of the sites in each region originated under different geologic influences, all are alluvial. The soil textures in the northeastern region are clay loam and loam; those in the central and southeastern regions are silt loam and loam (Table 1). The watershed areas above the study sites in the northeastern and southeastern regions are <52 km^2, and in the central region <78 km^2. Row-crop fields dominate the upland areas of all of the study watersheds with some pastures, homesteads, and occasional small pockets of forests. The topography of the watersheds in the northeastern and southeastern regions is hilly, while that of the central region is flat with occasional small, gently rolling hills. It was not possible to find all of the riparian land management practices of interest in each region.

Riparian Land Management Practices

The two principal conservation practices used in riparian areas in Iowa are riparian forest buffers and grass filters. Sites with these practices were selected only if they had been established for at least five years prior to the start of the study. Many riparian forest buffers and grass filters were relatively young when this study started because these practices only became available for cost sharing with the Conservation Reserve Program in 1996 (USDA-FSA 2008). The riparian forest buffers consisted of tree, shrub and warm-season grass zones (USDA-NRCS 1997b) while the grass filters consisted primarily of cool-season grasses (USDA-NRCS 1997c). The riparian forest buffers of the central region had previously been continuously grazed pastures, while the riparian forest buffers of the northeastern region had previously been row-crop fields. The grass filters in all regions had previously been row-crop fields.

Table 1 Study site characteristics

Riparian land management practice	Study sites (#)	Stream length[a] (km)	Severely eroding streambank area[b] (m^2)	Soil series[c]	Soil texture[c]	Stocking rate (AUM)
Central						
Row-cropped fields	2	1.6	1657	Spillville-Coland complex	Clay loam, loam	N/A
Continuously grazed pastures	2	1.7	1999	Coland, Colo, Spillville-Coland complex	Silt loam, Clay loam, Loam	16.3–23.5
Rotationally grazed pastures	2	1.3	899	Coland, Coland-Terrill complex	Clay loam	15.0–33.9
Grass filters	2	1.6	615	Spillville, Spillville-Coland complex	Clay loam, loam	N/A
Riparian forest buffers	2[d]	1.4	430	Coland, Hanlon-Spillville and Spillville-Coland complexes	Clay loam, loam	N/A
Northeast						
Continuously grazed pastures	3	1.6	1935	Dorchester, Radford, Otter-Ossian complex	Silt loam	15.6–22.5
Intensive rot. grazed pastures	3	1.5	1125	Dorchester, Dorchester-Chaeseburge-Viney and Dorchester-Chaeseburge complexes	Silt loam	9.6–19.5
Pastures–stream fenced	2	0.8	202	Radford, Spillville	Silt loam	N/A
Riparian forest buffers	2	0.8	243	Colo-Otter-Ossian complex, Spillville	Silt loam, loam	N/A
Southeast						
Continuously grazed pastures	3	1.8	2661	Nodaway, Nodaway-Cantril complex	Silt loam, Loam	15.4–22.6
Rotationally grazed pastures	2	1.5	2403	Nodaway	Silt loam	12.9–29.3
Intensive rot. grazed pastures	2	0.7	720	Nodaway, Nodaway-Cantril complex	Silt loam, loam	7.6–12.7
Pastures–stream fenced	1	0.3	223	Nodaway	Silt loam	N/A
Grass filters	2	0.7	289	Amana, Nodaway	Silt loam	N/A

AUM animal unit months, *N/A* not applicable

[a] The length of the streams with the specified riparian land management practice on both banks

[b] From Zaimes and others 2008. This value is for the entire length of the study sites with a specific riparian land management practice in each region

[c] From SSURGO 2004

[d] In this region, a natural forest was used as one of the riparian forest buffer sites

Annual row-crop fields with a corn (*Zea mays* L.)—soybean (*Glycine max* (L.) Merr.) rotation and continuously grazed pastures are common agricultural land management practices in Iowa. The un-buffered, row-cropped riparian areas usually have either narrow strips (<4 m) of annual and some perennial grasses and/or annual weeds or are cropped right up to the edge of the stream bank.

All pasture study sites were grazed by beef cattle and consisted primarily of cool-season grasses. In the continuously grazed pastures, the cattle had full access to the stream and the entire pasture area throughout the grazing season. In the northeastern and central regions, grazing started in early May and ended in early November. In the southeastern region, one of the continuously grazed pastures had grazing dates similar to the pastures in the other regions, while in the other two, the cattle grazed year-round, with supplemental feed provided during the winter.

Sites with rotationally or intensive rotationally grazed pastures or pastures in which the cattle were fenced out of the stream were selected only if the grazing practices had been established for at least three years prior to the start of the study. All sites that were currently under some type of alternative pasture management (rotationally grazed, intensive rotationally grazed, and cattle fenced out of the stream) had previously been used as continuously grazed pastures.

In the rotationally grazed pastures, each pasture was divided into 2 or 3 paddocks. Each paddock was grazed for 15–30 days and rested for about 30 days. In the intensive rotationally grazed pastures, each pasture was divided into more than 6 paddocks, with each paddock grazed for 1–7 days and rested for 30–45 days. For intensive rotationally grazed and rotationally grazed pastures in all regions, the grazing period started in early May and ended in early November.

The decades of similar land management practices on all selected study sites provided similar conditions for gully development prior to the establishment of the conservation and alternative grazing practices. The very recent establishment of the conservation and alternative grazing practices was a concern because past management practices (historical legacies) could still have lingering effects (Diebel and others 2009). Nonetheless at these same study sites, another study found that recently established conservation practices of riparian forest buffers, grass filters and eliminating livestock access to stream channels had statistically less streambank erosion than sites with agricultural practices (Zaimes and others 2008).

Gully Erosion Survey

Every gully in the study sites that either connected to the stream or ended within 5 m of the streambank was surveyed. The gullies were classified as: (a) classic continuous, (b) classic discontinuous, (c) ephemeral continuous and

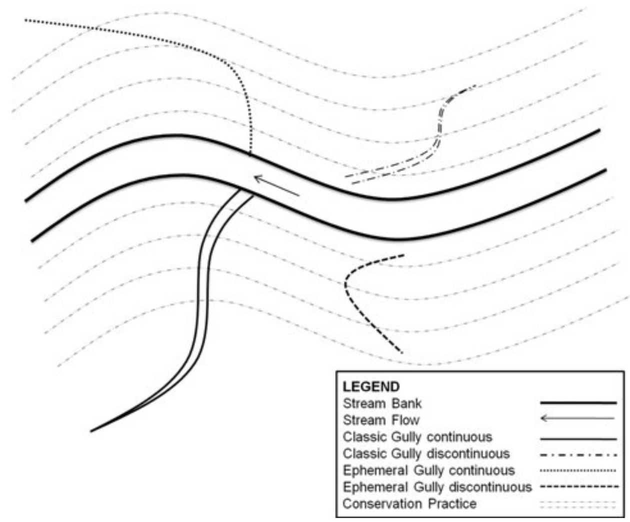

Fig. 2 An illustration of the four different types of gullies surveyed: classic continuous, classic discontinuous, ephemeral continuous and ephemeral discontinuous. The end points of all of the continuous gullies surveyed were connected to the stream, while the end points of the discontinuous gullies were located within 5 m of the streambank. Ephemeral gullies have channels that tillage can erase, while classic gullies have channels that common farm equipment cannot ameliorate. The areas where conservation practices were established are also indicated

(d) ephemeral discontinuous (Fig. 2). *Classic* gullies are defined as channels with depths ranging from 0.5 to 30 m that common farm equipment cannot ameliorate, while *ephemeral* gullies are defined as shallower channels that tillage can erase but often leave gentle swales (SSSA 2001). *Continuous* gullies are connected to the stream channel and gain depth rapidly after the head-cut while maintaining a constant gradient near the mouth of the gully that reaches the stream channel (Brooks and others 2003). *Discontinuous* gullies do not reach the stream channel, and the gully depth decreases from the head-cut (Brooks and others 2003).

Cattle access points to the stream channel were also surveyed in all of the continuously, rotationally and intensive rotationally grazed pasture sites. These access points can be considered as another type of gully because they are continuous from the top of the bank to the channel bed and ranged from 0.5 to 8 m in length and 0.2–1.5 m in depth at our study sites. Because they destabilize streambanks and are adjacent to the stream channel, they have the potential to be a major source of sediment for streams.

To minimize potential bias, one observer conducted the survey at all 30 study sites. During this survey, the following measurements were taken:

Classic Gullies (Continuous and Discontinuous)

(i) Continuous and discontinuous gullies were counted.
(ii) The length of each gully was measured.

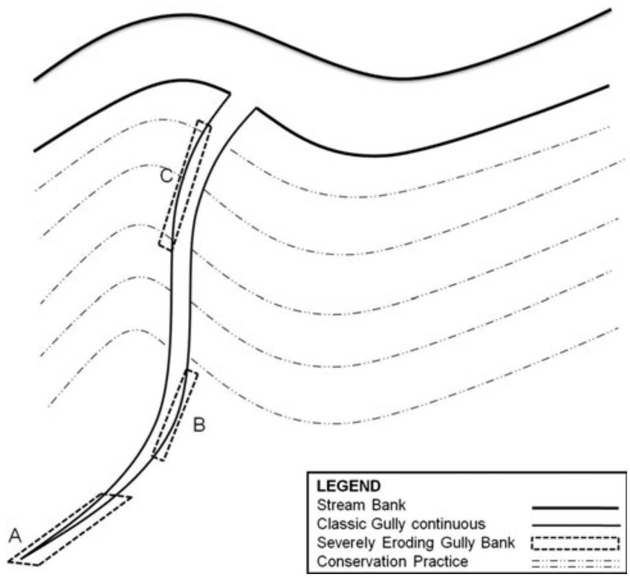

Fig. 3 Some of the banks of the classic gullies were severely eroding, while others were well vegetated and stable. The dotted lines illustrate the segments of a classic gully that were severely eroding. In the classic gullies, the length and average depths of only the severely eroding banks were measured. The areas where conservation practices were established are also indicated

(iii) The length and average depths of only the severely eroding gully banks were also measured (Fig. 3).

Ephemeral Gullies (Continuous and Discontinuous)

(i) Continuous and discontinuous gullies were counted.
(ii) The length and average depths of each gully were measured.

Cattle Access Points

(i) All cattle access points were counted.

Severely eroding banks are defined as bare with slumps, vegetative overhang and exposed roots (USDA-NRCS 1998). The depth of each gully was estimated with a scaled height pole, and their lengths were measured with a measuring tape. Severely eroding banks were the main focus of this study (Zaimes and others 2006) because they erode significantly more than vegetated banks (Beeson and Doyle 1995; Zaimes and others 2006). Many sections of the classic gully banks were well vegetated, while all the banks of the ephemeral gullies were bare of vegetation because they were annually reshaped during field preparation. As a result different measurements regarding severely eroding bank areas were conducted for the ephemeral and classic gullies.

Gully Erosion Variables

The following variables were estimated for each land management practice in each region:

(i) number of gullies per km of stream length (Ngully),
(ii) number of cattle access points per km of stream length (Ncattleaccess),
(iii) length of all gullies per km of stream length (Lgully),
(iv) minimum and maximum gully length (min Lgully and max Lgully, respectively),
(v) minimum and maximum gully depth (min Dgully and max Dgully, respectively),
(vi) total severely eroding gully bank areas (ErodGully),
(vii) total severely eroding gully bank areas per km of stream length (ErodGully/stream) and
(viii) total severely eroding gully bank areas per km of gully length (ErodGully/gully).

The severely eroding gully bank areas were estimated differently for the ephemeral and classic gullies. To estimate the severely eroding bank area of an ephemeral gully, the gully's entire length was multiplied by its average depth. For classic gullies, the area of every severely eroding bank was estimated individually, by multiplying its average depth by its length. The variable ErodGully was the sum of the severely eroding bank areas of all the ephemeral and classic gullies for each land management practice in a region.

Because of varying stream lengths in the study sites (Table 1), Ngully, Ncattleaccess, Lgully and ErodGully/stream were standardized to a 1-km stream length unit to allow comparisons of gully erosion among the riparian land management practices. ErodGully was also standardized to a 1-km gully length (ErodGully/gully). The ErodGully/stream variable indirectly estimates the gully bank areas as a source area of sediment for the stream. Large ErodGully/stream values are a strong indication of greater contributions of sediment from the gullies to the stream. The ErodGully/gully variable provides a robust estimate of the gully condition. Gullies for which most of the banks per km gully length were severely eroding had high instability.

It was assumed that classic gullies found in the riparian areas had developed during previous land management practices (row-crop fields or continuously grazed pastures) because the conservation practices and alternative grazing practices had been established at 3–5 years prior to the study. Typically, the development of a classic gully takes many years unless there is a dramatic change in the landscape or climate (Valentin 2005). Aerial photos from the early 1990s obtained from the Iowa State University GIS Support and Research Facility (2004), were examined, and most of the classic gullies identified in the field were also present in the aerial photos. In contrast, ephemeral gullies and cattle access points take much less time to develop and can be attributed to current land management practices. In classic gullies, the establishment of conservation practices should initially decrease their ErodGully values. Because Ncattleaccess, ErodGully/stream and ErodGully/gully should be the first variables impacted by the current practices, the response of these variables is emphasized in the discussion section. In the long term, conservation practices could also decrease Ngully, Lgully and Dgully values.

Finally, the ErodGully values for each land management practice were compared to their respective severely eroding stream bank areas (ErodStream) (Table 1). The ErodStream had been measured for another study by the same researchers using the same method as the one used for the classic gully banks in this study (Zaimes and others 2008). These comparisons provide information on the relative sediment contributions from the severely eroding banks of the streams and gullies in each land management practice.

Statistical Analysis

An analysis of variance (ANOVA) was conducted using the PROC MIXED procedure (used for unbalanced datasets) in SAS (SAS Institute 1999) to examine the impact of land management practices in each region on five of the gully variables (Ngully, Ncattleaccess, Lgully, ErodGully/stream and ErodGully/gully). These five variables were the dependent variables in the model, while regions and land management practices were the independent variables. Differences were considered significant at 5% (p-value < 0.05), unless otherwise specified.

Results

Number of Gullies per km of Stream Length (Ngully)

The Ngully values were ranked as follows: in the central region, row-crop fields > continuous pastures = rotationally grazed pastures > grass filters > riparian forest buffers; in the northeastern region, intensively grazed rotational pastures > pastures in which the cattle were fenced out of the stream > continuously grazed pastures > riparian forest buffers; and in the southeastern region, intensively grazed rotational pastures > rotationally grazed pastures > grass filters > continuously grazed pastures > pastures in which the cattle were fenced out of the stream (Table 2). Only the

Table 2 The number of gullies (Ngully) and cattle access points (Ncattleaccess) per km of stream length for the different riparian land management practices in the three regions of Iowa

Riparian land management practice	Total number of gullies					
	Classic Per unit stream length (# km^{-1})	Ephemeral	Both[a]	SigDiff[b]	Cattle access points per unit stream length (# km^{-1})	SigDiff[b]
Central region						
Row-cropped fields	3.2	3.8	7.0 (1.5)	a	NA	–
Continuously grazed pastures	2.8	0.7	3.5 (1.5)	ab	84 (7)	a
Rotationally grazed pastures	3.5	0.0	3.5 (1.5)	ab	66 (7)	a
Grass filters	3.0	0.0	3.0 (1.5)	ab	NA	–
Riparian forest buffers	1.5	0.0	1.5 (1.5)	b	NA	–
Northeastern region						
Continuous grazed pastures	1.3	0.0	1.3 (1.1)	a	149 (18)	a
Intensive rot. grazed pastures	3.0	0.0	3.0 (1.1)	a	75 (18)	b
Pastures–stream fenced	1.5	0.0	1.5 (1.3)	a	NA	–
Riparian forest buffers	0.0	0.0	0.0 (1.3)	a	NA	–
Southeastern region						
Continuously grazed pastures	3.5	0.8	4.3 (1.4)	a	139 (26)	a
Rotationally grazed pastures	6.5	0.0	6.5 (1.8)	a	54 (31)	a
Intensive rot. grazed pastures	8.0	0.0	8.0 (1.8)	a	101 (31)	a
Pastures–stream fenced	3.0	0.0	3.0 (2.5)	a	NA	–
Grass filters	5.0	0.0	5.0 (1.8)	a	NA	–

Values in parentheses are the standard errors

NA not applicable

[a] Includes both ephemeral and classic gullies

[b] Significant Differences. Different letters indicate significant differences among riparian land management practices

row-crop field sites in the central region were found to have significantly higher Ngully values than the riparian forest buffer sites (p-value = 0.059) because of the large number of ephemeral gullies that drain the row-crop fields (3.8 km^{-1}) compared to the other riparian land management practices of the region. In all three regions classic gullies were the predominant type of gully in the other non-row-crop riparian management practices.

Cattle Access Points per km of Stream Length (Ncattleaccess)

In all three regions, the continuously grazed pasture sites had the most Ncattleaccess (Table 2). In the southeastern region, the intensive rotationally grazed pastures had the second most Ncattleaccess, and rotationally grazed pastures ranked third. Statistically significant differences were only found in the northeastern region, where the continuously grazed pasture sites were found to have more Ncattleaccess than the intensive rotationally grazed pastures (p-value = 0.047).

Length of All Gullies per km of Stream Length (Lgully)

The ranking of Lgully values (Table 3) for all regions was similar to that of the Ngully values. There were two differences between the two rankings; the Lgully values for the rotationally grazed pastures ranked higher than those for both the continuously grazed pastures in the central region and the intensive rotationally grazed pastures in the southeastern region. No statistically significant differences were found among the land management practices.

Minimum and Maximum Gully Lengths (Min and Max Lgully) and Depths (Min and Max Dgully)

The min Lgully of all land management practices, in the northeastern and central regions were <10 m (Table 3). In the southeastern region, only two of the management practices had min Lgully <10 m. The max Lgully among both the land management practices and regions had substantially more variability. In the northeastern region, the max Lgully ranged from no gullies present to lengths of

Table 3 The length of all gullies per km of stream length (Lgully), maximum and minimum gully lengths (max and min Lgully, respectively) and maximum and minimum gully depths (max and min Dgully, respectively), for the different riparian land management practices in the three regions of Iowa

Riparian land	Length of all gullies[a]			Gully length (m)[a]		Gully depth (m)[a]	
Management practices	Total length[b] (m)	Per unit stream length		Min	Max	Min	Max
		($m\ km^{-1}$)	SigDiff[c]	(m)			
Central region							
Row-cropped fields	755	500 (308)	a	7	405	0.2	2.2
Continuously grazed pastures	185	100 (308)	a	4	124	0.2	2.2
Rotationally grazed pastures	224	233 (308)	a	2	153	0.3	1.0
Grass filters	59	32 (308)	a	4	22	0.2	1.6
Riparian forest buffers	34	30 (308)	a	8	26	0.3	1.7
Northeastern region							
Continuously grazed pastures	17	10 (12)	a	3	17	0.8	1.0
Intensive rot. grazed Pastures	107	37 (12)	a	8	86	0.2	1.5
Pastures–stream fenced	7	11 (15)	a	7	7	0.2	0.2
Riparian forest buffers	0[c]	0 (15)[c]	a	0[d]	0[d]	NA	NA
Southeastern region							
Continuously grazed pastures	446	208 (213)	a	4	256	0.2	2.4
Rotationally grazed pastures	1076	655 (261)	a	3	354	0.2	1.9
Intensive rot. grazed pastures	352	589 (261)	a	19	154	0.2	1.6
Pastures–stream fenced	32	103 (369)	a	32	32	1.3	1.8
Grass filters	335	544 (261)	a	19	294	0.2	1.2

Values in parentheses are the standard errors

NA Not applicable

[a] Includes both ephemeral and classic gullies

[b] This value is for the entire stream length with the riparian land management practice in each region

[c] Significant Differences. Different letters indicate significant differences among riparian land management practices

[d] No gullies were present

86 m. In the other two regions with more erodible soils, many land management practices had a max Lgully > 100 m. In the central region, the max Lgully ranged from 22 to 405 m, while that in the southeastern region ranged from 32 to 354 m. For the central region, the max Lgully was found in an ephemeral gully in a row-crop field.

Among the different land management practices, the min Dgully mostly ranged from 0.2 to 0.3 m. In contrast, the max Dgully varied more, but in most land management practices, it was >1.5 m (Table 3). These max Dgully values indicate gullies that were deeply incised.

Total Severely Eroding Gully Bank Areas per km of Stream Length (ErodGully/Stream)

The ErodGully/stream values among land management practices were ranked as follows: in the central region, row-crop fields > continuous pastures > rotational pastures > grass filters = riparian forest buffers; in the northeastern region, intensively grazed rotational pastures > continuously grazed pastures > pastures in which the cattle were fenced out of the stream = riparian forest buffers; and in the southeastern region, rotationally grazed pastures > continuously grazed pastures > intensively grazed rotational pastures > pastures in which the cattle were fenced out of the stream > grass filters (Table 4). Only the rotationally grazed pasture sites in the southeastern region had statistically larger ErodGully/stream values than the grass filter sites (p-value = 0.045).

Total Severely Eroding Gully Bank Areas per km of Gully Length (ErodGully/gully)

The rankings of the ErodGully/gully values were substantially different from all three previous rankings (Ngully, Lgully and ErodGully/stream) for the central and southeastern regions. The rankings were as follows: in the central region, rotationally grazed pastures > riparian forest buffers > row-crop fields > continuously grazed pastures > grass filters; in the northeastern region, intensive rotationally grazed pastures > continuously grazed pastures > pastures in which the cattle were fenced out of the stream = riparian forest buffers; and in the southeastern region, pastures in which the cattle were fenced out of the stream > continuously grazed pastures > rotationally grazed pastures > intensive rotationally grazed pastures > grass filters (Table 4). Statistically significant differences were found only in the northeastern region, where the

Table 4 The severely eroding gully bank areas for the different land management practices in the three regions of Iowa

Riparian land	Severely eroding gully bank areas[a]				
Management practice	Total (m^2)	Per unit stream length		Per unit gully length	
		(m^2 km^{-1})	SigDiff[b]	(m^2 km^{-1})	SigDiff[b]
Central region					
Row-cropped fields	198	130 (53)	a	456 (430)	a
Continuously grazed pastures	116	56 (53)	a	453 (430)	a
Rotationally grazed pastures	89	51 (53)	a	777 (430)	a
Grass filters	27	14 (53)	a	393 (430)	a
Riparian forest buffers	18	14 (53)	a	736 (430)	a
Northeastern region					
Continuously grazed pastures	4	2 (14)	a	78 (210)	b
Intensive rot. grazed pastures	41	38 (17)	a	1196 (210)	a
Pastures–stream fenced	0	0 (53)	a	0 (257)	b
Riparian forest buffers	0	0 (17)	a	0 (257)	b
Southeastern region					
Continuously grazed pastures	288	147 (61)	ab	663 (205)	a
Rotationally grazed pastures	468	286 (74)	a	393 (251)	a
Intensive rot. grazed pastures	101	125 (74)	ab	278 (251)	a
Pastures–stream fenced	29	93 (105)	ab	906 (355)	a
Grass filters	4	7 (74)	b	7 (251)	a

The severely eroding gully bank areas are presented as a total (entire study stream reach length) (ErodGully), per km of stream length (ErodGully/stream) and per km of gully length (ErodGully/gully). Values in parentheses are the standard errors

[a] Includes both ephemeral and classic gullies

[b] Significant Differences. Different letters indicate significant differences among riparian land management practices

intensive rotationally grazed pastures were found to have larger ErodGully/gully than the continuously grazed pastures (p-value = 0.009), pastures in which the cattle were fenced out of the stream (p-value = 0.011), and riparian forest buffers (p-value = 0.011).

Gully Erosion Among the Three Regions

The land management practices in the Southern Iowa Drift Plain most often had the largest Ngully, Lgully, max Lgully and ErodGully/stream values, followed by the Des Moines Lobe land management practices and those of the Iowan Surface and Paleozoic Plateau (Tables 2, 3, 4). Only the grass filters in the southeastern region had smaller ErodGully/stream values than the grass filters in the central region. For the ErodGully/gully, most land management practices (except the continuously grazed pastures and pastures in which the cattle were fenced out of the stream) did not follow the same trend among regions as the other gully variables, indicating that local watershed factors might be more important for this variable.

Total Severely Eroding Gully (ErodGully) and Stream (ErodStream) Bank Areas

The ErodGully values (Table 4) of every land management practice in each region were always smaller than the respective ErodStream values (Table 1). In the central region, the ErodStream values were 8–24 times larger than the ErodGully values. In the northeastern region, the ErodStream values of the continuously grazed pastures, pastures in which the cattle were fenced out of the stream, and riparian forest buffers were 202–484 times larger than the respective ErodGully values. The intensive rotationally grazed pasture sites of this region had ErodGully values 27 times smaller than their respective ErodStream values because they had the largest ErodGully values of all of the land management practices of this region. Finally, in the southeastern region, the ErodStream values of the four pasture management practices were 6–11 times larger than their respective ErodGully values. The grass filter sites of this region had ErodStream values 183 times larger than their ErodGully values.

Discussion

Riparian forest buffers, grass filters and pastures in which the cattle were fenced out of the stream maintain well-established perennial vegetation at the end points of gullies and along part of their banks, which helps reduce the overall erosion of gullies. In this study, the reduction of gully erosion was indicated primarily by the four significant differences between conservation and agricultural management practices (Tables 2, 4). More significant differences between the conservation and agricultural management practices in this study were expected. Many of the gully variables that exhibited their lowest values where grass filters, riparian forest buffers and pastures with streams fenced off were present (Tables 2, 3, 4), also indicating a reduction in gully erosion. This pattern was particularly evident in the rankings of the ErodGully/stream values. In contrast, the findings for some of the gully variables (primarily ErodGully/gully) contradicted the hypothesis (Table 4). Specifically, the Ngully and Lgully values for grass filters in the southeastern region were relatively large as a result of the classic gullies that had developed under the previous land management practices. However, the low ErodGully/stream and ErodGully/gully values indicate that the gully banks had begun to stabilize once the grass filters were established. The ErodGully/stream values for the grass filters in this region were statistically smaller than those of the rotationally grazed pastures. The channel incision (e.g., the smallest max DGully) of these gullies was also the smallest of all land management practices of this region, further indicating bank stabilization.

The riparian forest buffers in the northeastern region had no gullies and had statistically different ErodGully/gully values than the intensive rotationally grazed pastures (Table 4). The absence of gullies indicates that the establishment of riparian forest buffers can limit the development of new gullies in the riparian zone. In contrast, in the central region, the riparian forest buffers had the second largest ErodGully/gully values, indicating that a large portion of their gully banks were unstable (Table 4). Still, the riparian forest buffers in the central region had statistically lower Ngully values than the row-crop field sites and the smallest ErodGully/stream values of any land use in the region.

The pasture sites in which the cattle were fenced out of the stream had smaller ErodGully/stream values than the intensive rotationally, rotationally, and continuously grazed pastures. This indicates that fencing cattle out of the streams can reduce sediment contributions from gully bank erosion compared to pastures where the cattle have full access to the stream. In the northeastern region, the pastures in which the cattle were fenced out of the stream had statistically smaller ErodGully/gully values than the intensive rotationally grazed pastures. In contrast, in the southeastern region, the gullies in the pasture site in which the cattle were fenced out of the stream had the largest (although not statistically significant) ErodGully/gully value, an indication that many of their gully banks were unstable. A large portion of these gullies in the uplands were not fenced, so cattle could still walk in and out of them, destabilizing their banks which would contribute sediment to the stream.

Gully development and growth have been attributed to overgrazing (Schumm 1999; Webb and Hereford 2001). By dividing the pasture into smaller sections (paddocks), the pressure from grazing is distributed throughout the pasture instead of being concentrated in smaller areas, often the riparian area, potentially alleviating gully development and erosion. Comparisons among continuously, rotationally and intensive rotationally grazed pastures exhibited only two significant differences, both in the northeastern region. The continuously grazed pastures had statistically higher numbers of cattle access points per km of stream (Ncattleaccess) than the intensive rotationally grazed pastures, while the intensive rotationally grazed pastures had statistically larger areas of severely eroding gully banks per km of gully (ErodGully/gully) than the continuously grazed pastures. This second difference contradicted the study hypothesis. In addition, the rankings of the ErodGully/gully values for the intensive rotationally and rotationally grazed pastures were higher than those for continuous pastures in some cases. The hypothesized differences may not have been found because of the recent establishment of the intensive rotationally and rotationally grazed pastures or because these grazing systems do not always stabilize gullies because of the impact of higher densities of livestock even if they are over shorter time periods. When cattle have access to the whole pasture area even for short periods of time (e.g., rotationally and intensive rotationally grazed pastures), they still tend to access the stream and gully channels, destabilizing streambanks and developing and maintaining gullies. Clary and Kinney (2002) suggest that instead of changing the management practice from continuously to rotationally or intensive rotationally grazed pastures, it is more effective to stabilize banks in pastures by decreasing the animal stocking rates and avoiding grazing paddocks with gullies or streams during wet conditions that can be most damaging to the plants or by eliminating cattle completely until plants are re-established. Other measures (e.g., bioengineering techniques) might be required to stabilize classic gullies already developed in intensive rotationally or rotationally grazed pastures to reduce sediment production.

All pasture management practices where cattle had access to the stream had large Lcattleaccess values (Table 4). The streambanks of the conservation practices never had more than 5 access points per km stream length (authors' observations), and those were created by white-tailed deer (*Odocoileus virginianus*) or American beavers (*Castor canadensis*). The large number of Lcattleaccess suggest that they can be significant contributors of sediment to surface waters in pasture management practices.

The row-crop fields had the highest values of Ngully, Lgully and ErodGully/stream (Tables 2, 3, 4), indicating that this land management practice has the greatest potential for providing sediment to streams from gully erosion. The high rankings are the result of the larger number of ephemeral gullies found in row-crop fields compared to the other land management practices. Ephemeral gullies develop and dominate row-crop fields because fields are bare for parts of the year and because annual cultivation keeps most ephemeral gullies from developing into classic gullies (Poesen and others 2003).

Overall, the lack of many significant differences (a total of six) among land management practices could have been the result of the lingering effects of the previous land management practices in the riparian areas. All of the conservation and alternative pasture management practices had only recently been established (mostly for 3–5 years), while the land had previously been used as either continuously grazed pastures or row-crop fields for decades. Valentin and others (2005) report that once gullies are formed, they can continue to erode long after the initial causes of erosion have ceased. Even with well-established perennial vegetation, areas with extensive gullies can take long periods of time to heal (Gomez and others 2003). The structure of the perennial plant communities is also an important consideration. Knight and others (2010) found that remnant forest riparian areas with adjacent grass filters dispersed 100% of the concentrated flow in ephemeral gullies, while remnant forests without the grass filters dispersed 80% of the flow. Classic gullies that had developed within the remnant forest buffers before the grass filters were planted were no longer active once the grass filters were established.

Soils and the parent material in which gullies are formed are also critical factors in gully development and growth (Poesen and others 2003), which was evident in this study. In most cases, the gully variables for all land management practices in the southeastern region ranked the highest due to the highly erodible loess soils of this region. The gully variable values were lower in the central region because of its less erodible till-derived soils and were lowest in the northeastern region because of its least erodible limestone-derived soils (Prior 1991) (Tables 2, 3, 4). Simon and Rinaldi (2000) also found parent material impacts on stream channel incision in the Midwestern United States. Specifically, stream channel incision was greatest in western Iowa because of the thick cap of loess and the lack of sand-and gravel-sized bed sediments. In contrast, in east-central Iowa, where the loess cap is absent or significantly thinner and sand- and gravel-sized material is present on the bed, streams are closer to recovery even though their channels are widening by mass-wasting processes.

Finally, the higher values of ErodStream compared to ErodGully in all land management practices indicate that streambank erosion contributes more sediment to the stream than gully erosion. This finding corresponds well with that of Simon and others (1996) that streambank erosion can contribute the majority (up to 80%) of the sediment to streams in the Midwestern United States.

Conclusions

It has been suggested that re-establishing trees and/or grasses in the riparian areas in place of continuously grazed pastures or row-crop fields should reduce gully erosion. Well-established perennial vegetation in riparian areas, the end points of most gullies, should stabilize the base levels of gullies and reduce their down-cutting and overall erosion (Schumm 1999). The presence of well-established perennial vegetation can also buffer the impacts of the agricultural upland management practices by spreading the water from runoff and increase gully bank strength to resist water erosion compared to bare banks or those with degraded vegetation.

In many cases, the conservation practices in this study had less gully erosion than the agricultural management practices, indicating a reduction of gully erosion. Still, there were only a few statistically significant differences. More statistically significant differences were expected because in these same study sites, stream banks with established conservation practices exhibited significantly less stream bank erosion than banks along agricultural land management practices (Zaimes and others 2008). There were also no strong indications that moving from continuously to rotationally or intensive rotationally grazed pastures reduces gully erosion.

It is possible that few significant gully erosion differences were found between land management practices because the conservation and alternative grazing practices had only recently been established (mostly in the past 3–5 years). Once gullies are established, a long time may be needed to correct them (Gomez and others 2003). In addition, only the lower end segments of the gullies were in the area where conservation practices were implemented, and other segments of the gullies were still connected to agricultural uplands generating high runoff.

To mitigate gully erosion, additional in-field measures might be required. Some classic gullies might require setting aside narrow protection areas adjacent to the entire gullies and head-cut areas. In southeastern Iowa, with the highly erosive loess soil, bioengineering of the gully bank, head-cut, or control structures in the gully bed might be required. For ephemeral gullies, grass waterways can be very effective for minimizing erosion (USDA-NRCS 1999).

Cattle access points should also be a concern for pasture management practices where the cattle have full access to the stream and are potentially an important source of sediment to the streams. Establishing pastures in which the cattle are fenced out of the stream would reduce cattle access points. However, excluding cattle from the stream is a land management practice that many farmers in Iowa are reluctant to accept because it increases overall operational costs. The stream is a free water source for the cattle, and fences adjacent to streams may require frequent maintenance due to flash floods along low-order streams. This land management practice could be attractive to farmers if used in conjunction with fenced access points where cattle can obtain water and cross the stream.

With federal and state funds to improve stream water quality continuously decreasing, land managers need to strategically select erosion control measures based on the contributions of the various sources in each region. Based on these findings, stabilizing stream banks should be a higher priority than stabilizing gully banks in all regions because streambank erosion has a greater potential to contribute sediment to streams. However, stabilizing gullies and reducing their sediment and discharge to the stream will reduce stream channel discharge and help channels more rapidly approach a stable channel condition with reduced bank erosion.

Acknowledgment This research has been funded in its majority by the Iowa Department of Natural Resources under the Federal Non-point Source Management Program (Section 319 of the Clean Water Act) and in part by the University of Missouri Center for Agroforestry under cooperative agreements AG-02100251 with the USDA-ARS Dale Bumpers Small Farms Research Center, Booneville, AR and C R 826704-01-0 with the US EPA. The results presented are the sole responsibility of the authors and may not represent the policies or positions of the funding organizations. Firstly, we would like to thank Leigh Ann Long for her editing and revisions of the manuscript. Her input significantly improved the manuscript. We would also like to thank J. Herring, K. Kult, J. Love, M. Tufeckioglu and N. Zaimes for collecting data in the field. Finally, we would like to thank all the landowners that permitted us to use their farms as monitoring sites. This project would not have been possible without their cooperation.

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