Vegetation Production Responses to October Grazing in the Nebraska Sandhills

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Abstract

Understanding the long-term effect of summer grazing date and fall stocking rate on herbage production is critical to extending the grazing season in the Nebraska Sandhills. A study was conducted from 1997 to 2002 at the Gudmundsen Sandhills Laboratory located near Whitman, Nebraska, to determine the herbage production response to summer grazing date and October stocking rate on two different sites. Site 1 was dominated by warm-season grasses and site 2 was dominated by cool-season graminoids. At each site, three 0.37-ha pastures were constructed in each of four blocks before application of summer grazing treatments. Pastures in each block were grazed at 0.5 animal-unit months (AUM) $\cdot$ ha^{-1} in June or July, or were deferred from summer grazing. Following summer grazing treatments, October stocking rate treatments (no grazing or 1.0, 2.0, or 3.0 AUM $\cdot$ ha^{-1}) were applied to subunits of each summer grazing date pasture during mid-October. Vegetation was sampled in each pasture in mid-June and mid-August and sorted by functional group to determine the effect of 5 yr of grazing treatments on herbage production and residual herbage. Herbage production was not affected by summer or October grazing treatments on the warm-season grass–dominated site. Increasing October stocking rate, however, reduced cool-season graminoid production and subsequent herbage production 25% by year 5 of the study. Residual herbage at both sites at the end of the October grazing periods explained as much as 16% to 34% of subsequent year's herbage production. Grazing managers in the Nebraska Sandhills can extend the grazing season by lightly stocking pastures in the summer to facilitate additional fall grazing. Heavy stocking in October over several years on cool-season–, but not warm-season–, dominated sites will reduce production of cool-season graminoids on these sites.

Resumen

Entender el efecto a largo plazo del pastoreo durante la época de verano y la carga animal durante el otoño en la producción de forraje es crítica para prolongar la estación de pastoreo en los pastizales de Sandhills Nebraska. Este estudio se condujo de 1997–2002 en el laboratorio de Gudmundsen Sandhills cerca de Whitman Nebraska para determinar la respuesta de la producción de las plantas forrajeras al pastoreo de verano y la carga animal en Octubre en dos sitios diferentes. El sitio 1 estaba compuesto principalmente por gramíneas de crecimiento de verano y el sitio 2 por especies de gramíneas de crecimiento de invierno. En cada sitio, tres potreros de 0.37–ha se construyeron en uno de cada 4 bloques antes de la aplicación de los tratamientos del pastoreo del verano. Cada uno de los potreros en cada bloque fue pastoreado con 0.50 UAM $\cdot$ ha^{-1} en Junio o Julio, o el pastoreo fue diferido durante el verano. Después del tratamiento del pastoreo de verano, los tratamientos de la carga animal durante Octubre (no pastoreo, 1.0, 2.0, o 3.0 UAM $\cdot$ ha^{-1}) se aplicaron a mediados de octubre a las subunidades de cada fecha de pastoreo durante el verano. La vegetación se muestreó en cada uno de los potreros a mediados de Junio y mediados de Agosto, separando por grupo funcional para determinar el efecto de cinco años de los tratamientos de pastoreo en la producción de forraje y el forraje residual. La producción de forraje no fue afectada por los tratamientos de pastoreo de verano u octubre en el sitio dominado por las gramíneas de crecimiento de verano. Sin embargo, el incrementar la carga animal en octubre, reduce la producción de las gramíneas de crecimiento invernal y la subsecuente producción de forraje 25% por el 5 año de estudio. El forraje residual en ambos sitios, al final de los periodos de pastoreo en octubre explica tanto como el 16% a 34% de la producción de forraje del año subsecuente. Los manejadores de pastizales en los Sandhills de Nebraska pueden extender la estación del pastoreo por medio del uso de un pastoreo ligero durante el verano para facilitar un pastoreo adicional durante el otoño. Un pastoreo pesado en octubre sobre varios años en sitios dominados por especies de crecimiento invernal, pero sin especies de crecimiento de verano disminuirá la producción de las gramíneas de crecimiento invernal en estos sitios.

Key Words: C_3–C_4 production dynamics, October stocking rate, residual herbage, vegetation functional groups

INTRODUCTION

Grazing of upland range in the central North American Great Plains, including the Nebraska Sandhills, traditionally has been restricted largely to the summer grazing season from mid-May

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to mid-October. In the Nebraska Sandhills, cattle grazing for the remainder of the fall and winter are concentrated on meadow haylands and other lowland areas where cool-season grass aftermath is available and hay can be readily fed. As a strategy to deal with the increasingly high costs of beef cattle production, many ranchers now graze upland rangelands beyond the traditional summer grazing season and into the fall and winter as a means of increasing the grazing season length and decreasing the amount of mechanically harvested forages fed to cattle. Upland pastures grazed in the fall and winter commonly have been grazed in the spring and/or summer as well at light to moderate stocking rates. Although forage quality of upland vegetation is relatively low during the dormant season, the grazing season can be extended with supplementation of concentrate feeds or good quality hay (Adams et al. 1994).

A focus of range research in the Nebraska Sandhills has been evaluation of year-round forage programs that emphasize extending the grazing season on native upland range. Research has been conducted to determine effects of timing and intensity of grazing in the spring (Volesky et al. 2005, 2007) and summer (Reece et al. 1996; Downs 1997; Engel et al. 1998) on diet quality, herbage utilization and productivity, and botanical composition; however, research results on livestock and vegetation response to fall grazing has not been reported. Managing the vegetation response to grazing in the Sandhills with a multiple-season grazing approach can be challenging as it is a mixed-grass prairie characterized by a diverse mixture of warm- and cool-season grasses, sedges, and forbs. Warm-season grasses, e.g., sand bluestem (*Andropogon hallii* Hack.) and prairie sandreed (*Calamovilfa longifolia* [Hook.] Scribn.), are key forage species and contribute from 50% to 80% of the primary productivity on upland sites (Masters et al. 1990; Reece et al. 1996). Cool-season grasses, e.g., needle-and-thread (*Heterostipa comata* [Trin. & Rupr.] Barkw.) and prairie junegrass (*Koeleria macrantha* [Ledeb.]), are common in much of the Sandhills uplands, especially on north aspects and interdunal areas (Schacht et al. 2000). Timing of grazing is a critical consideration in managing for these key plant species and is essential in managing for sustainability of livestock production (Reece et al. 1999).

Defoliation of warm-season tallgrasses, i.e., big bluestem (*Andropogon gerardii* Vitman) and indiangrass (*Sorghastrum nutans* [L.] Nash) from October to April in Kansas has been shown to have no impact on subsequent years' herbage production even if the grasses were grazed closely early in the growing season (Auen and Owensby 1988). Similar results were reported on mesic sites of rough fescue prairie in southern Alberta; however, heavy winter defoliation over a 3-yr period reduced growing-season herbage production by 43% on more arid sites of mixed-grass prairie (Willms et al. 1986). Removal of standing plant material and litter was reported to be the principal factor causing reductions in soil moisture and plant production. Other research also has shown that residual herbage at the end of the growing season and into the dormant season is a determinant of subsequent-year herbage production on arid and semiarid grazing lands (Heady 1956; Bartolome et al. 1980; Whisenhunt 2006).

The effect of fall grazing at different stocking rates on residual herbage, and ultimately subsequent-year herbage production, is largely unknown for mixed-grass prairies of the central Great Plains, especially when combined with different dates of light grazing in the summer. The objective of this study was to determine the interacting effects of summer grazing date and fall stocking rate on herbage production of Sandhills rangeland on warm-season grass–and cool-season graminoid–dominated sites after 5 yr of grazing. We did not expect summer grazing date at a light to moderate stocking rate to interact with fall stocking rate in affecting herbage production; however, we hypothesized that increasing fall stocking rate would reduce herbage production of the cool-season component of pastures while not affecting warm-season grass production. We questioned whether the movement toward extending the length of the grazing season, especially in the fall, would disfavor cool-season grasses.

MATERIALS AND METHODS

Study Site

This study was conducted on two sands ecological sites at the Gudmundsen Sandhills Laboratory (GSL) located 11 km northeast of Whitman (lat 42°07′N, long 101°26′W, elevation 1 073 m). Soils are Valentine fine sands (mixed, mesic, Typic Ustipsamments). These soils are found on gently sloping to very steep surfaces and are on the foot slopes as well as the dunes themselves. The surface layer is grayish-brown, loose fine sand about 13 cm thick. The transition layer is brown, loose fine sand about 10 cm thick. The underlying material is pale brown and very pale brown, loose fine sands to a depth of 152 cm (Kuzila 1990).

Average annual precipitation for GSL is 468 mm and the growing season precipitation (May through September) is 345 mm (1987 through 2002; HPRCC 2005). About 50% of the annual precipitation occurs during May, June, and July. Winter precipitation is usually in the form of snow with short periods of thawing and freezing (Whilhite and Hubbard 1990). The lowest and highest monthly average air temperatures at GSL are 2.8°C in January and 29.4°C in July, respectively (HPRCC 2005). Average annual soil temperature at 10 cm is 10°C and average frost-free period is 129 d.

Grazing Treatments

In June and July 1997, each of four blocks of upland range (site 1) were fenced with permanent electric fence and separated into three 0.37-ha pastures with portable electric fencing. Pastures at site 1 were dominated by native warm-season grasses with relative species composition based on weight ranging from 55% to 70% for the warm-season grasses and 20% to 30% for the cool-season graminoids. The warm-season vegetation on these upland sites was dominated by little bluestem (*Schizachyrium scoparium* [Michx.] Nash), prairie sandreed, sand bluestem, switchgrass (*Panicum virgatum* L.), and sand lovegrass (*Eragrostis trichodes* [Nutt.] Wood). The cool-season graminoids consisted of prairie junegrass, needle-and-thread, scribner panicum (*Panicum oligosanthes* J.A. Schultes subsp. Scribnerianum [Nash] Fern.), and grasslike plants (*Carex* spp. and *Cyperus* spp.). Common forbs included western ragweed (*Ambrosia psilostachya* DC.), slimflower scurfea (*Psoralea tenuiflora* Pursh), heath aster (*Aster ericoides* L.), cutleaf ironplant (*Haplopappus spinulosus* [Pursh] DC.), and prairie clover (*Petalostemum purpureum* Vent.). Leadplant (*Amorpha canescens* Pursh) and small soapweed (*Yucca glauca* Nutt.) were common shrubs.

Pastures were grazed with yearling cattle (*Bos taurus* L.; 340 kg each) in mid-June or mid-July at 0.5 animal-unit months (AUM) $\cdot$ ha^{-1} for 4 to 7 d or were deferred from summer grazing. The light summer stocking rate represents half of the recommended season-long stocking rate. Using light summer stocking rates with short duration grazing periods (2 to 14 d) is a common practice in the Sandhills region, ensuring adequate herbage availability for a fall grazing period. Treatments were randomly assigned to the pastures. After the summer grazing treatments were applied, 0.07 ha was excluded from each pasture with an electric fence and was not grazed for the remainder of the calendar year.

Fall grazing treatments were applied during mid-October following several killing frosts. Warm-season grasses were senescent, although some cool-season graminoids were still green and photosynthesizing. In mid-October 1997, portions of the remaining 0.3 ha of each pasture was stocked at 1.0, 2.0, or 3.0 AUM $\cdot$ ha^{-1}. Using a summer stocking rate of 0.5 AUM $\cdot$ ha^{-1} during the summer grazing period and an October stocking rate of 1.0 AUM $\cdot$ ha^{-1} results in the total stocking rate applied to the site of 1.5 AUM $\cdot$ ha^{-1}. The heavier stocking rates were 2.5 AUM $\cdot$ ha^{-1} and 3.5 AUM $\cdot$ ha^{-1}.

A graze-down system using mature cows and heifers (570 kg and 340 kg each, respectively) was used in 1997 to apply the October grazing treatments. Cattle had access to the entire 0.3 ha on days 1 through 4. On day 5 the pastures were split in half with portable electric fencing and cattle were confined to 0.15 ha for 2 d. On day 7, the half pastures were split with portable electric fencing, leaving 0.075 ha (one-fourth pasture) for the cattle to graze. Cattle were removed from the pastures the morning of day 8.

A complete replication of grazing treatments was applied to each of four blocks at a second site (site 2) in 1998. Vegetation species on site 2 were identical to site 1; however, pastures at site 2 were dominated by native cool-season graminoids. Relative species composition by weight ranged from 50% to 60% for the cool-season graminoids and 30% to 40% for the warm-season grasses.

Pastures on site 2 were grazed with yearling cattle (340 kg each) in mid-June or mid-July at 0.5 AUM $\cdot$ ha^{-1} for 4 to 7 d or deferred from summer grazing. Treatments were randomly assigned to the pastures. A modified method of applying October grazing treatments was used in 1998 and each year thereafter to improve labor efficiency. The pastures were split with electric fencing into four sections: a 0.07-ha exclosure, a 0.15-ha paddock stocked with two 2-yr-old heifers (363 kg each) to accomplish a 1.0 AUM $\cdot$ ha^{-1} stocking rate, a 0.075-ha paddock stocked with two 2-yr-old heifers to accomplish a 2.0 AUM $\cdot$ ha^{-1} stocking rate, and a 0.075-ha paddock stocked with three 2-yr old heifers to accomplish a 3.0 AUM $\cdot$ ha^{-1} stocking rate. Cattle were placed on paddocks in blocks 1 and 2 and grazed for 2 d and were removed from the paddocks by 1800 hours of the second day. Water tanks and fences were moved and cattle were placed on blocks 3 and 4 for 2 d the day following removal from blocks 1 and 2. Each October stocking rate treatment was applied to the same paddock in each replication in mid-October at site 1 every year through 2001 and at site 2 through 2002.

Grazing research conducted on small experimental units with small numbers of animals is common in the literature (Reece et al. 1996; Mousel et al. 2003; Volesky et al. 2005). When constraints on land, infrastructure, and labor exist, using small experimental units allows for intensive sampling to keep sample variability low and increases the likelihood of detecting responses statistically. Research has shown that cattle adapt readily to experimental conditions, including small experimental units (Broweleit et al. 2000). In our experiment, the stocking rate treatments imposed by the cattle did result in the expected differences in grazing intensity as demonstrated by the wide range of standing crop among the experimental pastures (see the section on residual herbage). The population of inference certainly includes upland range of the Sandhills and other similar semiarid grasslands.

Vegetation Sampling

Residual herbage remaining at the end of October grazing periods was estimated in the first and fifth year at both sites. In year 1, all standing herbage (current year and previous year growth) within 10 randomly located quadrats (0.25 m^2) was clipped at ground level in each quarter (0.075 ha) of each pasture immediately following grazing. In year 5, 10 quadrats were clipped in each of the 2 AUM $\cdot$ ha^{-1} and 3 AUM $\cdot$ ha^{-1} paddocks and 20 quadrats were clipped in the 1 AUM $\cdot$ ha^{-1} paddocks. The 1 AUM $\cdot$ ha^{-1} paddocks were twice as large as the other paddocks and the number of clipped quadrats was increased proportionally. Unlike in year 1, the clipped standing herbage in year 5 was separated into two categories: current-year growth and previous-year growth. Litter also was gathered from the soil surface within each quadrat in year 5. Samples were placed in marked paper bags, oven-dried to a constant weight at 60°C, and weighed.

Effect of grazing treatments on subsequent-year herbage production was determined by sampling herbage production in mid-June and mid-August in alternate years on each site. Mid-June and mid-August correspond to the approximate time of peak cool- and warm-season herbage production, respectively (Northup 1993). Herbage production was estimated in 1998 (year 1), 2000 (year 3), and 2002 (year 5) on site 1 and 1999 (year 1), 2001 (year 3), and 2003 (year 5) on site 2. At the time of peak cool-season production and the time of peak warm-season production in 1997 at site 1, all herbage in five 0.25-m^2 quadrats was clipped to ground level in each quarter (0.075 ha) of each pasture (0.3 ha) and each exclosure. In all other years at the two sites, five of the quadrats were clipped in each of the 2 AUM $\cdot$ ha^{-1} and 3 AUM $\cdot$ ha^{-1} treatment paddocks as well as the exclosures, and 10 quadrats were clipped in the 1 AUM $\cdot$ ha^{-1} paddocks. Clipped herbage was sorted into the following plant functional groups: warm-season grass, cool-season graminoids (cool-season grasses and sedges), forbs and shrubs, and standing dead (standing residual from previous-year growth). Samples were placed in marked paper bags, oven-dried to a constant weight at 60°C, and weighed. Because of a shortage of labor at time of peak cool-season production in 1998, a complete set of yield data was not collected on site 1.

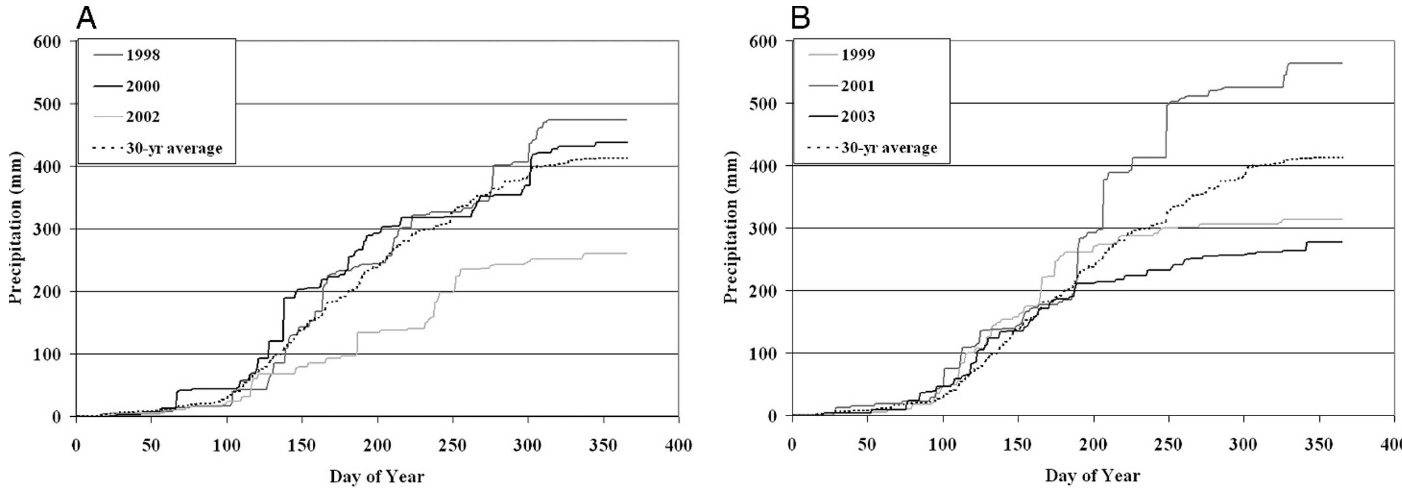

Figure 1. Accumulated precipitation at the Gudmundsen Sandhills Laboratory, Whitman, Nebraska, for sampling years on **A,** site 1 (warm-season dominated) in 1998 (year 1), 2000 (year 3), 2002 (year 5), and 30-yr average and **B,** site 2 (cool-season dominated) in 1999 (year 1), 2001 (year 3), 2003 (year 5), and 30-yr average.

Statistical Analysis

The experimental design was a randomized complete block with four replications. Summer grazing date was considered the main plot and October stocking rate the split plot. Summer grazing date and October stocking rate were factor combinations of treatment for testing the interacting effect of summer grazing date and October stocking rate on herbage production, including each functional group, at time of peak cool-season production. The peak warm-season harvests occurred after application of the late-June and late-July grazing treatments; therefore, summer grazing date effects and the interacting effects of summer grazing date and October stocking rate on herbage production could not be tested with peak warm-season production harvest data in years 1 and 3. However, the cumulative effect (year 5 data) was determined by clipping in the summer of year 6 when summer grazing treatments were not applied; therefore the effect of 5 yr of grazing can be analyzed for peak warm-season herbage production data.

Site 1 and site 2 were analyzed as separate experiments because the vegetation composition of the two sites was drastically different. Site 1 was characterized as having a dominant warm-season grass component (71% C_4 vs. 29% C_3) and site 2 was characterized as having a dominant cool-season graminoid component (65% C_3 vs. 35% C_4). Each of the sampling dates (peak cool-season production and peak warm-season production) also was analyzed separately.

All data were analyzed using the Mixed Model Procedure in SAS (Littell et al. 1996; SAS 2004). The effect of summer grazing dates on subsequent years' herbage production of each functional group (warm-season grasses, cool-season graminoids, forbs and shrubs, total graminoids, total herbage production) was tested using orthogonal contrasts. Linear and quadratic effects of October stocking rate and the summer grazing date by October stocking rate interaction were tested on subsequent-year herbage production of each functional group. Linear regression analyses were performed (Proc Reg, SAS 2004) to evaluate the effect of postgrazing residual herbage on components of subsequent-year herbage production. Residual variables evaluated included current-year growth, previous-year growth, litter, total standing residual (current and previous year's growth), and total residual herbage (total standing residual and litter). Each site (1 and 2), year (1 and 5), and sampling date (mid-June and mid-August) combination was analyzed separately. Treatment effects were considered significant at $P < 0.05$ for all analyses.

RESULTS

Precipitation

Cumulative annual precipitation in vegetation sampling years on site 1 in 1998 and 2000 was near the 30-yr average but was 50% below average in 2002 (Fig. 1; HPRCC 2005). Precipitation levels on site 2 in 2001 were 23% above average but were 28% and 35% below average in 1999 and 2003, respectively.

Herbage Production

Summer Grazing Effects. Summer grazing date and October stocking rate did not interact in affecting herbage production at the time of peak cool-season production on the two sites. Overall, in year 5 of this study, herbage production of warm-season grasses, cool-season graminoids, forbs and shrubs, or total herbage production were not different among summer grazing treatments, indicating that 5 yr of summer grazing at a light stocking rate did not have a cumulative effect on these vegetation components (Table 1).

Fall Grazing Effects. In general, 5 yr of October stocking rate treatments did not negatively affect subsequent-year yields of warm-season grasses (Table 2). The exception was at the time of peak warm-season production in year 5 on site 1 when the relatively high yield of warm-season grasses on the 0 $AUM \cdot ha^{-1}$ pastures resulted in a significant linear decline in warm-season grass yields with increasing stocking rate.

Conversely, 5 yr of October stocking rate treatments decreased yields of cool-season graminoids, particularly on site 2 (Table 2).

Table 1. Peak cool-season (Peak C_3) in mid-June and peak warm-season (Peak C_4) in mid-July herbage production ($kg \cdot ha^{-1}$) of current year warm-season grasses, cool-season graminoids, forbs and shrubs, total herbage production, and standing dead by summer grazing date after 5 yr of grazing treatments on site 1 (warm-season dominated) and site 2 (cool-season dominated).

	Summer grazing date				Deferred vs. grazed	June vs. July
	Deferred	Mid-June	Mid-July	SE		
	---------------- $kg \cdot ha^{-1}$	----------------			--------- $P > F$	--------
Peak C_3 site 1						
Warm-season	495	490	500	42	0.8935	0.9171
Cool-season[1]	380	340	300	45	0.2992	0.5377
Forbs and shrubs	60	80	105	25	0.2749	0.5318
Total	935	910	905	94	0.3824	0.4291
Standing dead	330	205	245	55	0.6465	0.0236
Peak C_3 site 2						
Warm-season	655	655	680	98	0.9767	0.9445
Cool-season[1]	865	860	845	43	0.7799	0.7964
Forbs and shrubs	160	155	185	20	0.5510	0.2329
Total	1 670	1 670	1 710	157	0.8721	0.7717
Standing dead	510	380	300	50	0.0079	0.2802
Peak C_4 site 1						
Warm-season	915	840	910	42	0.5436	0.2060
Cool-season[1]	260	255	255	45	0.9184	0.9388
Forbs and shrubs	105	95	110	25	0.7599	0.8374
Total	1 280	1 190	1 275	94	0.6285	0.5491
Standing dead	260	215	225	55	0.8100	0.4835
Peak C_4 site 2						
Warm-season	600	545	525	95	0.8534	0.9573
Cool-season[1]	875	865	830	43	0.5656	0.5136
Forbs and shrubs	140	130	150	20	0.9702	0.5249
Total	1 615	1 530	1 505	154	0.7937	0.8271
Standing dead	150	195	145	50	0.7772	0.5760

[1]Cool-season component includes grasses and sedges.

Table 2. Peak cool-season (Peak C_3) in mid-June and peak warm-season (Peak C_4) in mid-July herbage production ($kg \cdot ha^{-1}$) of current year warm-season grasses, cool-season graminoids, forbs and shrubs, herbage production and standing dead by October stocking rate after 5 yr of grazing treatments on site 1 (warm-season dominated) and site 2 (cool-season dominated).

	October stocking rate (AUM[1] $\cdot ha^{-1}$)						
	0	1.0	2.0	3.0	SE	Linear	Quadratic
	---------------- $kg \cdot ha^{-1}$			----------------		------- $P > F$	------
Peak C_3 site 1							
Warm-season	470	500	525	485	46	0.7210	0.4204
Cool-season[2]	370	375	335	280	55	0.4450	0.3452
Forbs and shrubs	80	80	55	110	30	0.7150	0.3900
Total	920	955	915	875	110	0.5819	0.6252
Standing dead	375	300	205	160	61	0.0004	0.7204
Peak C_3 site 2							
Warm-season	605	660	710	680	80	0.8536	0.8962
Cool-season[2]	1 055	870	795	715	51	0.0001	0.2345
Forbs and shrubs	130	140	190	205	25	0.0077	0.9115
Total	1 780	1 670	1 695	1 585	263	0.7064	0.9834
Standing dead	670	400	245	280	65	0.0001	0.0109
Peak C_4 site 1							
Warm-season	1 110	835	880	830	46	0.0089	0.1378
Cool-season[2]	300	285	210	225	55	0.0365	0.6164
Forbs and shrubs	105	100	80	125	30	0.8007	0.4389
Total	1 515	1 220	1 170	1 180	110	0.0001	0.0039
Standing dead	375	245	200	110	68	0.0005	0.6941
Peak C_4 site 2							
Warm-season	500	570	660	495	80	0.9541	0.7043
Cool-season[2]	970	875	810	765	51	0.0014	0.6113
Forbs and shrubs	110	150	145	155	25	0.2371	0.5090
Total	1 580	1 575	1 605	1 415	263	0.7685	0.7712
Standing dead	220	220	100	110	65	0.1749	0.9301

[1]AUM indicates animal-unit months.
[2]Cool-season component includes grasses and sedges.

A linear decline in year 5 yields of cool-season graminoids as October stocking rate increased was observed on both sites.

Forb production did increase with increasing stocking rate on site 2 by the fifth year in mid-June (Table 2). However, forbs had little influence on total herbage production at either site as forb production composed less than 10% of the total herbage production on most sampling dates.

In year 5, total herbage production had been affected by October stocking rate only on site 1 at the time of peak warm-season production (Table 2). Yields of both cool-season graminoids and warm-season grasses declined with increasing October stocking rate on site 1 at the time of peak warm-season production. The decline in yields of cool-season graminoids was not sufficient to affect total live herbage production on site 2 at the time of peak cool-season production or peak warm-season production.

Standing dead decreased with increasing October stocking rate at both the time of peak cool-season production and peak warm-season production in year 5 (Table 2). A significant decline at the time of peak warm-season production at site 2 likely was not detected because of the relatively high standard error and the low amount of standing dead on site 2.

Residual Herbage. We found significant linear relationships between standing residual herbage and subsequent-year herbage production on both sites, although the r^2 values were low. On site 2, there was a significant linear relationship between amount of standing residual herbage at the end of the October grazing period in 1998 (year 1) and total graminoid and total herbaceous standing crop (i.e., graminoids and forbs) at the time of peak cool-season production ($r^2 = 0.23$ and $r^2 = 0.22$, respectively) and the time of peak warm-season production ($r^2 = 0.34$ and $r^2 = 0.18$, respectively) in 1999 (Table 3). There also were significant linear relationships ($P < 0.05$) on site 1 between standing residual herbage in fall 2001 (year 5) and total graminoid and total herbaceous standing crop at the time of peak warm-season production in 2002 ($r^2 = 0.21$ and $r^2 = 0.19$, respectively; Table 3).

Table 3. Significant ($P < 0.5$) regression equations for postgrazing residual herbage (x) and subsequent-year standing crops (Y) of total graminoids and total herbaceous vegetation for site 1 (warm-season dominated) and site 2 (cool-season dominated) in mid-June and mid-August.

Response variable	Year	Site	Harvest date	Regression equation	r^2
Total graminoids	1999	2	June	$Y = 135 + 0.39$ (x)	0.23
Total herbaceous	1999	2	June	$Y = 383 + 0.33$ (x)	0.22
Total graminoids	1999	2	August	$Y = 279 + 0.48$ (x)	0.34
Total herbaceous	1999	2	August	$Y = 755 + 0.38$ (x)	0.18
Total graminoids	2002	1	August	$Y = 789 + 0.28$ (x)	0.21
Total herbaceous	2002	1	August	$Y = 907 + 0.23$ (x)	0.19

DISCUSSION

The results of this study indicate that land managers can successfully stock summer pastures at a light stocking rate and extend the grazing season with October grazing in the Sandhills. Additionally, the negative effects of October grazing appear to be limited to cool-season graminoids on cool-season–dominated sites. The lack of a production response to light summer stocking rate is not surprising given prior studies focusing on warm-season grass response to summer defoliation periods did not reduce end-of-year aboveground biomass of sand bluestem and prairie sandreed (Reece et al. 1996; Downs 1997; Engel et al. 1998).

Senesced warm-season grasses also would not be expected to be adversely affected by defoliation in October (Auen and Owensby 1988; Reece et al. 1996). Auen and Owensby (1988) reported no subsequent-year response of warm-season vegetation production to October defoliation in the tallgrass prairie of the Kansas Flint Hills. Increasing fall stocking rates beyond the recommended level did not consistently impact production of warm-season grasses on either site in this study. Studies in the Kansas Flint Hills have, however, demonstrated that combinations of summer defoliation and September defoliation can reduce production of warm-season grasses (Owensby et al. 1974), and a single defoliation in September can also reduce production of warm-season grasses (Owensby and Anderson 1969; Owensby et al. 1970). The longer growing season in Kansas likely can be attributed to the negative response of warm-season grasses to September defoliation observed in these studies.

Conversely, the response of cool-season graminoids as October stocking rate increased on both sites indicated that mid-October is a critical time for cool-season graminoid response to defoliation. Many cool-season species were green and growing in October because soil moisture and temperature levels were adequate. Furthermore, tillers of cool-season graminoids that start development during late June or early July usually do not produce an inflorescence and they generally overwinter, resuming active growth the following growing season (Briske and Richards 1995). Defoliation of cool-season graminoids this late in the growing season likely depleted these species of organic reserves (Coyne et al. 1995), which can decrease growth potential in subsequent growing seasons (Manske 1998).

Reductions in the amount of standing dead and residual herbage were expected as October stocking rate increased. Observations indicated that much of the standing dead at both sites was previous-year growth of little bluestem. The lack of significant relationships between residual herbage and components of subsequent-year herbage production in most date $\times$ site combinations calls to question the consistency of residual herbage effect on production. Residual herbage at the end of the growing season is reported to be a factor affecting subsequent-year herbage production of grazing lands, primarily because of its influence on the hydrologic cycle (Heady 1956; Bartolome et al. 1980; Willms et al. 1986; Whisenhunt 2006). Low levels of explanatory power for relationships between residual herbage and subsequent-year herbage production at these sites suggests that residual herbage may not be as important for infiltration in the Sandhills as in other grazing lands due to high infiltration rates on our sandy soils, thereby negating positive influence of residue on hydrologic conditions (Oldfather et al. 1989; Bartolome et al. 2007).

IMPLICATIONS

The majority of vegetation functional groups in this study were not adversely affected by the timing of a light summer grazing in June or July or by October stocking rate. Light utilization of summer pastures followed by grazing in October appears to be an acceptable management strategy to extend the grazing season in the Sandhills. Furthermore, the negative effects of October grazing in this system appear to be confined to cool-season–dominated sites and only for subsequent production of cool-season graminoids following repeated heavy stocking over several years. Therefore, the decreased productivity of cool-season graminoids in response to increased October stocking rate indicate that there are limits to the intensity at which Sandhills pastures can be stocked in October.

Additionally, managing for large amounts of residual herbage at the end of the growing season need not be a primary management objective in the Sandhills. Although some residual herbage is necessary to mitigate erosion on these sandy soils, the loss of residual herbage in response to October stocking at any level does not appear to be detrimental to subsequent-year production, especially in these sandy soils.

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