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Effect of Grazing System on Livestock Performance, Botanical Composition, and Standing Crop in the Nebraska Sandhills

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by

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A 10-year study compared a 4-pasture deferred-rotation (DR) grazing system with an 8-pasture short duration grazing (SDG) system at the Barta Brothers Ranch near Rose, NE to determine differences in livestock performance, botanical composition, and standing crop. Pastures were grazed by 50 to100 cow-calf pairs with both single (DR system) and multiple (SDG system) grazing periods from 15 May to 15 October. Livestock performance data were collected from spayed heifers substituted into each grazing system during the last 3 years of the study. Botanical composition was collected on 275 frequency of occurrence transects in 1998, 2003, and 2008. Standing crop data were collected biannually within 240 grazing exclosures placed at 4 topographic positions from 2000 to 2008. Average daily gain of the spayed heifers (0.84 $kg \cdot day^{-1}$) did not differ between grazing systems and years. The DR grazing system had minimal increases of standing crop and frequency of occurrence of desirable plant species. Standing crop and frequency of occurrence were more affected by topographic position and year than by grazing system treatments.

Effect of timing of grazing on subsequent-year standing crop was also determined with the DR and SDG grazing systems. Standing crop data were used to determine effect

of time of grazing on plant functional groups. Subsequent-year warm-season grass standing crop with the DR system was lowest when grazing occurred from 21 July to 31 August. Cool- season grass and forb standing crop was most affected when grazing took place in mid-May, mid-June, and late-August within the SDG system Browse production tended to be lower when grazing occurred early in the grazing season for both grazing systems. Grazing during times when standing crop is most limited in subsequent-years should not take place in consecutive years on pastures in either system unless specific management objectives are trying to be obtained.

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Introduction

Variations of short duration and deferred-rotation grazing systems are common on ranches throughout the Nebraska Sandhills (Reece 1986). Implementation of these grazing systems has provided range mangers greater opportunities to control the intensity, frequency, and timing of defoliation of plants by rotating cattle through several pastures in sequential patterns. Grazing systems can potentially increase grazing uniformity and livestock distribution by increasing the number of pastures and watering points on a rangeland unit. However, there has been much controversy over whether these grazing systems are beneficial to livestock and herbage production (Briske et al. 2008)

Deferred-rotation grazing systems are characterized by rotating livestock through 2 to 5 pastures. Sequence of pastures is rotated to allow one pasture deferment until after plants have reached reproductive maturity every year. The deferment period is believed to increase vigor and establishment of plant species that are sensitive to grazing, and enhance range condition (Stoddard et al. 1975). However, livestock performance tends to be negatively affected when animals are moved into the deferred pastures because of the decreased quality of mature forage (Owensby et al. 1973).

Short duration grazing systems move livestock through several pastures with short, intensive grazing periods. This movement is believed to mimic the natural movement of large herds of native ungulates (Savory 1999). Savory (1999) proposed that this system of grazing is more beneficial to rangeland health and livestock performance than other specialized grazing systems (i.e., deferred-rotation). In theory, short duration grazing systems benefit rangelands by limiting the number of plant tillers that reach maturity by uniformly grazing pastures multiple times over the growing season. Forage remains in a more nutritious, immature state as a result of this intermittent grazing. Short duration grazing is believed to increase livestock performance and allow for higher stocking rates as a result of the increased forage quality. Many studies in the Great Plains and western United States have specifically studied the effects of short duration grazing systems on livestock and vegetation production (Holecheck et al. 2000). A majority of these studies have concluded that short duration grazing systems do not increase herbage production or livestock performance more than less intensive grazing systems or continuous grazing. However, in spite of the lack of supporting data, there is still a belief by many that short duration grazing systems are superior to other grazing systems (Savory 2000).

The principal objective of this study was to compare short duration grazing and deferred-rotation grazing systems in terms of livestock performance, botanical composition, and subsequent-year standing crop on Sandhills upland range grazed by beef cattle during the growing season (May 15 to October 15). The interacting effect of topographic position (i.e., north-facing slope, dune top, south-facing slope, and interdune) on standing crop and botanical composition also was determined. Finally, the effect of timing of grazing within each of the grazing systems on subsequent-year standing crop also was analyzed.

Chapter 1
Literature Review

Definition of Grazing Systems

A grazing system is defined as a specialization of grazing management that provides a desired outcome to rangelands by the manipulation of livestock (Society for Range Management 1974). Grazing systems become a part of a grazing management plan by providing a sequential movement of grazing animals between a set number of pastures with defined and reoccurring periods of grazing and nongrazing. Reece (1986) expands this definition by explaining that grazing systems are a plan the range managers use to observe and integrate knowledge of available resources into the art and science of range management. The intent of grazing system designs are to improve or maintain rangeland resources while optimizing livestock performance (Taylor 1993; Shiflet and Heady 1971).

History of Grazing Systems in North America

Principles of rotational grazing systems were developed in the British Isles during the late 1700s (Vosion 1988). Movement from continuous grazing, or no systematic movement, to specialized grazing systems, movement through several pastures in a defined rotation, began in the Americas at the beginning of the 20^{th} century to restore depleted rangelands (Briske et al. 2008). Many western rangelands had reached their peak of degradation in the late 1800s as a result of heavy overgrazing. Cattle numbers in 17 western states increased from 4.6 million in 1870 to an estimated 35 to 40 million by 1884 (Holechek et al. 2004). Sheep numbers increased dramatically during this time as well. Although rangeland conservation had previously been a concern in some areas of the United States, it began to be a concerted effort nationwide in the early 20^{th} century as the consequences of overused rangeland resources were beginning to be understood (Heady 1999; Holechek et al. 2004).

The first recorded grazing system experiment on the North American continent was in 1913 by Arthur Sampson in northeastern Oregon (Sampson 1913). Sampson (1913) divided a rangeland parcel into 2 units and deferred summer grazing on each unit in alternating years. Sampson (1913) concluded that this system of grazing could restore depleted rangelands, and he and many other early pioneers in range management began a thought process that would lead to the implementation of grazing systems designed to increase livestock performance and production without further deterioration of rangelands. Grazing systems have flourished from the early 1900s until today with many land mangers developing and incorporating them into their grazing management plans. Rangeland scientists have provided much data on grazing system success and failure in many different ecological regions (Sampson 1951; Van Poolen and Lacey; Holecheck et al. 1999; Briske et al. 2008). As a result, several different types and variations of grazing systems have evolved. Some of the more common grazing systems are continuous grazing, deferred-rotation grazing, rest-rotation grazing, and short duration grazing.

Common Grazing Systems

Continuous grazing is a method of grazing livestock on a management unit for a full year or during the growing season with no non-grazing periods (Holechek et al. 2004). Continuous grazing has been linked with poor range condition. However, deterioration of rangeland under continuous grazing is more likely a result of improper stocking rate or poor livestock distribution (Vallentine 2001). At proper stocking rates, continuous grazing has produced superior results in forage production and individual livestock performance compared to other grazing systems (Vallentine 2001; Holechek et al. 2004; Briske et al. 2008). Continuous grazing may be linked with poor management because some areas of continuously grazed pastures may receive little defoliation while others receive frequent defoliations throughout the growing season (Gammon 1984). This causes uneven use of the pasture which leads to range deterioration in localized areas and complete rest in other areas. Animal production in a continuous grazing system is optimized at proper stocking rates and adequate distribution of livestock. This allows animals to selectively choose forage that will provide the highest level of nutrient quality (Gammon 1984).

Rest-rotation systems were developed in the 1950's in many areas of the intermountain and arid west based on research conducted in California by August L. Hormay (Hormay and Evanko 1958). Under rest-rotation systems, range is commonly divided into 3 or 4 pastures. One pasture receives rest from grazing for 12 months while the other pastures are grazed. This type of system is suggested for use in areas where there is rugged terrain to provide better livestock use of uplands and rest to riparian or lowland areas.

Deferred-rotation grazing systems are characterized by providing a portion of a management unit with deferment during the growing season. This is accomplished by dividing a rangeland into 2 or more pastures and deferring use on 1 of the pastures until the end of the growing season. Deferment of each pasture until the key management species have reached reproductive maturity will usually occur every 2 to 4 years. This periodic deferment provides uninhibited seed head and rhizome growth (Stoddard et al. 1975). Deferred-rotation systems became popular as Sampson (1951) reported that this system could restore depleted ranges by providing deferment to naturally reseed and improve range condition. The utilization of this system was accepted widely from 1913 through the end of World War II, and is still in use in several parts of North America (Vallentine 2001). Deferred-rotation is discussed in greater detail later in the review.

Short duration grazing was first reported in North America in 1969 by Sid Goodloe (Goodloe 1969), but Allan Savory is credited with developing this system in Zimbabwe, Africa and introducing it to the Americas in the late 1970's (Savory and Parsons 1980; Savory 1983). Short duration grazing is characterized by dividing rangeland into several paddocks, usually 8 or more, and moving cattle quickly from pasture to pasture in short, multiple grazing periods in an effort to mimic the natural effects of herding animals (Savory 1999; Manley 1997). This system became popular on claims made by Savory of increased herbage production, rangeland condition, and livestock gains while increasing stocking rate (Savory 1980; Savory 1983). This system, which is utilized and promoted in several areas of North America, has come under controversy from many range researchers for not producing benefits reported by Savory (Holechek 2000; Heitschmidt and Walker 1983; Vallentine 2001; Holechek et al. 2004). Short duration grazing is discussed in greater detail later in the review.

Purposes of a Grazing System

The main purpose of a grazing system is to increase livestock and forage production by improving the available forage resource, increasing harvest efficiency, and providing more options in managing the frequency and severity of plant defoliation (Heitschmidt and Walker 1983; Briske et al. 2008). The systematic movement through pastures to provide grazing and non-grazing periods has been reported to improve key plant species composition and productivity, reduce animal selectivity, and provide a better and more uniform distribution of animals across a landscape (Savory and Parsons 1983). Claims also have been made that the rotation of pastures will allow for an increase in stocking rate while either improving or causing no change to animal weight gains, range condition, forage production or botanical composition (Savory 1980). However, research throughout the Great Plains and western United States has conflicting and variable reports to whether grazing systems provide these results (Briske et al. 2008).

The occasional recovery time period that grazing systems provide is believed to allow plants time to establish and gain vigor and as a result increase herbage yield and range condition (Stoddart et al. 1975). Along with an increase in herbage yield, better distribution from additional water sources and fencing increase utilization of the available forage and increases animal production on a given land unit. The non-grazing periods also are credited with relieving grazing pressure on vegetation and limiting localized range depletion on areas that receive a high degree of use (Stoddard et al. 1975). Research has shown that using grazing systems on deteriorated ranges as a tool for range reclamation will benefit the range condition more than on range in good and excellent condition when compared to continuous grazing (Heady and Childs 1994; Owensby et al. 1973; Sampson 1951).

Grazing systems effect on herbage production has been reported in a review of 15 North American studies that compared continuous grazing with specialized grazing systems (Holechek et al. 1999). In their review, specialized grazing systems produced, on average, a 7% increase in herbage production over continuous grazing. However, rangeland and climate types were interacting variables. Arid and semi-arid rangelands showed little or no increase in herbage production with grazing systems, whereas humid regions averaged a 20 to 30% increase in herbage production with a specialized grazing system. Van Poolen and Lacey (1979) also reported an increase to herbage production from grazing systems based on a review of 18 North American studies. They found that specialized grazing systems produced 13% more herbage than continuously grazed pastures at a moderate stocking rate. However, they also concluded that a decrease in stocking rate from high (60-80% use) to moderate (40-60% use) stocking increased herbage production by 35%. This agrees with other studies that have concluded that proper stocking rate has a greater impact on herbage production than specialized grazing systems (Manley et al. 1997; Gillen et al. 1998; McCollum et al. 1999; and Heitschmidt et al. 1990).

Briske et al. (2008) reported that plant production was equal or greater on continuously grazed pastures when compared to a rotational grazing system in 87% (20 of 23 studies) of reviewed research experiments. Animal production was equal or greater per head on continuously grazed pastures in 92% (35 of 38 studies) of the studies and equal or greater per area in 84% (27 of 32 studies) of the reviewed studies. While this review showed little evidence of substantial benefits to vegetation and livestock production with specialized grazing systems in over 60 years of research, it mentioned that grazing systems may increase the management levels of range managers by increasing awareness and observation of the effects of grazing to range condition. Grazing systems also aid in controlling the frequency of defoliation and can increase the uniformity of grazing on a range unit. While results from these mentioned benefits are not evident in most studies, it is generally thought that grazing systems may play a part in the maintenance or increase of vegetation and livestock production (Briske et al. 2008; Derner and Hart 2007; Laycock 1983).

Timing of Grazing

A main objective of a rotational grazing system is to provide non-grazing periods to improve plant species composition and productivity (Briske et al. 2008). Grazing systems provide recovery periods that allow individual plants time to produce adequate leaf area to restore carbohydrate reserves between defoliations (Waller et al. 1986). Perennial plant species survival requires adequate carbohydrate reserves to survive during the winter, initiate spring growth, and provide new growth following defoliation. However, storage of carbohydrates in the roots is depressed when green leaf area is removed by grazing animals. Generally, it is assumed that the greatest amount of carbohydrate translocation to roots in the top 10 to 20 cm of soil occurs when growth of plant tillers has been completed (Reece et al. 2007). Because of this, defoliation early in the growing season, plant initiation to peak growth, followed by a period of non-grazing is less detrimental than defoliation when plants are in the later periods of the growth cycle (Vallentine 2001; Holechek et al. 2004). Additionally, subsequent-year herbage production for mid- and tall grasses is most effected when the plant is providing carbohydrates for rapid root growth, bud formation, or stolon or rhizome growth (Reece et al. 2007; Branson1953).

Timing of grazing can be used to change botanical composition of mixed grass rangelands (e.g., both cool- and warm-season grasses) because the influence of grazing at different stages of development is fairly consistent across grass species and types. Grass species and types vary in their timing of development; therefore, they are susceptible to defoliation at different times of the year. Annually grazing at the same time of the year can favor certain plants and disfavor others because of differing physiological stages of the plants.

A study conducted at the U.S. Sheep Experiment Station in Idaho found that subsequent-year herbage production for bluebunch wheatgrass (*Pseudoroegneria spicata* (Push) A. Love) decreased more when defoliation occurred later in the plants growth cycle compared to earlier defoliation (Blaisdell and Pechanec 1949). Plants clipped earlier in the growth cycle (April 8 to May 23) produced 33% to 63% of the unclipped plant herbage production. In contrast, plants clipped at ground level from seed stalk emergence (May 23) to flower bloom (June 25) were only 14.6% to 24% of the herbage production of unclipped plants in subsequent-years, respectively. Plants clipped after dormancy produced slightly more herbage than unclipped plants.

Moderate defoliation after plant dormancy is typically less detrimental to plant species than defoliation occurring during the growing season. A study in the Nebraska Sandhills showed that prairie sandreed (*Calamovilfa longifolia* Hook.) and sand bluestem (*Andropogon hallii* Hack.), when grazed in October, had similar amounts of total organic reserves as ungrazed plants (Reece et al. 1996). However, total organic reserves for prairie sandreed were 36% lower when grazed in June or July and 26% lower for sand bluestem when grazed in July compared to plants grazed during the dormant season (October). Effects of time of grazing on annual dry matter yield of these two species were determined in an earlier study in the Sandhills (Mullahey et al. 1991). Annual dry matter yield for prairie sandreed was greatest when plants were subjected to 2 defoliation periods, first in June and again in August, but yield for sand bluestem was greatest when a single defoliation occurred in either June or July.

Another study in the Sandhills found no difference in annual dry matter yield, tiller weight, number of buds per plant, or number of tillers per plant for little bluestem (*Schizachyrium scoparium* (Michx.) Nash) when clipped to 7 cm in June, July, August, or a combination of grazing in June and August or June, July, and August (Mullahey et al. 1990). However, annual dry matter yield and tiller weights were significantly greater on plants clipped in October when compared to all other clipping treatments.

The timing of when and how frequently grazing occurs can potentially affect the plant composition and subsequent-year herbage production (Reece et al. 2007). Grazing systems provide managerial opportunities to control this timing and frequency. This management may shift the composition of species within a pasture if grazing occurs at similar times in consecutive years.

Understanding Grazing System Research

A large amount of grazing systems research has been conducted over the past century in the United States (Holechek et al. 1999; Briske et al. 2008) and other countries (Gammon 1978). Vegetation and livestock production studies have reported that responses of livestock and vegetation to specialized grazing systems are often nonexistent or less than expected (Briske et al. 2008). Consequently, highly specialized grazing systems have been recommended only as a tool to achieve certain goals and not as systems that will benefit all rangelands (Vallentine 2001; Briske et al. 2008; Holechek et al. 2004). The complex nature of rangeland research has produced variable results when comparing grazing systems studies. Factors that limit the comparison of different grazing system studies include different grazing period lengths, different seasons of use, different vegetational types, different age or class of animal, different prior land use, different rainfall regimes, different stocking rates, and failure to compare the same grazing systems as other studies (Heady 1963; Briske et al. 2008; Kothmann et al. 1971). This makes comparing research of grazing systems from one area to another very difficult. Other factors that affect grazing system research are unrealistic rigidity in system design, insufficient size of experimental units, limited replication, and inadequate time to examine long term effect (Gammon 1978). A light stocking rate also may influence the ability of a study to show differences between grazing systems because the amount and quality of herbage is not a limiting factor (Gammon 1984).

Claims that implementation of specialized grazing systems can result in increased stocking rate on a range unit have lead some researchers to conduct studies comparing grazing systems with greater stocking rates to continuous grazing at lower stocking rates (Dormaar et al. 1989; Ralphs et al. 1990; Anderson 1988; Thurow et al. 1988; Pitts and Bryant 1987; Volesky et al. 1990). Differences between grazing systems, as a result, may be the effect of different stocking rates rather than the grazing system treatments (Derner and Hart 2007; Briske et al. 2008). In most instances, continuous grazing has been used as a control or standard with which to compare specialized grazing systems. In this review, deferred-rotation and short duration grazing systems were compared to continuous grazing, other grazing systems, and to each other in terms of botanical composition, herbage production, and livestock production at similar and different stocking rates.

Deferred-Rotation Grazing Systems

Deferred-rotation grazing systems have been reported to enhance vegetation production by increasing the vigor and vitality of desirable plant species (Owensby et al. 1973; Reardon and Merrill 1976). However, research results on deferred-rotation grazing systems have been variable and a majority of the research conducted in the Great Plains and western United States has found limited improvement in vegetation and livestock responses with this system compared to continuous grazing (Hart et al. 1988; Smoliak 1960; Holecheck et al. 1987; Olson et al. 1999; and Skovlin et al. 1976).

Botanical Composition

Research conducted in the Kansas Flint Hills reported increases in desired species composition of tallgrass prairie with a 3 pasture deferred-rotation system grazed with yearling steers (Owensby et al. 1973). Basal cover of little bluestem (*Schizachyrium scoparium* (Michx.) Nash) and indiangrass (*Sorghastrum nutans* (L.) Nash) had greater increases under a deferred-rotation system than continuously grazed pastures in a 6-year study. In contrast, basal cover of desired species on the shortgrass prairie in eastern Wyoming was not affected by a deferred-rotation grazing system (Hart et al. 1988). The botanical composition of blue grama (*Bouteloua gracilis* (Willd. *ex* Kunth) Lag. *ex* Griffiths), western wheatgrass (*Elymus smithii* (Rydb.) Gould), total cool-season graminoids, lichens, forbs, and half shrubs was not significantly different between a 4-pasture, deferred-rotation system and continuous grazing at light and heavy stocking rates. Similarly, a study in western Canada concluded that a deferred-rotation system produced only slightly greater amounts of grass and sedge ground cover and did not produce any advantage in desired plant species composition over continuously grazed pastures (Smoliak 1960).

Another study conducted on the shortgrass prairies in western Canada showed fewer desirable grass species and an increase in the amount of sandberg bluegrass (*Poa secunda* Presl) with continuous-grazing when compared to a deferred-rotation system (Hubbard 1951). Sandberg bluegrass is a less desirable, grazing tolerant grass species that is seen as an indicator of lower quality range condition. Preferred grasses such as blue grama, needleandthread (*Hesperostipa comata* (Trin. & Rupr.) Barkw.), western wheatgrass, and prairie junegrass (*Koeleria macrantha* (Ledeb.) J. A. Schultes) were maintained better with a deferred-rotation grazing system than with continuous grazing. The increase in Sandberg bluegrass and the lower amount of desired plants on continuously-grazed pastures likely resulted from of poor grazing distribution which caused some areas to be over utilized and degraded. The deferred-rotation system in this study increased distribution and limited the number of areas which received a high degree of use by providing a portion of the range with deferment for part of the grazing season every year.

A 10- year study in the sagebrush bunchgrass range in the northwestern United States found similar results to Hubbard (1951) (Hyder and Sawyer 1951). Sandberg bluegrass increased 13% in vegetation density under season-long, continuous grazing and only 7.9% under a deferred-rotation system. However, the two primary grasses, bluebunch wheatgrass (*Elymus spicatus* (Pursh) Gould) and Idaho fescue (*Festuca idahoensis* Elmer), increased in density by 2.4% with continuous grazing and only 1.1% under deferred-rotation. The density of desirable plants increased on lightly-grazed areas of continuously-grazed pastures, whereas more grazing tolerant species (i.e., Sandberg bluegrass) increased on the heavily-grazed areas. The authors concluded that deferred-rotation grazing systems may benefit rangelands by improved grazing distribution and decreased frequency of grazing on utilized areas within a pasture.

Herbage Production

Research on Kansas tallgrass prairie reported that deferred-rotation systems produced greater amounts of forage when compared to continuously-grazed pastures (Owensby et al. 1973). A 3-pasture, deferred-rotation system increased forage production on loamy upland, breaks, and clay upland range sites by 373 $kg{\cdot}ha^{-1}$, 940 $kg{\cdot}ha^{-1}$, and 900 $kg{\cdot}ha^{-1}$, respectively, when compared to continuous grazing at similar stocking rates. The results indicated that the increase in forage production could potentially lead to an increase in stocking rate with a deferred-rotation system.

A 20-year study on the Edwards Plateau in West Texas (Reardon and Merrill 1976) found similar results to Owensby et al. (1973). A 4-pasture, multi-species (cattle, sheep, and goats), deferred-rotation system was compared to a continuous-grazing system at light, moderate, and heavy stocking rates. Forage production was similar between the deferred-rotation system (2404 $kg{\cdot}ha^{-1}$) at a moderate stocking rate (0.15 $AUY{\cdot}ha^{-1}$) and the continuously-grazed pasture (2228 $kg{\cdot}ha^{-1}$) at a light stocking rate (0.06 $AUY{\cdot}ha^{-1}$). While the lightly-stocked, continuously-grazed system and the moderately-stocked, deferred-rotation system produced similar amounts of herbage, the stocking rate on deferred-rotation pastures was 0.06 to 0.10 $AUY{\cdot}ha^{-1}$ greater than on the continuous pastures. The increased stocking rate as well as the increase in herbage production led the authors to conclude that deferred-rotation was the optimal grazing system in that area to produce livestock while maintaining and improving wildlife habitat.

In contrast, studies in the shortgrass prairie have concluded that there is little difference in herbage production between deferred-rotation systems and continuous grazing. An 8-year study in southeastern Alberta reported no difference in the amount of herbage production for deferred-rotation systems and continuously-grazed pastures (Smoliak 1960). In a 6-year study in eastern Wyoming, herbage production with a 4-pasture, deferred-rotation system did not differ from continuous grazing at heavy and moderate stocking rates (Hart et al. 1988).

Livestock Production

Many studies have shown that there are no substantial increases in livestock production with the use of deferred-rotation systems compared to continuous-grazing (Owensby et al. 1973; Rogler 1951; Hart et al. 1988; Holecheck et al. 1987; Smoliak 1960; Olson et al. 1999; and Skovlin et al. 1976). Research conducted in the Kansas Flint Hills reported steers on a 3-pasture, deferred-rotation system weighed 10.4 kg less than steers on season-long, continuously-grazed pasture (Owensby et al. 1973). Steers in the deferred-rotation treatment were concentrated on two pastures from May 1 until July 1 and then moved to a third pasture from July 1 to October 1. Significant increases in daily gains of steers grazed on the continuously-grazed pastures compared to steers grazed on the deferred-rotation pastures began when steers were moved to the deferred pasture. Gains were lower on the deferred-rotation system, but it was concluded that a deferred-rotation system would allow stocking rate to be increased by 16% because of greater amounts of herbage. However, the increase in the amount of weight per land unit area did not offset the increased individual gains on continuously grazed animals (Kansas State University 1978; Owensby et al. 1973).

Similar results were found in North Dakota with yearling steers (Rogler 1951). Weight gains were significantly greater on steers grazed on continuously-grazed pastures from mid-May to mid-October than on steers that were grazed at relatively heavy stocking rates of 1.6 to 2.0 $ha \cdot hd^{-1} \cdot grazing\ season^{-1}$ on a 3-pasture rotation. Over the 8 year study the continuously grazed steers averaged 9 $kg \cdot hd^{-1} \cdot grazing\ season^{-1}$ more than steers on a deferred-rotation system. Moderately-stocked continuously grazed pastures at a stocking rate of 2.5 $ha \cdot hd^{-1}$ also were compared with the deferred-rotation at a higher stocking rate of 2 $ha \cdot hd^{-1}$. The steers on moderately–stocked, continuously-grazed pastures gained 13.1 $kg \cdot hd^{-1} \cdot grazing\ season^{-1}$ more than steers on the deferred-rotation. The authors concluded that if adequate forage is available, a deferred-rotation grazing system will not increase gains over continuous grazing (Rogler 1951).

Lower weight gain for steers on the deferred-rotation was believed to be caused by the consumption of the lower quality, mature forage in the deferred pasture; whereas, steers on the continuously-grazed pastures had access to higher quality regrowth and greater selectivity of desirable plant species throughout the growing season (Pfister et al. 1984; Rogler 1951; Gammon 1984). Under rotational-grazing systems, plant selection is limited by the timing of movement into or from pastures. This forces cattle to harvest plant material that is mature and lower in nutritional value. Some of the loss of forage quality in grazing systems can be attributed to limited use of preferred, seasonal plants. Forbs are an important part of cattle diets early in the growing season. Deferred-rotation grazing systems may limit livestock use on parts of the range when forbs are available

(Kirby et al. 1986). If livestock are allowed to have unlimited access to the whole range, as in a continuous grazing system, highly nutritious, short-lived forbs are better utilized and pressure on grass species is reduced (Holechek et al. 2004; Taylor et al. 1993; Pieper et al. 1978).

Other studies have shown that there is no difference between continuous grazing and deferred-rotation grazing systems (Hart et al. 1988; Holechek et al. 1987). Average daily weight gains (0.95 kg) for yearling steers on a 4-pasture, 3-herd deferred-rotation were not different when compared with continuously grazed steers from June to mid-October on northern mixed grass prairie in Wyoming (Hart et al. 1988). Similarly, a 5-year study on mountain, ponderosa pine-bunchgrass rangeland at the Starkey Experimental Forest and Range in northeastern Oregon determined that there was no difference in average daily gains of yearling heifers from June 20 to October 10 between a season-long continuous, a 4-pasture, 2-herd rest-rotation, and a 2-pasture deferred-rotation grazing system with average daily gains of 0.58 kg, 0.54 kg, and 0.59 kg, respectively (Holechek et al. 1987).

Calf weaning weights do not show a clear pattern in response to continuous grazing and deferred-rotation systems. In an 8-year Texas study there were no differences between calf weaning weights when cow-calf pairs were stocked in year-long light (11.5 $ha\cdot AU^{-1}$) continuous, moderate (8.4 $ha\cdot AU^{-1}$) continuous, and switchback deferred-rotation (8.4 $ha\cdot AU^{-1}$) systems (Kothmann et al. 1971). Calf weaning weights were only significantly heavier (7.3 $kg\cdot hd^{-1}$) for cow-calf pairs on the deferred-rotation when the switchback deferred-rotation was compared to heavy (5.2 $ha\cdot AU^{-1}$) continuous grazing. Research in southern Utah showed that calves grazed during the summer grazing season on continuously-grazed pastures gained 0.03 kg· day^{-1} more than calves grazed on a 2-pasture, deferred-rotation system (Olson et al. 1999). This increased daily gain resulted in significantly greater weaning weights (4.1 kg·hd^{-1}) at the end of the season for pairs on continuously-grazed pastures. Results in northeastern Oregon reported only a slight, non-significant (1.4 kg·hd^{-1}) increase in weaning weight when continuous grazing was compared to a 2- pasture, deferred-rotation system in a 10-year grazing study on ponderosa pine, bunchgrass range (Skovlin et al. 1976).

Short Duration Grazing Systems

Short duration grazing, also referred to as rapid-rotation, time-control, high performance, and cell grazing (Holechek et al. 2004; Quigley 1987) was developed in Africa in the 1960's by Allan Savory (Goodloe 1969; Savory 1978; Savory 1980) on ideas collected from French scientist Andre Voisin (Voisin 1988; Heitschmidt and Walker 1983). The grazing system was further refined and became known as the Savory Grazing Method or Holistic Resource Management (HRM) (Savory 1983). Even though Savory developed short duration grazing, he later discredited the grazing system and distinguished holistic resource management as a more thorough and encompassing management plan that can provide several benefits to ranches and rangelands (Savory 1983). While Savory distances holistic resource management from short duration grazing, many range scientists have regarded all the above terms as synonyms as similar systems of short duration grazing (Holechek et al. 2000; Quigley 1987; Heitschmidt and Walker 1983).

Short duration grazing became popular on claims of doubling and tripling stocking rate while increasing forage production, advancing plant succession, lowering labor requirements and expenses, improving water infiltration, and increasing animal productivity (Savory 1978; Savory 1980). Savory even commented, “The fate of many countries depends on how [Holistic Resource Management] is extended from America,” in regards to how necessary his system was to reversing the process of desertification in the world (Savory 1983). Since its introduction to the United States of America there have been many studies to determine the viability of short duration grazing (Holechek et al. 2000).

Short duration grazing is a grazing system based on the theory that many fast movements through multiple pastures will provide natural herd effects that benefit livestock, individual plants, and overall rangeland health (Savory 1978). Livestock, in theory, are moved according to the varying growth rate of the vegetation. Movement from pastures occurs before they can regraze new growth of previously grazed plants and also before there is a significant loss in gains because of increased grazing pressure (Hart et al. 1988). While many different schemes have been developed from this grazing system, most often livestock are grazed through 8 or more pastures 2 to 3 times during the growing season. Grazing periods generally last from 1 to 15 days with 20 to 60 days recovery following each grazing period (Vallentine 2001).

Botanical composition

A study on fescue rangeland in Alberta, Canada compared botanical composition of grazing excluded areas to a 17–pasture, short duration grazing system (Dormaar et al. 1989). This 5-year study operated at a production scale with herds averaging 278 cow-calf pairs being grazed multiple times (3 grazing and 2 recovery periods) from May to late October. Stocking rate on the short duration grazing system was increased 2 to 3 times the recommended stocking rate to test Savory's (1978) claim that short duration grazing can increase stocking rate without adverse effects to vegetation. Range condition of the pastures in the short duration grazing systems decreased from 50% to 39.2% of climax community over the course of the study. In contrast, grazing excluded range condition increased from 51.6% to 56.2% of climax community during the same time. Contribution of rough fescue, a common desirable species, was significantly lower under the short duration grazing system (0.7%) when compared to grazing excluded areas (6.0%) at the end of the 5-years. Other short duration grazing research in Canada supports these data with decreased range condition on both mixed native prairie and fescue grasslands with short duration grazing systems (Willms et al. 1990).

A study near Sonora, Texas also researched the possibility of achieving higher stocking rates with a short duration grazing system (Ralphs et al. 1990). Stocking rate was increased 2.5 times the recommended stocking rate on the short duration grazing pastures. The 8-pasture short duration grazing system was grazed by yearling cattle and sheep with grazing periods of 3 days and recovery periods of 51 days. After 6 years, the percentage of shortgrasses had not changed significantly (38% in 1980 and 41% in 1985). However, mid-grasses had decreased from 43% in 1980 to only 10% in 1985. Sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) and threeawns (*Aristida wrightii* Nash. and *Aristida purpurea* Nutt.) both decreased from 20% of the plant composition to only 4% of the plant composition, but forbs increased from 11% to 42% with the short duration grazing system. They concluded that short duration grazing would not be able to support higher stocking rates and sustain plant composition. These findings contradict Savory's claims that short duration grazing will advance plant succession to its climax and that increasing stocking rates with short duration grazing will not have an adverse effect on range condition (Savory 1978).

Research in Wyoming showed short duration grazing at a heavy (0.56 steers·ha^{-1}) stocking rate caused only minor botanical changes when compared to light (0.16-0.23 steers·ha^{-1}) and heavily (0.56 steers·ha^{-1}) stocked continuously-grazed pastures (Manley et al. 1997). However, the forb component of the heavily grazed short duration grazing system was 48% of the total botanical composition. In contrast, light-continuous and heavy-continuous pastures had a forb component of only 17% and 32%, respectively. Changes were more likely the result of a higher stocking rate on the short duration system and not because of the grazing system because when compared at similar stocking rates there was no difference in botanical composition between short duration grazing systems and continuous grazing.

In a multi-species (sheep, goats, and cattle) study conducted at the Sonora research station, short duration grazing was compared to a high intensity, low frequency (HILF) grazing system (Taylor et al., 1993a). Grazing treatments consisted of a 7-pasture, 1-herd short duration grazing system with a 7-day grazing period and a 42-day recovery period and a 7-pasture, 1-herd HILF system with a 14-day grazing period and an 84-day recovery period. Both systems were stocked at a rate of 10.4 ha·AUY^{-1}. After 4 years, aboveground net primary production increased for shortgrass and mid-grass species on the short duration grazing system by 29% and 9.8%, respectively. Conversely, shortgrass and mid-grass species increased 7% and 29.2%, respectively, for the HILF system. The longer recovery periods under the HILF system promoted secondary succession from shortgrass to mid-grass species better than short duration grazing. This suggests that in arid environments length of recovery period is more important to plant succession than the number of grazing periods.

Herbage production

A 10-paddock short duration grazing system showed little difference in herbage production on tobosa (*Pleuraphis mutica*) dominated ranges in New Mexico when compared to continuously-grazed pastures (Anderson 1988). Herbage production differences were also minimal between continuously-grazed pastures and short duration grazing systems that were stocked at 1.1 and 2.0 times that of the continuously grazed systems on blue grama grasslands in New Mexico (White et al. 1991). Standing crop of blue grama was variable between the systems, but other grasses, sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), wolfstail (*Lycurus phleoides* Kunth), sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), and creeping muhly (*Muhlenbergia repens* (J. Presl) Hitchc.), produced only slightly (100 $kg \cdot ha^{-1}$) more forage with continuous grazing.

Similar results were recorded in a 4-year study in Texas (Pitts and Bryant 1987). Herbage production for a short duration grazing system did not differ from production on continuously grazed pastures. Any difference in the amount of herbage produced was determined to be more related to precipitation amounts than to the grazing system. It was concluded that Savory’s claims that short duration grazing would allow for increased stocking rates was not achievable. In another Texas study, research on the Edwards Plateau reported that a moderately-stocked (8.1 $ha \cdot AU^{-1}$), continuously-grazed pastures had significantly greater amounts of herbage production than a heavily-stocked (4.6 $ha \cdot AU^{-1}$), 14-pasture short duration grazing system (Thurow et al. 1988). However, when continuously-grazed pastures were compared to a short duration grazing system at the similar stocking rate there was no difference in the amount of herbage produced.

Research on Oklahoma tallgrass prairie showed a significant increase in herbage production for a short duration grazing system (Cassels et al. 1995). An 8-pasture, short duration grazing system was compared to continuous grazing in a 5-year study. Herbage standing crop was analyzed in July and September of every year. Standing crop did not differ between short duration grazing and continuous grazing in July but was 20% greater for short duration grazing in September. The increase in herbage may have been a result of lower cattle intake and lower frequency of defoliation rather than an increase in individual plant vigor or production under a short duration grazing system. More recent studies have shown that digestible organic matter intake in steers is decreased by 19% (McCollum and Gillen 1998) and that cattle have a lower frequency of defoliation on little bluestem (Derner et al. 1994) under short duration systems compared to continuously-grazed pastures in Oklahoma.

Livestock production

A 4-year study conducted in Texas compared a 16-pasture, short duration grazing system with continuous grazing on shortgrass prairie in poor condition (Pitts and Bryant 1987). The stocking rate for the continuously grazed pastures remained constant at 13.3 $ha \cdot AUY^{-1}$, but the short duration grazing system was stocked at 13.3 $ha \cdot AUY^{-1}$ (1X) during the first year of the study, increased 2X (6.7 $ha \cdot AUY^{-1}$) during the second year, and increased 1.5X (8.9 $ha \cdot AUY^{-1}$) during the third and fourth years of the study. Livestock production per hectare for the short duration grazing system at 1X and 2X stocking rate did not differ from continuous grazing. However, stocking at 1.5X the continuously-grazed pastures in the third and fourth years resulted in a significant increase in livestock production per hectare. Livestock production for short duration grazing was 22.6 $kg \cdot ha^{-1}$ compared to only 16.75 $kg \cdot ha^{-1}$ for continuously grazed pastures during the last 2 years of the study. Individual animal livestock performance was generally lower for steers on short duration grazing systems at the 1.5X stocking rate. When the stocking rate was 2X greater for the short duration grazing system daily gains were 40% (0.10 $kg \cdot day^{-1}$) less than those achieved on the continuously grazed pastures. At similar stocking rates there was no difference in average daily gains between the systems (average of 0.33 $kg \cdot day^{-1}$).

Other research on Oklahoma tallgrass prairie reported greater yearly weight gains for yearling steers on continuous pastures than steers grazed with a short duration grazing system (McCollum et al. 1999). This 6-year study compared an 8-paddock, short duration grazing system with continuously grazed pastures at moderate (52 AUD) and heavy (90 AUD) stocking rates. Gains per head were significantly higher for steers grazed on the continuous pastures in all years of the study. At the moderate and heavy stocking rates, average gains for steers on the short duration grazing system were 12.8 kg (11%) and 22 kg (20%) less, respectively, than those on continuously grazed pastures. They concluded that lower weight gains were a result of reduced forage intake by steers on the short duration grazing system.

On non-native pastures, livestock production has not increased from the implementation of a short duration grazing system. Weight gains of heifers grazed on smooth bromegrass (*Bromus inermis* Leyss.) in eastern Nebraska with an 8-pasture short duration grazing system did not differ from heifers on continuously grazed pastures (Jung et al. 1985). In the first year of the study, average daily gains of heifers were 0.47 $kg \cdot d^{-1}$ and 0.48 $kg \cdot d^{-1}$ on continuously-grazed pasture and a short duration grazing system, respectively, at similar stocking rates (2.9 $animals \cdot ha^{-1}$). In the second year of the study, stocking rate for the short duration grazing system was increased by 131% (3.8 $animals \cdot ha^{-1}$) while stocking rate on continuously-grazed pastures remained constant (2.9 $animals \cdot ha^{-1}$). Heifer weight gains again did not differ (0.56 $kg \cdot day^{-1}$ for continuously-grazed heifers and 0.52 $kg \cdot day^{-1}$ for the short duration grazing system heifers). Research on crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) in central Utah found that weight gains were variable for short duration grazing systems and season-long continuous grazing (Olson and Malechek 1988). In the first year, average daily gains were greater for steers on continuously-grazed pastures, but there was no difference in weight gains in year 2 and significantly greater gains with the short duration grazing system in year 3. Results were not conclusive for heifer weight gains, but pregnancy rates were 3.6 to 8.3% lower for heifers grazed with the short duration grazing system even though diet quality was similar between systems. Because of this reduction in pregnancy rate the authors only recommended the use of short duration grazing for non-reproductive livestock on crested wheatgrass pastures.

Average daily gains of calves were found to be lower under a high performance short duration grazing system stocked at 0.65 $AU \cdot ha^{-1}$ when compared to a repeated season-long system stocked at 0.33 $AU \cdot ha^{-1}$ in South Dakota (Volesky et al. 1990). Heifer calves grazed with sheep in a 16-paddock, short duration grazing system gained 0.13 $kg \cdot d^{-1}$ less in year 1 and 0.06 $kg \cdot d^{-1}$ less in year 2 than the calves being grazed continuously. Calves in a short duration grazing system consumed a greater amount of annual grasses, but lower amounts of forbs and western wheatgrass. Even though individual animal gains were lower, the increased stocking rate with the short duration grazing system may increase animal production per unit area. Heifers on the short duration grazing system increased weight gains by 6.3 kg · ha^{-1} compared to continuously grazed heifers in the second year of the study.

Short duration Grazing Systems vs. Deferred-Rotation Grazing Systems

Three studies have reported on comparisons between short duration grazing systems and deferred-rotation systems (Heitschmidt et al. 1990; Hart et al. 1988; and Manley et al. 1997). Heitschmidt et al. (1990) examined cow-calf production and economic returns in the southern mixed-grass prairie region of Texas. Hart et al. (1988) and Manley et al. (1997) reported on the mid-term and long-term results of a grazing study at the High Plains Grassland Research Station in southeastern Wyoming. This study compared steer gains, peak standing crop, and basal cover of vegetation between the grazing systems after 6 and 13 years, respectively.

In Heitschmidt et al. (1990), a short duration grazing system was grazed by a herd of 125 cow-calf pairs (3.6 ha·$pair^{-1}$). The system had 16 paddocks, which allowed recovery periods of 30 to 65 days. The deferred-rotation system rotated 3-herds of 25 pairs (5.9 ha·$pair^{-1}$) so each pasture received deferment every 4 years. Hart et al. (1988) and Manley et al. (1997) both studied an 8-paddock, 1-herd short duration grazing system stocked with steers at light, moderate, and heavy stocking rates. Rotation through the paddocks was based on estimated forage availability and rate of forage growth from June to October. This system was compared to a 4-pasture, 3-herd deferred-rotation system grazed with steers at similar stocking rates. The rotation of pastures in the deferred-rotation allowed a different pasture to be deferred until September 1 every year.

Heitschmidt et al. (1990) found that end-of year weights for individual cows were consistently 32 kg heavier for the short duration grazing system. Average daily gains for calves over the 6 years of the study were similar from June to October under both systems. Conception rates were greater for cows with the deferred-rotation system (95%) compared to the short duration grazing system (89%). Estimated forage production for this study was similar between the grazing system, 2948 $kg \cdot ha^{-1}$ for the short duration grazing system and 3063 $kg \cdot ha^{-1}$ for the deferred-rotation.

Hart et al. (1988) found that the grazing systems were similar in livestock production, herbage production, and botanical composition when grazing yearling steers. During this 6-year study there was no difference in average daily gains (0.95 kg) between the two systems. There was also no difference in the herbage production (mean of 1170 $kg \cdot ha^{-1}$) between the grazing systems at either stocking rate. Average botanical composition remained constant under each system with 52% blue grama, 16% western wheatgrass, 18% other graminoids, and 14% forbs and half shrubs.

Manley et al. (1997) found similar results to Hart et al. (1988) after 13 years of research on the same study in Wyoming. There were no differences in steer average daily gains (0.82 kg) between grazing systems. Peak standing crop and botanical composition remained similar between the grazing systems and stocking rates. They attributed benefits from short duration grazing found in other studies to be a result of increased levels of management, better distribution of animals and higher grazing efficiency, and not a result of a particular specialized grazing system.

Conclusion

Research has shown mixed results on the benefits of grazing systems to plant composition, herbage production, and livestock production. However, most of the research suggests that if rangelands are in good condition it can be managed using a continuously-grazed system at a proper stocking rate and have either superior or equal results to a rotational-grazed system. Briske et al. (2008) concluded that rotational grazing may be a useful strategy for rangelands, but emphasized that research has not shown that it has any advantage over continuous grazing in herbage or livestock production. Short duration grazing systems have not shown the benefits that it was professed to provide by Savory (1978, 1983). When compared with a deferred-rotation system or continuous grazing, short duration grazing has been an equal or slightly inferior grazing system in terms of benefits to vegetation or livestock production. This literature review indicates that the benefit of implementing short duration grazing systems does not justify the added expense of the fencing, labor, and water that a short duration grazing system generally requires. Implementation of a deferred-rotation grazing system can increase animal distribution within large pastures with lower input costs than short duration grazing systems and provide similar or slightly better returns to cattle and rangeland vegetation. According to the research evaluated in this review there is little difference between deferred-rotation and short duration grazing systems in terms of botanical composition, herbage production, and livestock production.

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Chapter 2

Effect of Grazing System and Topography on Livestock Performance, Botanical Composition, and Standing Crop in the Eastern Nebraska Sandhills

Abstract

Short duration grazing systems have been researched in many areas of the Great Plains, but not extensively in the Nebraska Sandhills. A 10-year study compared a 4-pasture, deferred-rotation (DR) grazing system with an 8-pasture, short duration grazing (SDG) system at the Barta Brothers Ranch near Rose, NE to determine differences between grazing systems in livestock performance, standing crop, and botanical composition. Pastures (47 ha) were grazed by 50 to100 cow-calf pairs with both single (DR system) and multiple (SDG system) grazing periods from 15 May to 15 October. Livestock performance data were collected from spayed heifers substituted into each grazing system during the last 3 years of the study. Standing crop data were collected biannually within 240 grazing exclosures placed at 4 topographic positions common to the Sandhills. Exclosures were moved at the beginning of each grazing season to capture previous year grazing system treatment effect. Botanical composition was collected using frequency of occurrence transects to collect vegetation data in 1998, 2003, and 2008. Average daily gains of the spayed heifers (0.84 $kg \cdot day^{-1}$) did not differ between grazing systems and years. The DR grazing system had greater total standing crop in 2001 and 2007 and increased the frequency of occurrence of desirable plant species more than the SDG system. However, standing crop and frequency of occurrence were more affected by topographic position and year than by grazing system treatments. Claims that SDG will significantly increase livestock performance, standing crop, or frequency of desirable species when compared to a less intensive grazing system were not substantiated in this study.

Introduction

The benefits of short duration grazing (SDG) systems have been debated for decades. Since Allan Savory introduced the concept to North America in the early 1970s, grassland scientists have compared SDG to other grazing systems to quantify the response of rangeland vegetation and livestock performance. Proponents of SDG systems claim increases in stocking rate while increasing or maintaining desirable plant species composition, herbage yields, and livestock performance by rotating livestock through several pastures (> 7) with multiple, short grazing periods throughout the growing season (Savory and Parsons 1980; Savory 1983; 1999). Short duration grazing reportedly limits the number of plant tillers that reach maturity by uniformly grazing pastures multiple times over the growing season, keeping forage in a more nutritious, immature state. Additionally, SDG is reported to increase the use and efficiency of the available forage resource by limiting livestock selectivity of plants and increasing livestock distribution by increasing stocking density (Heitschmidt and Walker 1983). However, a majority of the research conducted over the last 30 years has concluded that SDG systems have little, if any, benefit to herbage production and livestock performance when compared to other grazing systems (Holecheck et al. 2000). Variations of SDG systems are common on ranches throughout the Nebraska Sandhills (Reece 1986).

Deferred-rotation (DR) grazing systems are also common within the Sandhills (Reece 1986). The DR system is less management intensive and requires fewer pastures (usually 2 to 5) than a SDG system. The DR system also differs from SDG systems by limiting grazing to a single grazing period during the growing season. Livestock are moved through pastures in a sequential rotation that allows pastures to have growing season deferment once every 2 to 5 years. Short duration grazing and DR systems have been researched in many areas of the Great Plains (Owensby et al. 1973; Hart et al. 1988; Cassels et al. 1995; McCollum et al. 1999; Manley et al. 1997). However, there is limited research available in the Nebraska Sandhills on the comparison of these grazing systems in terms of livestock performance and vegetation production. Long-term studies (10 years or more) at a production scale are also few and limited research is available that compares SDG with other grazing systems (Holecheck et al. 2000).

Topographic position has a large impact on the composition and distribution of vegetation within the Nebraska Sandhills (Tolstead 1942; Barnes and Harrison 1982; Barnes and Harrison 1984; Schacht et. al. 2000). Soil moisture holding capacity, transpiration rates, evaporation, temperature, and humidity are all affected by topographic variations over the landscape. The different topographic positions within the Sandhills provide a variety of suitable environments for a diversity of warm- and cool-season grasses, sedges, forbs, and shrubs (Schacht et al. 2000). Typically, dunes run west by northwest to east by southeast with slopes of 5 to 15%. North-facing slopes tend to be dominated by cool-season grasses, shrubs, and little bluestem (*Schizachyrium scoparium* [Michx.] Nash) whereas other warm-season grasses are dominant on south-facing slopes (Barnes and Harrison et al. 1982; Schacht et al. 2000). Topographic position has been reported to influence the grazing behavior of cattle in the Sandhills (Stubbendieck and Reece 1992), but no research has quantified the interactions of grazing systems and topography on vegetation cover.

For a grazing system to be beneficial, it must provide an increase in herbage and livestock production that will enhance the goals of a ranch operation while increasing or maintaining the range at a good to excellent condition (Vallentine 1979). Vegetation and livestock response to multiple grazing periods with SDG systems and single grazing periods with DR systems need to be researched and compared to help land managers determine if the increased costs in fencing, livestock water, and labor required by a SDG system will provide viable financial and ecological outcomes when compared to other less intensive grazing systems. The objective of this study was to determine differences in livestock performance, subsequent-year standing crop, and botanical composition between a 4-pasture DR grazing system and an 8-pasture SDG system on 4 different topographic positions within the Nebraska Sandhills.

Materials and Methods

Study Site

Research was conducted at University of Nebraska's Barta Brothers Ranch from 1999 through 2008. Barta Brothers Ranch is a 2,350-ha ranch located in the eastern Nebraska Sandhills near Rose, NE (42° 13' 32'' N, 99° 38' 09'' W; elev. 765 m above sea level). Climate is typical of a mid-continental, semi-arid prairie region. Weather data were collected from a High Plains Regional Climate Center station located approximately 48 km to the northwest in Ainsworth, Nebraska, and an onsite weather station. The 103-year average maximum annual temperature is 16.3ºC, and the average minimum temperature is 2.6ºC (HPRCC 2008). The lowest average minimum temperatures occur in January (-11.4ºC). The highest average maximum temperature occurs in July (31.5ºC). Average annual precipitation is 570 mm with 76% (435 mm) falling between April and September. On average, June is the wettest month (92 mm) of the year and January is the driest (12 mm).

Topography, soils, and vegetation are typical of the eastern Nebraska Sandhills. Ninety percent of the study area is classified as upland prairie and the remaining 10% is intermixed sub-irrigated meadows and wetlands (Schacht et al. 2000). Topography of the study area is approximately 60-70% north- and south-facing dune slopes, 10-20% dune tops, and 10-20% interdune valleys. Sands range sites dominate the study area with dominant soils being a Valentine series (mixed, mesic Typic Ustipsamments).

Vegetation of the study area is a mixture of warm- and cool-season grasses, forbs, shrubs, and sedges. Nomenclature of plant species follows Kaul et al. (2006). Dominant grasses include prairie sandreed (*Calamovilfa longifolia* [Hook.] Scribn.), sand bluestem (*Andropogon gerardii* subsp. *halli* (Hack.) J. Wipff), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), switchgrass (*Panicum virgatum* L.), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), blue grama (*Bouteloua gracilis* [Willd. *ex* Kunth] Lag. *ex* Giffiths), hairy grama (*Bouteloua hirsuta* Lag.), prairie junegrass (*Koeleria macrantha* [Ledeb.] J. A. Schultes), needleandthread (*Hesperostipa comata* Trin. & Rupr.), porcupinegrass (*Hesperostipa spartea* Trin.), Scribner panicum (*Panicum oligosanthes* Schult. var. scribnerianum [Nash] Fernald), Wilcox panicum (*Panicum wilcoxianum* Vasey), and bluegrass species (*Poa Compressa* L. and *Poa pratensis* L.). Several species of sedges (*Carex spp*.) and cactus (*Opuntia spp*.) are also common. Common forbs and shrubs are western ragweed (*Ambrosia psilostachya* DC.), cudweed sagewort (*Artemisia ludoviciana* Nutt.), prairie wild rose (*Rosa arkansana* Porter *ex* Porter & J.M. Coult.) and leadplant (*Amorpha canescens* Nutt. *ex* Pursh).

Grazing System Treatments

Grazing system treatments were initiated in 1999. Prior to the study the pastures on the ranch had been continuously grazed since the mid-1950s by cow-calf pairs at moderate stocking rates (about 1.8 $AUM \cdot ha^{-1}$). At the initiation of the study, rangelands were determined to be in good to excellent condition (Schacht et al. 2000).

Upland range was divided to create two replications of an 8-pasture SDG system and a 4-pasture DR grazing system. Average size of the pastures was 53 ha for SDG pastures and 40 ha for the DR pastures. The pastures within both systems were grazed by cow-calf pairs from 1999 through 2005 and by cow-calf pairs and spayed heifers from 2006 to 2008. Grazing dates for the study were from 15 May to 15 October except in 2002 and 2006 when cattle were removed on 15 September and 30 September, respectively, because of drought. Average stocking rate was 1.8 $AUM \cdot ha^{-1}$ over all treatments and years.

Approximately 100 cow-calf pairs were rotated through the 8 pastures of each replicate of the SDG system 3 times (cycles) per grazing season. Timing of grazing was based on the practice of moving cattle rapidly through the pastures early in the growing season and extending grazing cycles as forage matured. The first grazing cycle ran from mid-May to early June (16 days) with 2-day grazing periods within each pasture. The second cycle ran from early June to late July (~56 days) with 7-day grazing periods. The third cycle ran from late July to mid-October (~80 days) with 10-day grazing periods.

About 50 cow-calf pairs were rotated through the 4 pastures of each DR grazing system. Each pasture was grazed only once during the growing season at 30 to 45 $days \cdot pasture^{-1}$. Length of grazing periods within pastures increased as the growing season progressed. Sequence of grazing was rotated so pastures were not grazed at similar times during the growing season in consecutive years. Pastures were rotated so that each pasture preceded and followed every other pasture twice for the DR system and at least once for the SDG system during the course of the study.

Livestock Performance

In the last 3 years of the study, 20 Angus and Angus-cross, yearling, spayed heifers replaced 10 cow-calf pairs in each of the 2 replicates of the grazing treatments to determine grazing system effect on weight gain. The spayed heifers were moved into the pastures at the same date in May with the cow-calf pairs, but they were removed from the pastures about 1 to 4 weeks before the cow-calf pairs. Length of grazing season was 138 days (16 May to 1 October) in 2006, 152 days (12 May to 11 October) in 2007, and 116 days (22 May to 15 September) in 2008. In all years heifers received a Synovex H implant and were weighed on the first day of the grazing season. Average initial weights for heifers were 254 +/- 2.4 $kg \cdot hd^{-1}$ in 2006, 242 +/- 2.4 $kg \cdot hd^{-1}$ in 2007, and 270 +/- 2.4 $kg \cdot hd^{-1}$ in 2008. Final weights were taken at the end of the grazing season when the heifers were removed from treatment pastures. Feed and water were withheld for approximately 12 hours before initial and final weights were taken. Weight gains were determined by subtracting heifer initial weight from heifer final weight. Average daily gains were calculated by dividing the grazing season weight gain by the number of grazing season days.

Botanical Composition

Baseline frequency of occurrence data were collected in June and July 1998 at 87 permanently-marked sites with 4 transects per site (348 transects). Sites were distributed across the study with a spacing of one site per 20 ha. Transects were placed at each of the 4 topographic positions (north slope, south slope, dune tops, and interdunes) on the dunes at each site. Transects ran parallel with the contour of the land on dune tops, at the midpoint between dune tops and valleys for the north- and south-facing slopes, and through the center of narrow interdune valleys. Transects on slopes and dune tops were 100 m long whereas transects on interdunes were 50 m long because valleys were not as extensive as the other topographical positions and species diversity was relatively low. Frequency of occurrence data were collected using a 0.1-m^2 square quadrat placed at 4-m intervals along a tape stretched between the end points of each transect. A total of 25 quadrats per transect were read for slopes and dune tops and 13 quadrats per transect were read on interdunes. Occurrence of all plant species was identified and recorded at each quadrat placement. The 4-m interval was selected as a result of a preliminary process of developing a species-area curve relating interval to number of species (Mueller-Dombois and Ellenberg 1974). The 0.1-m^2 quadrat size was selected because it was the largest frame size that resulted in a frequency of occurrence less than 100% for each species encountered in the sampling process (Daubenmire 1968). Transects were revisited and read during the growing seasons of 2003 and 2008. Because some transects were unable to be located, the number of transects read in 2003 and 2008 was 275 and 301, respectively. To keep data consistent only transects read in all 3 years were used in the analysis.

Standing Crop

Cumulative effect of grazing system treatments on above-ground standing crop was determined by sampling standing crop annually in mid-June and mid-August beginning in 2000. Mid-June and mid-August correspond to the approximate time of peak cool- and warm-season herbage yields, respectively (Northup 1993). Two pastures within each of the grazing system replications were selected for standing crop data collection. Two sites in 2000 and 3 sites from 2001 through 2008 within the 2 pastures were selected and 5 exclosures (1.2 x 1.2 m wire panels) were placed along the transect lines of each topographic position. The design resulted in a total of 160 exclosures in 2000 and 240 exclosures (2 grazing system treatments x 2 replications x 3 sites x 4 topographic positions x 5 exclosures) in all other years. A 0.25-m^2 (0.25 x 1.0 m) quadrat was placed in either the north or south half of each exclosure in June (determined randomly) and in the other half in August. Exclosures were moved at the beginning of each year to capture previous years' grazing treatment effect. Standing crop was estimated by hand-clipping all standing herbaceous vegetation at ground level in the quadrat and separating it into one of the following categories: warm-season grasses, cool-season grasses, sedges, forbs, or standing dead. Current year's growth of shrubs (i.e., leaves and new stem tissue) and cactus (i.e., new leaves or pads) also were collected from plants rooted within the quadrats. Litter material within the quadrat also was collected. All separated plant material was placed in marked individual paper bags, oven dried to a constant weight at 60°C, and weighed.

Statistical Analysis

Livestock performance data were analyzed using a mixed procedure, analysis of variance with year and grazing system as treatments within SAS (SAS 2003). Grazing system was considered the experimental unit for all comparisons. Frequency of occurrence and standing crop data were analyzed using a mixed procedure, analysis of variance. Frequency of occurrence for 20 of the most common plant species was analyzed by comparing the change from baseline (1998) during the first 5 years (1998 to 2003) and the second 5 years (2003 to 2008). Year, grazing system, and topographic position were considered main treatment factors. All main effects and interactions were analyzed. Pastures were treated as a random effect within the model. An alpha level of 0.10 was used to determine significant differences between grazing system, topography, and year main effects and interactions.

Results and Discussion

Precipitation Data

Average yearly precipitation over the course of the study was 532 mm which was below the long-term (103 year) average of 571 mm. Total annual and growing season precipitation varied during the study (Figure 1). Precipitation in the driest years, 1999 and 2002, were 27% and 41% below the long term average, respectively. Precipitation in the wettest years, 2007 and 2008, were 1% and 25% above average, respectively (Figure 1). In 2002, accumulated precipitation through June was 44% below the long-term average, while in 2008 accumulated precipitation through June was 10% greater (Figure 2). Yearly precipitation during the first 5-year period (1999 to 2003) was 20% below the long-term average, whereas, precipitation during the second 5 year period (2004 to 2008) was 2% greater than the long term average, 454 mm and 582 mm, respectively.

Livestock performance

Heifer daily gain averaged 0.84 $kg \cdot day^{-1}$ and was not different between grazing system treatments or year. The claim that SDG increases livestock performance by grazing multiple times throughout the growing season (Savory 1980) did not occur in this study. Quality of available pasture forage likely was not different between the grazing systems. In a companion study, there were no differences in crude protein or digestibility of diet samples of cows grazing the pastures in the 2 grazing systems in 2005 and 2006 (Schroeder 2007). Weight gain of steers grazed with a 3 herd, 4 pasture DR system in the short grass prairie of eastern Wyoming were not different from steers that were grazed in a SDG system; however, daily gains decreased with increased stocking rates (Hart et al. 1988; Manley et al. 1997). With similar diet quality and stocking rates between the 2 grazing systems, weight gains of heifers would not be expected to differ between the grazing systems.

Botanical Composition

Warm-season Grasses

Little bluestem and sand bluestem were the only warm-season grasses to exhibit grazing system x topography x year and grazing system x year interactions, respectively. During the first 5 years of the study, little bluestem frequency of occurrence on north slopes increased more on DR pastures than SDG pastures (Figure 9A). Change in frequency of occurrence for little bluestem on north slopes was greater during the first 5 years than the second 5 years for both grazing system treatments. Sand bluestem frequency of occurrence increased more with the DR system (7.5 %) than with the SDG system (0.5%) during the first 5-year period. However, change in frequency of occurrence did not differ (mean increase of 5.8%) between grazing system treatments in the second 5 years.

The increase of little bluestem on north slopes and sand bluestem averaged over all topographic positions on DR pastures indicates that a single grazing period favored these warm-season grasses during the drier, first 5-year period. Studies in the Sandhills have determined that single growing season defoliations will generally maintain total organic reserves, bud and tiller numbers, and annual yields better than multiple growing season defoliations for sand bluestem (Engel et al. 1998; Reece et al. 1996; Mullahey et al. 1991) and little bluestem (Mullahey et al. 1990).

There were several topography x year interactions with the change in frequency of occurrence of warm-season grass species over the course of the study (Table 3). Change in frequency of occurrence for blue grama and sand dropseed was greater in the first 5 years on interdunes than on other topographic positions. Increases for sand dropseed also were greater during the first 5 years than during the second 5 years on all topographic positions. In contrast, indiangrass decreased in frequency of occurrence on all topographic positions during the first 5 years, and increased during the second 5 years (Table 3). Frequency of switchgrass increased more on south slopes during the first 5 years than during the second, but decreased more on interdunes during the first 5 years than during the second (Table 3).

Change in frequency of occurrence for hairy grama, prairie sandreed, and sand bluestem differed with topographic position when averaged over both 5-year periods (Table 2). Prairie sandreed increased more on dune tops, interdunes, and south slopes than on north slopes. Hairy grama and sand bluestem increased more on dune tops than on north slopes and interdunes.

Cool-season Graminoids

Bluegrasses and sedges responded differently to the drier conditions during the first 5 year period than blue grama and sand dropseed on interdune positions. In the first

5 years, bluegrass species (primarily *Poa pratensis* L.) decreased dramatically on interdunes but remained constant or increased on the other topographic positions (Table 3). In contrast, during the second 5-year period, bluegrasses increased more on interdunes and north slopes than other topographic positions. Change in frequency of occurrence for sedges followed a similar pattern to bluegrasses. However, sedges decreased over all topographic positions during the first 5 years and increased on all positions during the second 5 years (Table 3). Frequency of sedges also increased more during the second 5 year period on dune tops and north slopes than on interdunes and south slopes.

The differing results between blue grama and sand dropseed with cool-season graminoids (i.e., bluegrasses and sedges) on interdunes during the first 5-year period may be a result of differences in water use efficiencies between C_3 (cool-season) and C_4 (warm-season) species. Barnes and Harrison (1982) determined that transpiration rates were as much as 2 times greater for cool-season grasses than for warm-season grasses in the Sandhills and indicated that differences in vegetation cover may be a result of a soil moisture gradient over the different topographic positions. It was also determined that the finer textured soils on interdunes increased the water holding capacity relative to the coarse textured soils on the dune tops and slopes in the western Nebraska Sandhills. However, Schacht et al. (2000) reported that there were no differences in the soil texture among topographic positions on upland sites at the Barta Brother's Ranch, but found that soil organic matter was higher on interdunes than on other positions. Differences in organic matter and soil texture on interdunes may affect how the soil moisture that accumulates on interdunes in the winter and early spring is utilized. Generally, soil moisture on interdunes will become depleted through the growing season as a result of runoff, evaporation, and transpiration (Barnes and Harrison 1982; Barnes et al. 1984). In contrast, soil moisture in the top profiles of the slopes and dune tops is usually available until mid-summer and at deeper levels throughout the growing season because of high infiltration rates. Shallow-rooted, cool-season grass and sedge species are well adapted to the increased water holding capacity in the upper soil profiles on interdunes early in the growing season and during summers with above average precipitation, but these species are very sensitive to summer drought (Stubbendieck and Kotas 2005). During the first 5-year period when precipitation was limited, soil moisture on interdunes likely became depleted and negatively impacted cool-season grasses and sedge species. Warm-season mid- and short-grasses (i.e., sand dropseed and blue grama) increased during this time when there were lower amounts of precipitation and soil moisture in the upper soil profiles. The increase in frequency of occurrence of blue grama and sand dropseed on the interdunes indicate that they were better able to utilize the limited amount of soil moisture on interdunes during drought years than bluegrasses and sedges.

Scribner’s panicum and Wilcox panicum were the only cool-season grasses to have grazing system x year x topography and grazing system x topography interactions, respectively. During the first 5 years, Scribner’s panicum increased more on south slopes of DR pastures than on all other topographic positions (Figure 9B). Scribner’s panicum also increased more on south slopes of DR pastures than on SDG pastures, but increased more on dune tops of SDG pastures than DR pastures (Figure 9B). Frequency of occurrence of Wilcox panicum decreased 6.5 % on dune tops of DR pastures over the study, but remained constant (increase of 0.4%) on dune tops of SDG pastures. Wilcox panicum was not affected by grazing system treatments on the other topographic positions. When averaged over grazing systems, Wilcox panicum decreased in frequency of occurrence on all topographic positions during the first 5 years, but increased on dune tops and north slopes during the second 5-year period (Table 3).

Needlegrass species (porcupinegrass and needleandthread) when averaged over grazing system and topographic position increased 13.4% during the first 5-year period, but decreased 6.3% in the second 5 year period. It is not clear why needlegrasses increased when other cool-season grasses tended to decrease during the drier first 5 year period.

Other Species

Frequency of western ragweed decreased on all topographic positions on DR and SDG pastures during the first 5 year period (Figure 9C). However, frequency of western ragweed on interdunes decreased more on DR pastures than on SDG pastures. In contrast, during the second 5-year period, frequency of occurrence increased on dune tops, interdunes, and south slopes on DR pastures while frequency continued to decreased on these topographic positions on SDG pastures. During the second 5-year period, frequency of western ragweed on DR pastures increased more on dune tops, interdunes, and south slopes than during the first 5 years (Figure 9C). The decrease in the frequency of occurrence on SDG pastures did not differ among the topographic positions during either time period. Cudweed sagewort increased during both 5-year periods, but increased more on interdunes during the first 5-year period than the second 5-year period when averaged over both grazing systems (Table 3).

Western ragweed and cudweed sagewort appeared to be affected by differences in precipitation during the different time periods. Western ragweed is an opportunistic species that increases rapidly when adequate soil moisture is available and when vigor of associated grass species is reduced by drought or grazing management practices (Reece et al. 2004). Because of its low palatability and ability to use available resources, western ragweed is one of the most common species in the Nebraska Sandhills over all topographic positions (Schacht et al. 2000). The decline in western ragweed during the first 5 year period might have been related to the below average precipitation and, inversely, the above average precipitation during the second 5 years might explain the increase in western ragweed frequency on DR pastures. However, it is not clear why frequency of occurrence on SDG pastures responded differently than DR pastures to the different amounts of precipitation during the 2 time periods. Cudweed sagewort appeared to be better able to increase in frequency on interdunes during the drier first 5-year period, when bluegrasses and sedges declined, than during the second 5-year period.

Frequency of prairie wild rose on interdunes and north and south slopes increased during the first 5 years on DR pastures, but decreased during the second 5 years (Figure 9D). Frequency with the SDG system increased on north slopes during the first 5 years, but decreased during the following time period. Leadplant, averaged over grazing system treatments and topographic positions, decreased by 2.2 % during the first 5 year period, but increased 4.3 % in the second 5 years.

Standing Crop

Mid-June Harvest

Standing crop was clipped in June to capture peak standing crop of cool-season grasses as discussed in Northup (1993). However, it was determined that standing crop of cool-season grasses did not differ when clipped in mid-June and mid-August, 464 $kg \cdot ha^{-1}$ and 491 $kg \cdot ha^{-1}$, respectively.

Total live standing crop harvested in mid-June tended to vary with amount of precipitation. Standing crop was lowest in 2002 (834 $kg \cdot ha^{-1}$) and greatest in 2007 (1822 $kg \cdot ha^{-1}$). Total live standing crop was greater on interdunes than other topographic positions in 2001, 2005, 2007, and 2008 (Figure 3D). In the wettest years of the study, 2007 and 2008, standing crop also was greater on north slopes compared to south slopes and dune tops.

Standing crop of warm-season grasses was greater on south slopes in 2004 than on other topographic positions, whereas, interdunes had the greatest standing crop in 2007 and 2008. North slopes consistently had lower amounts of standing crop than other topographic positions (Figure 3A).

Standing crop of cool-season grasses was greater on the interdunes in 2000, 2001, 2005, 2007, and 2008 than other topographic positions (Figure 3B). During the driest year of the study (2002) and the 2 years immediately following (2003 and 2004), cool-season grass standing crop on the interdunes did not differ from the other topographic positions. Standing crop of cool-season grasses in 2007 on north slopes was greater than dune tops and south slopes, but still less than interdunes. Kentucky bluegrass made up a majority of the cool-season grass standing crop on interdunes whereas needleandthread, prairie junegrass, and Wilcox panicum were, generally, more common on north slopes and dune tops (Schacht et al. 2000). The dramatic decrease in frequency of occurrence for Kentucky bluegrass on interdunes during the first 5 years of the study (Table 3) may explain why cool-season grass standing crop was lower from 2002 until 2004. Increased levels of precipitation seemed to increase both the frequency of occurrence and standing crop of cool season graminoids on interdunes during the latter half of the study.

Standing crop of sedges in mid-June was greater on interdunes than other topographic positions in all years of the study (Figure 3C). Sedges were common on all topographic positions within the study, but sedges had the greatest frequency of occurrence on interdunes. In 2008, sedges on pastures grazed with the DR system produced nearly 70% (68 kg $\cdot$ ha^{-1}) more herbage than the SDG system pastures (DR= 167 kg $\cdot$ ha^{-1}, SDG= 99 kg $\cdot$ ha^{-1}). However, there were no other grazing system effects on sedge standing crop in all other years of the study.

Standing crop of forbs on interdunes and north slopes was approximately 85% greater than on dune tops and south slopes (Table 1). Western ragweed and cudweed sagewort made up a majority of the forb standing crop on interdunes and north slopes. Cudweed sagewort also increased in frequency of occurrence more on interdunes than on other topographic positions during the study (Table 3). Standing crop of forbs was greatest in 2007 (280 kg $\cdot$ ha^{-1}) when compared to all other years of the study.

Current year's growth of shrubs was greater on DR pastures than SDG pastures on dune tops in 2007 and north slopes in 2005 (Figure 4). Short duration grazing system pastures produced more standing crop than DR pastures on south slopes in 2003. North slopes tended to have higher occurrences of leadplant and prairie wild rose and similarly produced greater amounts of current year's growth on north slopes than other topographic positions for both systems.

Mid-August Harvest

Total live standing crop in mid-August on DR pastures was 33% and 17% greater than standing crop on SDG pastures in 2001 and 2007, respectively (in 2001; DR= 1714 kg · ha^{-1}, SDG= 1288 kg · ha^{-1} and in 2007; DR= 2099 kg · ha^{-1}, SDG=1801 kg · ha^{-1}). Greater amounts of total standing crop on DR pastures may be a result of increased precipitation early in the growing season. Accumulated yearly precipitation through May was 44% and 46% greater than the long term average in 2001 and 2007, respectively. Cool-season grass (Figure 5) and forb (Figure 7) standing crop on interdune positions increased more on DR pastures than on SDG pastures in 2001 and 2007 and accounted for a majority of the increased total live standing crop on DR pastures. Mean total standing crop did not differ between grazing systems in all other years. Total standing crop, averaged over grazing system treatments, was greatest on interdunes in all years except 2002, 2004, and 2006 (Figure 8A); during these 3 years, there were no differences in total standing crop among topographic positions. These years were some of the driest of the study, especially early in the growing season of 2002 and 2006.

The greater amount of total live standing crop for a DR system compared to SDG system differs from findings of other studies in the Great Plains. Hart et al. (1988) reported that forage production did not differ between a DR and a SDG system at moderate and heavy stocking rates on shortgrass prairie in Wyoming. Similarly, Heitschmidt et al. (1987) found that total live herbaceous standing crop was not different between a 14 pastures, SDG system and continuously grazed pastures in rolling plains region of Texas. Our results indicate that DR pastures may produce more standing crop than SDG pastures in the Nebraska Sandhills in years with above average early precipitation. However, the differences that were found in total standing crop were minimal and may have been the result of precipitation variations or variability of vegetation within the study site and not a result of grazing system treatments. Topographic position and year seemed to have a greater effect on total standing crop than grazing system treatments.

Standing crop of warm-season grasses in 2008 on SDG pastures was 26% greater than on DR pastures (SDG=1146 kg $\cdot$ ha^{-1}, DR=910 kg $\cdot$ ha^{-1}). However, standing crop did not differ between grazing systems in all other years of the study. Warm-season grasses on interdunes produced the greatest amounts of herbage compared to other topographic positions when averaged over grazing systems and years (Table 1). Conversely, north-facing slopes produced the least amount of warm-season standing crop. Greater amounts of warm-seasons grasses on interdunes may be the result of a greater abundance of switchgrass on these positions. Schacht et al. (2000) reported that warm-season grasses generally had a higher frequency of occurrence on south-facing slopes, but that switchgrass was more common within interdunes than on other topographic positions. The occurrence of blue grama and sand dropseed also increased substantially on interdunes over the course of the study (Table 3) and may have caused an increase in the standing crop on this topographic position.

Standing crop of cool-season grasses was greater on interdunes of DR pastures than on SDG pastures in 2001, 2007, and 2008 (Figure 5). Cool-season grass standing crop was greater on interdunes than other topographic positions in 5 of the 8 years for the DR system, but in only 2 years for the SDG system.

Standing crop of sedges on interdunes was greater on DR pastures than SDG pastures in 2000, 2002, 2003, and 2005 (Figure 6). Sedge standing crop within the DR system was also greater on interdunes than other topographic positions in 2000, 2002, 2003, 2004, 2005, 2006, 2007, and 2008. Whereas, standing crop within the SDG system was greater on interdunes in only 2004, 2005, and 2008.

Lower amounts of sedges and cool-season grasses on interdunes in SDG pastures may be the result of multiple grazing periods and the associated high grazing pressure. Mature cows prefer level, lowland areas to slopes and dune tops when grazing (Stubbendieck and Reece 1992) and field observations indicated heavy utilization of the cool-season grasses and sedges on the interdunes in the SDG pastures during each of the 3 grazing cycles. Interdunes of the DR pastures were grazed only once during the growing season which limited the frequency of grazing that plant species on interdunes were subjected to. Other research in the Sandhills (Reece et al. 1996) has shown that multiple, severe defoliations of perennial grasses tend to reduce plant productivity compared to a single defoliation.

Standing crop of forbs was variable by grazing system and topographic position. Forb standing crop on interdunes was greater on DR pastures in 2001 and 2007 than on SDG pastures. However, in 2004 and 2005 SDG pastures had greater amounts of forbs (Figure 7). Forb standing crop on interdunes was greater than on other topographic positions in 2001, 2003, and 2007 for the DR system and in 2003 and 2005 for the SDG system. Forb standing crop on dune tops, interdunes, and north slopes in both DR and

SDG pastures increased in 2003, the year following the driest year of the study. Forbs seem to have taken advantage of decreased competition and vigor of other species caused by below average precipitation in 2002.

Current year's growth of shrub species within the DR system was only 4% of the amount produced on SDG pastures, 8 and 188 $kg \cdot ha^{-1}$, respectively, in 2002. Current year's growth did not differ between grazing systems in all other years. Current year's growth of shrubs on north slopes was greater than south slopes, dune tops, and interdunes when averaged over grazing system treatments (Table 1). Distribution of leadplant is predominantly on north slopes (Schacht et al. 2000) so greater yields were expected on north slopes compared to other topographic positions.

Total standing dead and litter were variable in mid-August between topography and year (Figures 8B). In 2003, there was very little standing dead and litter material collected as a result of low total standing crop following the drought conditions in 2002. Interdunes tended to have lower amounts of standing dead and litter material during several years of the study. The lower amount of standing dead and litter biomass on interdunes may be attributed to a higher degree of use on these topographic positions. Stubbendieck and Reece (1992) suggested that cattle will generally concentrate on interdunes more than on slopes and dune tops. End of season visual observations indicated that interdunes received higher utilization than other topographic positions and therefore would have less standing dead and litter material in the subsequent-years.

Management Implications

The effect of number of grazing periods on vegetation response and yearling cattle performance was a key component of this study. The SDG system did not increase livestock or vegetation production. Frequency of occurrence of most of the palatable plant species did not differ between DR, with a single grazing period, and SDG, with 3 grazing periods, with the exception of little bluestem and sand bluestem. The greater increases of these 2 desirable warm-season grasses on DR pastures may be a result of single grazing periods during the growing season compared to multiple grazing periods with SDG. Standing crop in mid-August on DR pastures generally did not differ or was greater than on SDG pastures over the course of the study. These positive vegetation responses to DR and the comparable weight gains between the 2 grazing treatments suggest that DR has a comparative advantage for use in the Nebraska Sandhills. The lack of increased vegetation productivity and animal performance does not justify the likely increased cost and labor associated with a SDG system. The results of this study conclude that SDG systems are not a superior grazing system on upland ecological sites in the Nebraska Sandhills. Overall, topography and yearly precipitation fluctuations had more influence on standing crop and botanical composition than grazing system.

Rangeland on the Barta Brother's Ranch was continuously grazed for over 50 years and was in good to excellent range condition prior to the initiation of the study. The increase in desirable plant species composition in pastures of either grazing system treatment suggests that grazing systems, in general, may enhance desirable species composition beyond continuous grazing. While there was not a continuous grazing treatment in the study, the increase in desirable species during years that were mostly below the long-term average precipitation indicates that grazing systems may have a beneficial effect on botanical composition on Sandhills rangelands. More research on comparing the changes in botanical composition among grazing systems, including continuous grazing, is necessary to substantiate these claims.

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Tables and Figures

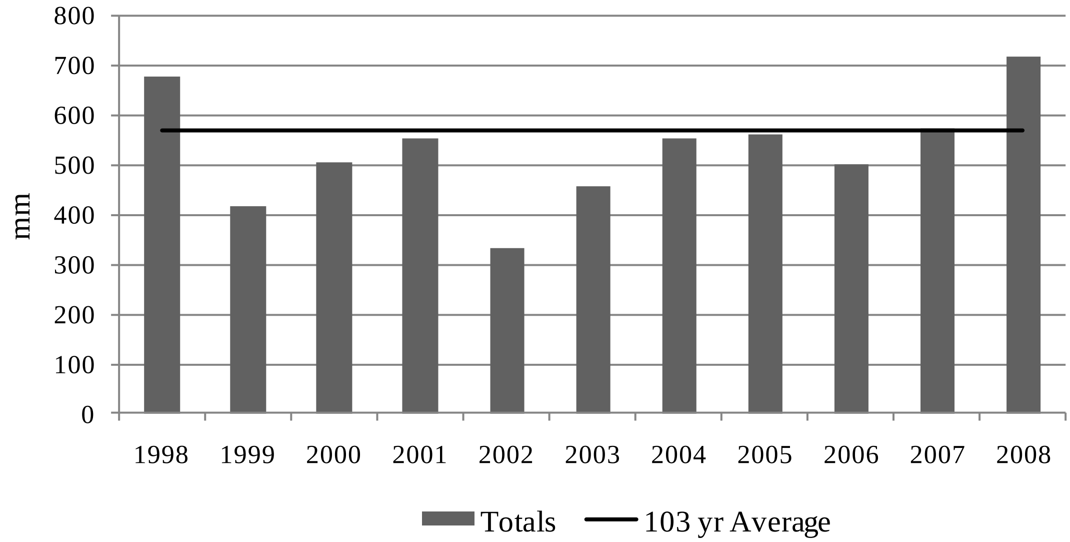


Figure 1. Annual precipitation (mm) from 1998 to 2008 and the 103-year average at the Barta Brother's ranch in the eastern Nebraska Sandhills.

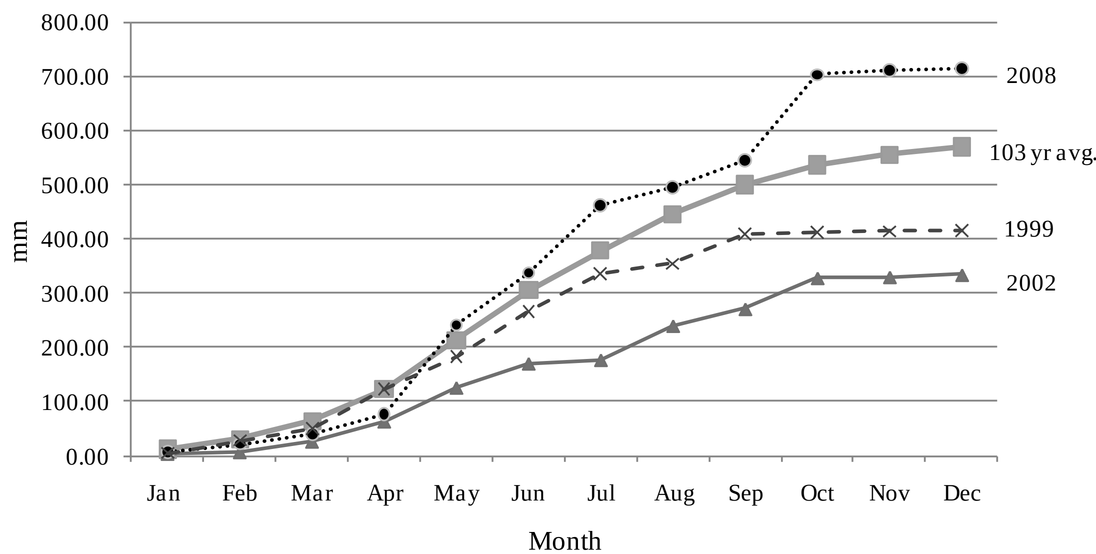
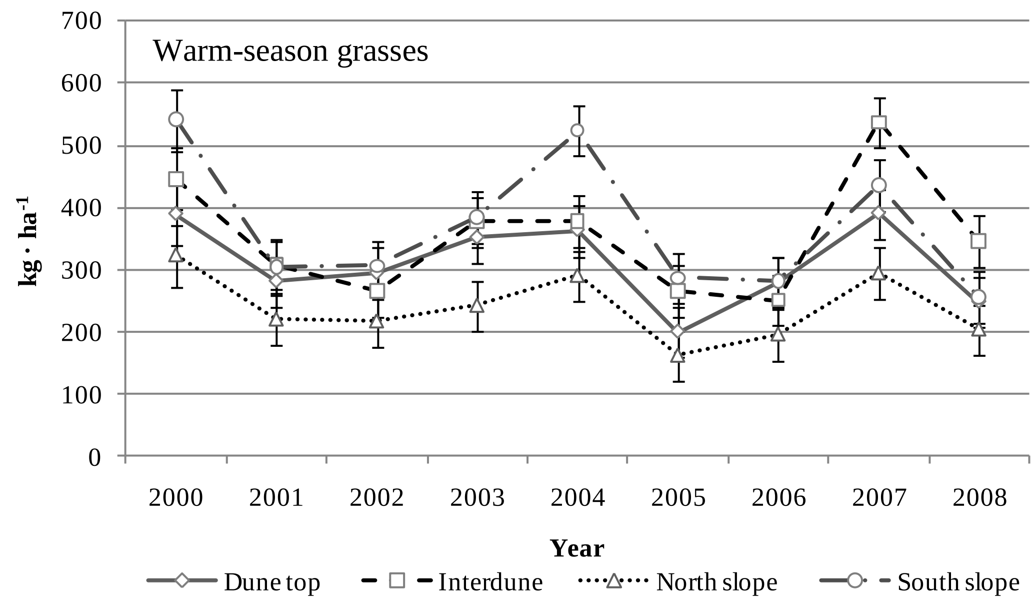
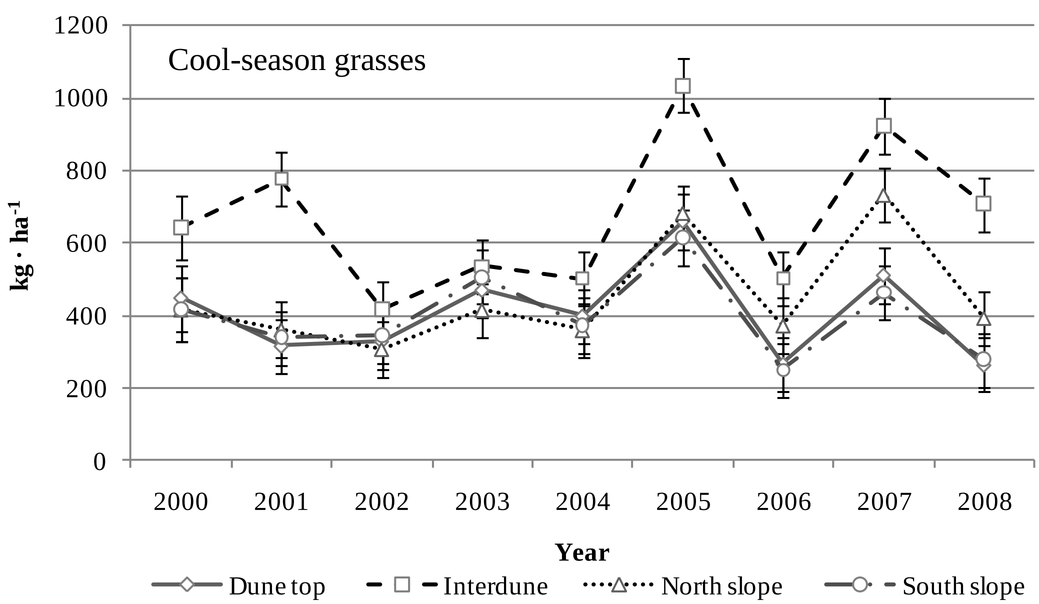


Figure 2. Monthly precipitation accumulations (mm) in the driest years (1999 and 2002) and the wettest year (2008) of the study at the Barta Brother's Ranch and the 103-year average monthly accumulation in Ainsworth, NE

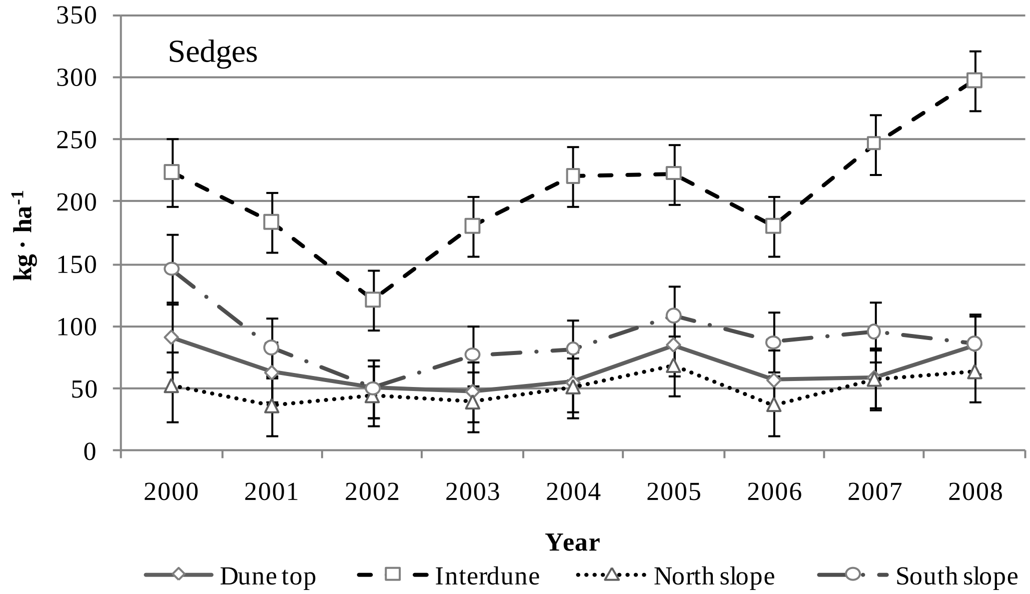
A)


Warm-season grasses
kg · ha-1
700
600
500
400
300
200
100
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Dune top
Interdune
North slope
South slope

B)


Cool-season grasses
kg · ha-1
1200
1000
800
600
400
200
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Dune top
Interdune
North slope
South slope

C)



D)

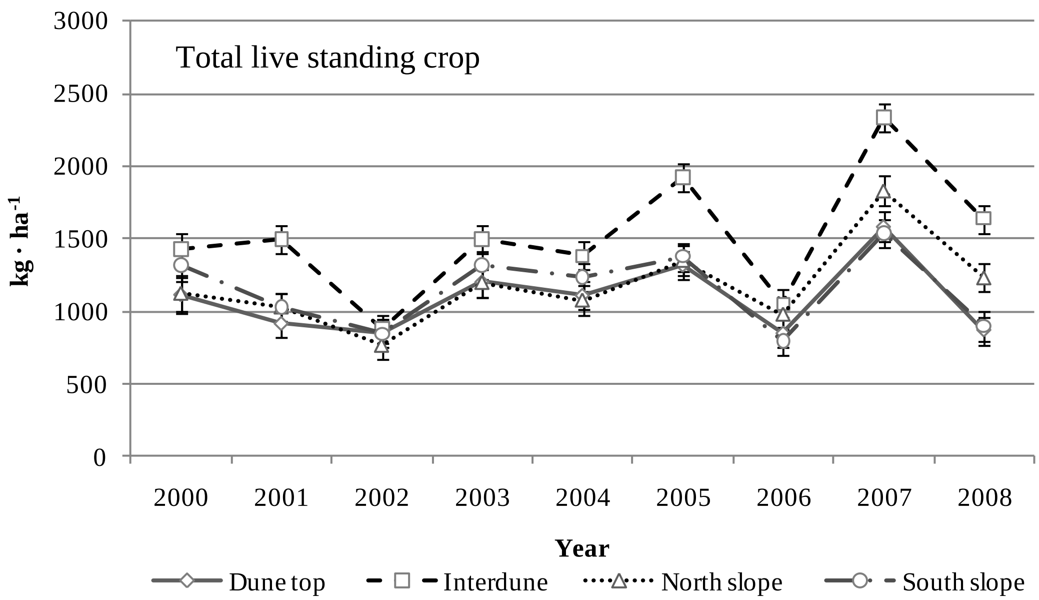


Figure 3. Mid-June standing crop (kg · ha^{-1}, 1 S.E.) for plant functional groups, A) warm-season grasses, B) cool-season grasses, C) sedges, and D) total live, with topography x year interactions at 4 topographic positions from 2000 through 2008.

Table 1. Standing crop ($kg \cdot ha^{-1}$) and shrub current year's growth ($kg \cdot ha^{-1}$) averaged over grazing system treatments and years for functional groups which had topography main effects in mid-June and mid-August clippings.

	Dune top	Interdune	North slope	South slope	
mid-June	----------	---------- $kg \cdot ha^{-1}$	----------	----------	S.E.
Forbs	98 b[1]	185 a	172 a	95 b	24
mid-August					
Warm-season grasses	311 b	353 ab	239 c	369 a	27
Shrubs	148 b	47 c	224 a	131 b	22

[1] Different letters within rows represent significant differences ($p < 0.10$).

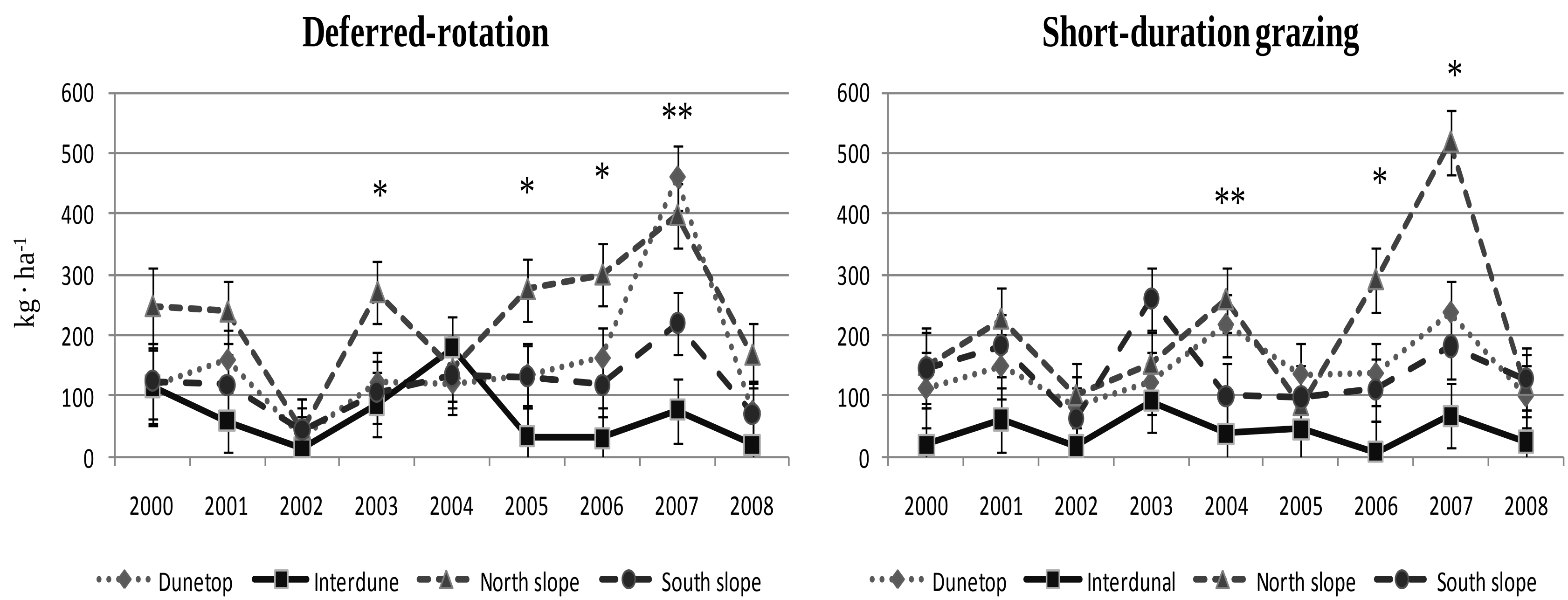


Figure 4. Mid-June shrub current year's growth from 2000 to 2008 with a deferred-rotation and a short duration grazing system at 4 topographic positions in the eastern Nebraska Sandhills. * Represent greater amounts of browse on north slopes compared to other topographic positions within each grazing system ($P < 0.10$). ** Represent greater amounts of browse on dune tops and north slopes compared to other topographic positions within each grazing system ($P < 0.10$).

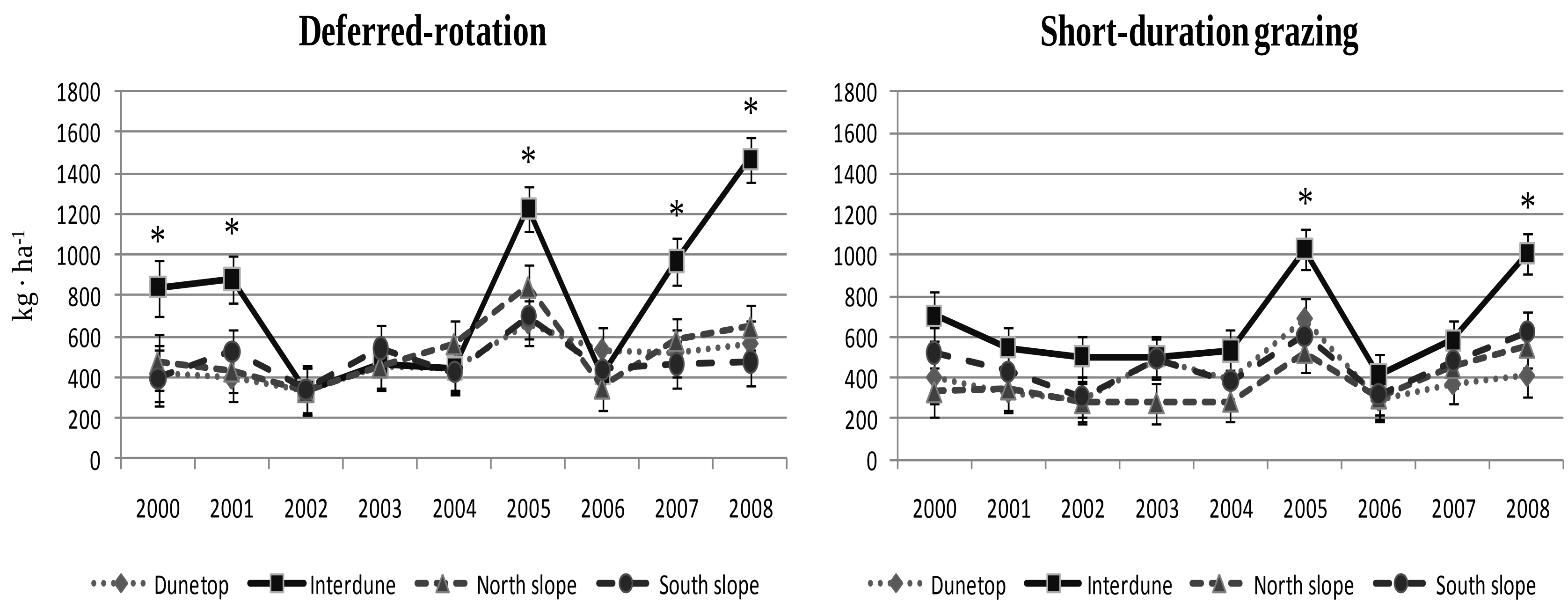


Figure 5. Mid-August cool-season grass standing crop from 2000 to 2008 with a deferred-rotation and a short duration grazing system at 4 topographic positions in the eastern Nebraska Sandhills. * Represent greater amounts of herbage on interdunes compared to other topographic positions with each grazing system ($P < 0.10$).

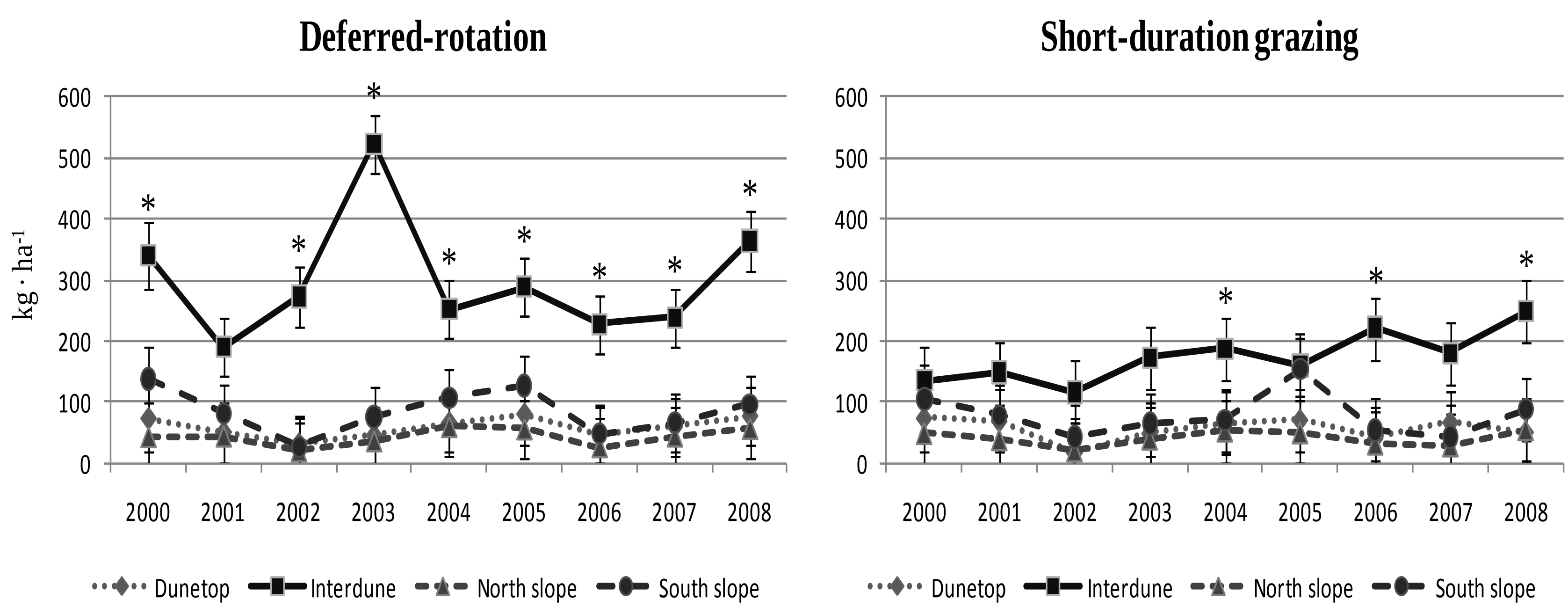


Figure 6. Mid-August sedge standing crop from 2000 to 2008 with a deferred-rotation and a short duration grazing system at 4 topographic positions in the eastern Nebraska Sandhills. * Represent greater amounts of herbage on interdunes compared to other topographic positions within each grazing system ($P < 0.10$).

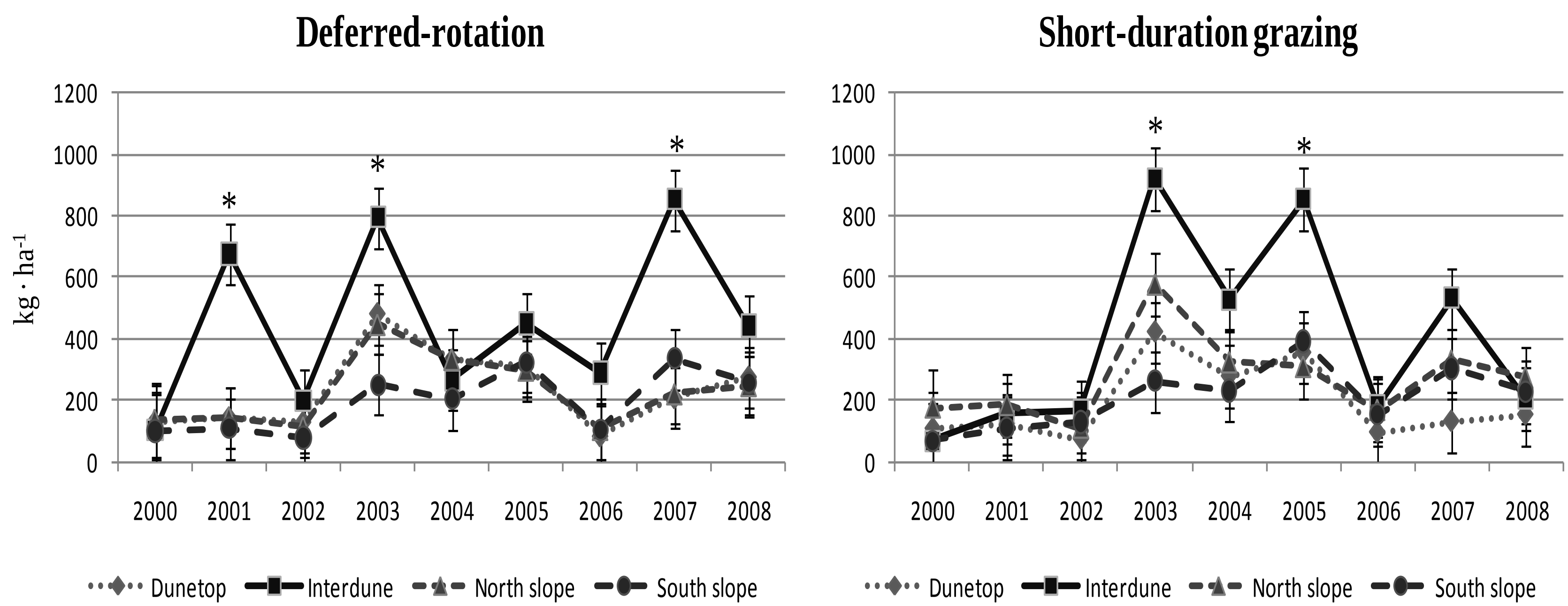
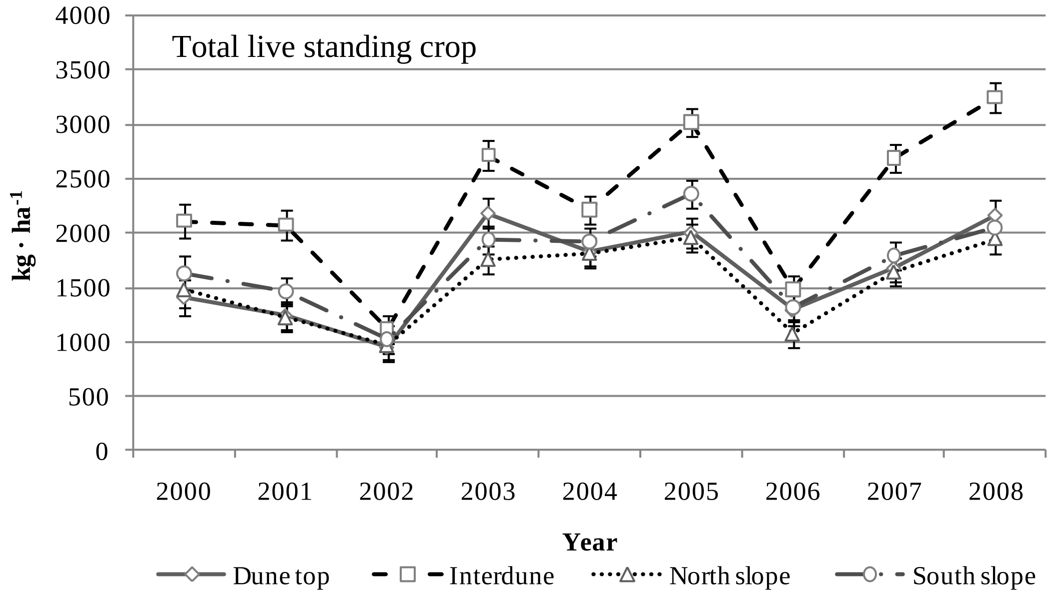


Figure 7. Mid-August forb standing crop from 2000 to 2008 with a deferred-rotation and a short duration grazing system at 4 topographic positions in the eastern Nebraska Sandhills. * Represent greater amounts of herbage on interdunes compared to other topographic positions within each grazing system ($P < 0.10$).

A)



B)

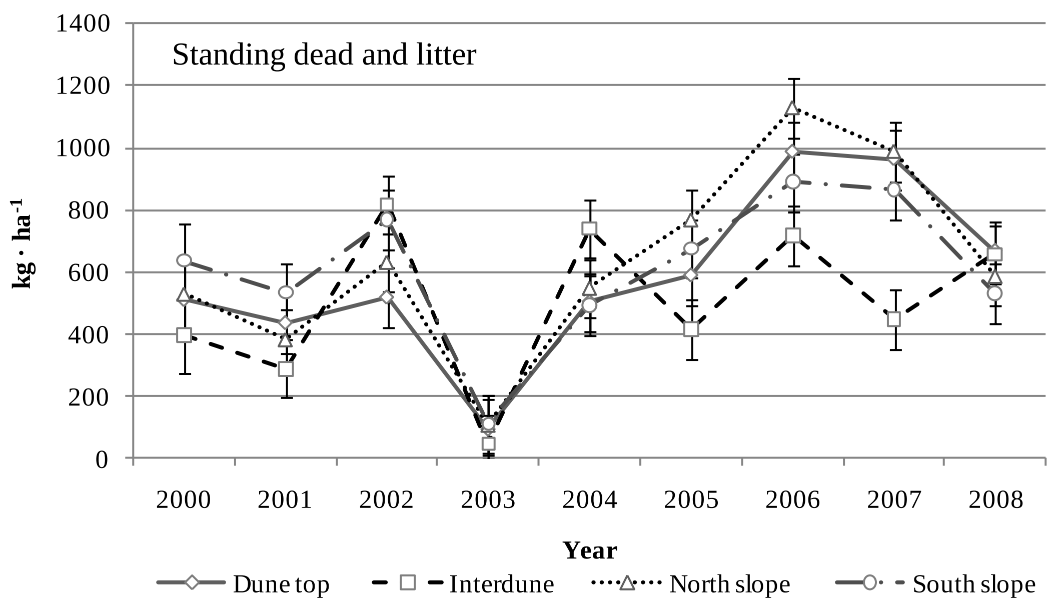
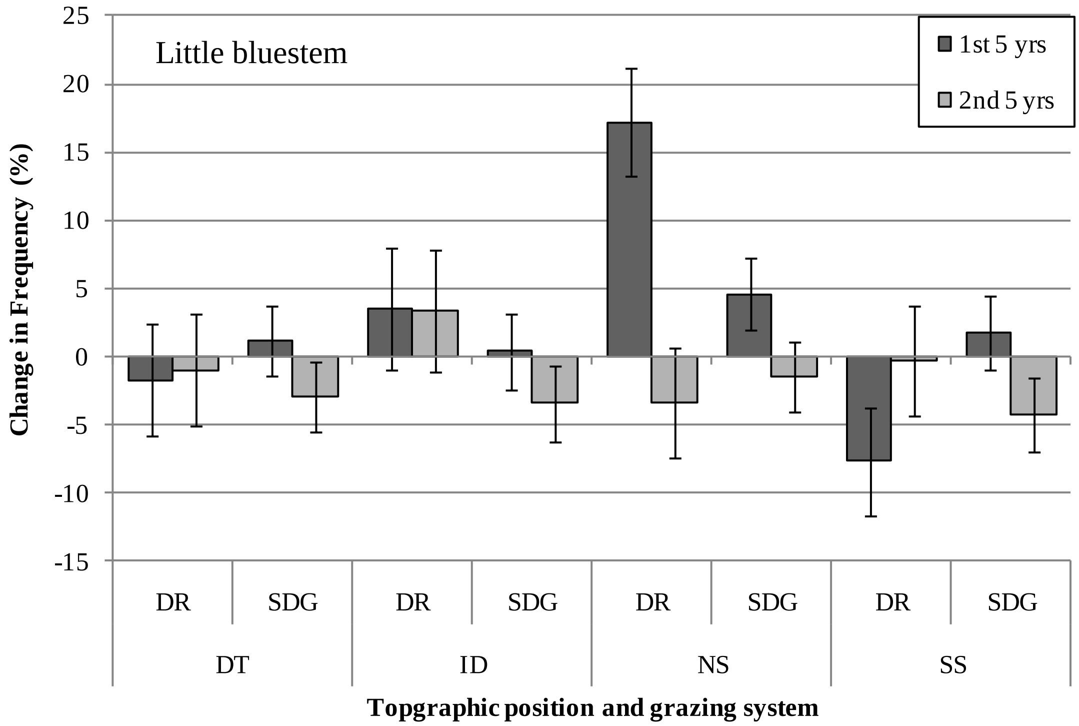
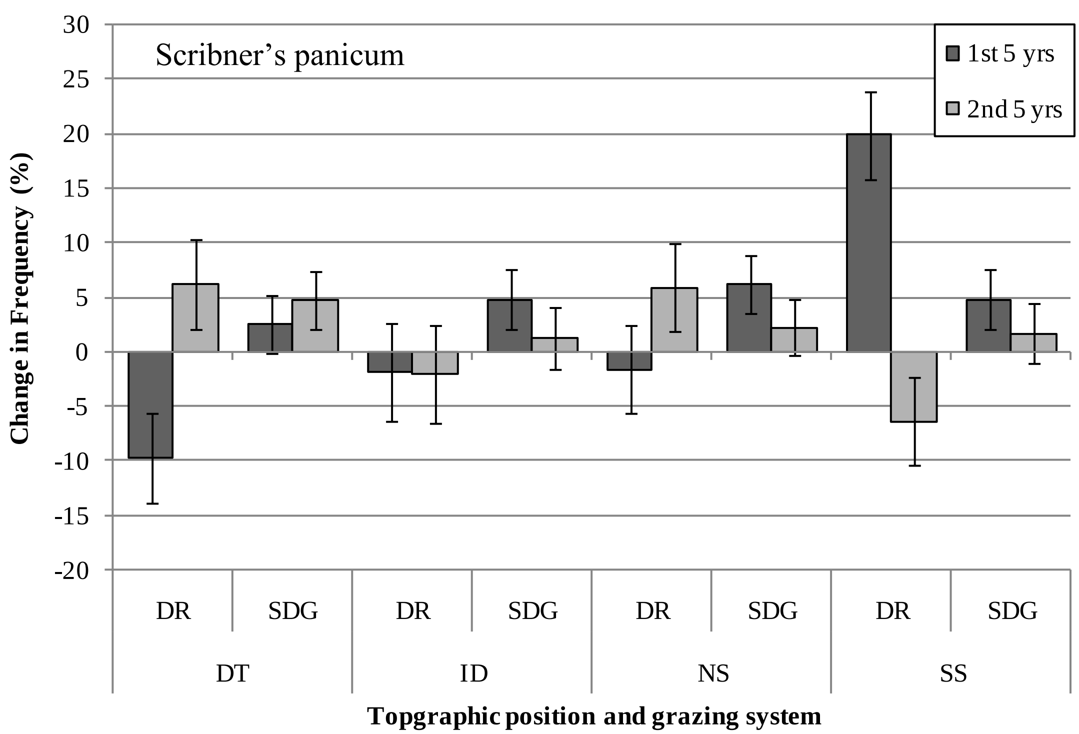


Figure 8. Mid-August standing crop (kg · ha^{-1}, 1 S.E.) for A) total live and B) standing dead and litter material topography x year interactions at 4 topographic positions from 2000 through 2008.

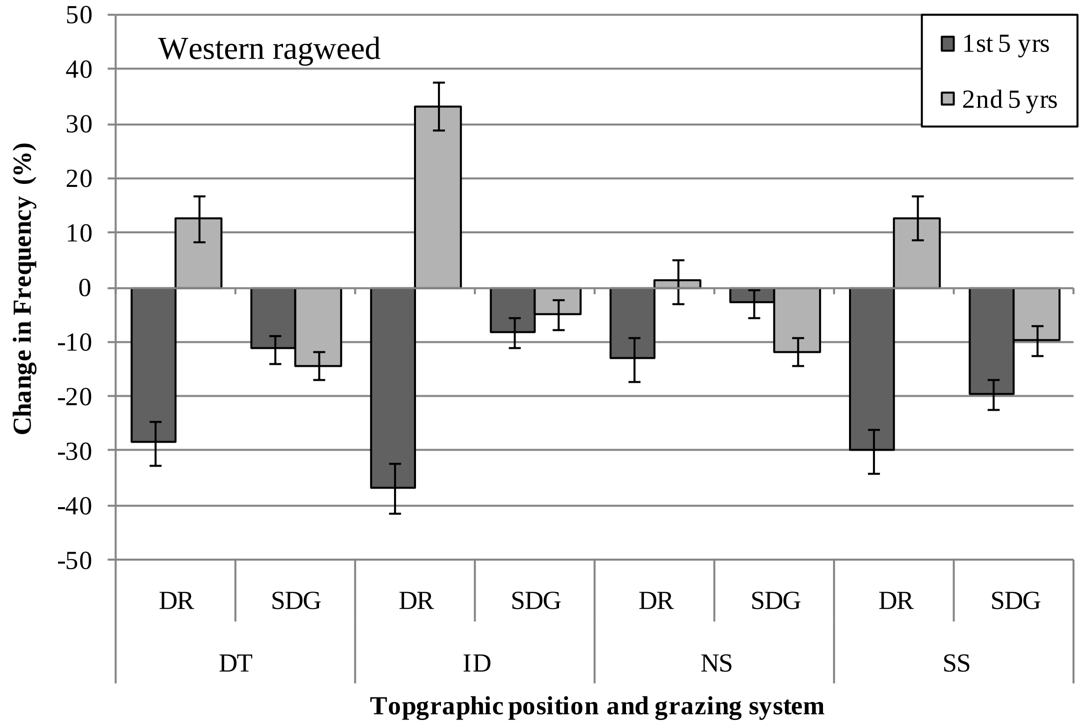
A)


Little bluestem
1st 5 yrs
2nd 5 yrs
Change in Frequency (%)
25
20
15
10
5
0
-5
-10
-15
DR
SDG
DR
SDG
DR
SDG
DR
SDG
DT
ID
NS
SS
Topgraphic position and grazing system

B)


Scribner's panicum
1st 5 yrs
2nd 5 yrs
Change in Frequency (%)
30
25
20
15
10
5
0
-5
-10
-15
-20
DR
SDG
DR
SDG
DR
SDG
DR
SDG
DT
ID
NS
SS
Topgraphic position and grazing system

C)


Western ragweed
1st 5 yrs
2nd 5 yrs
50
40
30
20
10
0
-10
-20
-30
-40
-50
Change in Frequency (%)
DR
SDG
DR
SDG
DR
SDG
DR
SDG
DT
ID
NS
SS
Topgraphic position and grazing system

D)

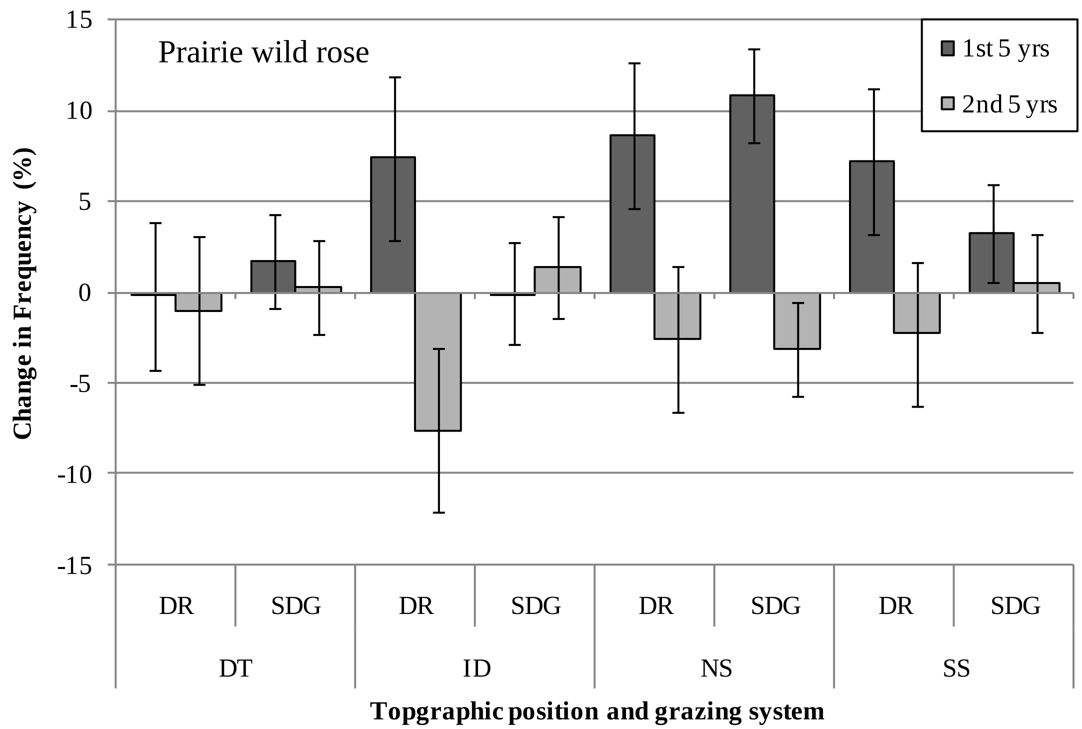

Prairie wild rose
1st 5 yrs
2nd 5 yrs
15
10
5
0
-5
-10
-15
Change in Frequency (%)
DR
SDG
DR
SDG
DR
SDG
DR
SDG
DT
ID
NS
SS
Topgraphic position and grazing system

Figure 9. Change in frequency of occurrence (%, 1 S.E.) from 1998 to 2008 during the first 5 years (1998 to 2003) and the second 5 years (2003 to 2008) for plant species having grazing system x year x topographic position interactions. Species include A) little bluestem, B) Scribner's panicum, C) western ragweed, and D) prairie wild rose. Topographic positions include Dune tops (DT), Interdunes (ID), North slopes (NS), and South slopes (SS). Grazing systems are a 4-pastures deferred-rotation (DR) and an 8-pasture short duration grazing (SDG) systems.

Table 2. Change in frequency of occurrence (%, 1 S.E.) for plant species with topography main effects at 4 topographic positions on upland sandhills range from 1998 to 2008.

	Dunetop	Interdune	North slope	South slope
Species	---------------------------------	%---------------------------------		
Hairy grama	7.5 (1.9) a[1]	2.1 (2.1) bc	0.1 (1.9) c	5.9 (1.9) ab
Prairie sandreed	14.0 (1.9) a	12.0 (2.1) a	4.9 (1.8) b	10.6 (1.9) a
Sand bluestem	7.0 (1.4) a	3.8 (1.5) bc	2.9 (1.4) c	6.2 (1.4) ab

[1]Different letters indicate means in rows are different ($P < 0.10$).

Table 3. Change in frequency of occurrence (%, 1 S.E.) for plant species with topography x year interactions during the first 5 years (1998-2003) and the second 5 years (2003-2008) of the study at 4 topographic positions on upland Sandhills range.

		Dune top	Interdune	North slope	South slope
Warm-season grasses		---------------------------------	%	---------------------------------	
Blue grama	1998-2003	3.7 (2.3) b[1]	24.1 (2.5) aA[2]	2.6 (2.2) b	5.5 (2.3) b
	2003-2008	3.8 (2.3) a	-1.2 (2.5) bB	5.5 (2.2) a	1.6 (2.3) ab
Sand dropseed	1998-2003	20.3 (3.0) bA	30.9 (3.2) aA	13.8 (3.0) cA	19.8 (3.0) bA
	2003-2008	10.2 (3.0) aB	8.6 (3.2) aB	5.2 (2.9) aB	8.5 (2.9) aB
Indiangrass	1998-2003	-3.7 (1.7) aB	-3.0 (1.9) aB	-4.0 (1.7) aB	-8.5 (1.7) bB
	2003-2008	4.4 (1.7) bA	4.1 (1.9) bA	11.0 (1.7) aA	11.2 (1.7) aA
Switchgrass	1998-2003	1.8 (2.7) b	-4.5 (2.9) cB	-0.6 (2.6) bc	10.1 (2.7) aA
	2003-2008	0.0 (2.7) a	4.9 (2.9) aA	3.9 (2.6) a	0.2 (2.7) aB
Cool-season grasses					
Prairie junegrass	1998-2003	0.1 (2.8) b	5.1 (3.0) a	1.6 (2.8) ab	-1.2 (2.8) b
	2003-2008	6.4 (2.8) a	-0.5 (3.0) b	4.5 (2.8) a	3.9 (2.8) ab
Bluegrass spp. [3]	1998-2003	-1.0 (3.0) bB	-34.7 (3.2) cB	7.8 (2.9) aB	0.3 (2.9) b
	2003-2008	6.5 (3.0) bA	16.3 (3.2) aA	16.5 (2.9) aA	3.2 (2.9) b
Wilcox panicum	1998-2003	-11.4 (1.9) cB	-1.0 (2.1) a	-5.9 (1.8) bB	-5.1 (1.9) abB
	2003-2008	5.2 (1.9) bA	-0.3 (2.1) c	11.0 (1.8) aA	0.0 (1.9) cA
Other					
Sedge spp. [4]	1998-2003	-21.5 (3.0) bB	-19.8 (3.3) bB	-20.0 (2.9) bB	-11.6 (3.0) aB
	2003-2008	19.6 (3.0) aA	8.6 (3.3) bA	19.1 (2.9) aA	12.1 (3.0) bA
Stiff sunflower	1998-2003	0.0 (1.8) aA	0.5 (2.0) a	2.5 (1.8) aA	2.3 (1.8) aA
	2003-2008	-5.8 (1.8) bB	-0.6 (2.0) a	-5.4 (1.8) bB	-6.0 (1.8) bB
Cudweed sagewort	1998-2003	1.3 (1.5) b	16.3 (1.7) aA	3.9 (1.5) b	2.4 (1.5) b
	2003-2008	2.7 (1.5) b	8.2 (1.7) aB	1.9 (1.5) b	0.4 (1.5) b

[1]Different lowercase letters indicate means in rows are different ($P < 0.10$).
[2]Different Uppercase letters indicate means between years are different ($P < 0.10$)within species.
[3]Includes *Poa compressa* and *Poa pratensis*
[4]Includes *Carex heliophila* and *Cyperus schweinitzii*

Chapter 3

Time of Grazing Effect on Subsequent-year Standing Crop in the Eastern Nebraska Sandhills

Abstract

Grazing systems provide range managers opportunities to change the timing of grazing on different pastures throughout the growing season. Timing of grazing effects have been studied on certain plants in the Nebraska Sandhills, but timing of grazing effect on total live herbage and plant functional group standing crop has not been researched. A 10-year study comparing a 4-pasture deferred-rotation (DR) and an 8-pasture short duration grazing (SDG) system included a determination of timing of grazing effect to subsequent-year standing crop on upland, Sandhills range. Herbage by functional group was collected annually from 240 cattle exclosures in mid-June and mid-August from 2001 to 2008. Cattle exclosures were moved each year to capture the effects of previous year time of grazing. Pastures in each system were grazed by 50 to100 cow-calf pairs with both single (DR system) and multiple (SDG system) grazing periods from 15 May to 15 October. Subsequent-year warm-season grass production with the DR system was lowest when grazing occurred from 21 July to 31 August. Cool-season grass and forb production in subsequent-years was most effected when grazing took place in mid-May, mid-June, and late-August within the SDG system. Shrub production tended to be lower when grazing occurred early in the grazing season for both grazing systems. Grazing during times when standing crop is most limited should not take place in consecutive years on pastures in either grazing system, unless specific management objectives being achieved.

Introduction

A main objective of rotation grazing systems is to improve plant species composition and productivity by matching the timing of grazing with requirements of the plant species to store carbohydrates. Perennial plants need adequate carbohydrate reserves to survive during winter dormancy, initiate spring growth, and provide new growth following defoliation (Waller et al. 1986; White 1973). Timing and frequency of defoliation impact the amount of carbohydrates that the plant is able to produce and store before winter dormancy (Reece et al. 1996).

Research in the Nebraska Sandhills on time of defoliation effects on herbage yields, plant physiology, and plant morphology has been limited to a few warm-season grasses (Mullahey et al. 1990; Mullahey et al. 1991; Reece et al. 1996; Engel et al. 1998; Moser and Perry 1983). The most detrimental time to graze has varied for the different warm-season grass species. Sand bluestem, one of the most common warm-season grasses in the Sandhills, decreased in annual dry matter yield more when defoliation occurred in mid-August than in June, July, or October after 3 consecutive years of defoliation (Mullahey et al. 1991). Biomass of etiolated sand bluestem tillers was lowest after 4 consecutive years of grazing in mid-July compared to grazing in June, August, and October (Reece et al. 1996). Prairie sandreed responded differently to time of grazing than sand bluestem. There was no difference in annual dry matter yield between defoliation in June, July, and August (Mullahey et al. 1991), and biomass of etiolated tillers was similar when grazing occurred in either June or July and greater when grazing occurred in August or October (Reece et al. 1996). Moser and Perry (1983) concluded that defoliation that occurred in August was more detrimental to sand lovegrass than defoliations that occurred in June within the Nebraska Sandhills. While there are differences between grass species in regards to when grazing is most harmful, studies have generally indicated that grazing from mid-July through August is the most detrimental time to defoliate warm-season grasses during the growing season.

Different plant functional groups are more susceptible to defoliation at different times of the year and at different growth stages (Holechek et al. 2004). In most cases, defoliation early in plant growth cycles, plant initiation to peak growth, followed by a period of recovery is less detrimental than defoliation when plants are in the later periods of their growth cycle (Vallentine 2001; Holechek et al. 2004; Stoddard et al. 1975). However, there are still questions regarding when and how many times to graze to optimize vegetation management goals and develop grazing systems (Reece et al 1996; Mullahey et al. 1990).

Time of grazing effect on herbage yields of different functional groups and total standing crop has not been researched at a production scale in the Nebraska Sandhills. The objective of this study was to determine the effect of time of grazing on subsequent-year standing crop within a 4-pasture deferred-rotation and an 8-pasture short duration grazing systems in the Nebraska Sandhills. It was hypothesized that grazing during the deferred-period (1 September to 15 October) of the 4-pasture deferred-rotation would result in greater amounts of subsequent-year standing crop than during other grazing periods. It was also hypothesized that grazing that limits multiple grazing periods from mid-June to mid-August would result in greater amounts of subsequent-year total standing crop and warm-season grasses compared to other grazing periods within the short duration grazing system.

Materials and Methods

Study Site

Research was conducted at University of Nebraska's Barta Brothers Ranch from 2001 through 2008. The Barta Brothers Ranch is a 2,350 ha ranch located in the eastern Nebraska Sandhills near Rose, NE (42° 13' 32'' N, 99° 38' 09'' W; elev. 765 meters). Climate is typical of a mid-continental, semi-arid prairie region. Climate data were collected from a High Plains Regional Climate Center station located approximately 48 km to the northwest in Ainsworth, Nebraska, and an onsite weather station. The 103-year average maximum annual temperature is 16.3 º C and the average minimum temperature is 2.6 º C (HPRCC 2008). The lowest average minimum temperatures occur in January (-11.4ºC). The highest average maximum temperature occurs in July (31.5ºC). Average annual precipitation is 570 mm with 76% (435 mm) falling between April and September. On average, June is the wettest month (92 mm) of the year and January is the driest (12 mm).

Topography, soils, and vegetation of the study site are typical of the eastern Nebraska Sandhills. Ninety percent of the study area is classified as upland prairie and the remaining 10% is intermixed sub-irrigated meadows and wetlands (Schacht et al. 2000). Sands ecological sites dominate the study area with dunes running west by northwest to east by southeast at slopes of 5 to 15%. Dune tops cover 20 to 25% of the upland prairie and north- and south-facing slopes compose 60 to 70% of the uplands; interdune valleys account for the remaining 10 to 20%. Dominant soils at the study site are a Valentine series (mixed, mesic Typic Ustipsamments).

Vegetation of the study area is a mixture of warm- and cool-season grasses, forbs, shrubs, and sedges. Nomenclature of plant species follows Kaul et al. (2006). Dominant grasses include prairie sandreed (*Calamovilfa longifolia* [Hook.] Scribn.), sand bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), switchgrass (*Panicum virgatum* L.), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), blue grama (*Bouteloua gracilis* [Willd. *ex* Kunth] Lag. *ex* Giffiths), hairy grama (*Bouteloua hirsuta* Lag.), prairie junegrass (*Koeleria macrantha* [Ledeb.] J. A. Schultes), needleandthread (*Hesperostipa comata* Trin. & Rupr.), porcupinegrass (*Hesperostipa spartea* Trin.), Scribner panicum (*Panicum oligosanthes* Schult. var. scribnerianum [Nash] Fernald), Wilcox panicum (*Panicum wilcoxianum* Vasey), and bluegrass species (*Poa Compressa* L. and *Poa pratensis* L.). Several species of sedges (*Carex spp.*) and cactus (*Opuntia spp*.) are also common. Common forbs and shrubs are western ragweed (*Ambrosia psilostachya* DC.), cudweed sagewort (*Artemisia ludoviciana* Nutt.), prairie wild rose (*Rosa arkansana* Porter *ex* Porter & J.M. Coult.) and leadplant (*Amorpha canescens* Nutt. *ex* Pursh).

Grazing System Treatments

Application of grazing system treatments began in 1999 on the ranch's upland range. The rangeland had been continuously grazed since the mid-1950s by cow-calf pairs at recommended stocking rates (about 1.8 AUM·ha^{-1}). At the initiation of the study pastures were determined to be in good to excellent condition (Schacht et al. 2000).

Upland range was divided to create two replications of an 8-pasture short duration grazing (SDG) system and a 4-pasture deferred-rotation (DR) grazing system. Average size of the pastures was 53 ha for the SDG system and 40 ha for the DR system. Both systems were grazed by cow-calf pairs from 1999 through 2005 and by cow-calf pairs and spayed heifers from 2006-2008. Grazing dates for the study were from May 15 to October 15 except in 2002 and 2006 when cattle were removed on September 15 and September 30, respectively, because of drought. Stocking rate was similar between the grazing systems and averaged 1.8 AUM·ha^{-1} over the course of the study.

Approximately 100 cow-calf pairs were rotated through the 8 pastures of each of the 2 SDG systems 3 times (cycles) per grazing season. Timing of the grazing was based on the practice of moving cattle rapidly through the pastures early in the growing season and extending the length of the grazing cycles as forage matured. The first grazing cycle ran from mid-May to early June (~16 days) with 2-day grazing periods within each pasture. The second cycle ran from early June to late July (~56 days) with 7-day grazing periods. The third cycle ran from late July to mid-October (~80 days) with 10 day grazing periods (Figure 1). Sequence of pasture rotation was designed so pastures were not grazed at similar times during the growing season in consecutive years. Pastures also were rotated so that each pasture preceded and followed every other pasture at least once over the course of the study. This grazing rotation in the SDG replications resulted in 8 combinations of grazing dates that were used in the analysis of effect of grazing date on subsequent-year standing crop.

About 50 cow-calf pairs were rotated through the 4 pastures of each DR grazing system. Each pasture was grazed only once during the growing season at 30 to 45 days·pasture^{-1}. Grazing periods for the DR system were from May 15 to June 14, June 15 to July 20, July 21 to August 31, and September 1 to October 15. Length of grazing periods within pastures increased as the growing season progressed from 30 to 45 days

(Figure 1). As with SDG, sequence of pasture rotation was designed so pastures were not grazed at similar times during the growing season in consecutive years. Pastures also were rotated so that each pasture preceded and followed every other pasture twice over the course of the study. This grazing rotation in the DR replications resulted in 4 grazing dates that were used in the analysis of effect of grazing date on subsequent-year standing crop

Standing Crop Sampling

Effect of timing of grazing on subsequent-year standing crop was determined by sampling standing crop annually in mid-June and mid-August from 2001 through 2008. Mid-June and mid-August harvests were chosen to correspond with the approximate time of peak cool- and warm-season herbage yields, respectively (Northup 1993). Two pastures within each of the 2 grazing system replications were selected for estimating standing crop. Three sites within the 2 pastures were selected and 5 exclosures (1.2 x 1.2 m wire panels) were placed on each topographic position of the dunes (north slopes, south slopes, dune tops, and interdunes). The design resulted in a total of 240 exclosures (2 grazing systems x 2 replications x 3 sites x 4 topographic positions x 5 exclosures). A 0.25-m^2 (0.25 x 1.0 m) quadrat was placed in either the north or south half of each exclosure in June (determined randomly) and in the other half in August. Exclosures were moved at the beginning of each year to capture previous year grazing treatment effect. Standing crop was estimated by clipping all standing herbaceous vegetation in the quadrat at ground level and separating it into one of the following categories: warm-season grasses, cool-season grasses, sedges, forbs, or standing dead. Browse production, current year's growth of shrubs (i.e., leaves and new stem tissue), also was collected from plants rooted within the quadrats. Litter within the quadrat also was collected. All separated plant material was placed in marked individual paper bags, oven dried at 60°C to a constant weight, and weighed.

Statistical analysis

Effect of grazing date on subsequent-year standing crop of different functional groups was analyzed using a mixed procedure, analysis of variance within SAS (SAS 2003). Grazing date was treated as the main effect. The residual effect of grazing dates that occurred 2 years previous was also placed within the model to account for past grazing period effects. Residual effects had very little impact on the previous year grazing period time of grazing, but were included in the determination of the lsmeans for the individual functional groups, total live forage, and litter and standing dead material on the 4-pasture deferred-rotation system analysis. Residual effects were not analyzed within the model for the 8-pasture short duration grazing system because too few years were studied to have adequate degrees of freedom. Pasture was treated as a random variable within the analysis of both grazing systems. An alpha level of 0.10 was used to determine significant differences between grazing periods.

Results and Discussion

Precipitation Data

Total annual precipitation levels varied during the study, but in most years precipitation was below average (Figure 2). Average yearly precipitation over the course of the study was 532 mm which was below the long-term (103 year) average (571 mm). Precipitation level in the driest year (2002) was 41% below the long term average. Precipitation level in the wettest year (2008) was 25% above average.

Deferred-Rotation Grazing System

Time of grazing (i.e., grazing period) generally did not affect subsequent-year standing crop of functional groups or total standing crop (Table 1). Only warm-season grasses and browse production were affected by time of grazing period. Standing crop of warm-season grasses in mid-June was 19 to 28% less on pastures grazed from July 20 to September 1 of the previous year when compared to other grazing periods over the grazing season (Figure 3A). Browse production in mid-August was greatest when grazing occurred from July 20 to September 1 of the previous year than when grazing occurred from May 15 to July 20 (Figure 3B).

Warm-season grasses, particularly sand bluestem and little bluestem, in the Sandhills generally begin to elongate and become the most abundant component of the total available herbage in mid-July and August. Selection of these warm-season grasses by grazing beef cattle on Sandhills prairie has been found to increase during this time (Schroeder 2007). Other related research has shown (Vogel and Bjugstad 1968; Mullahey et al. 1991; Moser and Perry 1983; Reece et al. 1996) that defoliation (clipping or grazing) in either July or August has the greatest negative impact on standing crop and other morphological characteristics of warm-season grasses.

Engel et al. (1998) found that time of grazing with a single year defoliation did not affect above-ground production of sand bluestem, but root area, root length, and weight of total non-structural carbohydrates were lower when defoliation occurred in mid-July or mid-August compared to defoliation in mid-June or October. A reduction in non-structural carbohydrates from grazing in mid-July and mid-August may explain why subsequent-year production of warm-season grasses harvested in mid-June was lower, but not lower when herbage was harvested in mid-August of the subsequent-year. The reduction in non-structural carbohydrates as a result of grazing in July and August may have decreased the ability of warm-season grasses to initiate growth as vigorously as plants grazed earlier or later in the growing season of the previous year. Subsequent-year warm-season grass standing crop appears to be able to recover by mid-August of the subsequent-year from the effects of one year of grazing during July and August of the previous year.

Grazing periods that occurred earlier in the growing season were more detrimental than later grazing periods to subsequent-year browse production in mid-August. The inverse relationship to previous year time of grazing between warm-season grasses and browse species may indicate that cattle were grazing more on warm-season grasses than shrubs as warm-season grasses became available in greater quantities from July 20 to September 1. Decreased palatability of maturing shrubs during this time may have also influenced the selectivity of the cattle towards warm-season grasses and less on browse. However, these assumptions contradict earlier findings that show that browse of leadplant, the most common shrub in the Sandhills, was high throughout the growing season (Schroeder 2007). Research in northern Colorado also found that shrub species were most detrimentally affected by defoliation occurring in the later part of the growing season rather than early (Buwai and Trlica 1977).

Short Duration Grazing System

Grazing period affected ($P < 0.10$) subsequent-year forb standing crop harvested in mid-June and cool-season grass standing crop and browse harvested in mid-August for the SDG system (Table 2). Grazing period also had an effect on litter and standing dead material when collected in mid-June. Warm-season grasses, sedges, and total live standing crop were not affected by time of grazing.

Forb standing crop harvested in mid-June was greatest when grazing occurred in mid-May, mid-June, and late-August of the previous year (Figure 4A). Cool-season grasses in mid-August responded oppositely with the lowest amount of herbage in subsequent-years occurring when grazing periods where in mid-May, mid-June, and late-August of the previous year (Figure 4B). There are not clear reasons to explain why subsequent-year standing crop of cool-season grasses was affected by time of grazing for the mid-August harvests and not affected for the mid-June harvests. Needleandthread, a dominant cool-season grass in the Sandhills, has responded negatively in subsequent-years to defoliation in July and August after the plants had reached seed maturity (Wright 1967). Wright suggested that because needleandthread plants are only semi-dormant during the summer months they may have a negative photosynthetic balance because of high respiration rates and use of stored carbohydrates as a result. In most years, needleandthread reached maturity by the mid-June grazing period within the short-duration grazing system, and may have initiated fall growth as temperatures began to lower in late-August. Grazing on needleandthread plants after they have reached maturity is limited because of decreased palatability as reproductive awns begin to form (Stubbendieck and Kottas 2005). However, it is uncertain why grazing in mid-May, mid-June, and late-August would impact cool-season grass production more than other grazing periods that immediately preceded or followed these periods. Reece et al. (1988) found that total non-structural carbohydrates within needleandthread were not negatively affected after 4 years of using a short-duration grazing system with multiple grazing periods during the growing season in western Nebraska.

In contrast to subsequent-year cool-season grass standing crop, forbs harvested in mid-June were greatest when grazing occurred in mid-May, mid-June, and late-August. Grazing which occurred in mid-May, early-June, and early-August of the previous year decreased subsequent-year forb production but increased cool season grass production (Figure 4A and 4B). The differing responses of forbs and cool-season grasses to previous year grazing periods may be the result of forbs low competitive ability. Western ragweed, the most common forb in the Sandhills, has been found to produce greater amounts of herbage by better utilizing available nutrients when associated grass species were removed (Reece et al. 2004).

Subsequent-year browse production in mid-June was not affected by grazing periods, but browse production in mid-August was greatest when grazing occurred in late-May, late-June/early-July, and early-September of the previous year (Figure 4C). Subsequent-year browse production in mid-August was relatively low on pastures grazed in June compared to those pastures not grazed in June. This response was similar to what was found in the DR pastures, subsequent-year browse production was lower when grazed in the first two grazing periods (mid May to late July).

Litter and standing dead material in subsequent-years varied with different grazing periods (Figure 4D). Litter and standing dead material was greatest when grazing occurred in late-May, mid-July, and late-September/early-October.

Management Implications

Subsequent-year standing crop of functional groups is affected by the time of grazing within the Nebraska Sandhills. It was determined in this study that the deferment period does not increase total standing crop or the standing crop of functional groups after one year of grazing in the Nebraska Sandhills. This is in contrast to generally held assumptions that a deferment period will increase pant vigor and production (Stoddart et al. 1975). However, grazing from mid-July through August is the most detrimental time of grazing for warm-season grass standing crop, but the most beneficial to browse in subsequent-years. Generally, the sequence of pastures should be rotated every year to limit the detrimental effects of grazing on plant functional groups in consecutive years.

Grazing in mid-May, mid-June, and late-August had a detrimental effect on cool-season grasses, but a beneficial effect on forb production in subsequent-years for the SDG system. Total live and warm-season grasses were not affected by multiple grazing periods between June and August. This suggests that one year of grazing during a certain time period does not have large effects on subsequent-year herbage production in the Nebraska Sandhill. Sequence of when pastures are grazed during the growing season should be rotated in consecutive years to limit grazing when key species are most susceptible. However, the understanding of when grazing is most detrimental to certain functional groups may be useful to manage for or against specific functional groups.

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Tables and Figures

A)

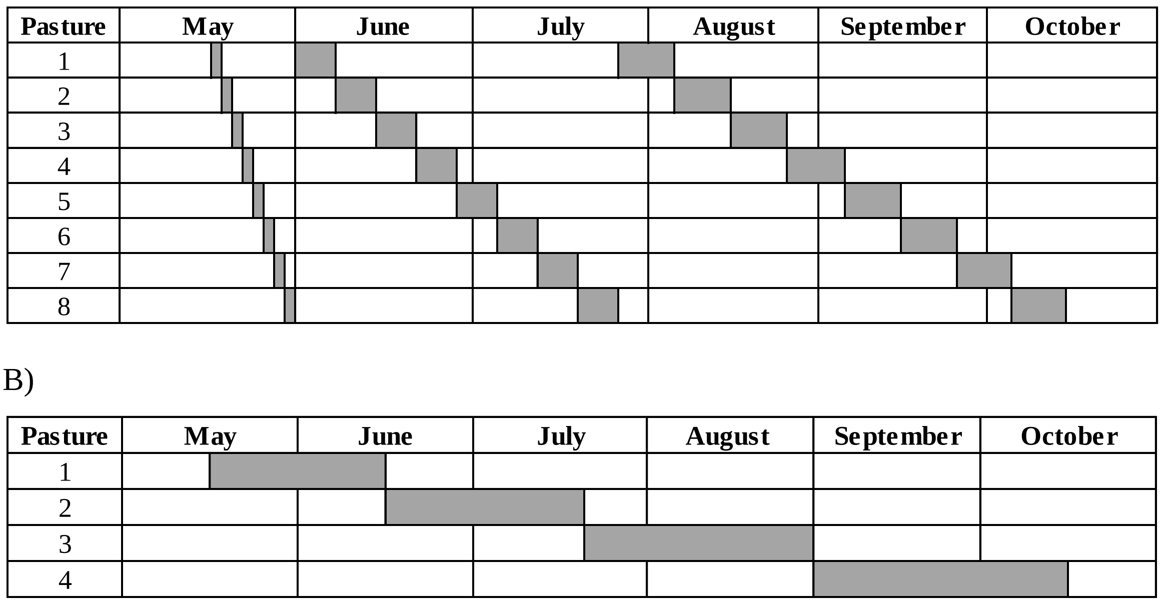


Figure 1. Grazing periods for an (A) 8-pasture short duration grazing system and a (B) 4-pasture deferred-rotation grazing system at the Barta Brother's ranch in the eastern Nebraska Sandhills.

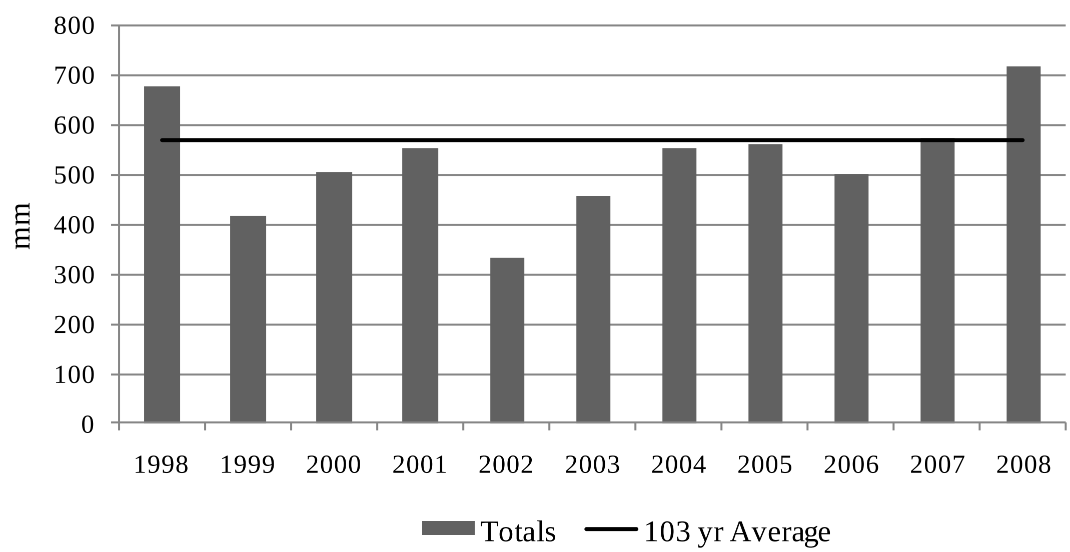
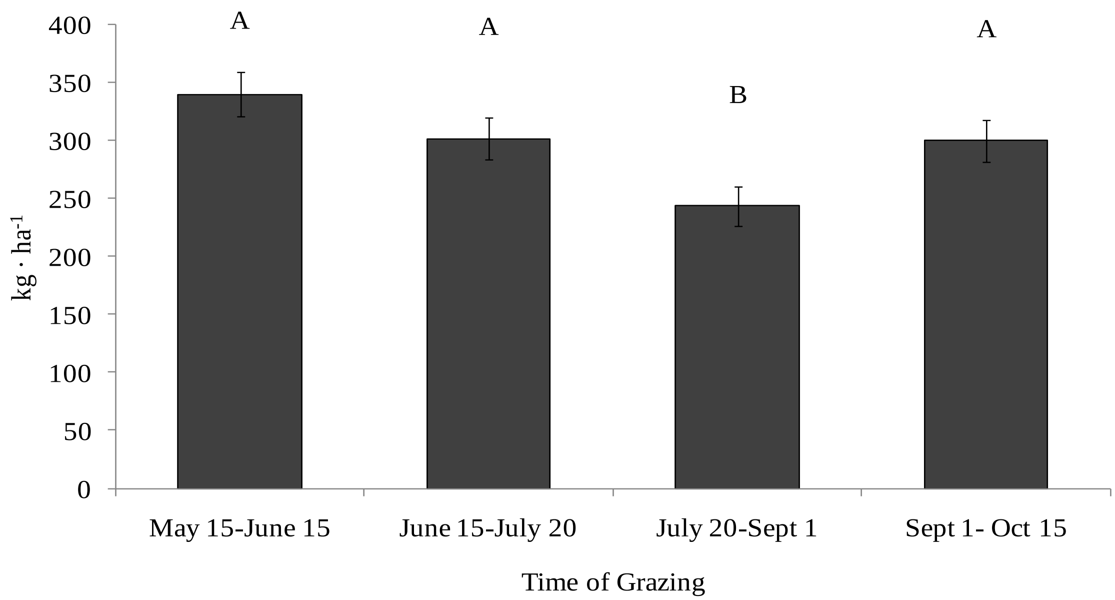


Figure 2. Annual precipitation (mm) from 1998 to 2008 and the 103 year average precipitation at the Barta Brother's ranch in the eastern Nebraska Sandhills

Table 1. The statistical analysis and mean weight for functional groups, total live forage, and litter and standing dead for herbage collected in mid-June and mid-August from exclosures that captured time of grazing effect on subsequent-year standing crop within a 4-pasture deferred-rotation grazing system.

	Overall Pr > F	Mean wt.
June		kg · ha^{-1}
Warm-season grasses	0.0199	303
Cool-season grasses	0.4304	523
Forbs	0.5029	170
Shrubs	0.8536	129
Sedges	0.8385	100
Total live forage	0.4429	1274
Litter and standing dead	0.1049	636
August		
Warm-season grasses	0.2989	690
Cool-season grasses	0.4161	552
Forbs	0.1637	316
Shrubs	0.0692	160
Sedges	0.6147	90
Total live forage	0.8334	1842
Litter and standing dead	0.4610	587

A)



B)

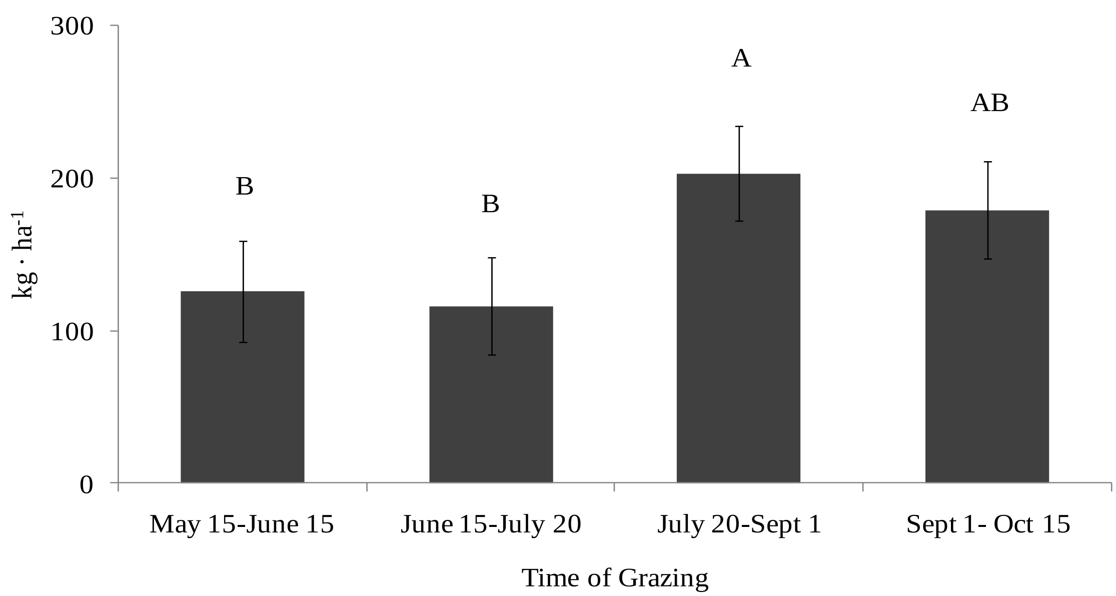
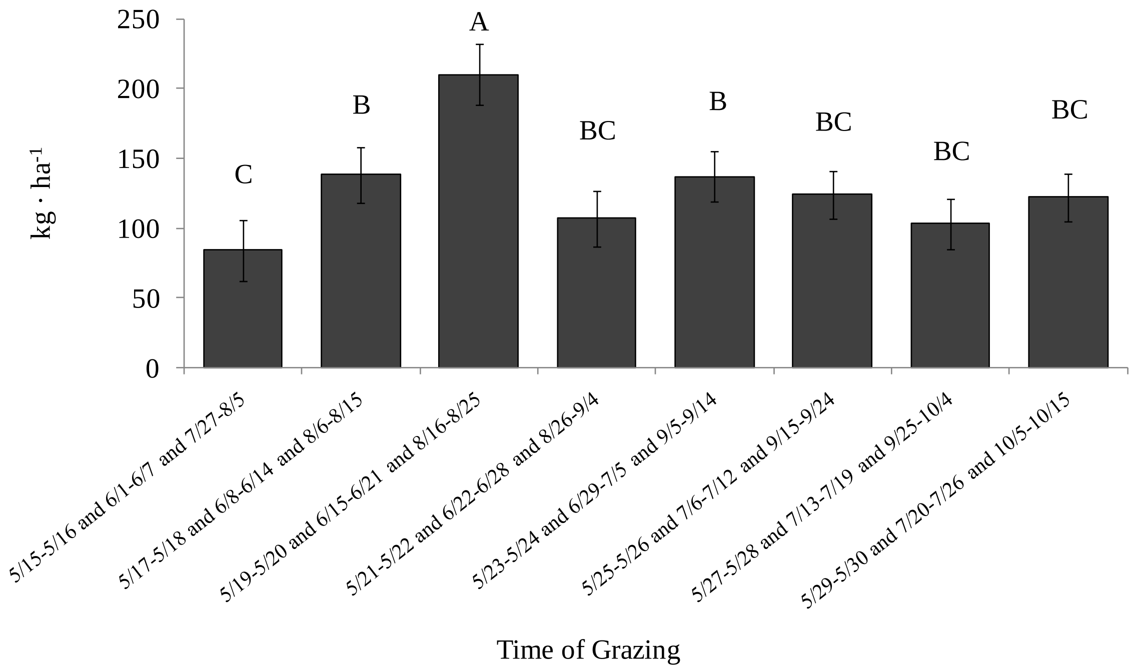


Figure 3. Time of grazing effect on subsequent-year standing crop for A) warm-season grasses collected in mid-June and B) browse collected in mid-August within a deferred-rotation grazing system. Different letters represent differences between grazing periods ($p < 0.10$).

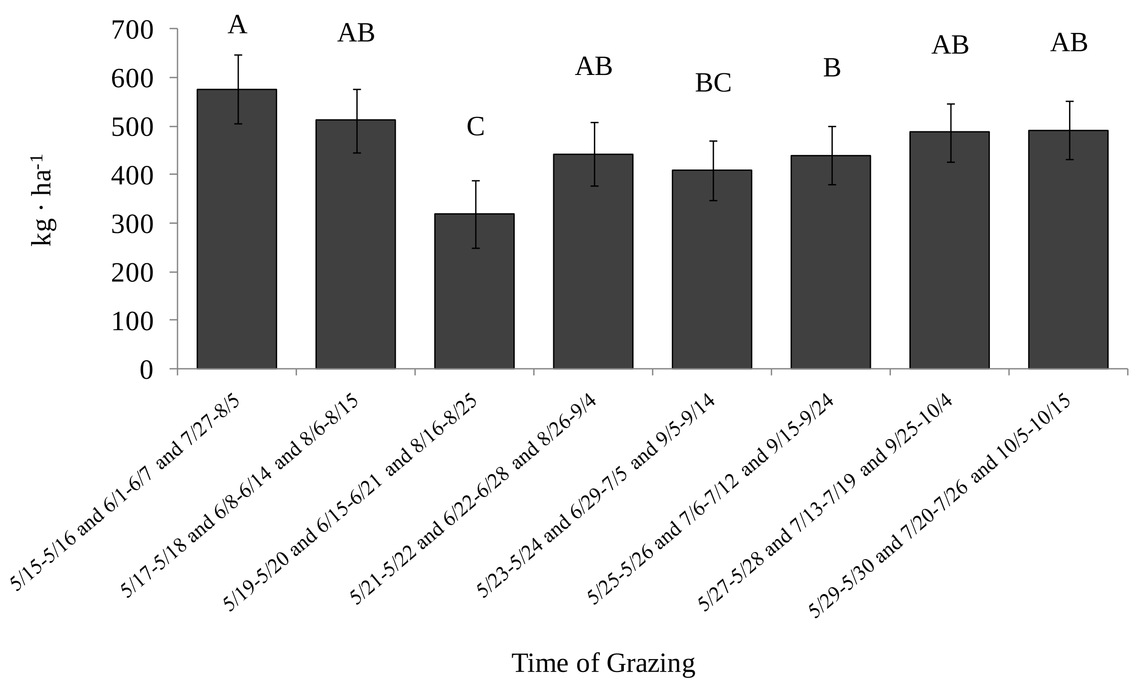
Table 2. The statistical analysis and mean weight for functional groups, total live forage, and litter and standing dead for herbage collected in mid-June and mid-August from exclosures that captured time of grazing effect on subsequent-year standing crop within an 8-pasture short-duration grazing system.

	Overall Pr > F	Mean wt.
June		kg · ha^{-1}
Warm-season grasses	0.3133	325
Cool-season grasses	0.5291	415
Forbs	0.0043	129
Shrubs	0.9791	123
Sedges	0.9916	90
Total live forage	0.5195	1153
Litter and standing dead	0.0048	660
August		
Warm season grasses	0.1562	745
Cool season grasses	0.0715	438
Forbs	0.1628	274
Shrubs	0.0903	170
Sedges	0.9762	83
Total live forage	0.4020	1748
Litter and standing dead	0.1613	603

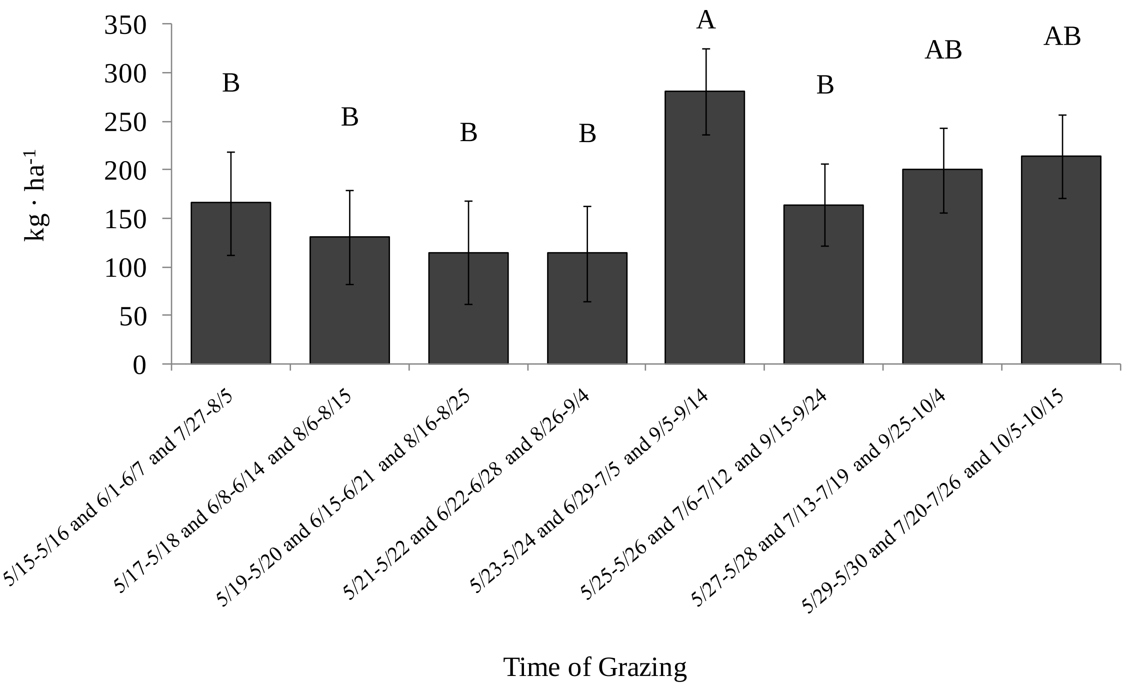
A) Forb Standing Crop in mid-June



B) Cool-Season Grass Standing Crop in mid-August



C) Browse in mid-August



D) Litter and Standing Dead in mid-June

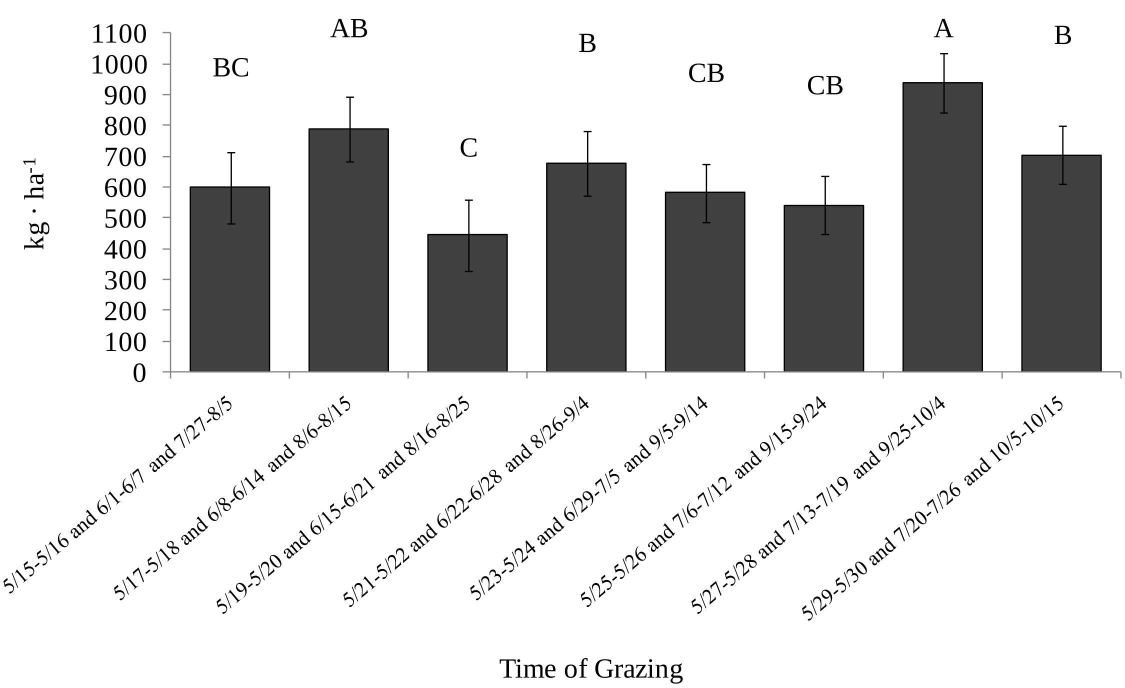


Figure 4. Time of grazing effect on subsequent-year standing crop of A) forbs harvested in mid-June, B) cool-season grasses harvested in mid-August, C) browse harvested in mid-August, and D) litter and standing dead collected in mid-June within a short-duration grazing system. Different letters represent differences between grazing periods ($p < 0.10$).

Conclusion

The limited response of short duration grazing systems to vegetation and livestock production was not an unexpected occurrence. Short duration grazing has not increased production in several studies within the Great Plains. However, the evaluation in this study of short duration grazing systems on a ranch scale provides conclusive evidence that short duration grazing systems will not increase livestock performance or standing crop when compared to less intensive grazing systems in the Nebraska Sandhills. Botanical composition of desirable species and total standing crop increased more with a deferred-rotation grazing systems than with a short duration grazing system. It was determined in this study that short duration grazing systems are not superior to a less intensive, deferred-rotation system, and, in some aspects, may be inferior. These results should be taken into consideration when range mangers are developing a grazing plan in the Sandhills.

Even though this study did not have a continuous grazing treatment, the increase in desirable plant species composition with the implementation of both grazing systems suggests that grazing systems may have a beneficial effect on the range condition regardless of which system is used. However, this may have been a result of increased awareness of the forage requirements or better distribution of livestock because of increased fencing and livestock watering points. More research is needed to determine if continuous grazing with adequate distribution and similar management would have similar results to these grazing systems in the increase in desirable species composition.

This study also provided a greater understanding of how functional groups and individual species are affected by topographic positions and amount of precipitation during different years. It was determined that interdunes tended to have increased amounts of cool-season graminoids compared to other topographic positions. It was also determined that warm-season grasses produced more herbage on interdunes and south slopes in different years of the study. Overall, total standing crop tended to be greater on interdunes in most years of the study. However, during dry years standing crop on interdunes was not different than other topographic positions.

Timing of grazing affected warm-season grass June standing crop in subsequent-years for the deferred-rotation grazing system. Subsequent-year cool-season grass and forb production was most affected by grazing during mid-May, mid-June, and late-August with a short duration grazing system. These results indicate that timing of grazing is an important factor to consider when developing a grazing system on Sandhills rangeland. The sequence of pasture rotation should be changed every year to limit grazing in consecutive years when plant species are most detrimentally affected unless specific management objectives are being achieved.