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Assessment of the risks of nonpoint source pollution of pasture streams related to grazing management

Kirk Albert Schwarte
Iowa State University

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Kirk A. Schwarte

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Daniel G. Morrical
John D. Lawrence

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ABSTRACT

Sediment, phosphorus (P), and fecal pathogens lost from grazed pastures contribute to the non-point source pollution of surface waters. Therefore, the objective of this experiment was to observe the effect of different grazing management techniques on the amount of time cattle spend in or near pasture streams and on the amount of sediment, P, and fecal pathogen loading of into the streams. During the 2008 and 2009 grazing season, a study was conducted at the Iowa State University Rhodes Research and Demonstration Farm utilizing six adjoining 12.1-ha pastures that were bisected by a 141-m reach of stream. The pastures were grouped into two blocks and assigned one of three treatments: continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access restricted to 4.9-m wide stabilized crossings (CSR), or rotational stocking (RS). Pastures were stocked with 15 fall-calving black Angus cows from mid-May to mid-October for 153 days in both years. For two weeks of each month, GPS collars were placed on at least one cow per pasture. For one of the two weeks, alternative off-stream water was made available to cattle in CSU and CSR pastures to determine the effect of off-stream water on cattle distribution. Each month the cattle were stocked on the pastures, bare and fecal-covered ground was measured. Rainfall simulations were conducted in June, August, and October of 2008, April, June, August, and October of 2009, and April of 2010 at six vegetated and six bare locations on the stream banks in CSU and RS pastures and six vegetated locations on the stream banks within the riparian buffer in CSR pastures. In June and August of both years, two cows per pasture were given a bolus of Cr-mordent fiber to determine total and P fecal output. Shedding of the fecal pathogens was measured by collected fresh fecal samples from all 90 cows in June, August, and September of both years. Stream bank erosion was measured by erosion pins at 10 equidistant transects that were measured monthly from May to November. Results show that off-stream water had no effect on cattle distribution. Compared to the CSU treatment, the CSR treatment reduced the probability ($P < 0.10$) that cattle were within the Riparian Zone (0 to 36 m from stream center) at black globe temperature humidity index (BGTHI) of 50 to 100. Bare ground in and near the stream was generally greater in pastures with the CSU than CSR and RS treatments. Rainfall simulations resulted in greater ($P < 0.10$) proportions of applied precipitation and amounts of sediment and P transported in runoff from bare than vegetated sites across grazing treatments and from vegetated sites in CSU and RS pastures than vegetated sites in the CSR pastures. The proportion of applied precipitation, sediment and P loading into surface runoff was most closely related to the proportion of bare ground (R^2 = 0.5217, 0.4512, 0.4082, respectively). Pathogen shedding of cattle occurred only once throughout the experiment and was never found in precipitation runoff from rainfall simulations. Bovine enterovirus, an indicator virus, was shed by an average of 24.3% of cows over the study and was collected in the runoff of 8.3 and 16.7% of the simulations on bare sites in CSU pastures in June and October of 2008, respectively, and from 8.3% of the simulations on vegetated sites in CSU pastures in April 2009. Stream bank erosion did not differ between treatments. Results of the experiment show that time spent by cattle near pasture streams can be reduced by RS or CSR treatments, thereby, decreasing risks of sediment and nutrient loading of pasture streams even during periods of increased BGTHI. Stream bank erosion via cut banks was the greatest contributor of both sediment and P loading of pasture streams; contributions of sediment and P from surface runoff and grazing animals were considerably less and were minimized by grazing management practices that reduced congregation of cattle by pasture streams.

CHAPTER 1. GENERAL INTRODUCTION

THESIS ORGANIZATION

This thesis is organized as an introduction to the research and related literature review followed by a brief description of the hypothesis for developing this research and its objectives. Manuscripts for submission to the Journal of Animal Science and the Journal of Environmental Quality follow the literature review and introduction of research. Following the manuscripts are a general conclusion, appendices of additional information, and acknowledgements.

INTRODUCTION

Eutrophication is the suffocation of a water source brought about by nutrient enrichment of the water source allowing large amounts of aquatic plants and algae to grow (USEPA, 1996). The decomposition of this intense growth consumes dissolved oxygen within the water, making it difficult for aquatic animals to survive (Sharpley et al., 1994).

Eutrophication is the leading cause for surface water impairment in the United States (USEPA, 1996). Classifying a body of water as an impaired water source deems the source as unfit for any of its intended uses including recreational and drinking purposes (IAC, 2002).

Eutrophication of many freshwater lakes, estuaries, rivers, and coastal oceans can be caused by high phosphorus concentrations (Smith, 1998). With increased regulation of point source pollution, most of the phosphorus (P) that enters surface waters occurs through non-discrete forms of pollution called non-point source (NPS) pollution (Sharpley et al., 1994). Non-point source pollution contributes 84% of the total amount of P that is discharged into receiving waters (Carpenter et al., 1998). The United States Geological Survey (USGS) recently published a paper (Alexander et al., 2008) that stated that pastures and rangeland account for the greatest amount (37%) of all P that reaches the Gulf of Mexico via the Mississippi and Atchafalaya River Basins. This amount is more than a previous estimate of 20% reported by Carpenter et al. (1998). Other important sources of P loading were lands used for the production of corn and soybeans (25%) or other crops (18%), and urban sources (12%; Alexander et al., 2008).

Controlling P transport from pasture and rangeland to surface waters is needed to minimize eutrophication issues. As most P loading occurs through surface runoff and bank erosion (Sharpley et al., 1994), management practices limiting these processes will decrease impairments associated with P loading.

CHAPTER 2. REVIEW OF LITERATURE

WATER QUALITY

Standards

Since enactment of the Clean Water Act (CWA) in 1972, states have had to monitor their surface waters to ensure that they are meeting water quality goals and standards set by the states themselves (Libra et al., 2004). According to Section 305(b) and Section 305(d) of the CWA, states are required to use available water quality data to assess the quality of their surface waters in relation to their set standards, and every two years, report any waters that did not meet these standards to the United States Environmental Protection Agency (USEPA). Any water body that does not meet the water quality standards is considered impaired. Each impaired water source must have an action plan to correct the water quality issue known as a total maximum daily load (TDML), which is the maximum amount of a pollutant that water can receive and still meet its intended use (Libra et al., 2004). In Iowa, 434 of 974 surface waters being assessed for water quality issues are on the Category 5 “impaired” list in 2008 (Libra et al., 2004).

However, all bodies of water are not required to meet the same standards. The criteria for a particular body of water are determined by its current or future uses (IAC, 2002). Surface waters can be classified into two categories; general use and designated use. General use waters are those that have intermittent flow, become dry for part of the year, and do not support a “viable aquatic community” (IAC, 2002). General use quality standards protect the water body’s use for many agricultural practices (i.e. livestock water and irrigation), industrial and non-contact recreational uses, and “other incidental withdrawal uses” (IAC, 2002). Designated use is divided into 13 categories ranging from different levels of recreational uses (Class “A”) to different levels of aquatic species (warm and cold) and habitat (Class “B”), drinking water supply (Class “C”), and a variety of others. A complete listing of water quality criteria is presented in the Water Quality Standards of the Iowa Code (IAC, 2002).

Although in place since 1972, many states, including Iowa, have yet to set standards for nutrients such as nitrogen and P (Libra et al., 2004). To aid the formation of standards, the EPA has set benchmark standards for regions throughout the nation. Most of the upper Midwest falls into the ecoregion VI (Corn Belt and Northern Great Plains; USEPA, 2000). This region has a reference standard of 76.25 $\mu g \cdot L^{-1}$ total P in surface waters. Therefore, any stream that has a TP concentration greater than 102.38 $\mu g \cdot L^{-1}$ TP may be at risk for impairment (USEPA, 2000). However, states are not required to follow these recommendations. Therefore, the use of narrative criteria and professional judgment, rather than a set nutrient standard, has been the method of determining impairment in the past (IDNR, 2009). While these are reference standards, concentrations of as little as 20 $\mu g \cdot L^{-1}$ TP can cause eutrophication issues and levels of 100 $\mu g \cdot L^{-1}$ TP have been noted as unacceptably high (Correll, 1998).

Eutrophication

Eutrophication of a body of water is defined as the depletion of dissolved oxygen caused by excess nutrients (Sharpley et al., 1994). Excess nutrients allow for accelerated plant and algal growth. Decomposition of such growth by bacteria consumes dissolved oxygen, causing adverse living conditions for aquatic species (Sharpley et al., 1994).

Levels of eutrophication are dependent upon the water body’s limiting nutrient. Typically, P is thought to be the limiting nutrient in NPS pollution-dominated freshwater rivers, lakes, and streams (Sharpley et al., 1994). Studies have also shown that algal growth responded to nitrogen, as well as combinations of nitrogen and P, in many freshwater lakes (Elser et al., 1990) and streams (Dodd et al., 2002). Francoeur (2001) believed that the historical representation of P as a single limiting nutrient relates to lack of previous studies to detect small biological changes. However, some algae have the ability to fix nitrogen from the atmosphere to overcome nitrogen limitations and, therefore, any growth response to nitrogen would likely only occur at points soon after a large influx of P (Schindler, 1997). Schindler (1977) observed that controlling for nitrogen instead of P may actually be detrimental to the lake, as a low nitrogen to P ratio would create a less desirable algae population, such as blue-green algae. Blue-green algae can produce toxins which can poison animals resulting in death (Cheeke, 1998).

TRANSPORT OF P IN NPS

Surface Runoff

Surface runoff occurs when the amount of precipitation in a rainfall event is greater than the infiltration rate (Horton, 1933). However, only 10-30% of rainfall events are great enough to cause overland flow on small, but consistent sources that make up less than 10% of the basin area (Freeze, 1972).

Phosphorus loading of surface runoff occurs as precipitation interacts with the top 1-2.5 cm of the soil surface (Sharpley, 1985a). Phosphorus that is transported in surface runoff can be quantified in numerous forms (Haygarth and Jarvis, 1999). A major distinction is whether the P is in the dissolved form (DP) that can pass through a 0.45-µm filter or the particulate P form (PP; Hart et al., 2004). Another distinction is whether the P is reactive (RP) to a molybdate reaction (Murphy and Riley, 1962). Because of complicated soil matrices, the sample would need to be digested before analysis in order to quantify the total P (TP) in a runoff sample (Rowland and Haygarth, 1997). The difference between TP and RP would give the amount of un-reactive P (UP) of a sample, which is usually P that is present in organic forms (Haygarth and Jarvis, 1999). Additionally, organic P that binds less strongly to particles in the soil is at greater risk of being leached to greater depths in the soil (Frossard et al., 1989) or may contribute to the amounts of P that is lost through tile drainage lines (Sims et al., 1998).

Soils with a low soil P content are less likely to release dissolved P to surface runoff than soils with higher P concentrations (Allen et al., 2006). Clay minerals within the soil can be responsible for binding of over 50% of P in the soil (Devau et al., 2009). Thus, soils with higher clay content have an increased ability to bind P and inhibit its loss by dissolution into surface runoff (Cox and Hendricks, 2000). However, at different levels of pH, P binds to different minerals within the soil (McDowell et al., 2003b; Devau et al., 2009). Aluminum and Fe minerals in soils tightly bind P in acidic soils (Hartikainen and Simonjoki, 1997; McDowell et al., 2003b), inhibiting P dissolution into runoff. In alkaline conditions, Ca becomes the primary binding mineral (McDowell et al., 2003b). As Ca does not bind as tightly to P as does Al or Fe, more P can be solubilized in alkaline pH (McDowell et al., 2003b).

Clay and other fine particles that preferentially bind P in the soil are eroded in preference to larger heavier sediments such as sand (Sharpley, 1985b). Therefore, soils eroded in surface runoff typically have higher P values than the source soils (Sharpley, 1985b). Additionally, the ratio between DP and PP in surface runoff varies greatly depending upon surface conditions. In tilled soils, P transport occurs primarily through PP, while DP is primarily lost in pastures and other dense areas of vegetation where little sediment is lost (Sharpley et al., 1994).

Continuous years of high P fertilizer application can lead to high soil P concentrations (Dougherty et al., 2008), and soils with high P levels are most at risk of releasing P in runoff (Sharpley et al., 1994; Allen et al., 2006). However, the ability of soil to retain applied P is highly dependent upon depth (Sharpley et al., 1994; 2001), timing (Sharpley et al., 1994; Schroeder et al., 2004), form (McDowell et al., 2003c), and rate (Dougherty et al., 2008) of P application. As the majority of P that is lost through surface runoff is mobilized within 1-2.5 cm of the soil surface (Sharpley, 1985a), incorporating added P into soil deeper than 5 cm soon after application can decrease total P loss through surface runoff. In contrast, allowing fertilizer P to remain on the soil surface creates the potential for very high P loss (Sharpley et al., 1994; 2001). Schroeder et al. (2004) observed that increasing the amount of elapsed time between fertilizer application and the first runoff event can play a significant role in reducing P loss through surface runoff, as P likely sorbs to soil sediment particles. Likewise, application of less soluble forms of P fertilizer (e.g. reactive phosphate rock v. superphosphate) can decrease P concentrations in overland flow (McDowell et al., 2003c).

The amount of P applied to the land through fertilization has been poorly correlated with the concentration of P in precipitation runoff (Dougherty et al., 2008), especially after multiple runoff events (Schroeder et al., 2004). This poor correlation is likely the result of fertilizers accounting for 10% or less of total P loss (McDowell et al., 2007). The top horizon soils of stream banks in the Midwest may contain 0.22 to 0.35 $g \cdot kg^{-1}$ P (Nellesen et al., 2011) while cattle feces may contain 5.5 $g \cdot kg^{-1}$ P (McDowell and Stewart, 2005). Therefore, cattle feces are a concentrated source of P that can account for as much as 30% P losses from a field (McDowell et al., 2006; 2007). However, the solubility of manure P quickly diminishes as the manure dries (McDowell and Stewart, 2005). Other sources of P include plants, as Bromfield and Jones (1972) observed decomposing plants leach 62% of their P stores with rainfall. Additionally, McDowell et al. (2007) observed that plant leaching can account for as much as 20% of total P leaving the field from rainfall.

Although the majority of P in run-off from agricultural lands is sediment bound (Hart et al., 2004), the majority of P from pastures is likely to be dissolved (Nash and Halliwell, 2000; McDowell et al., 2003a). Therefore, increased infiltration rates and buffer widths to inhibit total surface run-off are needed to diminish the P loss in grassland pastures, as dissolved P will not settle out of solution as quickly as sediment-bound P (Lee et al., 2003; White et al., 2007). The amount of sediment-bound P will increase in highly erosive areas (Hart et al., 2004) as dissolved P attaches to the sediment in the run-off (McDowell et al., 2003a).

Although numerous studies have shown that runoff P concentration is correlated to soil test P concentration (Pote et al., 1996; 1999; Torbert et al., 2002), rainfall simulations to produce surface runoff have shown that minimizing P lost in surface runoff in grazed pastures can be best accomplished by minimizing the amount of bare ground (Butler et al., 2006; Haan et al., 2006). Bare ground over 25 to 30% of the total ground cover has been observed as the threshold before significant increases in runoff and soil loss occur (Lang, 1979; Costine, 1980). Although greater forage sward heights have been observed to reduce the amount of P runoff (Edwards et al., 2000), the effect of the amount of bare ground seems to be greater than that of other ground characteristics (Haan et al., 2006).

Bare ground in riparian areas caused by grazing cattle is likely in the form of cattle ramps and congregation areas as cattle utilize the riparian area for thermoregulation, water, and forage (Kauffman and Krueger, 1984). Cattle ramps resulting from cattle traveling in and out of a stream in one location can cause significant bank erosion because of the condensed surface runoff on the ramp and through stream bank scouring at the ramp during high stream flow (Trimble, 1994). Congregation areas may form near feeding areas, gates, shade, and water (McIlvain and Shoop, 1971; Sanderson 2010). These congregation areas are characterized by a lack of vegetation and high soil densities which allow the formation of an erosive, concentrated water flow via the combination of surface runoff from adjacent slopes (Trimble, 1994; Trimble and Mendel, 1995). Although Sanderson et al. (2010) observed that most measured congregation areas were less than 100 m^2; soil P levels were higher within 20 to 40 m of the areas.

Therefore, a strategy to remove cattle congregation areas from riparian areas has been the formation of vegetated buffers by cattle exclusion (Bryant, 1982; Line et al., 2000; Miller et al., 2010b). A vegetated buffer may inhibit nutrient runoff by delaying water movement, allowing suspended sediment to settle, and promoting greater amounts of water and nutrients to infiltrate into the soil (Mukhtar et al., 1985; Lee et al., 2000). The ability of a buffer to inhibit non-point source pollution is related to many factors including: buffer width, vegetation type, density and spacing, sediment particle size, slope, water flow, infiltration capacity, and rate of infiltration (Lee et al., 2000; Yuan et al., 2009).

Studies have observed significant sediment reduction from buffers with widths as little as 3 m when conditions include non-rill water flow on gentle slopes with dense forage cover (Robinson et al., 1996; Lee et al., 1999; Blanco-Canqui et al., 2004a; 2004b).

However, other studies have found increased sediment retention in buffer widths greater than nine meters (Dillaha et al., 1989; Magette et al., 1989). According to White et al. (2007), most sediment particles greater than 20 µm in diameter can be captured within the first two meters of the buffer by settling out of solution. However, a 16 m wide filter strip was required to remove particles sized 2-20 µm (White et al., 2007). Smaller particles were not affected by filter width, but by infiltration rate of surface runoff into the soil. This result correlates with Mankin et al. (2007) who observed that greater than 75% of total suspended solid removal in riparian buffers results from infiltration of the water carrying the sediment. Therefore, increasing buffer width is needed to collect fine clay particles and soluble nutrients in a multi-species riparian buffer (Lee et al., 2003).

Accumulation of sediment and P can occur in buffers because of nutrient deposition from surface run-off (Moorman et al., 2007). As the concentration of P in the runoff is related to the P level in the soil (Pote et al., 1996; 1999; Sharpley et al., 2001; Torbert et al., 2002), riparian buffers may become a source of dissolved P in surface runoff occurring over the vegetative buffer (Cooper et al., 1995; Dillaha et al., 1989). Therefore, removal of nutrients from the buffer needs to match the nutrient inputs to reduce the possibility of a buffer becoming a source of P in runoff (Cooper et al., 1995).

Bank Erosion

Simon et al. (1996), as cited by Simon et al. (2000), found that as much as 80% of stream sediment in the loess region of the Midwest can come from incised banks. In a river in Mississippi, Simon et al. (1998), as cited by Simon and Thomas (2002), estimated that 939 tonnes$\cdot$ km^{-2} $\cdot yr^{-1}$ of sediment that entered the river were caused by stream bank erosion and stream bed degradation. Similarly, Schilling and Wolter (2000) observed that bank erosion accounted for about 50% of stream sediment. With annual erosion rates as little as 11.4 to 26.6 $cm^{-1} \cdot yr^{-1}$, 3.4 to 20.7 $g \cdot m^{-1}$ total P can be lost from stream banks each year (Nellesen et al., 2011), as riparian stream bank soils in Iowa contain from 0.23 to 0.55 $g \cdot kg^{-1}$ total P (TP; Zaimes et al., 2008b; Nellesen et al., 2011) with decreasing P concentrations at increased depths (Nellesen et al., 2011). Some banks may have P concentration values as high as 1.792 $g \cdot kg^{-1}$ TP at depths of 2.7 m below the ground surface (Schilling et al., 2009). However, these levels of P were not related to recent soil practices, but changes that might have taken place during soil deposition (Schilling et al., 2009). Therefore, a large amount of P is likely to be contributed to streams from bank erosion.

As stream bank P concentration is not likely altered by long-term surface land management (Schilling et al., 2009), the ability to abate P loss to streams via stream bank erosion requires strategies that minimize total bank erosion (Zaimes et al., 2008b). Bank erosion is considered to take place as a reaction of the three mechanisms: subaerial processes, fluvial entrainment, and mass failure (Abernethy and Rutherfurd, 1998; Couper and Maddock, 2001). Subaerial processes include both freeze-thaw and wet-dry cycles (Wynn and Mostaghimi, 2006b). Subaerial processes weaken stream bank cohesiveness and allow subsequent high water flows to remove the material (Lawler, 1986). Hence, these cycles are considered to be preparatory stages for bank erosion (Lawler, 1986), although some studies attribute subaerial processes as the major contributor to stream bank erosion (Couper and Maddock, 2001; Harden et al., 2009).

Fluvial entrainment removes sediment at the toe of the stream bank, causing an increase in both bank height and angle (Simon et al., 2000). Mass bank failure occurs when the bank height and angle become so great that the gravitational forces become greater than the matric suction holding the bank material to the bank (Simon et al., 2000). Bank failure of the stream bank was responsible for most of the bank erosion occurring mid-bank or higher in the Little River in Tennessee, although the authors found it hard to distinguish between bank failure and subaerial processes (Harden et al., 2009).

Studies have associated the impact of grazing on stream bank erosion with the removal of vegetation and hoof treading (Kauffman et al., 1983; Trimble, 1994). However, the effects of cattle on stream bank erosion is still largely unclear, as some studies have noted increased amounts of bank erosion with cattle grazing (Kauffman et al., 1983; Trimble, 1994; Zaimes et al., 2008a), while others have not found differences (Allen-Diaz et al., 1998; George et al., 2002). Additionally, many studies seem to have serious faults. Trimble et al. (1994) noted that a major consequence of cattle grazing on the stream banks was the formation of cattle ramps and the bank scouring erosion that occurred as a result of the ramps disrupting stream flow. However, this study only measured bank losses from the ramps and scouring points over the course of a few heavy rains, and did not take into account previously mentioned erosive processes or monitor stocking density. Similarly, Zaimes et al. (2008a) observed that buffered sites had less bank erosion than did grazed pastures; however, the authors inadequately accounted for the cattle stocking rates and the grazing system utilized on the pastures. Stream bank erosion was measured by too few erosion pins in Kauffman et al. (1983), as only 125 erosion pins were utilized over a 5,473 m of stream bank. In comparison, Nellesen et al. (2010) utilized 520 erosion pins over an 846 m of stream reach.

Vegetation on the stream bank provides both mechanical and hydrological benefits (Simon and Collison, 2002). Both forested and grass buffers can be effective at minimizing bank erosion (Lyons et al., 2000a; Wynn and Mostaghimi, 2006a; 2006b). Wynn and

Mostaghimi (2006a) observed that riparian forests may have greater bank stability because of the large quantity and distribution of large diameter roots. Additionally, Lyons et al. (2000a) stated that while grassy riparian buffers were effective at trapping suspended sediment in runoff, trees were effective on severely eroded banks.

Each type of riparian buffer provides a shield against wet-dry and freeze-thaw cycles that contribute to stream bank erosion during the year (Wynn and Mostaghimi, 2006b). In the spring and summer, trees provide an abundance of shade to minimize solar radiation from reaching the soil surface and meet most of their water needs from subsurface moisture, maintaining surface soil moisture. The maintained surface water level decreases the number of wet-dry cycles that may decrease bank stability (Wynn and Mostaghimi, 2006b).

As previously mentioned, stream banks are likely to be at the greatest risk of erosion in the winter (Lawler, 1986). At this time, trees provide little solar radiation shielding while dense grasses insulate the soil, minimizing the number of freeze-thaw cycles (Wynn and Mostahghimi, 2006b). Soils in forested areas had as much as 2 to 3 times the temperature range and 8 times the number of freeze-thaw cycles as a grass buffer (Wynn and Mostaghimi, 2006b).

EFFECTS OF GRAZING ON RIPARIAN AREAS

Soil

Grazing cattle can affect numerous soil properties including: density (McCarty and Mazurak, 1976; Dormaar et al., 1989; Greenwood et la., 1997; Bharati et al., 2002), infiltration rate (Nguyen et al., 1998; Singleton and Addison, 1999; Tian et al., 2007), and organic matter (Thurow et al., 1986; 1988; Franzluebbers et al., 2001).

Numerous studies have shown that soil density is greater in grazed pastures than non-grazed lands (Mullen et al., 1974; Wood, 1977; Dormaar et al., 1989; Meek et al., 1992; Taboada and Lavado, 1993). Greater soil densities are seen because the soil is compressed by hoof pressure, which degrades the structure of the soil (Radke and Berry, 1993; Taboada and Lavado, 1993). For example, a stationary cow exerts a greater amount of pressure on the ground as an unloaded tractor, 220 kPa compared to 74-81 kPa , respectively (Blunden et al., 1994; Di et al., 2001). However, the detrimental effects of grazing animals on soil bulk density qualities are confined to the top 5 to 10 cm of the soil (Ferrero, 1991; Greenwood et al., 1997; Singleton and Addison, 1999; Drewry and Paton, 2000; Wheeler et al., 2002), although Pietola et al. (2005) noted differences as deep as 25 cm. Although cattle affect soil density, it has also been shown that the impacts of grazing on soil bulk density occurring over the grazing season were lost over the winter season (Clary and Kinney, 2002) as a result of freeze-thaw cycles (Tollner et al., 1990).

The ability of a soil to become compacted is related to the moisture content in the soil, as soils with very low moisture levels are resistant to compaction, and moderately wet soils are at risk for compaction (Edmond, 1962; Warren et al., 1986b). Soil compaction will increase the soil bulk density as soil moisture increases, until the soil is so saturated that the particles will be pushed apart by the water within the soil (Hillel, 1980). Because soil compaction is related to soil moisture, Marlow et al. (1978) suggested that cattle's access to riparian areas should be limited to times in which soil moisture was low (<10%) to prevent excess damage to the banks.

Many studies have found increased soil bulk densities to be associated with decreased soil porosity (Nguyen et al., 1998; Drewry and Paton, 2000; Pietola et al., 2005). Singleton and Addison (1999) observed that grazed soils had the similar amounts of soil porosity as non-grazed soils; however, the number of macropores (pores > 30 µm) were less in the grazed soil than in non-grazed soil. Soils with greater amounts of macropores will have increased water infiltration rates (Warren et al., 1986b; Nguyen et al., 1998; Singleton and Addison, 1999), as macroporosity is a measure of pore continuity which provides a less hindered route for water absorption (Dixon and Peterson, 1971; Thomas and Philips, 1979). Because of this, macroporosity is considered a useful indicator of treading damage (Nguyen et al., 1998). Additionally, numerous studies have found that infiltration rates continue to decline with increased amounts of treading damage (Warren et al., 1986b; Mwendera and Saleem, 1997; Pietola et al., 2005; Tian et al., 2007). For example, Bharati et al. (2002) observed water infiltration rates as much as five times greater in buffer strips than in pastures.

Infiltration rates of the soil have a positive correlation with the amount of soil organic matter (Thurow et al., 1986; 1988; Bharati et al., 2002), and a negative correlation with soil density (Dormaar et al., 1989; Angers, 1990; Franzluebbers et al., 2001). Many studies have observed that soil organic matter is increased by reducing or removing grazing pressure (Dormaar et al., 1989; 1997; Wilms et al., 1998; Mapfumo et al., 2002).

Vegetation

Because grazing cattle affect the soil as shown above, differentiating the effects of grazing cattle on vegetation can be hard to distinguish from the effects of cattle treading (Greenwood and McKenzie, 2001). For example, soil organic matter is reduced by grazing (Wilms et al., 1988; Dormaar et al., 1989; 1997; Mapfumo et al., 2002). As soil organic matter is the source for the majority of soil nutrients (Chaneton et al., 1996), and soils with increased organic matter have higher plant productivity (Wilms et al., 1988), grazed pastures may have decreased vegetative productivity. In addition, soil macroporosity is also a measure of soil fertility (Ball et al., 2007), as increased amounts of macropores are correlated to increased forage yields in pastures (Drewry and Paton, 2000).

Along with these associated effects, grazing can also be directly detrimental to the riparian vegetation as cattle treading can bury, trample, tear, and defoliate the forage (Edmond, 1962; Clary, 1995; Pande and Yamamoto, 2006). Yet, moderate defoliation through grazing activities has been observed to increase forage production over that of non-grazed forage through a process known as "over-compensatory growth" (Hilbert et al., 1981; McNaughton, 1983). However, total forage production will decrease with increasing grazing pressure (Hilbert et al., 1981; Milchunas and Lauenroth, 1993). The reduced production is partially the result of defoliated plants having less plant leaf area to capture light energy through photosynthesis (Parsons et al., 1983) and being less efficient at producing forage (Brougham, 1956). For example, Brougham (1956) observed that pastures defoliated to a height of 2.5 cm produced less dry matter per unit area of leaf than pastures defoliated to 7.6 or 12.7 cm.

Additionally, grazing activities have been shown to allow for greater plant diversity (Milchunas and Lauenroth, 1993; Green and Kauffman, 1995; Bai et al., 2001) and inhibit the establishment of weed species (Milchunas et al., 1992) without affecting root mass (Milchunas and Lauenroth, 1993; Greenwood et al., 1997). When land is frequently grazed, plant morphology changes to have shorter stems, shorter leaves, and greater tiller density (McNaughton, 1984). Patch selection of forages in pastures occurs when forage supply is greater than the forage demand (Ring et al., 1985), creating patches of forage that preferentially re-grazed throughout the grazing season because the re-growth is highly palatable and of higher nutritional content than the non-grazed patches (WallisDeVries et al., 1999) . The non-grazed patches become a source of forage when the grazed patches can no longer produce an adequate amount of forage, such as times of little precipitation (Wilms et al., 1988). As grazing cattle concentrate grazing efforts on a repeated area, the removed vegetation mass and sward height may lead to increased amounts of surface runoff (Haan et al., 2006). Additionally, the congregation of cattle in a riparian area may remove vegetative cover producing areas of bare ground with a high susceptibility to surface runoff (Line et al., 1998; Butler et al., 2006).

Cattle Excretions

As much as 75 to 95% of the nutrients ingested by a grazing animal are returned to the pasture through urine and feces (Whitehead, 1995). Direct deposition of cattle feces into surface water sources is a source of NPS pollution, as cattle feces contain high levels of P (McDowell and Stewart, 2005). Gary et al. (1983) observed that 6 to 11% of the total defecations by cattle during an 11-hr day took place while cattle were directly within a stream. However, Ballard and Krueger (2005) observed that cattle spent less than 0.01% of their time directly defecating within a stream. Differences between the time spent defecating within a stream are likely related to the amount of total time the cattle spend within a stream, as distribution of cattle feces is directly proportional to the amount of time an animal spends in an area (Ballard and Krueger, 2005; Haan et al., 2010).

Defecations on the banks of surface waters pose water quality concerns, as fecal phosphorus can contribute to nutrient loading in surface runoff (McDowell et al., 2007), creating higher concentrations of P in the runoff that enter surface water resources. However, P solubility declined with time and drying of the feces (Smith et al., 2001; McDowell et al., 2006). Risks of fecal contamination also decreased with increasing distance between the fecal material and the water's edge (Larsen et al., 1994).

Allowing a drying period for the feces and increasing distance of fecal deposition from a water source can decrease the probability of transporting viable pathogens to the water source (Pell, 1997; Entry et al., 2000), as cattle can shed pathogens through their feces that can present health hazards to humans (Pell, 1997). More than 150 of these pathogens can transmit an infection from animals to humans (Strauch and Ballarini, 1994). Pathogenic bacteria (e.g. Escherichia coli O157:H7), protozoa (e.g. Crypotosporidium), and a number of viruses (e.g. Bovine rotavirus and Bovine Coronavirus) can all be shed from cattle and cause human illness (Pell, 1997).

Cryptosporidiosis is a cause for gastroenteritis associated with water. The entire life cycle of cryptosporidium takes place within a single host (Odonghue, 1995); however, it has also been observed to occur without a host (Higgawi et al., 2004). Infection of cryptosporidium begins with the ingestion of viable oocysts (Fayer and Ungar, 1986; Odonoghue, 1995), followed by release of infectious sporozoites from the oocysts (Reduker and Speer, 1985). The oocysts then attach to epithelial cells in the intestine and reproduce in both asexual and sexual stages to produce more oocysts which can be shed in the feces once again (Thompson et al., 2005). These protozoa are difficult to control because their oocysts remain viable for over a year and resist many commercially available disinfectants when used at standard concentrations (Odonoghue, 1995).

Cizek et al. (2008) observed that transport of cryptosporidium in NPS runoff was in low concentrations compared to indicator organisms. A study by Atwill et al. (2002) found that soil types with reduced bulk densities and greater infiltration capacities had a better ability to inhibit cryptosporidium transport than soil with greater bulk density and less water infiltration. Tate et al. (2000) observed that bank slope was an important factor in the pathogen transport and that most oocysts are released from feces during the first rainstorms after manure deposition. Transport of cryptosporidium occurs as a single unit unattached to soil particles (Kaucner et al., 2005); however, the concentration of the organism can be reduced by 99.9% with vegetative buffers greater than 3-m in mild to moderate storms (Atwill et al., 2002).

Viral pathogens such as Bovine coronavirus can be transmitted via feces or nasal secretions from an infected animal to the nasal or oral cavities of a non-infected animal (Saif et al., 1986). Bovine coronavirus is prevalent in both calves and adult cows (Langpap et al., 1979; Crouch and Acres, 1984). Contracting the virus in young calves leads to diarrhea caused by poor absorption of nutrients and lesions occurring in the intestines (Langpap et al., 1979; Saif et al., 1986). Transport ability of viral pathogens in precipitation runoff is still largely unknown (Ferguson et al., 2003); however, Bovine coronavirus adsorbs tightly to clay and clay minerals (Clark et al., 1998). Therefore, the virus is likely to remain within the soil unless sediment is removed in runoff.

Of the bacteria that are excreted by cattle, *E. coli* O157:H7 is the most pathological, causing hemolytic-uremic syndrome (HUS) in humans. This disease is characterized by bloody diarrhea and kidney failure (Pell, 1997). In order for an animal to show clinical signs of *E. coli* O157:H7 infection, the bacteria must first colonize the intestines, where the bacteria are able to produce a Shinga-like toxin, causing HUS (Gyles, 2007). Less than 700 organisms are needed for infection to take place in humans (Tuttle et al., 1999), as the bacteria is resistant to the acid defense mechanisms of the gastric system in the body (Benjamin and Datta, 1995; Lin et al., 1996).

Infectious doses of the bacteria in cattle range from less than 300 cfu for calves (Besser et al., 2001) to over 10^4 cfu for adult cattle (Cray and Moon, 1995). Along with a higher required infectious dose, adult cattle shed the bacteria in lesser amounts and for a shorter amount of time after infection than calves (Cray and Moon, 1995). The reduced risk seen in adult cattle is likely due to the adult cattle having a well-developed rumen, as *E. coli* O157:H7 grows poorly in a well-fed rumen environment (Rasmussen et al., 1993).

Most cattle remain clinically normal after infection with *E. coli* O157:H7 has taken place (Cray and Moon, 1995). Additionally, shedding of the bacteria can vary from a week to a few months or longer (Cray and Moon, 1995; Grauke et al., 2002). Also, some cattle may be chronic shedders, shedding high amounts of the bacteria over very long periods of time (Matthews et al., 2006). Shedding of the bacteria by the cow does not correlate to shedding of the bacteria by the calf (Pearce et al., 2004; Shaw et al., 2004). Survival of *E. coli* O157:H7 outside the animal's body varies based on the outside environmental conditions (Pell, 1997). *Escherichia coli* O157:H7 has been observed to survive in individual fecal pats for 18 weeks when stored at 15 °C (Fukushima et al., 1999).

Avery et al. (2008) conducted a study comparing the survival of *E. coli* O157:H7 in streams, puddles, lakes and animal water troughs. After a two-month incubation period, *E. coli* O157:H7 remained in all sites. However, concentrations were greater in lakes and manured water puddles than in rivers and water troughs. Because cattle may carry *E. coli* O157:H7 in their saliva, the bacteria can last over six months in animal water toughs, because cattle drinking from the trough are continually re-infecting the trough with the bacteria (LeJeune et al., 2001), increasing the likelihood of re-infection and spread of the bacteria through the cattle herd (LeJeune et al., 2001; Avery et al., 2008).

Escherichia coli concentrations in feces have been observed to be greater in summer than in winter periods (Muirhead, 2006; 2009). Additionally, *E. coli* bacteria increase in concentration once the feces are deposited (Muirhead, 2009). The amount of *E. coli* in the surface runoff can vary as much as seven orders of magnitude and is closely related to the concentration of bacteria in the feces (Muirhead et al., 2006). Additionally, Doran and Lynn (1979) found that fecal coliforms were five to ten times greater in runoff from grazed pastures (approx. 1 cow-calf pair·ha^{-1} than from non-grazed areas. *Escherichia coli* are typically found in runoff in individual organisms, not clumped together or attached to soil particles (Muirhead et al., 2005; 2006).

Fish and Wildlife

Vegetation along the banks of streams can comprise more than 90% of the total energy and organic matter that is needed to support aquatic ecosystems (Kauffman and Krueger, 1984). Streamside vegetation can also account for a majority of food that is utilized by fish in large streams. In the Missouri River, plant seed and debris make up much as 54% of the organic matter ingested by fish (Berner, 1951).

Streamside vegetation is important for stream water temperature regulation (Meehan et al., 1977). Vegetation can minimize high temperature extremes as well as temperature range (Kauffman and Krueger, 1984; Hickey and Doran, 2004). Temperature regulation can be the most important factor in the presence of sporting fish species, such as trout (Barton et al., 1985).

Likewise, birds have been found to be highly dependent upon the riparian habitat or to utilize riparian habitat almost exclusively (Kauffman and Krueger, 1984), although some prefer to nest in spaces typical of a grazed pasture as compared to a buffered site (Renfrew and Ribic, 2001).

Livestock can negatively impact small mammals by trampling burrows, compacting soil, and competing for food (Hayward et al., 1997). Small mammals that prefer vegetative cover are the quickest to take advantage of newly fenced riparian areas (Giuliano and Homyack, 2004). After only a few years (1 to 2 years) of livestock exclusion from a riparian buffer, small mammal species richness increased 1.7 times and animal abundance increased 2.2 times (Giuliano and Homyack, 2004). Additionally, reclaimed riparian buffers of adequate size may result in formation of vegetated land areas large enough to allow transfer of genetics within an animal species from one area of isolation to another (Gregory et al., 1991). However, species that benefit the most from livestock exclusion from riparian areas are species that are widespread and are not considered an endangered species (Hayward et al., 1997).

EFFECT OF GRAZING MANAGEMENT ON CATTLE DISTRIBUTION

Measurement of Cattle Distribution

In order to determine the effect of a particular management technique, one needs be able to track where cattle are spending their time. Historically, cattle distribution has been measured by trained observers during daylight hours (Gary et al., 1983; Sheffield et al., 1997). However problems with visual observations including observation restriction to daylight hours, potential to alter grazing patterns, and observer fatigue have led to the utilization of GPS collars to monitor cattle movement (Agouridis et al., 2004). The GPS collars have inherent pitfalls, such as loss of accuracy near fences and under tree cover (Agouridis et al., 2004), limited memory (Franklin et al., 2009) or battery life, and a significant purchasing expense. However, GPS collars have the ability to monitor cattle location 24 hours a day with an accuracy of only a few meters (Agouridis et al., 2004; Franklin et al., 2009; Haan et al. 2010).

Off-stream Water, Shade, and Mineral

Grazing management practices of providing off-stream resources such as water, shade, and mineral are intended to lure cattle from pasture streams to minimize their effects on stream characteristics. If cattle spend less time in and near a stream, there will likely be less negative consequences caused by the cattle (Ballard and Krueger, 2005; Haan et al., 2010). Off-stream water, shade, and mineral have all been shown to effectively alter cattle distribution to upland portions of pastures (McIlvain and Shoop, 1971; Godwin and Miner, 1996; Sheffield et al., 1997; Porath et al., 2002; Bailey and Welling, 2007; Bailey et al., 2008a; Franklin et al., 2009).

Porath et al. (2002) found that cattle were drinking as much as 45% of their daily water requirements from off-stream water sources in 10 to 15 ha pastures in northeastern Oregon. A similar study was conducted by Sheffield et al. (1997) on three pastures, 14.2 to 22.3 ha, in southwest Virginia. Cattle activity and distribution were measured during 3 day-long observations both before and after implementation of an off-stream water source. The average time spent drinking or being located within the stream area was reduced from 6.7 to 0.7 $min \cdot d^{-1}$ and 12.7 to 6.2 $min \cdot d^{-1}$, or by 89 and 51%, respectively.

Franklin et al. (2009) conducted a similar study in the Georgia Piedmont on 2 pastures sized 15.3 and 17.5 ha. Time spent within the riparian area of the pasture stream was reduced by 63% (52 min·d^{-1}) when cattle were allowed access to off-stream water approximately 86 m from the stream if the temperature humidity index (THI) was 62 to 72. However, during times of environmental stress (THI > 72), providing alternative water to cattle through water troughs had no effect on cattle distribution from the stream. Thus, alternative water may be a viable management practice during less stressful environmental conditions (Franklin et al., 2009). On a previous study at the same site, Byers et al. (2005) found a 40 to 96% reduction in the amount of time spent in the riparian zone with the availability of off-stream water. In a much smaller pasture in Oregon (1.2 ha), during a short duration study (42 d), off-stream water approximately 23 m from the stream decreased the time that cattle were near the stream by 75 % (Godwin and Miner, 1996).

However, not all studies monitoring the effect of off-stream water have shown such significant results. In central Iowa, short term access to off-stream water was not shown to affect cattle distribution near pasture streams (Haan et al., 2010). Also, studies on small pastures in New Zealand (1.1 ha; Bagshaw et al., 2008) and Kentucky (2.3 -3.4 ha; Agouridis et al., 2005) did not find an effect of off-stream water altering cattle usage of the riparian area. Additionally, a study by Bryant (1982) on large (345 ha) pastures in northeast Oregon also found no effect of off-stream water on cattle distribution.

Providing an alternative water source coupled with supplementing a trace-mineral salt away from pasture streams can also effectively alter cattle distribution (Porath et al., 2002). Bailey et al. (2008a) compared the effects of either salt or a low-moisture mineral block (LMB) together or salt alone on their ability to attract cattle to underutilized portions of rangeland away from water sources. Results of the study showed that salt along with a LMB did entice the cattle to utilize higher elevations, travel farther, and spend more time away from a water source compared to supplementing with salt alone (Bailey et al., 2008a). Likewise, a LMB had a greater ability to alter cattle distribution than a conventional dry supplement, as cattle made more trips to the LMB than the dry mix (Bailey and Welling, 2007). Supplementing molasses to grazing cattle may also attract cattle to underutilized areas of a pasture (Bailey and Welling, 1999), and may decrease the use of riparian areas by the cattle (McDougald, 1989 as cited by Bailey and Welling, 1999). However, like most strategies, off-stream supplementation is not always effective. For example, cattle usage of the riparian areas was not affected by addition of off-stream salt supplement in a study by Bryant (1982).

Benefits of shade to altering cattle distribution would likely be dependent upon environmental conditions (Schutz et al., 2010). Ittner et al. (1954) observed that feedlot beef cattle require approximately 5.6 m^2 of shade per animal ; however, Schutz et al. (2010) observed that pastured dairy cattle will spend greater amounts of time under shade if more is provided. In a study by Schutz et al. (2010), grazing dairy cows with no or little shade (2.4 $m^2 \cdot hd$) spent more time within 4.5 m of a water trough than cows with greater shade (9.6 $m^2 \cdot hd$) with an increasing effect as the ambient temperature increased. In pastures with streams surrounded by well-shaded riparian areas, Zuo and Miller-Goodman (2004) did not see any effect of constructed off-stream shade and water troughs on cattle distribution. Therefore, only if shade is limited in a pasture will installing off-stream shade encourage cattle to congregate away from the stream during periods of heat stress (Byers et al., 2005).

As seen above, off-stream water, mineral, and off-stream shade are heavily employed practices to alter cattle distribution and behavior; however, other techniques have also been successfully implemented. For example, low stress mid-day herding of cattle to upland areas effectively reduced the amount of time that cattle utilized riparian areas in Montana rangeland (Bailey et al., 2008b). Also, the implementation of selective culling can remove cattle that prefer to loiter in streams in comparison to cattle that spend more of their time in upland areas of pastures (Howery et al., 1996).

Rotational Stocking

Rotational stocking is a popular form of managing cattle distribution which incorporates rest and re-growth periods allowing increased growth of highly palatable and photosynthetic young leaves (Parsons et al., 1988; Parsons and Penning, 1988), increased land carrying capacity, and increased grazing season length (Hull et al., 1967). The formation of a rotational stocking system requires fragmenting a pasture into smaller paddocks. The formation of these paddocks can be variable in size, depending upon desired stocking time and intensity. With the formation of these paddocks, one is able to limit cattle distribution to the boundaries of paddock, and can limit cattle's access to riparian areas with the formation of a riparian paddock (Bryant, 1982; Haan et al., 2010). Therefore, the timing of the periods in which the riparian area is stocked can be managed by producers to prevent cattle access to stream banks when stream banks are most susceptible to erosion, such as early spring (Simon and Collison, 2002).

Minimizing the time cattle spend in a riparian paddock can also be accomplished with altered grazing practices when cattle are stocked in a riparian zone paddock. Such practices include limiting the time that cattle are stocked in the riparian paddock, or limiting the residual sward height before cattle are moved from paddock (Haan et al., 2010). Strategies such as rotational stocking allow cattle to be stocked in a riparian area for a time long enough to utilize forage, but short enough to minimize cattle impacts on the stream and provide resting periods between grazing bouts long enough to allow the area to recover (Warren et al., 1986a; Lyons et al., 2000b).

Riparian Buffers

Fencing stream banks and only permitting cattle access to designated stream crossings is another method to improve cattle distribution (Haan et al., 2010). However, most grazing studies implementing riparian buffers with stream crossings did not quantify the presence of cattle within or near a pasture stream, but focused on the effects of cattle exclusion on stream bank erosion (Agouridis et al., 2005; Miller et al., 2010a).

Haan et al. (2010) restricted cattle access to a stream to crossings in central Iowa that were approximately 33 m long by 4.9 m wide on either side of the stream. Time spent by cattle within the stream banks and within 33 m of the stream banks was reduced by 90.7 and 94.2%, respectively. Additionally, with increasing temperatures, the probability of cattle being present in or near the stream in restricted access pastures increased less than in pastures in which cattle had free access to the pasture stream.

EFFECT OF GRAZING MANAGEMENT ON NPS POLLUTION

Off-stream Water, Shade, and Mineral

Although the amount of activity rather than presence of cattle in a stream may be a better indicator of erosion caused by cattle (Agouridis et al., 2005), management strategies have been studied to reduce the amount of time cattle spend near a stream and, thereby, reduce stream bank erosion and improve stream water quality in pastures (Nellesen et al. 2010) (Godwin and Miner, 1996; Sheffield et al., 1997; McInnis and McIver, 2001; Agouridis et al., 2005; Byers et al., 2005; Haan et al., 2006; Magner et al., 2008; Zaimes et al., 2008a; Miller et al., 2010a).

In a study in southwest Virginia by Sheffield et al. (1997), providing cattle access to off-stream water reduced stream bank erosion by 77%. Likewise, suspended sediment and total P in the stream were reduced in the stream by 90 and 81%, respectively, by offering off-stream water to grazing cattle. Byers et al (2005) found that allowing cattle access to an off-stream water trough significantly decreased the amount of suspended solids, total P, dissolved reactive P, and Escherichia coli in the stream. Additionally, off-stream water allowed a 75% reduction in the amount of water drank from the stream (Byers et al., 2005). Godwin and Miner (1996) found that providing off-stream water resulted in a similar reduction in time spent by cattle in a stream which caused a 75% reduction in the amount of feces deposited into the stream.

McInnis and McIver (2001) provided both off-stream water and mineral in 12 ha pastures in Oregon. Although an erosion index showed that there was no significant difference in the potential for stream bank erosion to take place between supplemented and non-supplemented pastures, uncovered and unstable stream banks were reduced from 9 to 3% by implementing off-stream practices.

Rotational Stocking

In addition to forage quantity and quality benefits, rotational stocking systems have potential to deter stream bank erosion, surface runoff, degradation of stream quality (Lyons et al., 2000b; Sovell et al., 2000; Haan et al., 2006; Magner et al., 2008; Zaimes et al., 2008a). Intensive rotational stocking (IRS), incorporating 0.4 to 2 ha paddocks with grazing limited to less than 4 days with 15 to 45 day rest period, was studied by Lyons et al. (2000b). The authors found that utilizing IRS in riparian areas near pasture streams was comparable to a vegetative buffer strip in regards to minimizing bank erosion and the amount of fine substrates within the streams.

In an Iowa study by Zaimes et al. (2008a), rotational stocking, IRS, and continuous stocking, were compared to row-crop and different streamside buffers; riparian forest buffers, grass filters, and pastures with cattle fenced out of the stream. Results showed that the stocking treatments had similar bank erosion rates; however, in some cases IRS showed reduced erosion. These rates were greater than those seen from riparian forest buffers, grass filters, and pastures with cattle fenced out of the stream, but lower than those seen from row-crop fields (Zaimes et al., 2008a).

In a similar study in southeastern Minnesota, Magner et al. (2008) found that non-grazed sites had less soil compaction and greater bank stability than grazed sites and continuously grazed sites had greater soil density, greater stream evolution, and less stream bank vegetation than non-grazed sites. Short duration grazing resulted in stream channel characteristics that were between non-grazed and continuously stocked values. As a result, grazing stream banks for short periods of time may have environmental benefits over continuous grazing (Magner et al., 2008).

Utilization of rotational stocking can allow the management of forage height in a pasture (Haan et al., 2006; 2010). Haan et al. (2006) observed that increasing the residue sward height from 5 to 10 cm decreased runoff of both sediment and P to levels observed in a non-grazed control. Similar results were seen by Sovell et al. (2000), as streams in rotational stocking treatments had less fecal coliforms and a lower turbidity than continuously stocked pasture streams.

Riparian Buffers

Installation of riparian buffers on stream banks has met opposition from producers and land owners because of the costs of creating the buffer, formation of weeds and general appearance, fence maintenance, and loss of pasture (Hafner and Brittingham, 1993; Unterschultz et al., 2004). Nevertheless, non-grazed pastures or riparian buffers have been used in many studies to decrease erosion rates (Kauffman et al., 1983; Lyons et al., 2000b; Zaimes et al., 2008a), and surface runoff amounts (Thurow et al., 1986; Haan et al., 2006; Miller et al., 2010b) compared to continuous grazing pasture treatments.

In a study by Miller et al. (2010b), fencing pasture streams and limiting cattle access to cattle crossings improved stream health by improving vegetative cover, standing litter, and reducing soil bulk density. Also, water quality degradation was prevented by reducing surface runoff and sediment, and P loading in the runoff after three years of grazing management techniques (Miller et al., 2010b).

In a non-grazed control, Haan et al. (2006) found decreased total runoff and P loading in surface runoff compared to a continuously stocked pasture. Along with improved runoff effects, there were increased vegetative ground cover, sward height, and forage mass, which also improved runoff characteristics (Haan et al., 2006). Thurow et al. (1986) found that sediment production was reduced in a non-grazed livestock enclosure compared to rangeland that was heavily continuously stocked at 4.6 $ha \cdot au^{-1} \cdot y^{-1}$. Results of the study also found that sediment production was highly related to vegetative cover and above-ground forage biomass.

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CHAPTER 3. EFFECTS OF PASTURE MANAGEMENT AND OFF-STREAM WATER ON TEMPORAL/SPATIAL DISTRIBUTION OF CATTLE IN COOL-SEASON GRASS PASTURES[1,2,3]

A paper to be submitted to the Journal of Animal Science

K. A. Schwarte*, J. R. Russell*[4], D. G. Morrical*

*Department of Animal Science, Iowa State University, Ames, Iowa 50011

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[4]Correspondence: 313 Kildee Hall (e-mail: jrussell@iastate.edu)

ABSTRACT

A two-year grazing experiment was conducted to assess the effects of grazing management on cattle distribution and pasture and stream bank characteristics. Six 12.1-ha cool- season grass pastures in central Iowa were allotted to one of three treatments: continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access restricted to 4.9-m wide stabilized crossings (CSR), or rotational stocking (RS). Pastures were stocked with 15 fall-calving Angus cows (*Bos taurus* L.) from mid-May to mid-October for 153 d in 2008 and 2009. A GPS collar programmed to record cow position every 10 min was placed on at least one cow per pasture for two weeks of each month from May through September. Off-stream water was provided to cattle in CSU and CSR treatments during one of the two weeks when GPS collars were placed on the cattle. A black globe temperature relative humidity index (BGTHI) was measured at 10 min intervals to match the time of the GPS measurements. Each month that cattle were stocked on the pastures, forage characteristics (sward height, forage mass, and CP, IVDMD, and phosphorus concentrations) and bare and fecal-covered ground were measured. Stream bank erosion susceptibility was visually scored in May, August, and October (pre-, mid-, and post-stocking). Cattle in RS and CSR treatments spent less time ($P < 0.10$) within the Stream Zone (0 to 3 m from stream center) in June and August and in the Streamside Zone (0 to 33 m from Stream Zone) in May through August and May through September, respectively,

than cattle in CSU pastures. However, off-stream water had no effect on cattle distribution. Compared to the CSU treatment, the CSR treatment reduced the probability ($P < 0.10$) that cattle were within the Riparian Zone (0 to 36 m from stream center) at BGTHI of 50 to 100. Bare ground was greater ($P < 0.10$) in pastures with the CSU than CSR and RS treatments in the Stream and Streamside Zones in September and October and in July and September, respectively. Streams in pastures with the CSU treatment had less stable banks ($P < 0.10$) mid- and post-stocking than RS or CSR treatments. Results of the experiment show that time spent by cattle near pasture streams can be reduced by RS or CSR treatments, thereby, decreasing risks of sediment and nutrient loading of pasture streams even during periods of increased BGTHI.

Key Words: beef cows, cattle distribution, GPS collars, grazing management, riparian buffer, stream bank erosion

INTRODUCTION

Deterioration of stream bank vegetation and stability from congregation of cattle in riparian areas of grazed lands can lead to increased stream bank erosion and surface runoff (Trimble and Mendel, 1995). Both erosion and runoff from pastures and rangelands are major routes of phosphorus (P) transport (Carpenter et al., 1998; Alexander et al., 2008), which may lead to the eutrophication of freshwater sources (Sharpley et al., 1994).

Riparian areas within a pasture are sources of highly palatable forages, water, and shade for thermoregulation of grazing cattle (Kauffman and Krueger, 1984). The favorable microenvironment in a riparian area entices grazing cattle to spend disproportionate amounts of time within the area, resulting in over-grazing and accelerated stream bank erosion (Belsky et al., 1999).

Effects of cattle on the deterioration of riparian areas are likely dependent on the amount of time and activity of the cattle within the area (Agouridis et al., 2005). However, complete exclusion of cattle from pasture streams is often impractical because of financial costs and loss of grazing land (Untershultz et al., 2004). Off-stream water (Godwin and Miner, 1996; Sheffield et al., 1997; Byer et al., 2005), supplements (Bailey and Welling, 2007; Bailey et al., 2008; George et al., 2008), and shade (McIlvain and Shoop, 1971) have improved grazing distribution or reduced impacts of grazing cattle on non-point source (NPS) pollution of streams in western rangelands or southern pastures in the United States. However, there has been limited evaluation of these management strategies in the temperate environment of the Midwest.

The objective of this experiment was to evaluate the efficacy of restricting stream access to stabilized sites or riparian paddocks or providing off-stream water to improve grazing distribution and reduce stream bank deterioration associated with grazing cattle in Midwestern cool-season grass pastures.

MATERIALS AND METHODS

All procedures for animal use in this experiment were reviewed and approved by the Institutional Animal Care and Use Committee at Iowa State University.

Site Description

This experiment was conducted during the 2008 and 2009 grazing seasons at the Iowa State University Rhodes Research Farm (lat 42° 00’N, long 93° 25’W) in the Willow Creek watershed in central Iowa (Figure 1). The site contained six adjoining 12.1-ha cool-season grass pastures, each bisected by 141-m reach of a perennial flowing stream. Soils at the experiment site were classified as Ackmore (fine-silty, mixed, nonacid, mesic Aeric

Fluvaquent) and Nodaway (fine-silty, mixed, nonacid, mesic Mollic Udifluvent) silt loams. Pastures primarily contained a mixture of smooth bromegrass (*Bromus inermis* L.) and reed canarygrass (*Phalaris arundinacea* L.) with lesser amounts of tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.) and legumes. Pastures were not fertilized during the experiment or for at least three grazing seasons prior to the experiment.

In 2005, during a previous experiment by Haan et al. (2010), the pastures were grouped into two blocks and randomly assigned one of three grazing treatments. Treatments included: continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access restricted to 4.9 m wide stabilized crossings (CSR), or rotational stocking (RS). In the CSR treatment, cattle were not allowed access to the streamside buffer (approximately 0.91 ha) which reached approximately 33 m to either side of the stream. The stream access ramp was stabilized in the stream and to 11.3 m on either side of the stream by a geofabric base covered with 15.2 cm deep polyethylene webbing (Presto Geosystems, Appleton, WI) filled with crushed rock. Pastures in the RS treatment were divided into a five-paddock rotation with 4 upland paddocks (2.78 ha) and a single riparian paddock (0.91 ha). Upland paddocks were grazed until half of the forage was consumed as estimated with a falling plate meter (4.8 $kg \cdot m^{-2}$; Haan et al., 2007) or for a maximum of 14 d. Riparian paddocks were grazed for a maximum of 4 d or to a minimum sward height of 10 cm (Clary and Leininger, 2000) as measured by the falling plate meter (Haan et al., 2007).

Ninety fall-calving Angus cows (*Bos taurus* L.; initial BW (mean ± SD) 618.6 ± 47.4 and 576.9 ± 48.7 kg, respectively) were blocked by age and weight and randomly assigned to one of the six pastures in 2008 and 2009. Cows were stocked on the pastures from mid-May to mid-October for 153 d in both years.

On both sides of the stream, off-stream water sites were located at least 240 m away from the stream in the upland portions of the pasture. Fences were placed around water sites in CSU and CSR pastures to control cattle access. Cattle were offered a P-free mineral (calcium max 30% min 25%, NaCl max 19.4 min 16.2%, magnesium 1.0%, potassium 0.5%, copper 1,000 ppm, manganese 3,750 ppm, selenium 24 ppm, zinc 3,750 ppm, Vitamin A 250,000 IU/lb, Vitamin D_3 100,000 IU/lb, and Vitamin E 400 IU/lb; Kent Feeds, Inc., Muscatine, IA) free-choice in mineral feeders placed adjacent to each off-stream water site.

Weather

A data logging HOBO weather station (Onset Comp. Co., Bourne, MA), located in the streamside buffer in the middle of the experiment site, recorded black globe temperature (BGTemp) and relative humidity (RH) at 10 min intervals and total precipitation throughout the grazing season (Figure 2a,b). In 2008, the data logger measuring RH failed in the months of June and July. Therefore, for consistency purposes, RH data for the 2008 season was downloaded from the NOAA weather station in Marshalltown, IA (approx. 24.1 km from the experiment site). To measure stream stage height, pressure transducers (GE Druck, Inc., New Fairfield, CT) were placed near the upstream and downstream borders of the experiment site. A measurement was taken every 15 min and daily high and low stages were recorded on Campbell CR-10 and CR-510 data loggers (Campbell Scientific, Logan, UT) from May through October of each year (Figure 2a,b).

Cattle Distribution

Pastures were divided into four zones to determine cattle location in relation to distance from the stream using ArcGIS 9.1 (ESRI, Redlands, CA) of aerial maps of known pasture coordinates (Haan et al., 2010). Pasture zones included: Stream Zone (3 m buffer from the center of the stream), Streamside Zone (0 to 33 m from the Stream Zone), Exchange Zone (33 to 66 m from the Stream Zone), and the Upland Zone (greater than 66 m from the Stream Zone). For determination of the effect of climate on cattle distribution, the Stream and Streamside Zones were combined to form the Riparian Zone. The Stream, Streamside, Exchange, and Upland Zones were 0.6, 6.6, 6.6, and 86.2% of the pasture area, respectively. The Riparian Zone was approximately the same size as the riparian paddocks and buffers in the RS and CSR treatments, respectively.

Cattle distribution was measured at 10 min intervals 24 $hr \cdot d^{-1}$ by placing GPS collars (AgTraX^{tm} - BlueSky Telemetry, Aberfeldy, Scotland and Ames Laboratory's Engineering Services Group (ESG), Ames, IA) on 1 to 2 cows per pasture for two weeks each month in May through September (Figure 2a,b). In 2008, the experiment utilized six AgTraX^{tm} collars; however, successive collar failure generated a need for additional collars. Prototype collars of comparable accuracy, designed by the Ames Laboratory's ESG, provided a cost effective option (Table 1) with the additional advantage of immediate repair service. Collar accuracy was tested in an open field with a clear view of the sky for 139 consecutive hours by placing collars on wooden stands located at coordinates marked by a RTK-GPS unit (Agouridis et al., 2004). Differential correction of the GPS data was not possible as collars only recorded date, time, position, and battery status.

Cattle in the CSU and CSR treatments were allowed access to off-stream water for one of the two weeks of GPS data collection to monitor the effects of off-stream water. At the end of the two week period, collars were removed and data points were downloaded onto ArcGIS 9.1 for processing and deletion of erroneous positions. Erroneous positions (< 2% of total) included positions recorded while cattle were traveling to and from working facilities, and positions recorded well outside pasture fences.

A black globe temperature humidity index (BGTHI; Figure 2a, b; Mader et al., 2006) was calculated for every 10 min interval using the equation;

$$BGTHI = [0.8 \times BGTemp] + [(RH \div 100) \times (BGTemp - 14.4)] + 46.4$$

and paired with each GPS observation. The number of observations of a cow within a given zone was divided by the total number of observations at that BGTHI unit to determine the probability of a cow being in a zone at that BGTHI unit (Haan et al., 2010).

Pasture Characteristics

Pasture characteristics (sward height, forage mass and composition, and bare and fecal-covered ground) were measured monthly May through October in each zone (Stream, Streamside, Exchange, and Upland). For pasture characteristic determinations, the Stream Zone was considered to extend to the top of the stream banks, approximately 3 m from the edge of the stream. The remaining zones were approximately at equivalent distances from the stream as the zones used for cattle distribution measurements.

Pasture characteristics were measured from three randomly selected sites in open and congregation areas on each side of the stream in the Stream, Streamside, and Exchange Zones. Congregation areas were considered to be areas under the drip line of trees or near stream access points or off-stream water and mineral supplementation sites. In the Upland Zone, 24 open and 12 congregation sites were measured on each side of the stream; however, forage mass and composition were only measured in half of sites in the open areas. Because soil on the stabilized stream ramps and access sites was covered with geofabric, polyethylene webbing, and crushed rock and feces were difficult to identify on the crushed rock, no pasture characteristics were measured on the ramps or the access sites in the Stream or Streamside Zones of the pastures with the CSR treatment.

At each site, sward height was measured with a falling plate meter (4.8 $kg \cdot m^{-2}$; Haan et al., 2007), and forage was hand-clipped within a 0.25-m^2 square to a 2.5 cm stubble height. Forage samples from open or congregation areas within each zone were composited by pasture monthly. Bare and fecal-covered ground was measured parallel to the stream using the line-transect method over 15.2 m (Laflen et al., 1981). The total amount of congregation area within each zone in each pasture was measured with a tape measure in July of each year and subtracted from the total area of each zone in each pasture to calculate the size of open areas. Mean percentages of congregation area were 22.5, 32.4, and 28.3% in the Stream Zone and 3.6, 4.6, and 1.5% in the Streamside Zone for CSU, CSR, and RS treatments, respectively. Sward height, forage mass, forage composition, and bare and fecal-covered ground of each zone within each pasture were calculated as means weighted by the proportion of congregation and open areas within that zone and pasture.

Laboratory Analysis

Forage samples were dried for 48 hr at 65°C and weighed. Dried samples were ground through a 1-mm screen using a Wiley Mill (Arthur H. Thomas Co. Philadelphia, PA) and sub-sampled for laboratory analysis. Forage CP was determined as 6.25 times total Kjeldahl nitrogen (AOAC, 1990). Forage IVDMD was measured by a 48-hr incubation in ruminal fluid, collected from a fistulated steer fed a grass hay diet, and the NC-64 buffer followed by a 24 hr incubation after addition of a HCl-pepsin solution (Tilley and Terry, 1963 as modified by Barnes and Marten, 1979). Forage P was determined by combustion in a muffle furnace at 550^{o}C for 4 hr followed by an acid extraction of the ash with 6N hydrochloric acid, a molybdovanadate reaction and colorimetric determination against a standard curve (Spectronic Instruments, Rochester, NY) at 400 nm (AOAC, 1990).

Stream Bank Erosion Susceptibility

In May, July, and October (pre-, mid-, and post-stocking) of each year, stream banks were visually scored by a single person using an erosion susceptibility score (Nellesen et al., 2011). Erosion susceptibility scores were the product of slope [1(flat) to 3(steep)], vegetative cover [1 (heavy) to 4 (bare)], and stability [1 (stable) to 5 (very unstable)] scores and were weighted for their percentage of the length of stream including the ramps of the stabilized stream crossings. Scores could range from 1 to 60 with a lower score representing a bank that was less susceptible to erosion and a higher score representing a bank with greater potential for stream bank erosion.

Statistical Analysis

For all analyses, pasture was considered the experimental unit. Effects of grazing treatment (CSU, CSR, and RS) on the distribution of cattle within each zone were measured using GPS data when off-stream water was not available to the cattle. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) was used to determine treatment differences for cattle distribution, stream bank slope, vegetation, stability, and erosion susceptibility scores, and pasture and forage characteristics with a model that included the fixed effects of year, treatment, and their interactions, and a random effect of block by treatment to account for repeated measures on the same pastures. Block was not a significant effect in most analyses; therefore, it was removed from the model statement. To analyze the effects of grazing treatment (CSU and CSR) and off-stream water on cattle distribution, off-stream water availability (water) and the water by year interaction were inserted into the model as fixed effects. An additional random effect of the water by cow interaction was applied because collars were placed on the same cow in each pasture over the two-week data collection period.

The GLIMMIX procedure (SAS Inst. Inc., Cary, NC) was utilized to analyze the effect of BGTHI on the probability of cattle being located within the Riparian Zone at each BGTHI unit. The model included the fixed effects of year, treatment, off-stream water availability (water) and their interactions, and random effects of block by treatment and water by cow. The probability of cattle being within the Riparian Zone occurred at 10 integer intervals from 50 to 100, as points beyond this range were scarce, using the AT statement in the LSMeans.

Differences between means of variables with significant treatment effects were determined by comparing the LSMeans using the PDIFF statement along with a Tukey adjustment. Significance was determined at a level of $P < 0.10$. Cattle distribution, pasture characteristics, and erosion susceptibility data were analyzed by month and zone when applicable.

RESULTS

Cattle Distribution

Cattle in the CSU treatment spent a greater proportion of time within the Stream Zone than cattle in either CSR or RS treatments in June and August ($P < 0.10$; Figure 3a). In each month, cattle spent a greater proportion of time ($P < 0.10$) within the Streamside Zone in the CSU treatment than in the CSR treatment (Figure 3b). Similarly, cattle in the RS treatment spent less time ($P < 0.10$) in the Streamside Zone than cattle in the CSU treatment in all months except September (Figure 3b). However, by chance, periods when GPS collars were placed on cattle and when cattle were stocked within the riparian paddock in the RS pastures never occurred at the same time except for September of 2009. Cattle were stocked in the riparian paddock of the RS pastures for 6 d (3.9%) of the grazing season in both 2008 and 2009.

Allowing cattle access to off-stream water did not consistently alter cattle distribution (Figure 4a,b). Access to off-stream water increased ($P < 0.10$) the proportion of time cattle spent within the Stream and Streamside Zones in the pastures with the CSU treatment in June. However, off-stream water decreased the proportion of time that cattle spent within the Streamside Zone in pastures with the CSU treatment in May and September ($P < 0.10$). Off-stream water caused no differences in the proportions of time that cattle were in the Stream or Streamside Zones in pastures with the CSR treatment in any month.

Year and year by treatment interactions on cattle distribution rarely occurred within the Stream or Streamside Zones. Cattle spent more time within the Stream Zone of pastures with the CSR treatment during May of 2008 than in 2009 causing both year effects (Year, $P = 0.0474$) and year by treatment interactions (Year x Treatment, $P < 0.10$). In contrast, cattle in all treatments spent more time within the Streamside Zone in August of 2009 than in 2008 (Year, $P < 0.0856$).

Statistical differences observed in the proportion of time that cattle spent in the Exchange and Upland Zones of CSU, CSR, and RS pastures were minimal or irrelevant with or without the presence of off-stream water (data not shown).

Cattle in the CSU treatment had a greater probability ($P < 0.05$) of being within the Riparian Zone from a BGTHI of 50 to a BGTHI of 100 than cows in the CSR treatment (Figure 5). Also, the probability of cattle being within the Riparian Zone increased more rapidly (*P* = 0.0014) for pastures with the CSU than CSR treatments as BGTHI increased. As observed above, off-stream water did not affect the probability of time that cattle spent within the Riparian Zone at any index in CSU or CSR pastures (data not shown). No effects of year or year by treatment were observed for the effect of BGTHI on the probability of cattle being in the Riparian Zone (*P* > 0.10).

Forage Characteristics

Forage sward heights in the Stream Zone were greater (*P* < 0.10) in July, September, and October in pastures with the CSR than CSU treatment (Table 2). Forage sward heights in the Stream Zone of pastures with the RS treatment did not differ from either the CSU or CSR treatment in any month. In the Streamside Zone, forage sward heights were greater (*P* < 0.10) for pastures with the CSR than CSU treatment in every month except May and were greater (*P* < 0.10) than pastures with RS treatment in July through October. However, pastures with the RS treatment had greater (*P* < 0.10) sward heights than the CSU treatment in June through August. Sward heights were greater (Year, *P* < 0.10) in 2009 than 2008 in the Stream Zone in May, June, September, and October, which may be partially caused by the heavy rains and increased stream flow in May and June of the 2008 grazing season. However, sward height was greater (Year, *P* = 0.0816) in the Streamside Zone in May of 2008 than 2009. Year by treatment effects occurred in August in the Streamside Zone as CSR and RS treatments had a greater difference (Year x Treatment, *P* < 0.01) in sward heights from the CSU treatment in 2009 than in 2008. No treatment differences in sward heights were seen in the Exchange or Upland Zones (*P* > 0.10; data not shown).

Although differences in sward heights were observed in the Stream Zone, the Stream Zone of pastures with the CSR treatment had greater (*P* < 0.10) forage mass than either the

CSU or RS treatment only in October. The difference between these measurements may have resulted from the uneven terrain on the stream banks which may have caused less accurate readings from the falling plate meter. In the Streamside Zone, pastures with the RS and CSR treatments had greater ($P < 0.10$) forage mass than the CSU treatment from June through September and July through October, respectively. Pastures with the CSR treatment maintained greater ($P < 0.10$) forage mass than the RS treatment in September and October. Forage masses in the Stream Zone were greater (Year, $P < 0.10$) in July, August, and October of 2009 than 2008, which may have also been partially caused by heavy rains occurring in May and June of the 2008 grazing season. In the Streamside Zone, forage mass was greater (Year, $P < 0.10$) in 2008 than 2009 in the months of July and September, but greater (Year, $P = 0.0143$) in October of 2009 than 2008. Year by treatment effects occurred in October in the Streamside Zone as the CSR treatment had greater forage mass in 2009 than in 2008 (Year x Treatment, $P = 0.0105$) compared to CSU and RS treatments.

Few treatment differences in forage mass were observed in the Exchange or Upland Zones ($P > 0.10$; data not shown). Also, few differences in forage quality characteristics (CP, IVDMD, and P) were observed in the Stream and Streamside Zones between treatments in any month (Appendix Table 1).

Ground Cover

The proportions of bare ground in the Stream and Streamside Zones were greater ($P < 0.10$) in the CSU treatment than the CSR and RS treatments in September and October, and July and September, respectively (Table 3). Although large numeric differences in bare ground occurred in each month in the Stream Zone, lack of statistical differences between treatments in other months may be attributed to high variability in the measurements and few treatment replicates. Bare ground was greater (Year, $P < 0.10$) in the Stream Zone in June and in the Streamside Zone in July of 2008 than 2009, but was greater (Year, $P < 0.10$) in Stream Zone in May of 2009 than 2008. Year by treatment effects occurred in the Streamside Zone as there was greater bare ground in the CSU treatments in July of 2008 than in 2009 (Year x Treatment, $P = 0.0429$) compared to CSR and RS treatments.

Because cattle were not allowed to graze the riparian buffer on either side of the stream crossings in pastures with the CSR treatments and feces was too difficult to identify to be able to be measured on the stabilized crossings, no cattle feces were found in either the Stream or Streamside Zones of the CSR treatment. Therefore, treatment differences between CSR and CSU or RS were tested by whether the treatments were statistically different from zero. Fecal-covered ground in the Stream Zone of pastures with the CSU treatments was greater ($P < 0.10$) than the CSR treatment in June, July, September, and October, and greater ($P < 0.10$) than RS treatments in June and October (Table 3). Pastures with the RS treatment had greater ($P < 0.10$) fecal-covered ground than the CSR treatments in July. In the Streamside Zone, fecal-covered ground in pastures with the CSU treatment was greater ($P < 0.10$) in May through September than the CSR treatment and in May, June, and August than the RS treatment. Pastures with the RS treatment had greater ($P < 0.10$) fecal-covered ground than the CSR treatment in September. The assumption that pastures with the CSR treatment had no manure in the Stream and Streamside Zone likely underestimated the amount of feces in these zones, as fecal-covered ground on the stabilized crossings could not be measured and the distribution of defecations is proportional to the distribution of cows in these zones (Haan et al., 2010). Because time spent by cows in CSR pastures in the Stream and Streamside Zones was 5.1 and 4.6 times, respectively, lower than cows in CSU pastures, there would be proportionally less feces in these zones in pastures with the CSR treatment.

Fecal-covered ground was greater in the Stream Zone in June of 2009 than 2008 (Year, $P = 0.0018$). Fecal-covered ground was also greater (Year, $P < 0.10$) in the Streamside Zone in May and July of 2009 than 2008, but was lower (Year, $P < 0.10$) in the Streamside Zone in June in 2009 than 2008. Year by treatment effects in the Stream Zone occurred in July and September as more fecal-covered ground was found ($P < 0.10$) in the CSU treatment in 2009 than 2008, but fecal-covered ground did not differ between years for the CSR and RS treatments. In the Streamside Zone, more fecal-covered ground was found in June of 2008 than 2009 in the CSU treatment (Year x Treatment, $P = 0.0472$).

Erosion Susceptibility

Stream bank slope score did not differ ($P > 0.10$) between treatments (Table 4). However, the stream bank stability score was lower ($P < 0.10$) in pastures with the CSR and RS treatments than the CSU treatment mid- and post-stocking, implying greater bank stability in CSR and RS pastures. Stream banks in pastures with the CSR treatment had a lower ($P = 0.07$) vegetation cover score than the CSU treatment post-stocking, implying greater vegetation on banks of CSR pastures. As the product of these combined measurements, the stream bank erosion susceptibility score was lower ($P = 0.0530$) for pastures with the CSR and RS treatments than the CSU treatment post-stocking, implying that stream banks with the CSR and RS pastures were less susceptible to erosion than CSU pastures. However, the differences in the bank stability and erosion susceptibility scores may have related to intrinsic channel conditions as the stream bank stability and erosion susceptibility scores of pastures with the CSU treatments were 12.9 and 38.5% greater than pastures with the CSR treatment and 29.6 and 58.8% greater than pastures with the RS treatment when initiated in May, 2005 (Nellesen et al., 2011). These differences were likely the result of the stream in both CSU pastures and one RS pasture having oxbows opposite of cut banks while the stream in CSR pastures did not have any oxbows (Figure 1).

Yearly effects of bank slope score occurred in post-grazing as the banks had a greater (Year, $P = 0.0156$) slope in 2009 than in 2008, which may be caused by bank cutting that took place over the winter across treatments between the two grazing seasons. As the proportion of bare ground was greater on the stream banks in 2008 than 2009, the mean pre-grazing vegetation score on stream banks was lower (Year, $P = 0.0054$), implying less vegetative cover in 2008 than 2009. This lower vegetative cover and high rainfall in May and June of 2008 (Figure 2a) may have reduced bank stability as stream banks were less stable mid-grazing of 2008 than 2009 and pre-grazing in 2009 than 2008 as indicated by greater (Year, $P < 0.10$) bank stability scores. The effects of reduced pre-grazing vegetative cover and May and June rainfall on bank stability were less in the CSR treatment than the other treatments as the bank stability in the CSR treatment was lower mid-grazing in 2008 than 2009 (Year x Treatment, P = 0.0391) compared to CSU and RS treatments. The effects of reduced pre-grazing vegetation and increased early precipitation on subsequent bank stability are also supported by the erosion susceptibility scores which were lower (Year, $P < 0.05$) pre-grazing in 2008 than 2009, but greater mid-grazing in 2009 than 2008. The timing of these erosive processes apparently varied as the post-grazing erosion susceptibility score was greater for the CSR treatment, but lower for the RS treatment in 2008 than 2009 (Year x Treatment, $P < 0.05$).

DISCUSSION

Grazing cattle congregate in riparian areas within pastures because they are sources of food, water, and heat stress relief (Ballard and Krueger, 2005). Allowing grazing cattle unrestricted access to pasture streams at high stocking rates can cause damage to stream banks resulting in increased erosion and surface runoff (Trimble, 1994; Line et al., 2000; Byers et al., 2005). In the current experiment, averaged over all months, cattle in the CSU treatment spent 1.8 and 9.0% of the time within the Stream and Streamside Zones, respectively, when off-stream water was not available. Thus, allowing cattle unrestricted stream access increased the risk of nonpoint source pollution of pasture streams.

Restricting cattle access to pasture streams through stabilized crossings reduced the percentage of time that cattle were in the Stream and Streamside Zones by 5.1 and 4.6 times compared to the CSU treatment, respectively. Similar observations were reported by Haan et al. (2010). It seemed that cattle were uncomfortable loitering within the stream crossing, whether caused by the close proximity to the electric fences or the crushed rock that lined the stream crossing. Additionally, rapid transition of the cattle through stream crossings may have resulted in undocumented cattle presence in or near the stream, as the GPS collars only recorded position every 10 min. However, the stabilization of the stream crossing should minimize any erosion that takes place from these short stays.

Restricting cattle access to pasture streams by the use of riparian paddocks in rotationally stocked pastures also reduced the percentage of time that cattle were in the Stream and Streamside Zones by 20.7 and 2.3 times (as measured by GPS collar) compared to the CSU treatment, respectively. Even if using the actual days that cattle were in the riparian paddock, this management would reduce the percentage of time they were in the riparian zone by 63.9% compared to the CSU treatment. Furthermore, incorporating a riparian paddock into a rotational stocking system allows for control of cattle stream bank access to a time when the banks are less vulnerable to failure, such as when the stream banks are excessively wet or dry (Langendoen et al., 2009). During the 2008 season of the present experiment, grazing of the riparian paddock in the RS treatment was delayed until late July (ordinal day 212) because of flooding events (Figure 2a). Therefore, stocking of the riparian paddock only occurred from July to October, allowing stream banks to stabilize after the wet spring.

Studies have shown decreased erosion and improved riparian characteristics from the exclusion of cattle from stream banks (Trimble, 1994; Miller et al., 2010). A reduction in the amount of bare ground can significantly reduce the sediment load in precipitation runoff (Russell et al., 2001; Butler et al., 2006; Haan et al., 2006); thereby decreasing bank erosion and NPS pollution. Additionally, increased vegetative cover can reduce the number of freeze-thaw cycles that a stream bank experiences during the winter, reducing the likelihood of bank failure (Wynn and Mostaghimi, 2006). In the current experiment, forage mass, vegetative cover and score, and erosion and stability scores of stream banks were superior in CSR and RS pastures in comparison to CSU pastures. Therefore, restricting cattle access of pasture streams to stabilized stream crossings or implementing a riparian paddock in a grazing system may minimize the risks of stream bank erosion and surface runoff. However, evaluation of the effectiveness of such treatments in preventing stream bank erosion needs to consider the initial and long-term changes in the conditions of the stream banks at the implementation of the treatments. While the rate of increase in the erosion susceptibility score for stream banks in the CSU pastures was nearly 4 times greater than CSR pastures over the five years since implementation of the treatments (Nellesen et al., 2011), the rate of increase in the bank stability scores did not differ between these treatments. This observation is supported by the lack of difference in erosion rates between treatments as measured with erosion pins (Nellesen et al., 2011; Schwarte, 2010). Thus, differences in erosion susceptibility scores between these treatments were primarily the result of changes in the vegetative cover score which increased $2.9\%\cdot yr^{-1}$ and decreased $2.7\%\cdot yr^{-1}$ for stream banks in the CSU and CSR pastures, respectively, while not changing in RS pastures over the five years since implementation of the treatments.

Cattle feces are rich in nutrients, including P, and may contain pathogenic organisms (McDowell et al., 2006). Therefore, reductions in the amount of feces deposited in streams or on stream banks will reduce the potential for NPS pollution. As the distribution of fecal deposits is highly related to cattle location, reductions of the proportion of time cattle spend in and near a stream will reduce the amounts of feces in and near the stream (Haan et al., 2010). The proportion of ground covered with feces within the riparian zone and the proportion of time cattle spent near the stream in this experiment was reduced in the CSR and RS treatment. Therefore, the risk of feces contaminating a pasture stream would be reduced by restricting cattle access to a stabilized stream crossing compared to the CSU treatment. While not as great as the CSR treatment, pastures with the RS treatment also had reductions in the proportions of fecal-covered ground and the presence of cows in the Streamside Zone compared to the CSU treatment. Thus, the use of a riparian paddock would also reduce the risk of NPS of pasture streams by reducing the load and transport of fecal nutrients from the Streamside Zones of pastures.

Cattle prefer to graze regions with high quality forages which may be localized in riparian regions in western rangelands (Bailey, 2005). However, throughout the pastures in this experiment, few differences in forage quality were observed between treatments and zones. Therefore, it is unlikely that cattle distribution was altered by differences in forage quality.

Off-stream water has been effective in reducing the amount of time cattle spend in riparian areas of both western rangelands and eastern pastures (Sheffield et al., 1997; Porath et al., 2002). In contrast, short-term cattle access to off-stream water in this experiment did not decrease the amount of time that cattle spent in or near a stream in cool-season grass pastures in central Iowa. Similarly, Haan et al. (2010) found little response in cattle distribution to short-term access to off-stream water on the same pastures during the three years preceding this experiment. The lack of effectiveness of off-stream water at this site may be a result of ample precipitation that occurred during this experiment (Figure 2a, b). Monthly precipitation averaged 10.4, 22.4, 10.3, 7.2, 8.8, and 6.0 cm from May to October during the 2008 and 2009 grazing seasons while the average monthly precipitation in May to October at this site is 10.8, 13.4, 12.6, 11.5, 8.1, and 6.6 cm, respectively (NOAA, 2008). These amounts of precipitation resulted in a large number of natural off-stream water sources such as small puddles and gullies throughout the pastures. Therefore, in years in which pastures in the Midwest receive adequate rainfall to produce natural off-stream watering sites, there may be no benefit from the implementation of additional off-stream watering troughs. Although inconsistent effects of off-stream water on cattle distribution were observed in the CSU treatment, no benefits to off-stream water were ever observed in the

CSR treatment; suggesting that the addition of off-stream water to pastures with restricted stream access to a stream crossing would not be effective in altering cattle distribution.

Along with ambient temperature, black globe temperatures can account for solar radiation (Buffington et al., 1981), allowing BGTHI to be a useful measure of environmental stress on black-hided cattle (Mader et al., 2006). Franklin et al. (2009) observed that off-stream water troughs were more likely to result in a reduction of time that cattle spent in pasture riparian zones at a non-stressful temperature humidity index (THI) than at stressful THI. In the present experiment, off-stream water did not affect the probability of cattle being within the Riparian Zone at any BGTHI. However, in May and September, which had lower maximum BGTHI than the other months during the experiment (Figure 2a, b), off-stream water reduced the proportion of time cattle were in the Streamside Zone. Because cattle may not be able to dissipate accumulated heat during hot and humid days (Mader et al., 2006), off-stream water may have greater effectiveness during less stressful days with a greater proportion of the day at a lower heat index.

CONCLUSION

Allowing grazing cattle unrestricted access in and near pasture streams can increase the potential for NPS pollution by increasing bare and fecal-covered ground and reducing stream bank vegetation and stability. With proper grazing management, cattle can be allowed to graze riparian areas of a pasture without increasing the stream bank's susceptibility to erosion. Both rotational stocking and restricting stream access to stabilized crossings are effective in minimizing the amount of time cattle spend in and near pasture streams; even during periods of elevated heat stress. The altered temporal/spatial distribution increases stream bank vegetation and reduces fecal accumulation and erosion susceptibility of stream banks. However, short term access to off-stream water has little effect on cattle distribution in Midwestern pastures in years with adequate precipitation.

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Table 1. Comparison of the accuracy of GPS collars from two sources.

Type	Times Used[a]	Percentage of points within specified distance from standardized location 3 m	5 m	10 m
Prototype[b]	25	53.73	75.32	91.15
AgTraX[tm, c]	35	49.28	68.17	97.78

[a]Number of times a collar was placed on a cow throughout experiment.

[b]Designed by Ames Laboratory's Engineering Services Group, Ames, IA.

[c]BlueSky Telemetry, Aberfeldy, Scotland.

Table 2. Effects of cattle grazing management on forage characteristics within the Stream (3 m from stream) and Streamside (3 to 33 m from stream) Zones.

		Month					
		May	June	July	August	September	October
Item	Treatment[a]	Stream Zone					
Sward height, cm	CSU	5.3	11.4	9.5[b]	9.6	7.0[b]	3.9[b]
	CSR	10.0	18.9	23.1[c]	27.1	19.8[c]	16.4[c]
	RS	9.6	20.8	16.9[bc]	14.4	15.4[bc]	9.6[bc]
	SEM[e]	1.5	4.1	1.9	4.2	1.9	1.8
		Streamside Zone					
	CSU	12.3	17.7[b]	11.4[b]	9.1[b]	5.3[b]	4.5[b]
	CSR	16.6	34.3[c]	35.3[c]	30.4[c]	20.2[c]	18.6[c]
	RS	15.7	36.1[c]	25.0[d]	21.9[d]	11.5[b]	8.9[b]
	SEM	1.8	1.4	1.9	1.3	1.5	1.1
		Stream Zone					
Forage mass, kg/ha	CSU	457.2	943.6	1160.2	1211.7	1003.2	515.8[b]
	CSR	790.0	1513.8	2337.8	2292.9	2295.6	2270.3[c]
	RS	929.5	2018.2	2772.0	1883.3	1790.4	1353.9[b]
	SEM	168.9	412.5	475.3	394.3	332.9	190.5
		Streamside Zone					
	CSU	1499.5	1541.9[b]	1715.8[b]	1564.5[b]	843.5[b]	678.3[b]
	CSR	1827.0	3226.4[bc]	3457.9[c]	5345.5[c]	4426.6[c]	4430.9[c]
	RS	1883.9	4089.8[c]	3608.3[c]	4447.3[c]	2948.9[d]	1787.5[b]
	SEM	199.4	442.8	230.2	563.6	302.9	535.1

[a]CSU= continuous stocking with unrestricted stream access, CSR= continuous stocking with restricted stream access to 4.9 m stabilized stream crossing, RS= rotational stocking.

[b-d]Means within a column with different subscripts differ ($P < 0.10$).

[e]Standard error of the means (n=4).

Table 3. Effects of cattle grazing management on ground cover characteristics within the Stream (3 m from stream) and Streamside (3 to 33 m from stream) Zones.

		Month					
		May	June	July	August	September	October
Item	Treatment[a]	Stream Zone					
Bare ground,%	CSU	46.16	36.66	31.75	34.69	39.98[b]	25.75[b]
	CSR	19.88	18.20	10.12	11.61	9.58[c]	2.85[c]
	RS	24.87	17.71	18.87	18.79	14.53[c]	8.45[c]
	SEM	6.62	8.45	6.03	5.28	5.03	2.22
		Streamside Zone					
	CSU	3.08	0.42	1.53[b]	3.30	2.36[b]	0.56
	CSR	0.04	0.25	0.16[c]	0.14	0.13[c]	0.04
	RS	0.16	0.26	0.02[c]	0.05	0.08[c]	0.00
	SEM	0.89	0.15	0.09	0.74	0.46	0.16
		Stream Zone					
Fecal-covered ground, %	CSU	0.07	0.27[b]	0.52[b]	0.48	0.68[b]	0.89[b]
	CSR	0.00	0.00[c]	0.00[c]	0.00	0.00[c]	0.00[c]
	RS	0.03	0.00[c]	0.42[b]	0.51	0.39b[c]	0.17[b]
	SEM	0.05	0.01	0.13	0.21	0.20	0.06
		Streamside Zone					
	CSU	0.18[b]	0.30[b]	0.86[b]	0.75[b]	1.03[b]	0.61
	CSR	0.00[c]	0.00[c]	0.00[c]	0.00[c]	0.00[c]	0.00
	RS	0.04[c]	0.00[c]	0.50b[c]	0.21[c]	0.75[b]	0.72
	SEM	0.03	0.08	0.22	0.11	0.18	0.31

[a]CSU= continuous stocking with unrestricted stream access, CSR= continuous stocking with restricted stream access to 4.9 m stabilized stream crossing, RS= rotational stocking.

[b-d]Means within a column with different subscripts differ ($P < 0.10$).

[e]Standard error of the means (n=4).

Table 4. Effect of cattle grazing management on the stream bank erosion susceptibility scores.

Item[b]	Treatment[c]	Period[a] Pre-stocking	Mid-stocking	Post-stocking
Stream bank slope score	CSU	2.42	2.43	2.47
	CSR	2.61	2.69	2.64
	RS	2.63	2.54	2.57
	SEM[d]	0.18	0.24	0.16
Stream bank vegetation score	CSU	3.19	3.16	2.92[e]
	CSR	2.28	2.03	1.70[f]
	RS	2.29	2.24	2.09[ef]
	SEM	0.30	0.37	0.24
Stream bank stability score	CSU	4.07	4.20[e]	4.06[e]
	CSR	3.27	2.96[f]	3.05[f]
	RS	3.26	3.33[f]	3.38[f]
	SEM	0.19	0.19	0.10
Stream bank erosion susceptibility score	CSU	33.84	33.73	30.82[e]
	CSR	23.31	19.86	17.00[f]
	RS	22.25	20.99	19.90[f]
	SEM	2.80	3.35	2.41

[a]Measurements were taken pre-, mid-, and post-stocking (May, July, and October, respectively)

[b]Slope = 1(flat) to 3(steep), vegetative cover = 1 (heavy) to 4 (bare), and stability = 1 (stable) to 5 (very unstable), erosion susceptibility score = 1 (less prone to erosion) to 60 (highly prone to erosion)

[c]CSU= continuous stocking with unrestricted stream access, CSR= continuous stocking with restricted stream access to 4.9 m stabilized stream crossing, RS= rotational stocking.

[d]Standard error of the means (n=4).

[e,f]Means within a column with different subscripts differ ($P < 0.10$).

Figure 1. Pasture design of the Rhodes Research Farm

Figure 2a,b. Daily mean black globe temperature humidity index (BGTHI), maximum stream stage, and precipitation throughout the 2008 (a) and 2009 (b) grazing seasons. Shaded periods indicate times when GPS collars were placed on cattle. Ordinal day 136 = May 16th.

Figure 3a,b. Mean proportion of time spent within the Stream Zone (a; 0 to 3 m from stream center) and Streamside Zone (b; 0 to 33 m from Stream Zone) by cattle grazing pastures with treatments of continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), and rotational stocking (RS). Treatment means within a month with different letter differ ($P < 0.10$). Standard error of the means is shown as positive value only. RS Riparian Paddock refers to the proportion of time that cattle were actually stocked in the riparian paddock

Figure 4a,b. Mean proportion of time spent within the Stream Zone (a; 0 to 3 m from stream center) and Streamside Zone (b; 0 to 33 m from Stream Zone) by cattle grazing pastures with treatments of continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR) when off-stream water was made available (open) or not available (closed). Means within treatment within month with a different letter differ ($P < 0.10$). Standard error of the means is shown as positive value only.

Figure 5. Probability that cattle will be within the Riparian Zone (0 to 33 m from stream center) at differing black globe temperature humidity index (BGTHI) values when grazing pastures with treatments of continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR) when off-stream water was made available (Open) or not available (Closed). Treatments within a BGTHI with differing letters differ ($P < 0.10$). A 90% confidence interval of the means is shown by extending bars.

Figure 1.

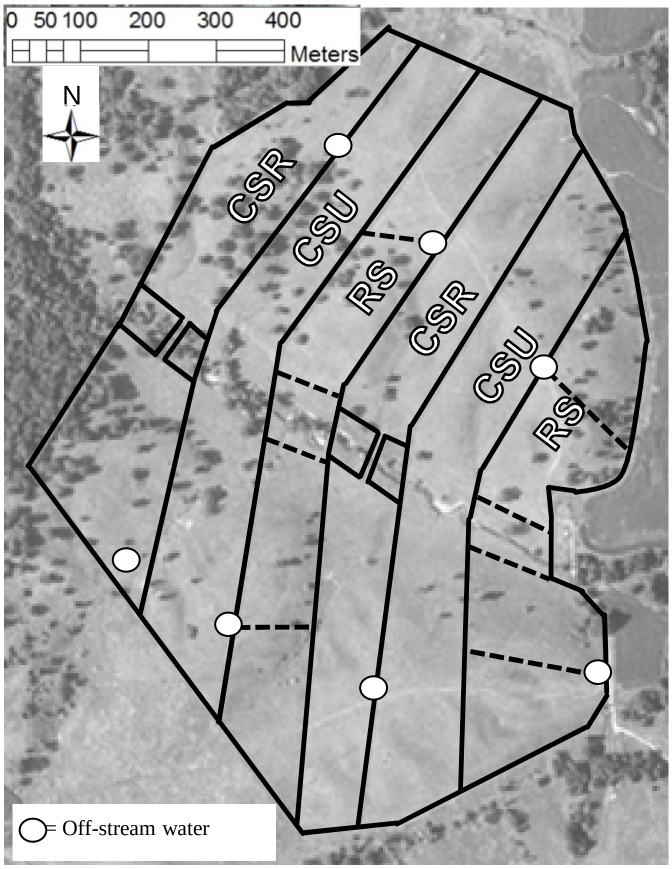

0 50 100 200 300 400
Meters
N
CSR
CSU
RS
CSR
CSU
RS
= Off-stream water

Figure 2a,b.

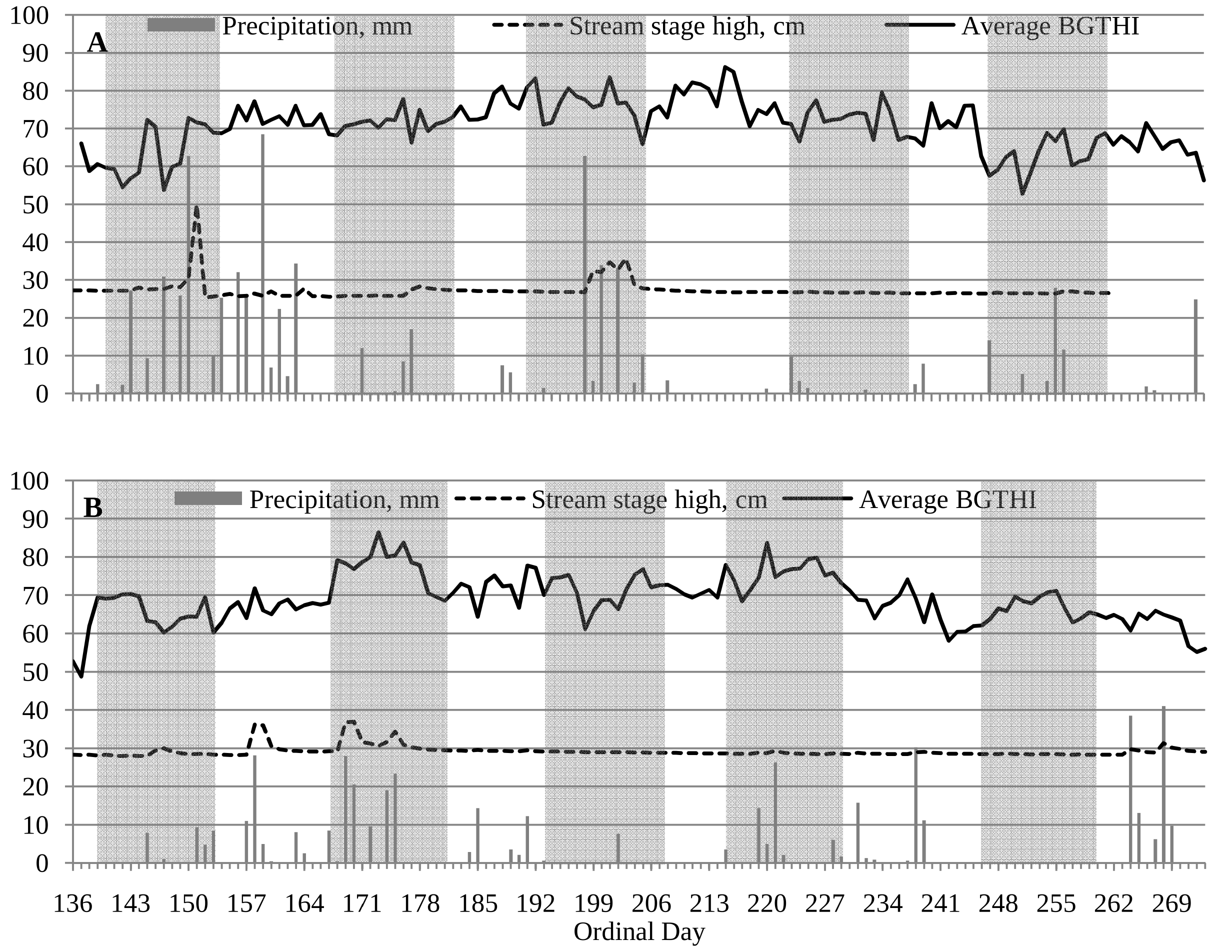

A
B
Precipitation, mm
Stream stage high, cm
Average BGTHI
100
90
80
70
60
50
40
30
20
10
0
136 143 150 157 164 171 178 185 192 199 206 213 220 227 234 241 248 255 262 269
Ordinal Day

Figure 3a,b.

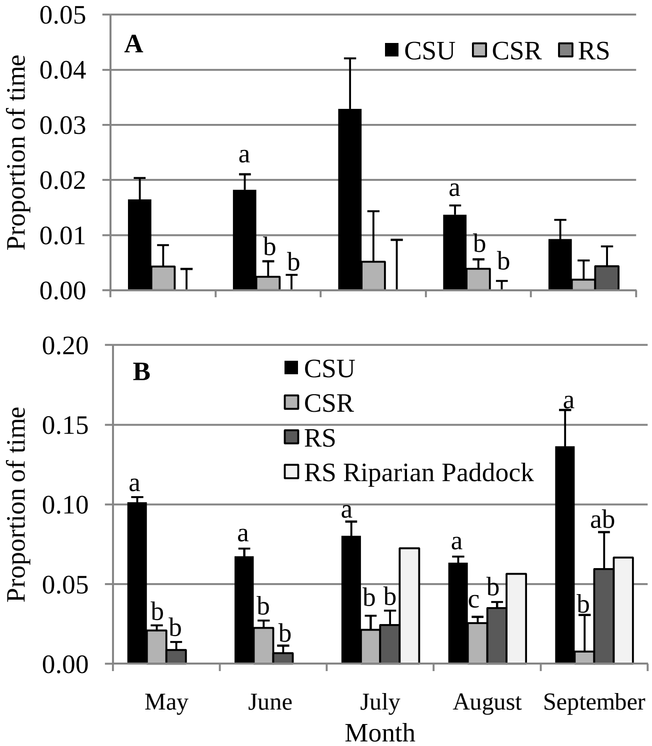

0.05
0.04
0.03
0.02
0.01
0.00
Proportion of time
A
CSU
CSR
RS
a
b
b
0.20
0.15
0.10
0.05
0.00
B
CSU
CSR
RS
RS Riparian Paddock
ab
c
May
June
July
August
September
Month

Figure 4a,b.

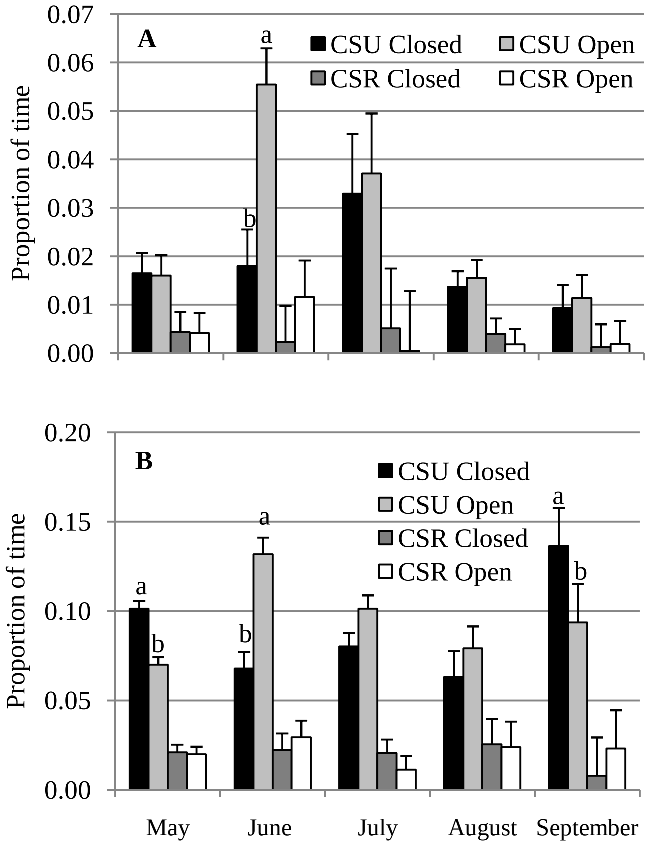
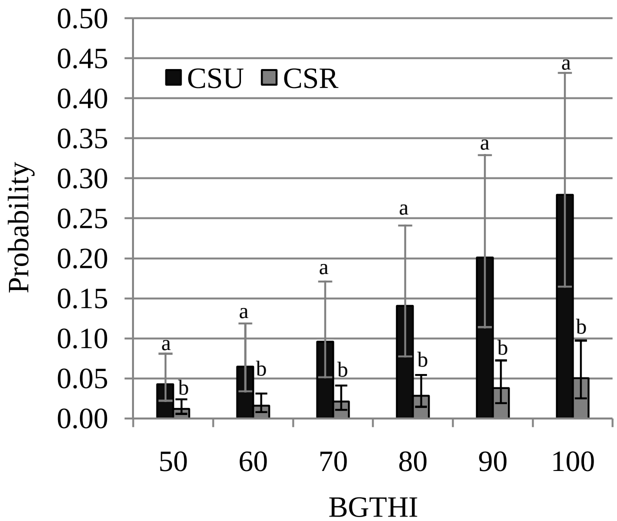

A
B
CSU Closed
CSU Open
CSR Closed
CSR Open
Proportion of time
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.20
0.15
0.10
0.05
a
b
May
June
July
August
September

Figure 5.


0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Probability
CSU
CSR
a
b
50
60
70
80
90
100
BGTHI

CHAPTER 4. GRAZING MANAGEMENT EFFECTS ON SEDIMENT, PHOSPHORUS, AND PATHOGEN LOADING OF STREAMS IN COOL-SEASON GRASS PASTURES

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Kirk A. Schwarte, James R. Russell* Iowa State University

John L. Kovar USDA-ARS

Daniel G. Morrical, Steven M. Ensley, Kyoung-Jin Yoon, Nancy A. Cornick, and Yong-Il Cho Iowa State University

K. A. Schwarte, J. R. Russell, Dept. of Animal Science, Iowa State Univ., Ames, IA 50011; J. L. Kovar, USDA-ARS, National Laboratory for Agriculture and the Environment, Ames, IA, 50011

D. G. Morrical, Dept. of Animal Science, S. M. Ensley and K. J. Yoon, Dept. of Vet. Diagnostics and Production Animal Med., N. A. Cornick and Y. I. Cho, Dept. of Vet. Microbiology and Preventative Med., Iowa State Univ., Ames, IA 50011. Mention of a proprietary product does not constitute a guarantee or warranty of the product by Iowa State University, USDA-ARS, or the authors and does not imply its approval to the exclusion of other products that also may be suitable.

*Corresponding author (jrussell@iastate.edu)

Abbreviations: CSU, continuous stocking with unrestricted stream access; CSR, continuous stocking with restricted stream access; RS, rotational stocking; BEV, Bovine enterovirus; BRV, Bovine rotavirus; BCV, Bovine coronavirus; *E. coli* O157:H7, *Escherichia coli* O157:H7; P, phosphorus

ABSTRACT

A two-year grazing study was conducted to quantify effects of grazing management on sediment, phosphorus (P), and pathogen loading of streams in cool-season grass pastures. Six adjoining 12.1-ha pastures bisected by a stream in central Iowa were divided into three treatments: continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), or rotational stocking (RS). Rainfall simulations on stream banks resulted in greater ($P < 0.10$) proportions of applied precipitation and amounts of sediment and P transported in runoff from bare than vegetated sites across grazing treatments and from vegetated sites in CSU and RS pastures than vegetated sites in CSR pastures. Bovine enterovirus was shed by an average of 24.3% of cows over the study and was collected in the runoff of 8.3 and 16.7% of the simulations on bare sites in CSU pastures in June and October of 2008, respectively, and from 8.3% of the simulations on vegetated sites in CSU pastures in April 2009. Incidence of fecal pathogens [Bovine coronavirus (BCV), Bovine rotavirus (group A), and *Escherichia coli* O157:H7] shed or collected in runoff was almost non-existent, as only BCV was found in feces of one cow in August of 2008 and was never collected in simulation runoff. Stream bank erosion via cut-banks was the greatest contributor of sediment and P loading of pasture streams; contributions of sediment and P from surface runoff and grazing animals were considerably less and minimized by grazing management practices that reduced congregation of cattle by pasture streams.

INTRODUCTION

Erosion and precipitation runoff from pastures and rangelands are major sources of sediment and phosphorus (P) loading of streams (CAST 2002; Alexander et al., 2008), which can lead to the eutrophication and impairment of freshwater sources (Sharpley et al., 1994). Grazing management can decrease the quantities of sediment and P transported in surface runoff (Haan et al., 2006), as well as reduce the quantity of feces directly deposited into the stream (Haan et al., 2010). Off-stream water (Sheffield et al., 1997; Byers et al., 2005), rotational grazing (Lyons et al., 2000; Sovell et al., 2000), and stream bank fencing (Line et al., 2000) have reduced the impact of cattle on the non-point source pollution of pasture streams.

If unmanaged, grazing cattle may congregate in riparian areas of pastures in search of high quality forages, drinking water, and thermoregulation (Kauffman and Krueger, 1984) resulting in decreased vegetation height and cover (Miller et al., 2010), increased soil compaction (Greenwood and McKenzie, 2001), and concentration of feces (Ballard and Krueger, 2005; Haan et al., 2010). Therefore, allowing cattle unrestricted access to pasture streams may increase precipitation runoff and transport of sediment and nutrients in precipitation runoff (Russell et al., 2001; Butler et al., 2006; Haan et al., 2006). Additionally, feces deposited in or near a pasture stream increases the risks of fecal borne pathogens and nutrients reaching the water source (Entry et al., 2000; McDowell, 2006), as most non-point source pollutants from pastures arise from congregation areas near streams (Line et al., 1998; Pionke et al., 2000).

Previous studies have linked stream bank erosion to grazing cattle (Kauffman, 1983; Trimble, 1994). However, these studies fail to account for or separate the amount of bank erosion caused by mass bank failure, primarily linked to stream hydrology (Simon et al., 2000), from the amount caused by gully, rill, or inter-rill erosion, which may be linked to grazing cattle through the formation of cattle paths and bare ground on the stream banks (Elliott et al., 2002; Strunk, 2003).

The objective of this study was to quantify the effects of different grazing management practices on the sources and amounts of sediment, P, and fecal pathogen loading of a pasture stream in grazed pastures.

MATERIALS AND METHODS

All procedures for animal use in this study were reviewed and approved by the Institutional Animal Care and Use Committee at Iowa State University.

Site Description

A two-year study was conducted during the 2008 and 2009 grazing seasons at the Iowa State University Rhodes Research Farm (lat 42° 00’N, long 93° 25’W) in the Willow Creek watershed in central Iowa (Figure 1). The site contains six adjoining 12.1-ha cool-season grass pastures, bisected by 141-m reach of a perennial flowing stream. Soils at the study site were classified as Ackmore (fine-silty, mixed, nonacid, mesic Aeric Fluvaquent) and Nodaway (fine-silty, mixed, nonacid, mesic Mollic Udifluvent) silt loams. The pastures primarily contained a mixture of smooth bromegrass (*Bromus inermis* L.) and reed canarygrass (*Phalaris arundinacea* L.) with lesser amounts of tall fescue (*Festuca arundinacea* Schreb.), Kentucky bluegrass (*Poa pratensis* L.) and legumes. Pastures were not fertilized during the study or for at least three grazing seasons prior to the study.

In 2005, the pastures were grouped into two blocks and randomly assigned to one of three grazing treatments. Treatments included: continuous stocking with unrestricted stream access (CSU), continuous stocking with stream access restricted to 4.9 m wide stabilized crossings (CSR), or rotational stocking (RS). In the CSR treatment, cattle were not allowed access to the streamside buffer (approximately 0.91 ha) which reached approximately 33 m on either side of the stream. Pastures in the RS treatment were divided into a five-paddock rotation with 4 upland paddocks (2.78 ha) and a single riparian paddock (0.91 ha). Upland paddocks were grazed for a maximum of 14 d or until half of the forage was estimated to be removed as measured by a falling plate meter (4.8 $kg \cdot m^{-2}$; Haan et al., 2007). Riparian paddocks were grazed for a maximum of 4 d or to a minimum sward height of 10 cm (Clary and Leininger, 2000) as measured by the falling plate meter. Pastures had been grazed by their respective treatment for three years preceding this experiment and pasture treatments and data related to the temporal\spatial distribution of the grazing cattle have been described previously (Haan et al., 2010; Schwarte et al., 2010). Data related to characteristics of the riparian area and stream bank erosion in these pastures during the first three years of the study were reported by Nellesen et al., (2010).

Ninety fall-calving Angus cows (*Bos taurus* L.; initial body weight (mean ± SD) 618.6 ± 47.4 and 576.9 ± 48.7 kg in 2008 and 2009, respectively) were blocked by age and weight and assigned one of the six pastures. Cows were stocked on the pastures from mid-May to mid-October for 153 d in 2008 and 2009. Cattle were offered a P-free mineral (calcium max 300 $g \cdot kg^{-1}$ min 250 $g \cdot kg^{-1}$, NaCl max 194 $g \cdot kg^{-1}$ min 162 $g \cdot kg^{-1}$, magnesium 10 $g \cdot kg^{-1}$, potassium 5 $g \cdot kg^{-1}$, copper 1 $g \cdot kg^{-1}$, manganese 3.75 $g \cdot kg^{-1}$, selenium 24 $mg \cdot kg^{-1}$, zinc 3.75 $g \cdot kg^{-1}$, Vitamin A 550,000 $IU \cdot kg^{-1}$, Vitamin D_3 220,000 $IU \cdot kg^{-1}$, and Vitamin E 880 $IU \cdot kg^{-1}$; Kent Feeds, Inc., Muscatine, IA) free-choice in mineral feeders.

A data logging HOBO weather station (Onset Comp. Co., Bourne, MA) recorded precipitation using tipping buckets throughout the grazing season.

Rainfall Simulations

Because the average height of the stream bank was approximately 3 m, total area of bare ground, cut-banks, and depositional areas on the stream banks was measured within 3 m of the stream with a tape measure in June, August, and October of 2009 and April of 2010. Vegetated ground cover was considered to be the difference between the total bank area and the area that was bare ground, cut-banks, or depositional areas.

Rainfall simulations were conducted in year 1 (June, August, and October of 2008 and April of 2009) and 2 (June, August, and October of 2009 and April of 2010) at three vegetated and three bare locations with similar slopes (0.21 $\pm$ 0.075 SD rad.) on the stream banks on each side of the stream in CSU and RS pastures and three vegetated locations on the stream banks on each side of the stream within the riparian buffer in CSR pastures. The same sites were used in successive simulations.

Drip-type rainfall simulators (1.0 x 0.5 m; Bowyer-Bower and Burt, 1989) were placed parallel to the bank slope at a height of 1.0 m from the soil surface at the uphill end of the simulator and leveled, allowing simulated rainfall to reach 56% of terminal velocity (Gunn and Kinzer, 1949). Application water, derived from municipal water, was filtered through a 0.45-μm sediment filter and precipitation was applied for 1.5 hr at a rate of 8.4 $cm \cdot hr^{-1}$ to simulate a storm with a 100-year reoccurrence (Huff and Angel, 1992). At 10 min intervals, amounts of precipitation and runoff were recorded and runoff was sub-sampled and added to a composite sample for each simulation. At the end of each simulation, sub-samples of the composited sample were taken for analysis of sediment, P, bovine enteric viruses, and *E. coli* O157:H7. In addition, application water was sampled daily for baseline levels of P, bovine enteric viruses, and *E. coli* O157:H7. Water samples were stored in coolers until transport to the laboratory. Samples for analysis for sediment and P were frozen until analysis. Samples for analysis of bovine enteric viruses and *E. coli* O157:H7 were refrigerated overnight at 4^{o}C and analyzed the following day.

In order to quantify factors affecting the amounts of precipitation runoff and sediment, P, bovine enteric virus and *E. coli* O157:H7 transported, characteristics of each site were measured before each simulation. Ground slope was measured with a digital level (Stabilia, South Elgin, IL). Forage sward height was measured with a falling plate meter (4.8 $kg \cdot m^{-2}$; Haan et al., 2007). Forage mass was determined by hand-clipping an adjacent 0.25-m^2 area with the same sward height as the rainfall site to a stubble height of 2.5 cm (Haan et al., 2006). Surface roughness was measured as the standard deviation of the length of adjacent pins on a 41-pin meter with a length of 2 m (Betteridge et al., 1999). Proportions of bare and fecal-covered ground were determined by counting the number of pins from the pin meter that contacted bare or fecal-covered ground (Betteridge et al., 1999). Soil samples were taken at three sites adjacent to each simulation location at depths of 0 to 5 cm and 5 to 10 cm for determination of antecedent soil moisture.

Fecal Dry Matter and Pathogen Excretion

In order to determine total fecal dry matter excreted, two cows in each pasture were pulse-dosed with 30 g of Cr-mordanted fiber (Russell et al., 1993) in June and August of both years. After dosing, fecal samples were collected at 0, 18, 22, 26, 30, 42, 54, 66, 78, 90,102, and 114 hr. Fecal samples were dried and ground through a 1 mm screen of a Wiley mill (Arthur H. Thomas Co. Philadelphia, PA). Fecal samples and Cr-mordanted fiber were analyzed for Cr by atomic absorption spectrophotometry with an air-acetylene flame of phosphoric acid-manganese sulfate-potassium bromate extracts of ashed samples (Williams et al., 1962). The initial concentration (C_0 in gm·kg^{-1}) and rate of passage (k_p in hr^{-1}) of Cr were estimated from passage kinetics of the Cr-mordanted fiber using nonlinear regression analysis (SAS Inst. Inc., Cary, NC) with a two-compartment age-dependent model (Pond et al., 1988).

Gut fill was calculated as:

$$\text{Gut fill, kg} = \text{Amount of Cr dosed} / C_0$$

Fecal output was calculated as:

$$\text{Fecal output, kg} \cdot \text{d}^{-1} = \text{Gut fill} \times k_p \times 24$$

In order to measure the incidence of shedding of the fecal pathogens, fresh fecal samples were aseptically collected immediately post-excretion from all 90 cows in June, August, and September of both years, stored overnight at 4^{o}C, and analyzed.

Stream Bank Erosion

Stream bank erosion was measured on ten equidistant transects along the stream in each pasture. In 2004, total stream bank area was measured and fiberglass erosion pins, 1.6 cm diameter by 84 cm length, were driven 78 cm perpendicularly into the bank at 1 m intervals from the side of the stream to the top of the bank (Nellesen et al., 2011). Erosion pins were measured monthly from May through October with a measurement of 63 cm (75% of total length) recorded if an erosion pin was lost to bank erosion (Lawler, 1993). Net erosion and erosion\deposition activity were calculated as the means of the measurement and absolute value of the measurement of each pin in each transect, respectively (Nellesen et al., 2011).

Net erosion and erosion\deposition activity and sediment and P loss throughout each grazing season were calculated as the sum of the monthly values. To separate effects of freeze-thaw cycles from effects occurring during the grazing season, data from the grazing season (May to November) were calculated separately from winter data (November to May).

Laboratory Analysis

Sediment in application water and runoff samples was determined by filtering 20 ml of each sample through a pre-weighed 0.45 µm filter paper. The filter paper was dried for 24 hr at 100°C and weighed (APHA, 1995). Total P concentration in application water and runoff samples was determined by digestion of 5 ml samples, followed by colorimetric analysis with the ascorbic acid method P (Hach Company, Loveland, CO; AOAC, 2003).

To measure fecal P, fecal samples from each cow were composited on an equal dry weight basis within month and year and analyzed by combustion in a muffle furnace at 550°C for 4 hr followed by an acid extraction of the ash with 6N hydrochloric acid, a molybdovanadate reaction and colorimetric determination against a standard curve (Spectronic Instruments, Rochester, NY) at 400 nm (AOAC, 1990). Total fecal P excretion was calculated by multiplying the fecal P concentration by the fecal output calculated above.

Incidence of BEV, BCV, and BRV in application water, runoff, and fecal samples were determined by a multiplex real-time reverse transcription-polymerase chain reaction (rRT-PCR), following the methods presented in Cho et al. (2010) with modifications to detect BEV in the samples. Primers and the probe for BEV were adopted from a previous work by Jimenez-Clavero et al. (2005), modified to cover newly reported BEV strains and then included in the rRT-PCR. Extraction procedure and PCR conditions remained the same as previously reported by Cho et al. (2010).

To determine the presence of *E. coli* O157:H7, fecal samples (10 g) were added to 90 ml of GN broth containing 8 $\mu g \cdot ml^{-1}$ vancomycin, 50 $ng \cdot ml^{-1}$ of cefixime and 10 $\mu g \cdot ml^{-1}$ of cefsulodin (Smith et al., 2004). Water samples (10 ml) were inoculated into 90 ml of GN broth. After overnight incubation at 37^{o}C, a 1 ml aliquot was concentrated using O157 specific immunomagnetic beads (Dynal) and plated onto selective agar (sorbitol MacConkey agar with cefixime and tellurite). Pale colonies (non-sorbitol fermenters) were counted and confirmed to be *E. coli* O157:H7 using latex agglutination (Oxiod).

Statistical Analysis

Pasture is considered the experimental unit for all analyses. Precipitation runoff, sediment and P transport, and site characteristic data from the rainfall simulations were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Because there were few bare areas other than cut-banks or depositional areas on the banks in the CSR pastures, pasture treatment and site vegetation were combined to form five site classes: CSU Bare (CSUbare), CSU Vegetated (CSUveg), CSR Vegetated (CSRveg), RS Bare (RSbare), and RS Vegetated (RSveg). The model included the fixed effects of block, year, site class, month, and the interaction of site class and month. Random effects included year by site class by month and block by site class by simulation site to account for repeating the simulation trials at the same simulation sites. Because of non-normal distribution of data, sediment and P concentrations and sward heights were log transformed prior to analysis.

Step-wise multiple regression in SAS (SAS Inst. Inc., Cary, NC) was used to determine the effects of site characteristics (slope, roughness index, sward height, surface cover, soil moisture) on the percentage of precipitation and the amounts of sediment and P transported in runoff. Variable site characteristics with significance of $P > 0.15$ were omitted.

Amounts of bare ground, cut-bank, and depositional area on the stream banks were analyzed by month using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with fixed effects of block and treatment and a random effect of block by treatment.

Fecal dry matter and P excretion data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with a model statement of year, treatment, month, and their interactions. Random effects included block by treatment and block by treatment by cow because fecal analysis was done on the same cows within treatments in both months of a given year.

Net erosion and erosion\deposition activity were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with a model statement of block, year, treatment, season (grazing vs. winter), and the interactions of season by treatment, season by year, and year by treatment. Random effects included block by treatment and year by season by treatment.

Differences between means with significant treatment effects in all analyses were determined by comparing the LSMeans using the PDIFF statement along with a Tukey adjustment for multiple comparisons. Significance was determined at a level of $P < 0.10$.

Treatment differences for the incidences of the viruses and *E. coli* O157:H7 shed by the cattle or collected in the precipitation runoff were not statistically analyzed because of very low occurrence.

Model Calculations

To quantify the sources of sediment, P, and pathogen loading of pasture streams, a model was developed (Figure 2).

As distribution of cattle feces is proportional to the amount of time spent within a pasture zone relative to a stream (Ballard and Krueger, 2005; Haan et al., 2010), the amounts of fecal dry matter and P excreted daily per cow were multiplied by the number of days in a month and the percentage of time cattle spent within the Stream Zone (0 to 3 m from stream center) as measured by GPS collars from Schwarte et al. (2010) to calculate the total amounts of fecal dry matter and P deposited into the stream each month. Annual dry matter and P deposition in the stream per pasture were calculated as the sum of the monthly values multiplied by the stocking rate of 15 cows per pasture.

To predict precipitation runoff from each rainfall event which occurred over the grazing seasons in both years, the REG procedure of SAS (SAS Inst. Inc., Cary, NC) used rainfall simulation data comparing the amount of simulated precipitation applied to the amount of runoff at 10 minute intervals from each site class within each month and year to produce runoff regression equations (Table 1). As the application rates during the simulations was 8.4 $cm \cdot hr^{-1}$, these run-off values should represent a worst case scenario. Linear regressions were used because there was little benefit to the correlation coefficient (< 0.001) by using quadratic equations. Amounts of daily precipitation throughout the entire grazing season of both years were entered into the regression equation at the nearest date to calculate predicted runoff from each site class from a 0.5 m^2 area of land. These runoff quantity data were multiplied by the means of the sediment and P concentrations in the runoff of each rainfall simulation site class, weighted for the volume of runoff from each simulation, to yield the predicted amounts of sediment and P transported from each site class during a runoff event based on a 0.5 m^2 area of land. Mean sediment and P transported within 0.5 m^2 sites of each site class of a pasture were doubled and multiplied by the area of land in that site class within 3 m of the stream to calculate the total amounts of sediment and P transported in runoff from the stream bank within each pasture in each month of each grazing season. Although rainfall simulations could not be conducted on the stabilized stream crossings, P and sediment loads in runoff from these areas were calculated using concentrations and rates from the CSUbare site class and multiplied by the area of bank covered with the stabilized crossing to account for sediment and P loading of the runoff from these stream crossings. Previously, runoff from stabilized sites on 3% slopes with rainfall intensities of 50 $mm \cdot hr^{-1}$ have been reported to be approximately half of that from bare ground (Singh et al., 2008). Therefore, sediment and P loads in run-off from CSUbare site class were halved to calculate the sediment and P loss per m^2. Annual sediment and P transported in runoff during the grazing season of each year were calculated as the sum of the amounts of sediment and P transported monthly.

Sediment and P loss from cut-banks and depositional areas were included in the total sediment and P losses were calculated using erosion pins. The volume of stream bank sediment lost was calculated by multiplying the area of the bank within each pasture by the net erosion, as measured from the erosion pins each month during the grazing season. To calculate the volume of sediment and P lost via cut-bank erosion, the area of cut-bank within each pasture was multiplied by net erosion measured from transects located on cut-banks. Amounts of sediment and P lost from the total bank or cut-bank areas were calculated by multiplying the volume of sediment lost from the total bank or cut-bank area by the bulk density and total P concentration data of bank soil samples taken from the A and C soil horizons in 2006 by Nellesen et al. (2010). Total sediment and P loss from the total bank or cut-bank area in each pasture were calculated as the sum of the sediment and P loss from A and C soil horizons on both sides of the stream.

RESULTS

Stream Bank Cover

The amounts of bare and vegetated ground and cut-bank did not differ (P > 0.10) by treatment (Table 2). However, the stream banks in the CSU treatment had a greater (P < 0.10) proportion of depositional area than did the stream banks in the CSR treatment.

Rainfall Simulations

As designed, bare simulation sites had a greater ($P < 0.01$) proportion of bare ground than vegetated sites, and the slopes of the sites did not differ ($P > 0.10$) between treatments (Table 3), and did not vary by month or years. Forage sward heights at CSRveg sites were greater ($P < 0.10$) than CSUveg sites, and all vegetated sites had greater ($P < 0.05$) sward heights than bare sites. Sward height was greater at the rainfall simulation sites in year 2 (Year, $P = 0.0002$) than year 1. Likewise, sward height differed between each month (Month, $P < 0.10$) with height being greatest in June, followed in order by August, October, and April. Multiple month by treatment effects also occurred (Month x Treatment, $P < 0.10$).

Forage mass of CSRveg sites did not differ ($P > 0.10$) from CSUveg or RSveg sites, but was greater ($P < 0.05$) than CSUbare or RSbare sites. Forage mass was greater in June than other months (Month, $P < 0.05$).

Moisture contents of the top 5 cm of soil were lower ($P < 0.10$) in the CSUveg and CSUbare sites than CSRveg sites (Table 3). Also, moisture contents of the lower 5 cm of soil were lower ($P < 0.10$) in the CSUveg and CSUbare sites than RSveg sites. Soil moisture contents at both depths were greater in year 2 than in year 1 (Year, $P < 0.10$), and were greater in June than August and October (Month, $P < 0.05$). Similarly, soil moisture contents at both depths were also greater in April than August (Month, $P < 0.05$), and soil moisture content in the lower 5 cm was greater in October than August (Month, $P < 0.05$). Soil roughness of the sites did not differ ($P > 0.10$) by treatment, but did differ by month (Month, $P < 0.05$) as sites in April were rougher than the sites in June and August (Table 3).

Precipitation runoff, expressed as l·hr min^{-1} or as a proportion of applied precipitation was greater ($P < 0.05$) from bare than vegetated sites across grazing management treatments (Table 3). Also, RSveg and CSUveg sites had greater ($P < 0.05$) amounts and proportions of runoff than the CSRveg site. Of the characteristics measured, the proportion of runoff of applied precipitation was best predicted by the proportion of bare ground, sward height, antecedent soil moisture (0-5 cm), roughness index, and bank slope ($R^2 = 0.5782$; Table 4). Similar to runoff, transport of sediment ($P < 0.05$) and P ($P < 0.10$) in runoff were greater from bare than vegetated sites across grazing management treatments, and the RSveg and CSUveg sites had greater ($P < 0.05$) amounts of sediment and P transported in runoff than the CSRveg sites. Sediment transport in precipitation runoff was best predicted by the proportion of bare ground and slope ($R^2 = 0.3992$). Phosphorus transport was most accurately predicted by the proportion of bare ground, sward height, and slope ($R^2 = 0.4483$). Of the characteristics measured, the proportion of bare ground was the most significant factor for determining the proportion of runoff of applied precipitation and the amounts of sediment and P transport in runoff resulting in the following regressions (Figure 3):

Runoff, % of applied precipitation = 27.83 + 0.5565x ($R^2 = 0.5050$)

Sediment loss, kg·m^2 = -218.6 + 61.65x ($R^2 = 0.3811$)

P loss, g·m^2 = -68.18 + 150.3x ($R^2 = 0.4302$)

Simulated precipitation runoff was greater in April and October than in August (Month, $P < 0.01$). Similarly, sediment transport in runoff was greater in April and June than in August (Month, $P < 0.01$), and P transport in runoff was greater in October than August (Month, $P < 0.05$). These effects were likely caused by wet conditions observed in early spring and lower sward heights and forage mass observed early and near the end of the grazing season. Both sediment and P transport in runoff were greater in year 1 than year 2 (Year, $P < 0.10$) which was likely the result of the above average rainfall that occurred in May and June of year 1 (2008; Schwarte et al., 2010).

Escherichia coli O157:H7, BCV, and BRV were never detected in runoff samples over the two years of the study. Bovine enterovirus, an indicator of fecal contamination (Ley et al., 2002), was found in 8.3 and 16.7% of the runoff samples from CSUbare sites in June and October of 2008 and 8.3% of the CSUveg sites in April of 2009 (data not shown). No observations of BEV were detected in runoff samples from RSveg, RSbare, and CSRveg sites.

Fecal Dry Matter and P Output and Pathogen Shedding

Fecal dry matter output by the cows did not differ ($P > 0.10$) by treatment (Table 5). Fecal dry matter output was greater in 2009 than 2008 (Year, $P < 0.05$) and greater in June than August (Month, $P < 0.05$). Mean P concentrations in the feces were greater ($P < 0.05$) in the CSR and CSU than RS treatments. Mean P concentrations of the feces were also greater in August than June (Month, $P < 0.01$), and increased greater in RS treatment feces from June to August than the other treatments (Treatment x Month, $P < 0.01$). As a result of the differences in fecal P concentration, total P excretion in the feces tended to be greater ($P =$

0.1110) for the CSR and CSU treatments than the RS treatments and also differed by year (Year, $P = 0.0073$).

Bovine enterovirus was found in feces from 4.4, 28.8, and 41.1% of cows in June, August, and September of 2008, respectively, and 38.9, 18.9, 13.3% of cows in June, August, and September of 2009, respectively (Table 6). Bovine coronavirus was shed in the feces of one cow in August of 2008. *Escherichia coli* O157:H7 and BRV were never detected in the fecal samples over the two years of the experiment.

Stream Bank Erosion

There were no significant differences in either net erosion or erosion\deposition activity between treatments or seasons or years (Figure 4). Averaged over treatments, years, and seasons, the stream banks had a net erosion of 5.2 cm and erosion\deposition activity of 11.1 cm per season per year.

Model Results

Comparisons of the estimations of the annual sediment and P loading of the pasture stream by precipitation runoff, cattle feces, and stream bank erosion show that cut-bank erosion is the greatest contributor to sediment and P loading of pasture streams as losses from cut-banks were approximately 1.5 times the measured losses from the total stream bank erosion (Table 7). Averaged over 2008 and 2009, stream bank erosion accounted for 99.5 and 94.4% of the sediment and P, respectively, transported to the pasture streams. Although amounts of sediment and P loading from direct fecal deposition or precipitation runoff were small when compared to bank erosion, the amount of sediment loading of the stream from direct deposition of feces was 46.4% less than that in precipitation runoff across grazing treatments at a stocking density of 0.106 cows m^{-1} stream. However, the amount of P entering the stream from direct fecal deposition was 32.5% greater than that in precipitation runoff.

DISCUSSION

Previous studies measuring stream water quality have shown that pastures and rangelands are the largest contributor to phosphorus levels in surface waters (Downing, 2000; Alexander et al., 2008). Results of this study showed that indeed considerable amounts of sediment and P are lost from pasture stream banks on an annual basis; however, the major source of the sediment and P in pasture streams is stream bank erosion, specifically cut-bank erosion, and not surface runoff nor fecal deposition. Surface runoff and fecal deposition are undoubtedly linked to grazing animals; however, the effects of grazing animals on stream bank erosion are yet to be fully understood. As discussed by Magner et al. (2008) and, Zaimes et al. (2008), many Midwestern pastures are located on long narrow sections following streams of land that is not suitable for row-crop production. Therefore, erosion from pasture stream banks is likely confounded by the land on which most pastures are located.

Sediment and P lost via cut-bank erosion was near equal or greater than the total amounts of sediment and P lost by stream bank erosion, suggesting that most erosion occurs from cut-banks in pasture streams (Table 7), and that other areas of the stream banks are trapping the eroded sediment and P lost from the cut-banks (Lauer and Parker, 2008). While the amounts of cut-bank in the CSU pastures appeared to be numerically greater than the CSR or RS pastures, these differences were related to stream channel conditions. Streams in both CSU pastures and one RS pasture had ox bows opposite from cut-banks while CSR pastures had no ox bows (Figure 1). Furthermore, the mean bank stability score of CSU pastures was 12 and 30% greater than CSR and RS pastures when the treatments were initiated in May, 2005 (Nellesen et al., 2011), implying that the banks in the CSU pastures were more unstable than banks in the CSR and RS pastures at the initiation of treatments within these pastures. From May, 2005 to September, 2009, bank stability scores increased by 1.68, 1.66, and 4.03% yr^{-1} in CSU, CSR and RS pastures, implying that stream bank stability in RS pastures was declining more rapidly than CSU or CSR pastures (Nellesen et al., 2011; Schwarte et al., 2010). However, trend analysis of the monthly erosion/deposition data from 2005 through 2007 showed that RS pastures had an increasing trend, i.e., a decrease in bank erosion, while no trend was observed in CSU and CSR pastures (Nellesen et al., 2011).

Although studies have shown significant reductions in stream bank erosion resulting from cattle exclusion (Kauffman et al., 1983; Trimble, 1994; Zaimes et al., 2008), other studies have not (Allen-Diaz et al., 1998; George et al., 2002; Nellesen et al., 2011). These results suggest that the effect of cattle on stream bank erosion is site or method-specific. In the current study, stream bank erosion was variable between treatments and seasons.

Managed grazing can reduce the impact of grazing cattle on surface runoff and stream water quality (Sheffield et al., 1997; Haan et al., 2006). However, sediment and P loading via fecal deposition and surface runoff together accounted for 0.5% and 5.6% of average sediment and P loss, respectively. A greater percentage of P loading than sediment loading was attributed to runoff and direct deposition because of the high concentration of P in the cattle feces. While soil P at the study site measured between 0.18 to 0.35 $g \cdot kg^{-1}$ (Nellesen et al., 2011), fecal P was approximately 20 times greater at 4.8 to 6.8 $g \cdot kg^{-1}$. Additionally, if P is fed in concentrations higher than necessary, the total P concentration and the proportion of water soluble P in fecal excretion increases (Dou et al., 2002). Since the forage P concentrations at the farm where adequate to meet the cattle's nutritional requirements (approx. 2.0 g·kg^{-1} DM; Haan et al., 2007) and the mineral supplement used in this study was void of P, it is likely that P excretion values observed in this study were lower than the values would have been if a P supplement had been offered. Therefore, direct deposition of cattle feces into a pasture stream may add a significant amount of P to the water if cattle are spending a large amount of time within the stream. However, in the current study, cattle in the CSU treatment spent 1.8% of their time in the stream while cattle in the CSR and RS treatments spent 5.1 and 20.7 times less time in the stream than cattle than the CSU treatment (Schwarte et al., 2010).

Rainfall simulations in the riparian buffer had less runoff and lower amounts of sediment, and P transported in runoff than all sites where cattle had access. However, vegetated sites in CSU and RS treatments also had less runoff and sediment and P transport in runoff than bare sites in either treatment. Therefore, management practices to minimize bare ground on the stream banks will be the most effective tool to reduce the amount of sediment and P entering pasture streams in precipitation runoff. These results are similar to Butler et al. (2006) and Haan et al. (2006) who observed minimizing bare ground as the most important factor in reducing sediment and P transport in precipitation runoff.

Cattle may shed fecal pathogens such as BCV, BRV, and *E. coli* O157:H7 (Crouch and Acres, 1984; Wells et al., 1991; Lucchelli et al., 1992). Shedding of pathogens in the present study was rare, occurring only once throughout the entire study, when BCV was shed by one cow. However, in 2007, the year prior to the study, *E. coli* O157:H7 was recovered from 12 of the 90 cows during the September collection with 10 of these cows present in one of the RS pastures (unpublished data). The presence of Bovine enterovirus was analyzed because it has been proposed as a good indicator of fecal contamination (Ley et al., 2002). Results of this study showed that shedding of BEV was highly variable, but was high enough to be infrequently detected in runoff samples. Additionally, as cattle were not stocked on the pastures prior to the rainfall simulation conducted in April 2009, BEV was either able to survive the winter or it was shed by another host source (Ley et al., 2002). This study shows that viruses shed by cattle may be transmitted through surface runoff, with a greater number transmitted on bare compared to vegetated ground. Therefore, the major factors in controlling the risk of pathogen loading of pasture streams, in order of importance, are the occurrence of pathogen shedding, the temporal\spatial distribution of grazing cattle, and surface runoff.

CONCLUSION

Estimations of annual sediment and P loading into the pasture stream show that stream bank erosion via cut-bank erosion is the greatest contributor of sediment and phosphorus to pasture streams. Improvements in sediment and P loading from precipitation runoff may result by use of cattle-excluded riparian buffers; however, the greatest differences in sediment and P loading of runoff occur between bare and vegetated ground on stream banks in grazed pastures. Minimizing the amount of bare ground on the stream banks is critical to minimize the amounts of sediment and P in precipitation runoff and may be attained by use of rotational stocking as well as riparian buffers. Additionally, pathogen loading of pasture streams by grazing cattle is infrequent and dependent upon the pathogen shedding, temporal\spatial distribution of grazing cattle, and surface runoff from stream banks, in respective order.

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Table 1. Estimations of the effects of rainfall simulation site class on the quantity of runoff (ml) from precipitation (mm) on pasture stream banks.

		Treatment†														
		CSUveg			CSUbare			CSRveg			RSveg			RSbare		
Year‡	Month	Intercept	Coeff.	R^2	Estimate	Coeff.	R^2	Estimate	Coeff.	R^2	Estimate	Coeff.	R^2	Estimate	Coeff.	R^2
Year 1	June	-1170.9	191.2	0.3624	-1578.1	412.8	0.9230	-498.1	121.6	0.1921	-1572.1	223.7	0.3689	-463.3	312.9	0.5028
	August	-1889.9	153.5	0.4885	-5646.1	420.6	0.9495	-914.3	52.3	0.1581	-4790.3	223.7	0.6365	-5306.8	410.0	0.8969
	October	-1456.1	202.4	0.5793	-5088.5	414.6	0.9322	-1863.6	115.6	0.3076	-2924.7	233.8	0.6254	-5119.7	398.2	0.9103
	April	-2516.4	200.0	0.4359	-4093.0	400.4	0.9397	-1706.2	120.3	0.3042	-3309.2	232.9	0.5888	-4348.8	368.7	0.8795
Year 2	June	-2135.5	183.8	0.3814	-3213.8	422.7	0.9030	-976.2	75.3	0.2046	-1517.6	128.8	0.2854	-2762.6	397.7	0.8100
	August	-1160.9	137.4	0.2590	-4157.0	428.9	0.9584	-373.0	21.4	0.1286	-1612.3	83.0	0.2235	-3569.4	345.0	0.7384
	October	-2145.3	250.1	0.4571	-3736.0	441.5	0.9805	-1647.2	107.3	0.2558	-2648.8	221.5	0.4837	-3920.7	426.5	0.9144
	April	-2718.3	229.5	0.6138	-3303.5	439.6	0.9856	-1171.8	70.4	0.1883	-2391.1	192.4	0.5071	-4363.4	394.2	0.8568

† Continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), rotational stocking (RS), simulation on vegetated (veg) or bare (bare) ground.

‡ Year 1 = June, August, and October of 2008 and April 2009. Year 2 = June, August, and October of 2009 and April 2010.

Table 2. Effects of grazing management on the percentage of stream bank ground cover in different months of 2009.

Item	Treatment†	June	August	October	April
Bare ground	CSU	20.04	12.00	12.14	17.38
	CSR	4.59	4.01	0.85	4.82
	RS	12.92	5.69	4.24	6.18
	SEM‡	4.23	1.96	2.77	3.49
Vegetated ground	CSU	29.06	35.64	44.29	35.10
	CSR	76.60	79.62	82.10	70.02
	RS	53.61	67.78	73.22	63.86
	SEM	14.32	10.95	10.17	12.48
Cut-bank	CSU	34.14	28.81	25.68	28.40
	CSR	13.22	12.69	12.69	19.48
	RS	16.52	15.91	14.77	20.62
	SEM	6.53	9.17	8.02	1.09
Sand-bar	CSU	16.77	23.54a§	17.89a	19.12
	CSR	1.85	0.00b	0.62b	0.75
	RS	16.95	10.62ab	7.76ab	9.34
	SEM	8.08	5.00	3.37	4.74

†Continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), and rotational grazing (RS).

‡ Standard error of the mean (n = 6).

§ Means within a column with different letters differ ($P < 0.10$).

Table 3. Effects of grazing treatment and ground cover on rainfall simulation characteristics.

Item	Treatment†					Statistics	
	CSUveg	CSUbare	CSRveg	RSveg	RSbare	SEM‡	P-value
Bare ground, %	16.84a§	79.27b	5.01a	13.64a	61.76b	5.76	P < 0.0001
Slope, rad.	0.23	0.21	0.23	0.24	0.22	0.02	P = 0.9339
Sward height, cm ¶	1.53c (3.62)	0.15a (0.16)	2.20d (8.01)	1.95cd (6.01)	0.74b (1.09)	0.12	P < 0.0001
Forage mass, $kg \cdot ha^{-1}$	1327.8abc	141.0a	2365.3c	1997.8bc	655.9ab	399.7	P = 0.0049
Antecedent soil moisture, 0-5 cm $g \cdot kg^{-1}$	149.51a	148.30a	201.52b	189.11ab	184.47ab	12.56	P = 0.0223
Antecedent soil moisture, 5-10 cm $g \cdot kg^{-1}$	143.08a	143.84a	166.19ab	171.00b	168.47ab	6.94	P = 0.0163
Roughness index	1.01	0.95	1.19	0.99	1.01	0.07	P = 0.1312
Runoff, $l \cdot hr^{-1}$	14.98a	32.09b	6.35c	14.01a	28.89b	0.64	P < 0.0001
Runoff, %	36.55a	78.71b	15.32c	33.98a	70.76b	3.89	P < 0.0001
Sediment, $kg \cdot ha^{-1}$ ¶	4.73a (112.3)	8.29b (3983.2)	2.72c (14.2)	4.73a (111.9)	7.16b (1290.2)	0.33	P < 0.0001
Phosphorus, $g \cdot ha^{-1}$ ¶	6.29a (536.2)	9.31b (11085.7)	4.18c (64.5)	6.21a (495.7)	8.18b (3565.4)	0.33	P < 0.0001

† Continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), rotational stocking (RS), simulation on vegetated (veg) or bare (bare) ground.

‡ Standard error of the means (n=16).

§ Means within a row with different letters differ (P < 0.10).

¶ Log transformed for data analysis (Ln (x + 1)). Natural number in parentheses.

Table 4. Regressions predicting runoff and sediment and P loading during rainfall simulations on bare and vegetation sites from site characteristics.

Item	Independent variable	Coefficient	Partial R^2
Runoff, % of applied precipitation	Intercept	31.03	-
	Bare ground, %	0.47	0.5050
	Sward height, cm	-1.06	0.0610
	Antecedent moisture content, $g \cdot kg^{-1}$ (0-5 cm)	0.05	0.0055
	Roughness index, cm	-5.42	0.0046
	Slope, rad.	16.18	0.0022
	Total	-	0.5782
Sediment, $kg \cdot ha^{-1}$	Intercept	-1564.16	-
	Bare ground, %	61.40	0.3811
	Slope, rad.	5964.1	0.0181
	Total	-	0.3992
Phosphorus, $g \cdot ha^{-1}$	Intercept	-1996.75	-
	Bare ground, %	142.78	0.4302
	Sward height, cm	-80.90	0.0045
	Slope, rad.	11654.0	0.0136
	Total	-	0.4483

Table 5. Effects of grazing management on fecal excretion of dry matter and phosphorus per cow over two years.

Item	Month	Treatment†			SEM‡
		CSU	CSR	RS	
Fecal DM, $kg \cdot d^{-1}$	June	7.02	7.94	7.54	0.55
	August	6.72	6.84	6.11	
Fecal phosphorus, $g \cdot kg^{-1}$	June	6.41a§	6.05a	4.84b	0.17
	August	6.77a	6.38a	5.74b	
Fecal phosphorus, $g \cdot d^{-1}$	June	44.7	47.8	36.5	2.4
	August	44.7	43.3	35.3	

† Continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), rotational stocking (RS).

‡ Standard error of the mean (n = 8)

§ Means within a row with different letters differ ($P < 0.10$).

Table 6. Incidence of viral and bacterial shedding in the feces of cattle.

Item†	2008			2009		
	June	August	September	June	August	September
E. *coli* O157:H7	0‡	0	0	0	0	0
BCV	0	1	0	0	0	0
BRV	0	0	0	0	0	0
BEV	4	26	37	35	17	12

† *Escherichia coli* O157:H7, Bovine coronavirus (BCV), Bovine rotavirus (BRV), Bovine enterovirus (BEV)

‡ n = 90 cows sampled

Table 7. Estimates of sediment and phosphorus loading of pasture streams from stream bank runoff, cattle feces, and stream bank erosion in 2008 and 2009.

Item	Treatment†	Sediment, kg			Phosphorus, gm		
		2008	2009	Cut-banks§	2008	2009	Cut-banks§
Runoff‡	CSU	554.72	257.04	-	1122.26	812.45	-
	CSR	53.84	8.23	-	174.75	57.24	-
	RS	371.91	82.02	-	933.59	343.08	-
Cattle feces¶	CSU	267.98#	298.61	-	1795.48	1884.47	-
	CSR	41.35	77.64	-	256.07	476.90	-
	RS††	0	25.59	-	0	147.09	-
Net Erosion-		$\times 10^3$					
Grazing season	CSU	85.84	37.95	54.87	20.33	9.16	13.29
	CSR	84.92	-4.11	13.78	21.03	-0.29	2.85
	RS	188.25	30.40	49.96	42.22	7.95	9.59
Winter	CSU	49.12	170.08	412.26	11.47	42.90	99.80
	CSR	11.10	89.75	97.09	2.63	23.49	19.87
	RS	136.28	98.07	131.36	25.66	21.95	28.66

† Continuous stocking with unrestricted stream access (CSU), continuous stocking with restricted stream access (CSR), rotational stocking (RS), simulation on vegetated (veg) or bare (bare) ground.

‡ Runoff data includes precipitation occurring from May to Oct 31, 2008, and April 1 to Oct 31, 2009, precipitation for April, 2009 retrieved from NOAA weather station in Marshalltown, IA. Based on 141 m of stream in each pasture with 3 m bank height.

§Amounts estimated to be lost from transects located on cut-banks in 2009

¶ Based on 15 cows stocked on a 12.1-ha pasture.

#Total feces deposited into stream.

††Cattle were not stocked riparian area at the same time as location determination except for one September in 2009.

Figure 1.

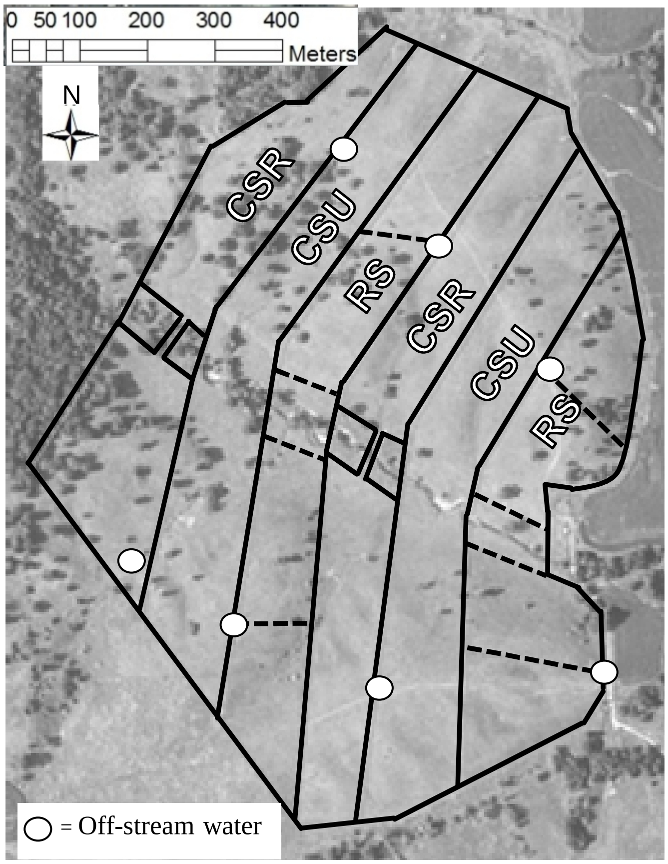

0 50 100 200 300 400
Meters
N
CSR
CSU
RS
CSR
CSU
RS
= Off-stream water

Figure 2.

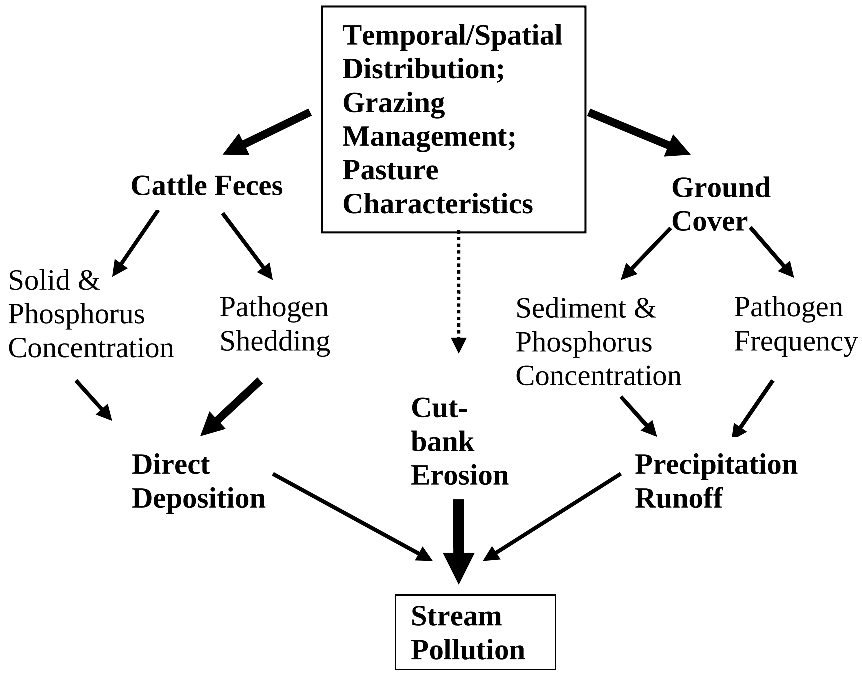

Temporal/Spatial Distribution; Grazing Management; Pasture Characteristics
Cattle Feces
Ground Cover
Solid & Phosphorus Concentration
Pathogen Shedding
Sediment & Phosphorus Concentration
Pathogen Frequency
Cut-bank Erosion
Direct Deposition
Precipitation Runoff
Stream Pollution

Figure 3.

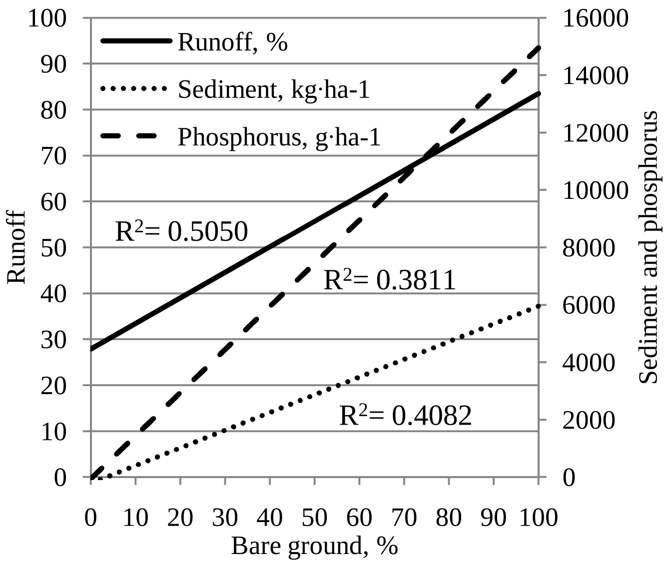
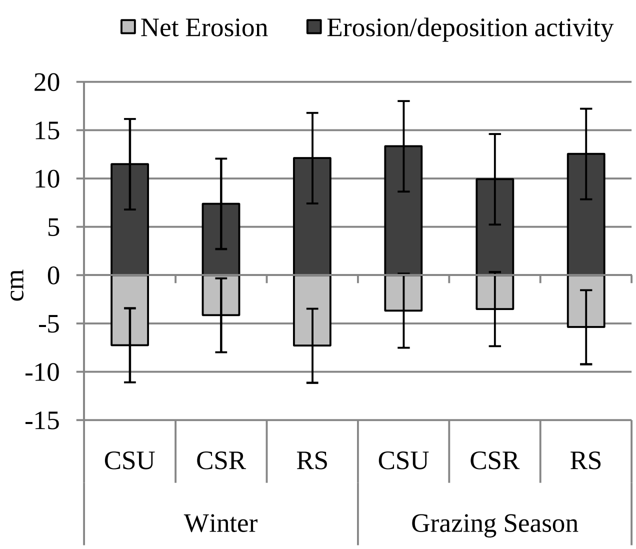

Runoff, %
Sediment, kg·ha-1
Phosphorus, g·ha-1
R2= 0.5050
R2= 0.3811
R2= 0.4082
Runoff
Sediment and phosphorus
Bare ground, %
0
10
20
30
40
50
60
70
80
90
100
2000
4000
6000
8000
10000
12000
14000
16000

Figure 4.


Net Erosion
Erosion/deposition activity
20
15
10
5
0
-5
-10
-15
cm
CSU
CSR
RS
CSU
CSR
RS
Winter
Grazing Season

CHAPTER 5. GENERAL CONCLUSIONS

GENERAL DISCUSSION

Maintaining surface water quality is vital, as it is the source of drinking water, recreation, and industrial uses for much of the world. Grazing cattle congregate near or in riparian areas of pastures because it is a source of food, water, and thermoregulation. In doing so, the cattle remove the vegetative cover that protects the stream banks from sediment and P loss via surface runoff. Additionally, these cattle may deposit feces in or near the water. Therefore, allowing grazing cattle unrestricted access to riparian areas near pasture streams will increase the risk of NPS pollution occurring via surface runoff or direct fecal deposition.

The installation and use of alternative off -stream water over a short time period as a means lure cattle away from pasture riparian area is an ineffective solution in Midwest pastures that receive adequate rainfall to produce natural off stream water sources. Short-term off-stream water's ability to reduce cattle presence in riparian areas is likely limited to arid regions, or to places where natural off-stream water is not available.

Managed grazing of riparian areas near pasture streams through the restriction of stream access to a stabilized stream crossing or through the utilization of riparian paddocks may decrease the quantity of sediment and P loaded into pasture streams. Grazing management techniques that reduce the amount of time that cattle spend in riparian areas near pasture streams may increase forage mass, sward height, and vegetative cover, which will hinder losses of sediment and P through surface runoff. Additionally, as the location cattle fecal depositions are proportionally correlated with cattle positioning, minimizing time spent by cattle in riparian areas near pasture streams will decrease the probability of cattle feces being deposited into the pasture stream.

However, although managed grazing can reduce the amount of sediment and P reaching pasture streams via surface runoff and fecal deposition, the vast majority of sediment and P that enters pasture streams are not related to surface runoff or fecal deposition, but is related to stream bank erosion, specifically cut bank erosion. The effect of grazing cattle on cut bank erosion is not well understood, and is likely site or study specific.

NEEDS FOR FUTURE RESEARCH

Surface runoff of fecal pathogens on the stream banks of pasture streams was not detected in this study. The lack of detection may be due to the excretion of fecal pathogens by grazing cattle being highly variable, or that the fecal pathogens are not readily transported via surface runoff. Therefore, more specific studies on the ability of fecal pathogens to be transported through surface runoff need to take place.

Likewise, more information is needed on what causes cattle to shed fecal pathogens. In the year prior to the current study, there were 12 incidences of *Escherichia coli* O157:H7 shedding, with 10 occurring in rotational stocking pastures. However, no incidences were seen in 2008 or 2009. Additionally, Bovine enterovirus shedding increased as the season progressed in 2008, but decreased as the season progressed in 2009. More research is needed to discern what causes grazing cattle to shed fecal pathogens.

Stream bank erosion via cut bank erosion is responsible for the greatest amount of sediment and P to reach pasture streams. However, the effect of cattle on cut banks is unclear, and requires greater research. Cut bank erosion is related the number of freeze-thaw and wet-dry cycles that occurs in a bank. Numerous factors affect the number of cycles that a bank goes through, including forage cover type and quantity. Studies monitoring the direct effect of grazing cattle on cut bank erosion should be enacted.

APPENDIX A. SUPPLEMENTAL TABLES

Appedix Table 1. Effects of cattle grazing management on forage quality characteristics within the Stream (3 m from stream) and Streamside (3 to 33 m from stream) Zones.

		Month					
		May	June	July	August	September	October
Item	Treatment[a]	Stream Zone					
CP, % DM	CSU	14.54	9.48	9.32	8.60	10.68[b]	10.43[b]
	CSR	13.87	10.23	9.17	7.68	8.48[c]	8.33[bc]
	RS	14.55	11.01	8.07	8.93	11.38[b]	10.81[c]
	SEM[d]	0.58	0.25	0.31	0.87	0.25	0.73
		Streamside Zone					
	CSU	14.33	9.63	8.96	9.23	9.93[b]	10.66
	CSR	16.49	10.20	9.06	9.56	8.16[c]	8.90
	RS	15.45	10.33	8.31	9.37	9.58[b]	9.44
	SEM	1.03	0.86	0.53	0.78	0.47	0.52
		Stream Zone					
IVDMD, % DM	CSU	59.33	61.50	47.22	41.28	39.46	38.23
	CSR	50.86	49.30	47.27	41.75	36.11	31.47
	RS	57.06	51.46	46.28	41.46	37.27	36.51
	SEM	0.78	0.95	0.65	1.93	1.93	2.89
		Streamside Zone					
	CSU	59.28	52.18	47.32	43.96	42.98	32.27
	CSR	60.18	52.07	48.81	47.22	42.19	33.39
	RS	59.01	51.44	45.99	44.45	41.98	36.17
	SEM	2.50	1.66	0.24	1.08	0.82	2.10
		Stream Zone					
Phosphorus, % DM	CSU	0.3432	0.2600	0.2679	0.2397	0.2487	0.2008[b]
	CSR	0.2774	0.2717	0.2673	0.2246	0.2366	0.1685[c]
	RS	0.3275	0.2749	0.2332	0.2210	0.2215	0.1870[bc]
	SEM	0.0235	0.0075	0.0119	0.0209	0.0313	0.0245
		Streamside Zone					
	CSU	0.2988	0.2600	0.2630	0.2492	0.2622	0.1771
	CSR	0.3515	0.2539	0.2594	0.2514	0.2330	0.1980
	RS	0.3258	0.2755	0.2455	0.2285	0.2520	0.1928
	SEM	0.0275	0.0202	0.0216	0.0110	0.0065	0.0061

[a]CSU= continuous stocking with unrestricted stream access, CSR= continuous stocking with restricted stream access to 4.9 m stabilized stream crossing, RS= rotational stocking.

[b-c]Means within a column with different subscripts differ ($P < 0.10$).

[d]Standard error of the means (n=4).

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