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Stocking Rate and Riparian Vegetation Effects on Physical Characteristics of Riparian Zones of Midwestern Pastures

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Abstract

Grazing at high stocking rates May Increase sediment and nutrient loading of streams pasture Through Transport in precipitation runoff and bank erosion. A 3-yr (2007-2009) grazing study was Conducted on 13 cool-season grass pastures to quantify effects of stocking rate and botanical composition on forage sward height, proportions of bare and manure-covered ground, and bank erosion adjacent to streams. Pastures ranged from 2 ha to 107 ha with stream Reaches of 306 m to 1778 m That has drained watersheds of 253 to 5660 ha. Bare and manure-covered ground Were Measured at 15.2-m distance perpendicular to the stream at 30.5-m intervals at up to 30 locations on each side of the stream by the line transect method in May, July, September, and November of each year. At the midpoint of the 15.2-m line, forage sward height was Measured with a falling plate meter ($4.8 \ \mathrm{kg \cdot m^{-2}}$) and plant species identified. In November 2006, fiberglass pins (1.6×76.2 cm) 73.7 cm Were driven into the stream bank at 1-m intervals from the streambed to the top of the bank along 10 transect equidistant locations on each side of the stream bank erosion to measure During spring, summer, and fall of each year. Increasing pasture stocking rates Increased manure-covered ground and Decreased sward height, but did not Affect proportions of bare ground. The greatest, intermediate, and Least net soil erosion rates occurred During the winter / early spring, late spring / early summer, and late summer / fall seasons. Stocking rates Between measurements, Expressed as $\mathrm{cow\text{-}days \cdot m^{-1}}$ stream, Were not related to bank erosion. Increasing stocking rates per unit of stream length will cover manure Increase and decrease forage sward height, but not Affect proportions of bare ground or bank erosion rates pasture adjacent to streams. THEREFORE, managing stocking rates May reduce nutrient loading of streams pasture.

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Abstract

Grazing at high stocking rates may increase sediment and nutrient loading of pasture streams through transport in precipitation runoff and bank erosion. A 3-yr (2007–2009) grazing study was conducted on 13 cool-season grass pastures to quantify effects of stocking rate and botanical composition on forage sward height, proportions of bare and manure-covered ground, and bank erosion adjacent to streams. Pastures ranged from 2 ha to 107 ha with stream reaches of 306 m to 1 778 m that drained watersheds of 253 ha to 5 660 ha. Bare and manure-covered ground were measured at a 15.2-m distance perpendicular to the stream at 30.5-m intervals at up to 30 locations on each side of the stream by the line transect method in May, July, September, and November of each year. At the midpoint of the 15.2-m line, forage sward height was measured with a falling plate meter (4.8 kg $\cdot$ m^{-2}) and plant species identified. In November 2006, fiberglass pins (1.6 $\times$ 76.2 cm) were driven 73.7 cm into the stream bank at 1-m intervals from the streambed to the top of the bank along 10 equidistant transect locations on each side of the stream to measure bank erosion during spring, summer, and fall of each year. Increasing pasture stocking rates increased manure-covered ground and decreased sward height, but did not affect proportions of bare ground. The greatest, intermediate, and least net soil erosion rates occurred during the winter/early spring, late spring/early summer, and late summer/fall seasons. Stocking rates between measurements, expressed as cow-days $\cdot$ m^{-1} stream, were not related to bank erosion. Increasing stocking rates per unit of stream length will increase manure cover and decrease forage sward height, but not affect proportions of bare ground or bank erosion rates adjacent to pasture streams. Therefore, managing stocking rates may reduce nutrient loading of pasture streams.

Resumen

La alta densidad de pastoreo puede incrementar la carga de los sedimentos y nutrientes en los arroyos que atraviesan los pastizales mediante el transporte de los escurrimientos y bancos de erosión. Un estudio de pastoreo de tres años (2007–2009) se llevó a cabo en trece pastizales compuestos de especies de pastos invernales para evaluar los efectos de la densidad de pastoreo y la composición botánica sobre la altura del corte del pasto, proporción de suelo desnudo y proporción de suelo cubierto con estiércol, y los bancos de erosión contiguos a los arroyos. Los pastizales oscilaron de 2 ha a 107 ha, con longitudes de arroyos de 306 m a 1178 m que drenaron cuencas de 253 ha a 5660 ha. Suelo desnudo y cubierto por estiércol fue medido a un distancia de 15.2 m perpendicular al arrollo, a intervalos de 30.5 m, en 30 sitios a cada lado del arroyo mediante el método de transecto lineal durante Mayo, Julio, Septiembre, y Noviembre de cada año. En el punto medio de la línea de 15.2 m, la altura del corte de las plantas se midió con la técnica del plato descendiente (4.8 kg $\cdot$ m^{-2}) y se identificaron las especies de plantas. En Noviembre de 2006, pernos de fibra de vidrio (1.6 $\times$ 76.2 cm) fueron puestos a 73.7 cm dentro del banco del arroyo a intervalos de 1 m del cauce a la parte superior del banco a lo largo de 10 localidades equidistantes del transecto en cada lado del arroyo para medir el banco de erosión durante la primavera, verano y otoño de cada año. El incremento en la intensidad de pastoreo incrementó la cobertura de estiércol y redujo la altura de la vegetación pero no afectó la proporción del suelo desnudo. El mayor intermedio y la menor tasa de erosión se presentaron durante las épocas de invierno/inicio de la primavera, finales de la primavera/inicio del verano, y al final del verano/otoño. La densidad de pastoreo cuando las mediciones se expresaron como días-vaca m^{-1} arroyo, no fueron relacionadas con el banco de erosión. Incrementos en la densidad de pastoreo por unidad de longitud de arroyo aumentaron en el incremento en la cobertura de estiércol y disminuyeron la altura de los pastos, pero no afectaron las proporciones de suelo desnudo o la tasa de erosión del banco adyacente a los arroyos de los pastizales. Entonces, se concluye que si se maneja la densidad de pastoreo se podría reducir la carga de nutrientes en los arroyos de los pastizales.

INTRODUCTION

Pasturelands have been cited as major contributors to sediment and nutrient loading of surface water resources (Zaimes et al. 2004, 2008; Alexander et al. 2008). Although these effects may be related to poor grazing management, little information has been published on the effects of pasture stocking rate and riparian vegetation on the risk of nonpoint source pollution (NPS) of streams in Midwestern pastures.

Studies on Western rangelands have shown that maintaining adequate vegetation contributes to prevention of degradation of riparian areas (Butler et al. 2006; Schoonover et al. 2006) and NPS of pasture streams by providing cover and resistance to erosion (Klemmedson 1956; Kauffman and Krueger 1984; Trimble 1994). Vegetation cover provides resistance to topsoil detachment by reducing raindrop forces (Hofman and Ries 1991; Pearce et al. 1998) and may limit concentrated flow and runoff events (Self-Davis et al. 2003; De Baets et al. 2007). Furthermore, vegetation cover will entrap and retain sediment that is transported in precipitation runoff before it can enter streams (Clary et al. 1996; Clary and Leininger 2000; Butler et al. 2006).

Vegetation stubble height has been proposed as a tool to assess the ability of a sward to filter sediment from precipitation runoff (Clary and Webster 1990). However, stubble height alone is not a suitable guideline to estimate sediment infiltration because vegetation density, soil surface characteristics, sediment particle size, and buffer length also influence sediment movement in riparian zones (Pearce et al. 1997, 1998; Frasier et al. 1998). But although stubble height of riparian vegetation may have a limited role in sediment filtration, it may be important in maintaining plant vigor and stream bank stability (Frasier et al. 1998).

Beyond the height of the forage, effectiveness of forages to prevent erosion is dependent on the density and strength of the vegetation and roots of the plant species that dominate the riparian zone. Sod grasses, such as reed canarygrass (*Phalaris arundinacea* L.), Kentucky bluegrass (*Poa pratensis* L.), and smooth bromegrass (*Bromus inermis* L.) are generally more tolerant of frequent defoliation events and develop a more uniform sod and tiller density compared to bunch-type grasses such as tall fescue (*Festuca arundinacea* Schreb.), timothy (*Phleum pratense* L.), orchardgrass (*Dactylis glomerata* L.), and ryegrass (*Lolium perenne* L.; Sanderson et al. 1997; Carlassare and Karsten 2002; Lee et al. 2009). Therefore, sod grasses may be more effective than bunchgrasses in preventing precipitation runoff and sediment transport and because of the deep root structure of perennial grasslands, sediment and nutrient transport is controlled and water infiltration increased during high-intensity rainfall events (De Baets et al. 2007; Kemp and Michalk 2007).

Research conducted on Western rangeland conditions has shown that overgrazing of forages or the increased space between bunchgrasses near surface waters decreases the effectiveness of the forage to reduce the velocity of overland water flow (Temple 1982; Masterman and Thorne 1992), thereby increasing the risk of sediment and nutrient loading of the streams (Alderfer and Robinson 1947; Warren et al. 1986). Overgrazing may be caused by high stocking rates (Manley et al. 1997), long grazing duration (Krueger et al. 2002), or

congregation of cattle near streams (Tate et al. 2003), particularly during seasons with low vegetation productivity (Miner et al. 1992). White et al. (2001) and Ballard and Krueger (2005) reported that an increase in the duration of cattle presence in an area increased the amount of manure in that area. The high soil-nutrient concentrations resulting from the concentration of feces in congregation areas may be transported in precipitation runoff and negatively impact aquatic ecosystems (Reynoldson 1987; Belsky et al. 1999; Wang et al. 2007). As the previous results were observed from research conducted on Western rangelands, these findings may not be applicable to management of Midwestern pastures because of differences in rainfall, climate, forage and soil types, and management.

Therefore, the objectives of this project were to evaluate the effects of stocking rates and botanical composition on forage sward heights and proportions of bare and manure-covered ground in the riparian zone, and the amount of bank erosion along streams in riparian areas of southern Iowa pastures.

MATERIALS AND METHODS

Study Location

The study was conducted in the Lake Rathbun watershed in southern Iowa (lat 40°45′N, long 93°18′W, approximately 300 m above sea level). The Rathbun Lake watershed includes more than 143 283 ha, encompasses six southern Iowa counties, and contains Rathbun Lake, which is more than 4 451 ha in size. Located within the Loess Flats and Till Plains ecoregion, the landscape within the Rathbun Lake watershed is characterized by deep to moderate loess deposits over glacial till and dark, shallow soils. The topography of the area varies from flat to moderately hilly. The region lacks glacial till in many places, but comprises greater drainage density and woody vegetation within the stream reaches compared to other areas of the ecoregion (Griffith et al. 1994; Rathbun Land and Water Alliance 2001). The 30-yr mean annual precipitation for the watershed is 93.4 cm.

Soil erosion from stream banks in riparian areas has been identified as an important source of sediment and associated phosphorus delivery to Rathbun Lake, accounting for 26% of the total estimated sediment delivery from the watershed (Isenhart and Sitzmann 2001). Livestock grazing was implicated as the primary factor of this erosion during visual assessment of the watershed.

Pasture Characteristics

Thirteen pastures on 12 cooperating cow–calf farms in the Rathbun Lake watershed were identified as suitable for the project in the fall of 2006. Sites selected were based on the producers' willingness to maintain cattle stocking records and allow pasture access to conduct measurements during May, July, September, and November from 2007 to 2009, and on the presence of a perennial flowing stream. Pasture sizes ranged from 2.8 ha to 107.2 ha with first- to third-order streams that drained watershed areas of 253 ha to 5 660 ha (Table 1). Stream lengths within each pasture, measured with a rotary tape measure in November 2006, ranged from 306 m to 1 778 m. At the initiation of the study, two of the 13 pastures

Table 1. Pasture stream reaches, areas, watershed areas, cattle breeds, and water sources on farms of cooperating producers.

Pasture	Stream reach (m)	Pasture area (ha)	Watershed area (ha)	Cattle breeds	Water sources
Pasture 1	598	20.2	318	Angus/cross	Stream
Pasture 2	1 778	51.4	1 090	Red Angus	Stream
Pasture 3	1 162	10.4	480	None	Stream
Pasture 4	306	2.8	579	Angus/cross	Stream and tanks
Pasture 5	1 610	29.1	444	Angus/cross	Stream and ponds
Pasture 6	922	28.7	5 660	Angus	Stream and tanks
Pasture 7	890	25.1	709	Cross	Stream
Pasture 8	1 260	33.2	756	Cross	Stream
Pasture 9	1 040	107.2	472	Angus	Stream
Pasture 10	1 138	55.4	2 007	Angus	Stream and pond
Pasture 11	1 039	48.2	3 630	Hereford/cross	Stream and tanks
Pasture 12	1 120	28.7	393	Angus/cross	Stream and tanks
Pasture 13	1 179	13.8	253	None	Stream

were ungrazed vegetation buffers. Stream order of each stream was determined using the Strahler (1957) classification system. Bed slope and sinuosity measurements of each stream were calculated at two different scales on 2002 digital orthophotos using geographic information system Arc Map 9.2 tools (Table 2). One set of measurements was calculated at the grazed pasture stream reach (station) scale where the erosion pin plots were located. The other set included measurements at the catchment scale of stream reaches located above each of the treatment pastures. Stream bed slope values were calculated as the difference in elevations (rise) between the lowest and highest point of stream reach divided by the horizontal stream length (run) of a given stream reach. Sinuosity was estimated by first digitizing the total meandered length of a given stream reach at 1 m resolution from 2002 color infrared digital orthophotos and then dividing that value by the straight line valley length of the reach.

Of the 11 stocked pastures, eight of the pastures in the study were continuously stocked at 2.71–31.67 cow-days · m^{-1} stream annually with cattle having year-round access to surface waters. Three of the pastures were rotationally stocked at 2.21–

19.24 cow-days · m^{-1} stream annually. Because one of the two vegetation buffers was grazed from October through November 2007, the stocking rates of the vegetation buffers ranged from 0.00 cow-days · m^{-1} stream to 0.45 cow-days · m^{-1} stream annually. Water sources across farms included streams, streams and off-stream water tanks, and streams and ponds on seven, four, and two of the farms, respectively. Cattle stocked on the pastures on 11 of the farms were all *Bos taurus* breeds of Angus or Angus crossbreds with the remaining two farms including Red Angus and Hereford.

Precipitation Data

A HOBO weather station (Onset Comp. Co., Bourne, MA) with a Rain Gauge Smart Sensor (Onset Comp. Co.) was placed adjacent to 6 of the 13 pastures to record rainfall at 10-min intervals from April through November in each of the 3 yr. Weather stations were removed from the pastures when temperatures reached freezing conditions to protect the tipping bucket equipment. Precipitation data for pastures without weather stations were assumed to be equal to that of the nearest pasture with a weather station. Precipitation data for the remainder of the year and until the weather stations were replaced the following spring were downloaded from the NOAA weather stations in Allerton (approx. 6.6 km from 7 study pastures) or Chariton, Iowa (approx. 10 km from 6 study pastures).

Table 2. Stream morphologic characteristics at field and catchment scales.

Pasture	Stream bed slope[1]	Stream sinuosity[1]	Stream order[2]
Pasture 1	2.0 (1.8)	1.2 (1.4)	I
Pasture 2	0.7 (0.8)	1.4 (1.3)	II
Pasture 3	1.6 (1.4)	1.3 (1.3)	I
Pasture 4	2.0 (1.3)	1.5 (1.3)	I
Pasture 5	1.3 (2.0)	1.6 (1.4)	I
Pasture 6	1.5 (0.3)	1.2 (1.4)	III
Pasture 7	1.6 (0.7)	1.1 (1.2)	I
Pasture 8	0.8 (0.8)	1.4 (1.4)	II
Pasture 9	0.6 (1.6)	2.0 (1.2)	I
Pasture 10	0.4 (0.6)	1.5 (1.3)	II
Pasture 11	0.3 (0.3)	1.1 (1.4)	III
Pasture 12	0.8 (1.7)	1.4 (1.2)	I
Pasture 13	1.7 (2.1)	1.1 (1.1)	I

[1]Numbers inside the parentheses represent the given stream feature at the catchment scale.
[2]Stream order category based on Strahler (1957).

Cattle Stocking Rates

All cooperating producers maintained stocking records of the duration and number of cows, heifers, and bulls stocked on each pasture during the 3-yr study. The number of cow-days stocked on each pasture during the periods between the dates of each measurement of bare soil, fecal-covered ground, forage sward height, and stream bank erosion were calculated as

$$\mathrm{Cow-day} = (\text{No. of cows} \times 1.00 \times \text{days stocked})$$
$$+ (\text{No. of heifers} \times 0.84 \times \text{days stocked}) \quad [1]$$
$$+ (\text{No. of bulls} \times 1.29 \times \text{days stocked})$$

based on the animal's metabolic size to standard livestock units (Allen 1991). Stocking rates were calculated per measurement

period per stream distance (cow-days · m^{-1} stream) by dividing total cow-days by the stream reach length within each pasture. The rationale for expressing the stocking rate on a per meter of stream reach basis as opposed to a per unit of land area basis was to adjust for the effects of varying sizes and shapes of pastures on cow grazing distribution near pasture streams. Although calves may contribute to deterioration of riparian areas and streams through their hoof action, fecal matter, and vegetation removal, they were not considered in the calculation of stocking rates, but these effects should be proportional to the cow stocking rates across farms.

Riparian Area Characteristics
Proportions of bare ground, manure-covered ground, forage sward height, and vegetation species were evaluated in May, July, September, and November in 2007 through 2009 on both sides of the stream at up to 30 locations at 30.5-m intervals. Proportions of bare and manure-covered ground were measured perpendicular to the stream by the line transect method (Canfield 1941; Anderson et al. 1979) over a 15.2-m distance beginning at the edge of the stream. One hundred beads, spaced at 15.2-cm intervals on the line, were used to evaluate the percentages of bare and manure-covered ground located directly underneath each bead at each location. Forage sward height was measured with a falling plate meter (4.8 kg · m^{-2}; Hermann et al. 2002) and vegetation species were identified at the midpoint of the transect line. The falling plate meter was constructed of a 3.18-mm thick plexiglass plate with an area of 2 500 cm^2 attached to a 1.27-cm-diameter polyvinyl chloride tube of variable length so that the apparatus weighed 1.2 kg. This apparatus slid down a calibrated aluminum rod with an outer diameter of 1.27 cm, thereby yielding an estimated measure of live forage mass from the height. Sward height was not measured at sites in which shrubs were the vegetation species. Botanical composition of the riparian zones was calculated as a proportion of the herbaceous vegetation species located at each vegetated site.

Stream Bank Erosion Measurements
In each pasture, 10 transects were placed at 30.5-m intervals, five on the upstream and five on the downstream side of the midpoint of the pasture stream length. In order to estimate the amount of sediment loss from stream banks, erosion rates were measured with 1.6 × 76.2 cm fiberglass pins driven 73.7 cm into the stream bank at 1-m intervals from the streambed to the top of the bank on each side of the stream (Wolman 1959). If the stream bank height did not exceed 1 m, only one pin was placed at approximately half the distance of the height of the bank. Pin measurements were taken in midspring, midsummer, and late fall to evaluate erosion that occurred during the winter through early spring, late spring through early summer, and late summer through fall periods. At each measurement date, net erosion was calculated by the subtracting the pin length exposed or covered since from the previous measurement. Individual pin measurements were averaged across all of the 10 transects to determine net erosion rates occurring from the stream banks of pastures. Positive exposed fiberglass values represented erosion and negative values represented deposition. In the event that fiberglass pins were lost from the stream bank,

an erosion rate of 60 cm was assumed (Hooke 1979; Lawler 1993; Zaimes et al. 2004).

Statistical Analyses
Riparian characteristics were analyzed as repeated measures using an AR (1) covariance MIXED procedure model of SAS (SAS Institute Inc., Cary, NC) between pastures. The model statement included fixed effects of pasture, month, and year with month as the repeated factor and year as the experimental unit. Random effects included the pasture by year interaction. Differences between means with significant treatment effects in all analyses were determined by comparing the least-squares means using the PDIFF statement with a Tukey adjustment for multiple comparisons. Significance was determined at a level of $P < 0.05$.

Regression equations were calculated to quantify the relationship between the dependent variables of proportion of bare soil, proportion of manure-covered ground, forage sward height, and net stream bank erosion at each measurement with the independent variables of the stocking rate per meter of stream reach for the time interval preceding the measurement and the proportion of each vegetation species of the total vegetated sites (SAS Institute). In order to determine significant regressions from the 13 pastures in the study, a Bonferroni adjustment was performed (0.05 divided by the 11 regressions performed) to determine significant pasture characteristic effects. Significance was determined at a level of $P < 0.0045$.

RESULTS

Riparian Vegetation
Vegetation species observed included tall fescue; reed canarygrass; Kentucky bluegrass; smooth bromegrass; orchardgrass; timothy; legumes, which were primarily white clover (*Trifolium repens* L.) or red clover (*Trifolium pretense* L.); squarrose sedge (*Carex squarrosa* L.); weed grasses, primarily green foxtail (*Setaria viridis* L.); broadleaf weeds, which were primarily giant ragweed (*Ambrosia trifida* L.), stinging nettles (*Urtica dioica* L.), and wild parsnips (*Pastinaca sativa* L.); and shrubs, primarily multiflora rose (*Rosa multiflora* L.).

The proportion of vegetation species comprising tall fescue, reed canarygrass, legumes, sedge, broadleaf weeds, and shrubs differed ($P < 0.01$) between pastures (Table 3). Pastures 3, 4, 9, and 13 had the least proportion of vegetated sites as tall fescue, but the highest proportion of reed canarygrass. Proportions of vegetation species as tall fescue, Kentucky bluegrass, orchardgrass, and broadleaf weeds differed ($P < 0.01$) and proportions of reed canarygrass and sedge tended to differ ($P < 0.08$) between sampling intervals (data not shown). The proportion of tall fescue in the pastures was greater in November than in May, July, and September. However, the proportions of Kentucky bluegrass and orchardgrass were greater in May than in July, September, and November. Proportions of broadleaf weeds were greater in July and September than in May, which was also greater than November. Proportion of reed canarygrass tended to be greater in May than in July and September, but was not different from November. As expected, because of forage type and growth characteristics, the proportions of sedge observed in the pastures tended to be greater during the warm

Table 3. Proportions of bare soil, proportions of manure-covered ground, forage sward heights, and proportions of vegetated sites as tall fescue, reed canarygrass, legumes, sedge, broadleaf weeds, and shrubs within 15.2 m of streams in pastures during the 3-yr study.

Pasture[1]	Bare soil	Manure-covered ground	Forage sward height	Tall fescue	Reed canarygrass	Legumes	Sedge	Broadleaf weeds	Shrubs
	---------------- (%) ----------------		(cm)	--(% of vegetated sites)---					
Pasture 1	13.4 bcde[2]	1.0 a	5.7 d	70.9 ab	3.0 c	3.2 bc	0.7 b	12.2 bcd	2.8 bcd
Pasture 2	16.9 bc	0.5 abcd	6.5 cd	58.2 abc	5.5 c	5.1 bc	0.8 b	24.0 ab	9.0 a
Pasture 3	6.0 ef	0.0 d	23.4 a	8.3 e	67.8 a	0.1 c	0.7 b	22.6 bc	5.5 ab
Pasture 4	8.5 def	0.6 abc	13.8 bc	25.9 de	65.8 a	2.6 bc	2.6 ab	2.1 d	0.4 cd
Pasture 5	12.0 cde	0.3 cd	6.3 cd	76.2 a	2.6 c	1.8 c	0.8 b	12.9 bcd	4.4 bc
Pasture 6	31.3 a	0.2 cd	4.5 d	54.0 bc	9.1 c	9.2 abc	0.4 b	20.9 bc	3.6 bcd
Pasture 7	17.3 bc	1.0 a	5.9 d	69.8 ab	5.1 c	18.7 a	0.0 b	2.2 d	0.2 d
Pasture 8	14.3 bcd	0.6 abc	5.6 d	53.2 bc	10.5 c	3.9 bc	1.2 b	21.1 bc	4.9 ab
Pasture 9	7.3 def	0.2 cd	16.5 ab	16.2 e	62.9 a	1.1 c	4.6 a	12.5 bcd	0.6 cd
Pasture 10	20.2 b	0.4 bcd	6.2 cd	44.9 cd	2.8 c	6.2 bc	0.6 b	35.6 a	5.6 ab
Pasture 11	36.6 a	0.9 ab	2.4 d	74.0 a	0.8 c	6.0 bc	0.2 b	10.5 cd	3.0 bcd
Pasture 12	16.7 bc	0.6 abc	4.7 d	49.1 c	7.8 c	13.2 ab	0.3 b	21.1 bc	3.7 bcd
Pasture 13	3.3 f	0.0 d	24.0 a	24.7 e	40.8 b	0.1 c	0.8 b	28.7 ab	3.2 bcd
SE	1.51	0.10	1.46	3.87	2.86	2.21	0.57	2.59	0.84

[1]Differences among farms were determined by $n = 12$.
[2]Within a column, least squares means without a common lowercase letter differ ($P < 0.05$).

seasons of July and September than in November, but were not different from May. Variations in species prevalence imply that cattle selected the more palatable vegetation species, such as Kentucky bluegrass, smooth bromegrass, and orchardgrass early in the growing season, which thereby decreased their presence later in the season. This decrease in palatable species allowed less-palatable and colder-tolerant species such as tall fescue to predominate in the riparian zones of pastures later in the season.

Manure-Covered Ground

Proportions of manure-covered ground along the stream banks differed ($P < 0.05$) between pastures (Table 3) and sampling intervals (Table 4). The greatest and least proportions of manure-covered ground occurred in November and September, respectively, with measurements in May and July not differing from either month. These differences may have resulted from seasonal differences in precipitation and pasture stocking rates. During the 3 yr, above-average rainfall amounts that occurred between the July and September measurements (Fig. 1) may have contributed to an increase of overland flow, decreasing the amount of manure-covered ground observed within the riparian zones in September. The proportion of manure-covered ground

Table 4. Proportion of bare soil, proportion of manure-covered ground, and forage sward heights within 15.2 m of streams in pastures by period during the 3-yr study.

Sampling month	Bare soil (%)	Manure-covered ground (%)	Forage sward height (cm)
May	16.4	0.5 ab[1]	11.9 a
July	14.7	0.5 ab	14.1 a
September	16.0	0.3 b	8.7 b
November	15.6	0.6 a	3.9 c
SE	0.67	0.06	0.8

[1]Within a column, least squares means without a common lowercase letter differ ($P < 0.05$).

within 15.2 m of the stream (%) increased as the stocking rate between measurements (cow-days $\cdot$ m^{-1} stream) quadratically increased according to the following equation (Fig. 2):

$$y = 0.15 + 0.18x - 0.0088x^2 \, (r^2 = 0.35). \qquad [2]$$

The two pastures with the least amount of manure-covered ground were Pastures 3 and 13, which were ungrazed vegetation buffers at the initiation of the experiment. The vegetation buffers also contained two of the highest proportions of vegetated sites as broadleaf weeds, which may have resulted in a coincidental correlation of a quadratically decreasing percentage of manure-covered ground as the percentage of broadleaf weeds in the vegetation increased:

$$y = 0.77 - 0.026x + 0.00030x^2 \, (r^2 = 0.15). \qquad [3]$$

In addition, manure-covered ground quadratically increased as the percentage of tall fescue increased

$$y = 0.20 + 0.00081x + 0.000078x^2 \, (r^2 = 0.23) \qquad [4]$$

but quadratically decreased as the percentage of reed canary-grass increased

$$y = 0.67 - 0.017x + 0.00015x^2 \, (r^2 = 0.17) \qquad [5]$$

The greater concentration of cattle manure near the pasture streams in November than September may have also been related to factors affecting distribution within the pasture such as a decrease in the quantity or quality of forage in pasture uplands (Bailey 2005), a decrease in natural off-stream water sources, or a decrease in the ambient temperatures resulting in less heat stress in periods of the late fall than mid- to late summer. Climatic conditions near pasture streams may have been more comfortable for cattle within these areas later in the grazing season combined with less insect annoyance than during the summer grazing.
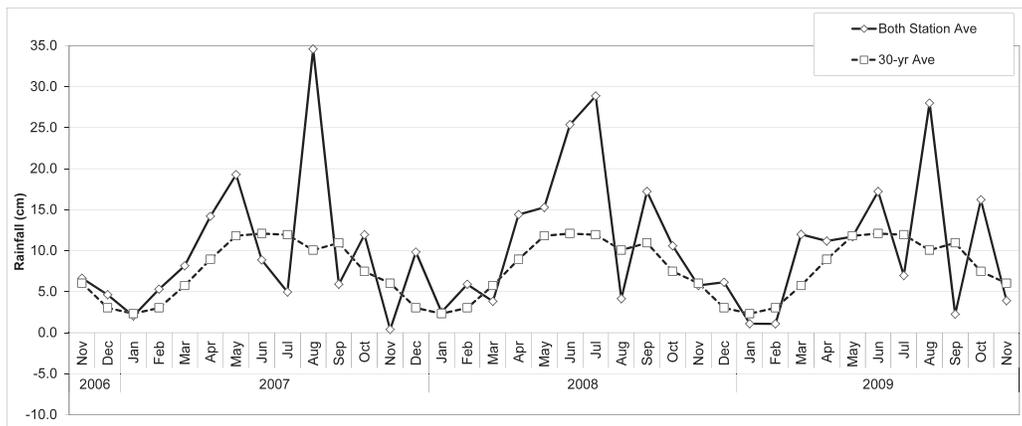
Figure 1. Monthly precipitation over the 3-yr study compared to 30-yr average with monthly departure. Monthly precipitation amounts were averaged between the nearest national weather stations, Chariton 1E and Allerton, Iowa.

Forage Sward Height

Mean sward heights, measured with a falling plate meter, were different ($P < 0.01$) between pastures (Table 3) and months (Table 4). Mean sward height decreased from July to November. Stocking rate between measurements (cow-days $\cdot$ m^{-1} stream) was quadratically related to the forage sward height (cm) measured 7.6 m from the stream (Fig. 3):

$$y = 16.28 - 4.37x + 0.33x^2 \, (r^2 = 0.31). \qquad [6]$$

This relationship implies that stocking rates greater than 1.63 cow-days $\cdot$ m^{-1} stream during the approximately 60 d between measurements from May through November or the approximately 180 d between measurements in November and May or 6.52 cow-days $\cdot$ m^{-1} stream annually would result in a sward height less than the 10 cm needed to protect against soil detachment during precipitation and treading events (Clary and Leininger 2000). Although the use of stubble height alone has been reported to be not suitable to predict sediment infiltration (Pearce et al. 1997, 1998), Haan et al. (2006) reported lower quantities and phosphorus loading of runoff from pastures that were rotationally stocked to a residual height of 10 cm than in pastures continuously stocked to a residual height of 5 cm in

cool-season grass pastures. By maintaining adequate vegetation cover and height, plant vigor may be preserved (Frazier et al. 1998; Clary and Leininger 2000) and reduce NPS pollution from riparian areas of pastures (Warren et al. 1986; Elliott et al. 2002; Reed and Carpenter 2002). In the current study, forage sward heights within riparian areas of pastures quadratically increased as the proportion of reed canarygrass increased

$$y = 4.06 + 0.40x - 0.0027x^2 \, (r^2 = 0.42) \qquad [7]$$

but quadratically decreased as the proportion of tall fescue

$$y = 25.57 - 0.55x + 0.0034x^2 \, (r^2 = 0.50) \qquad [8]$$

and legumes

$$y = 12.75 - 0.94x - 0.019x^2 \, (r^2 = 0.17) \qquad [9]$$

increased. These results infer that the presence of tall sod-forming grasses near pasture streams may be more effective at preventing NPS of pasture streams than shorter bunchgrasses. However, similar to broadleaf weeds, this relationship might relate to absence of grazing, as two of the four pastures with the greatest proportions of reed canarygrass were ungrazed buffers.
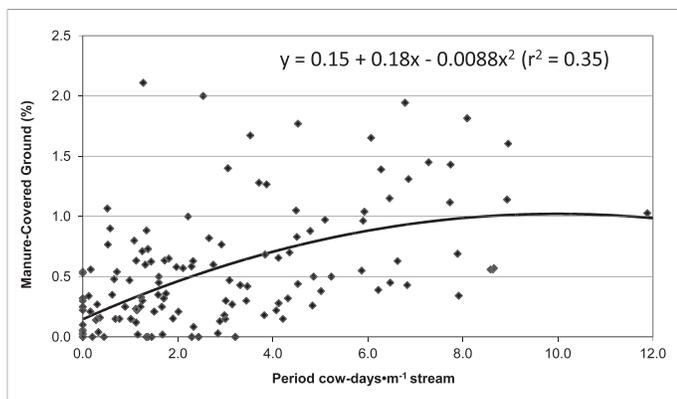
Figure 2. Effect of period stocking rate per stream meter on manure-covered ground (%) observed within 15.2 m of a stream.
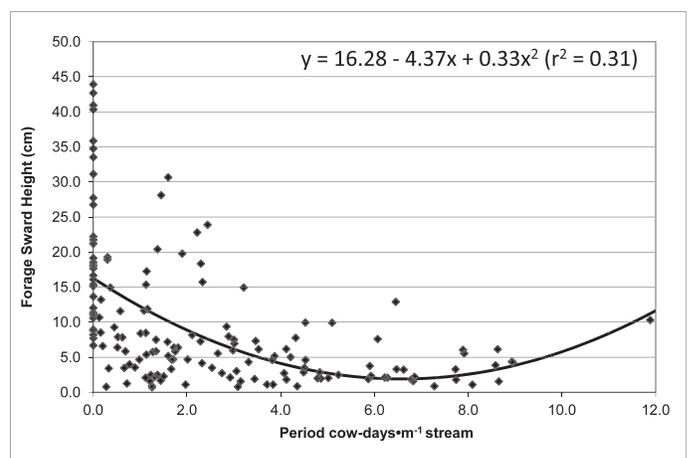
Figure 3. Effect of period stocking rate per stream meter on forage sward height (cm) observed within 15.2 m of a stream.
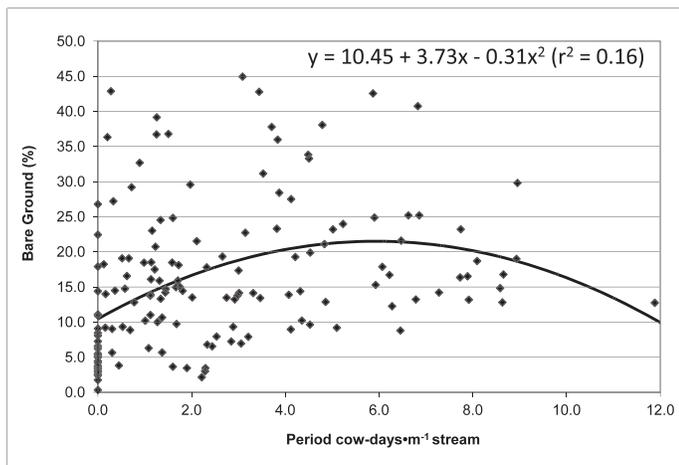
Figure 4. Effect of period stocking rate per stream meter on bare ground (%) observed within 15.2 m of a stream.

Bare Soil

Proportions of bare soil along the stream banks differed among pastures ($P < 0.01$; Table 3), but did not differ ($P > 0.10$; Table 4) between sampling intervals. The proportion of bare soil along the stream banks was not related to the stocking rate between measurements (cow-days $\cdot$ m^{-1} stream; Fig. 4):

$$y = 10.45 + 3.73x - 0.31x^2 \left(r^2 = 0.16\right). \quad [10]$$

This result may have been related to the measurement method. Because the proportion of bare soil was determined perpendicular to the stream edge, these measurements included eroded stream banks with variable lengths along with areas above the crest of the bank. Therefore, the bare soil measurements were likely affected by factors related to stream bank erosion.

The proportions of bare soil in riparian areas of pastures were related to the botanical composition of species within riparian areas of the pastures evaluated. Similar to sward height, the proportions of bare ground in riparian areas quadratically increased as the proportion of tall fescue

$$y = 3.83 + 0.40x - 0.0024x^2 \left(r^2 = 0.24\right) \quad [11]$$

and legumes

$$y = 12.13 + 1.12x - 0.024x^2 \left(r^2 = 0.18\right) \quad [12]$$

increased, but quadratically decreased as reed canarygrass increased

$$y = 21.10 - 0.37x + 0.0023x^2 \left(r^2 = 0.35\right) \quad [13]$$

as would be indicative of the type and growth rates of the forages observed.

Stream Bank Erosion Rates.

Across the 3-yr study, net erosion rate was greater ($P < 0.05$) during the winter through early spring than either the late spring through early summer or late summer through fall periods (Fig. 5). During the current study, above-normal precipitation occurred prior to entering or exiting the winters,
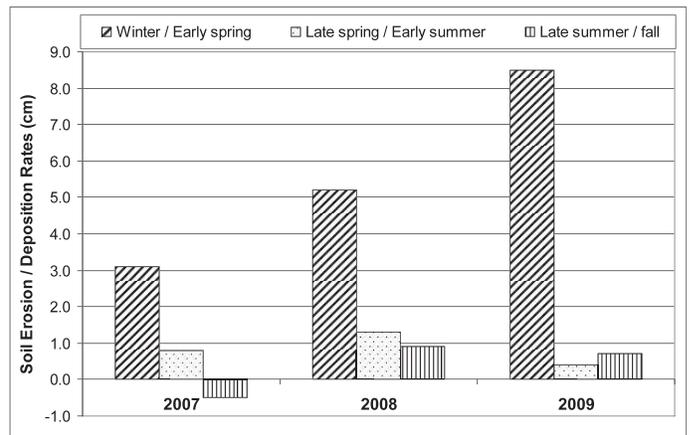
Figure 5. Seasonal stream bank erosion/deposition rates occurring from 2007 to 2009.

which when combined with preexisting saturated stream banks during the periods with the greatest freeze–thaw activity likely resulted in the winter through early spring period having the greatest amounts of stream bank erosion.

Stocking rate between measurements (cow-days $\cdot$ m^{-1} stream) was not correlated to net stream bank erosion rates (cm; Fig. 6):

$$y = 3.28 - 0.48x - 0.026x^2 \left(r^2 = 0.06\right). \quad [14]$$

Therefore, it seems that natural factors of hydrology such as stream stage flow and rainfall characteristics (Tufekcioglu 2010) had larger effects on stream bank erosion than a direct, immediate effect of cattle traffic did in this study. The amounts of precipitation between measurements (cm) accounted for 15%, 24%, and 44% of the variation in net stream bank erosion rates (cm) during the winter through early spring
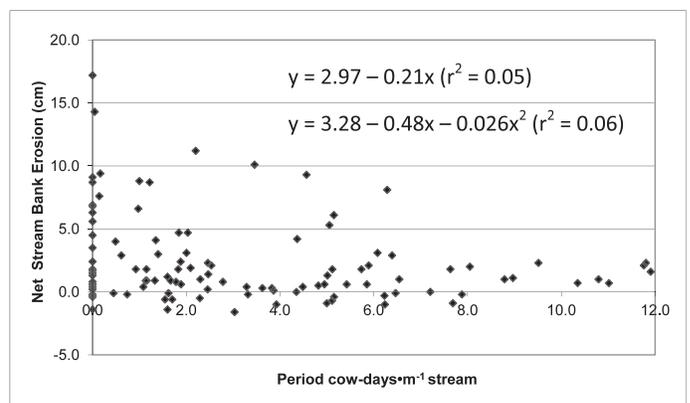
$$y = 5.60 + 0.15x - 0.0036x^2 \quad [15]$$

late spring through early summer

$$y = 3.02 - 0.17x + 0.0025x^2 \quad [16]$$

and late summer through fall seasons

$$y = -2.54 + 0.11x - 0.00058x^2. \quad [17]$$

Figure 6. Effect of period stocking rate per stream meter on period net stream bank erosion rates.

Watershed size that drained through each of the 13 pastures accounted for over 68% of the variation in percentage of bare soil on the stream banks

$$y = 4.59 + 0.013x - 0.000015x^2 \qquad [18]$$

but watershed size did not impact ($P > 0.10$) stream bank erosion along the riparian zones of pastures.

DISCUSSION

It can be inferred by these results that reducing the stocking rate or altering the distribution of grazing cattle will reduce the risks of polluting pasture streams by reducing manure concentration and maintaining forage height to minimize nutrient transport in precipitation runoff. Differences in manure distribution between seasons and pastures in this study could have resulted from interactions between stocking rate and natural factors such as rainfall in the riparian zones of pastures that altered cattle distribution and transported manure into pasture streams. Cattle distribution patterns are representative of manure nutrient distribution throughout grazed pastures (White et al. 2001; Ballard and Krueger 2005; Haan et al. 2010). Fecal loads have been reported to be greater near cattle attractants of salt, mineral, or energy/protein supplements implying that these attractants may be used to reduce fecal loads in pasture riparian areas (Tate et al. 2003; Bailey et al. 2008a, 2008b). The attractants may be more effective in altering cow distribution during the dry seasons than during wet seasons (Tate et al. 2003). During wet seasons, an increase in watering locations other than streams reduced congregation of cattle near water sources and thus decreased the proportion of fecal deposits located near attractant areas. With above-normal rainfall amounts from July to September of this study, similar conditions may have resulted in the observed decrease in the proportion of manure-covered ground near pasture streams. Furthermore, during the periods of above-normal rainfall throughout the study, an increase in overland flow may have dispersed some fecal deposits, reducing the percentage of observed manure-covered ground in September, but increasing the risk of water quality impairment (Davies et al. 2004).

Heavily stocked pastures may result in the loss of vegetation cover and promote accumulation of manure near streams (Line 2003; Tate et al. 2003; Hubbard et al. 2004). Cattle may congregate near pasture streams to obtain water and shade for thermoregulation (Kauffman and Krueger 1984; Bailey 2005; Franklin et al. 2009) as temperature (McIlvain and Shoop 1971; Zuo and Miller-Goodman 2004; Haan et al. 2010), relative humidity (Black Rubio et al. 2008), and solar radiation (Tucker et al. 2008) increase or as seasons change (Tate et al. 2003). Cattle distribution is affected by factors of pasture size and shape, shade distribution, and forage quality and quantity (Bailey 2005; Haan et al. 2010; Bear 2011). Because stocking rate was not related to bare soil and only weakly related to forage sward height in this study, factors affecting cattle distribution and congregation may be as or more important than stocking rate in their impacts on the physical characteristics of riparian areas.

Because there were no differences between months in the proportion of bare soil in the riparian areas of pastures, nonvegetated areas within riparian areas may contribute to risks of sediment loading of streams year-round. The proportion of bare soil is a major factor associated with soil erosion (Russell et al. 2001; Haan et al. 2006). Not surprisingly, concentration of sediment in surface runoff has been linearly related to the amount of bare ground of a given area, as exposed soil is more susceptible to soil detachment by overland flow (Hofman and Ries 1991; Elliott et al. 2002; Persyn et al. 2004) and erosive energy of raindrops (Young and Wiersma 1973; Morgan 1978; Kinnell 2005). As a result, bare ground in riparian areas of pastures may contribute significant sediment and phosphorus loads to surface waters during heavy rainfall events (Line et al. 2000; Byers et al. 2005; Butler et al. 2006). Although stocking rate did not affect the proportion of bare ground within 15.2 m of pasture streams in the current study, measuring bare ground from each stream's edge likely confounded the effects of cow traffic on the proportion of bare ground with those caused by precipitation runoff and erosive energy of the stream flow (Tufekcioglu 2010). These natural events may impact the proportion of bare ground in riparian areas of pastures, specifically in stream banks, regardless of cattle presence or absence from these areas.

Stream bank erosion rates, eroded bank length, and sediment loading of streams along riparian areas and stream hydrology are impacted by grazing, wildlife herbivory (Fritz et al. 1999), and land use of the area (Trimble 1994; Zaimes et al. 2004, 2008). However, the current study found only a minimal impact of stocking rates between measurements on net stream bank erosion rates at each measurement date. Therefore, the effects of grazing on stream bank erosion may not be immediate and additional environmental conditions and factors may have contributed to the observed erosion rates. Within the current study, the greatest amount of erosion occurred during the winter/early spring period, which is similar to the results of Buckhouse et al. (1981) and Zaimes et al. (2004). Higher rates of erosion that occurred during this period may have resulted from seasonal effects preceding winter causing saturated stream banks and short vegetation cover. During the study, nearly two-thirds, or 23 mo, had above normal rainfall whereas nearly only a third, or 14 mo, experienced below normal rainfall. The study was preceded by 3 yr with below normal precipitation compared to the 30-yr average of 93.4 cm. As a result of little change in land management, observed stream bank erosion was believed to be related to the high number of rainfall and storm events and accounted for severity and widening of the streams observed within the watershed.

MANAGEMENT IMPLICATIONS

These results imply that increasing stocking rate will result in increased manure-covered ground and decreased forage sward heights in riparian zones of Midwestern pastures, which may increase the risks of nutrient and sediment loading in precipitation runoff. These factors may be managed by reducing pasture stocking rate or using practices that alter cow distribution. These practices would be particularly important in the fall to maintain adequate forage sward height and minimize manure concentration near pasture streams to prevent sediment and nutrient transport in spring snowmelt in addition to reducing the risks of stream bank erosion. However, the immediate effects of stocking rate on the proportion of bare soil adjacent to streams and net stream bank erosion are small.

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