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Yield Response of Needle-and-Thread and Threadleaf Sedge to Moisture Regime and Spring and Fall Defoliation

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Abstract

Little information is available to help managers of cool-season dominated semiarid rangelands determine when to begin and end grazing in the spring and fall. Therefore, we evaluated the effects of clipping spring and fall growth on subsequent-year yield of needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth) and threadleaf sedge (*Carex filifolia* Nutt.) (USDA-NRCS 2012) using a randomized complete block, split-plot experimental design with fall moisture regimes (ambient or supplemental water) applied to main plots and defoliation treatments applied to subplots. Two combinations of spring defoliation, one for each fall moisture regime, were composed of a factorial array of three spring clipping dates (early May, late May, mid-June) and three levels of defoliation (0%, 40%, 80%). A third combination of treatments was composed of the supplemental water regime and an array of a single spring clipping date (late May), a single fall clipping date (late September, after regrowth), and three levels of defoliation (0%, 40%, 80%) in the same year. Ambient fall moisture was low, leading to continued senescence of needle-and-thread and threadleaf sedge, whereas the application of 10 cm of supplemental water in mid-August stimulated fall growth. The study was replicated with two sets of main plots at four sites in consecutive years, 2002 and 2003. Yield data were collected in mid-June of the year following treatment. Subsequent-year yield of needle-and-thread was not affected by defoliation under average plant-year precipitation conditions (2003) ($P > 0.05$); however, it was reduced following heavy (80%) late spring (late May or June) defoliation during a drought year (2002) ($P > 0.05$). Subsequent-year yield of threadleaf sedge was not affected by defoliation in either year ($P > 0.05$). Because it is difficult to predict when drought will occur, avoiding heavy late-spring grazing in needle-and-thread–dominated pastures in consecutive years would be prudent.

Key Words: *Carex filifolia*, drought, fall regrowth, *Hesperostipa comata*, *Stipa comata*

INTRODUCTION

Maintaining viable spring forage resources depends on spring-grazing tolerance of preferred cool-season species, the effects of precipitation regime (Olson et al. 1985; Epstein et al. 1997, 1998), and grazing management during the balance of the grazing season (Olson et al. 1985). Grazing semiarid rangeland only during the dormant season least impacts graminoid vigor and forage production (Trlica et al. 1977; Reece et al. 1996). Conversely, heavy defoliation during periods of rapid growth in spring or summer can reduce plant vigor (Pearson 1964; Reece et al. 2007a).

Native cool-season grasses and sedges comprise relatively high percentages of the herbage produced in mixed-grass prairies. Needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth) and threadleaf sedge (*Carex filifolia* Nutt.) are among the most common and abundant cool-season species in semiarid regions of the northern and central Great Plains (Weaver and Albertson 1956; Coupland 1992). These species typically senesce as the growing season progresses, in response to increasing temperatures and/or soil moisture deficits. Needle-and-thread and threadleaf sedge may resume growth in the fall as temperatures moderate, if soil moisture levels are adequate. Traditionally, grazing managers have considered flushes of fall growth in cool-season graminoids to be a nutritional windfall for livestock production. However, initial growth in the spring or fall occurs at the expense of plant energy reserves. The effects of factorial arrays of spring and fall defoliation have not been reported for any species of *Stipa* or upland *Carex* in such semiarid ecosystems where fall growth is common. Most published clipping or grazing studies on needle-and-thread have been limited to a single date or degree of defoliation, and none have involved fall growth because little or no soil moisture was available during the fall (Peterson 1962; Pearson 1964; Wright 1967; Burleson and Hewitt 1982; Reece et al. 1988). Research on herbage yield and response to defoliation is even more limited for threadleaf sedge (Stubbendieck and Foster 1978; Fassett 2003).

Level of defoliation by season of grazing interactions could affect the ability of ranchers to sustainably use these range resources. This study was designed to explore the effects of selected spring and/or fall defoliation treatments combined

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Table 1. Water and defoliation treatments randomly assigned to the main plot and subplot experimental units, respectively. Three of the nine subplots (one per row and column) in each main plot were assigned the nondefoliated control treatment. All treatments were applied within individual calendar years.

	Spring defoliation (%)			Supplemental water (cm)	Fall defoliation (%)
Defoliation treatment	Early May	Late May	Mid-June	Mid-August	Late September
Spring defoliation with ambient fall moisture (Spring/Ambient)					
Nondefoliated	0	0	0	0	0
Early May 40%	40	0	0	0	0
Early May 80%	80	0	0	0	0
Late May 40%	0	40	0	0	0
Late May 80%	0	80	0	0	0
June 40%	0	0	40	0	0
June 80%	0	0	80	0	0
Spring defoliation with supplemental fall moisture (Spring/Supplemental)					
Nondefoliated	0	0	0	10	0
Early May 40%	40	0	0	10	0
Early May 80%	80	0	0	10	0
Late May 40%	0	40	0	10	0
Late May 80%	0	80	0	10	0
June 40%	0	0	40	10	0
June 80%	0	0	80	10	0
Spring and fall defoliation with supplemental fall moisture (Spring + Fall/Supplemental)[1]					
Nondefoliated	0	0	0	10	0
Late May 0% September 40%	0	0	0	10	40
Late May 0% September 80%	0	0	0	10	80
Late May 40% September 40%	0	40	0	10	40
Late May 40% September 80%	0	40	0	10	80
Late May 80% September 40%	0	80	0	10	40
Late May 80% September 80%	0	80	0	10	80

[1]For the analysis of the Spring + Fall/Supplemental main plots, we included the two late May defoliation treatments (40% and 80%) from the adjacent Spring/Supplemental main plots (September 0%) to complete the factorial array of spring and fall defoliation treatments.

with different fall moisture regimes to enhance grazing management of nonrhizomatous, cool-season graminoids. We hypothesized that the timing and level of defoliation would affect subsequent-year yield of needle-and-thread and threadleaf sedge, with later and heavier defoliation resulting in greater reduction of subsequent-year herbage production. We also hypothesized that late-season application of supplemental water would reduce the impact of defoliation. This information will help grazing managers optimize range-based livestock production while maintaining healthy rangeland ecosystems.

METHODS

Study Sites

This study was conducted at the Wagon Box Ranch, 55 km south-southeast of Scottsbluff, Nebraska, in the Wildcat Hills (lat 41°26′N, long 103°21′W, elevation 1 400 m), on limy upland ecological sites in good range condition. Soils are Mitchell silt loams (coarse, silty, mixed calcareous, mesic, ustic Torriorthents).

We selected four sites co-dominated by needle-and-thread (42%) and threadleaf sedge (40%) for this study. Mean composition percentages were based on herbage clipped from nondefoliated plots in each subsequent year. Other species present included blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), western wheatgrass (*Pascopyrum smithii* [Rydb.] Á. Löve), prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), and sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray). Forbs made up < 2% of the standing herbage. Nomenclature follows the USDA PLANTS database (USDA-NRCS 2012).

We determined plant-year precipitation using data for Potter, Nebraska (High Plains Regional Climate Center 2004), the nearest reporting station, located 21 km south of the ranch (lat 41°13′N, long 103°19′W, elevation 1 350 m). Plant-year precipitation includes precipitation received during the preceding dormant season (October–March), plus that received during the current growing season (April–September).

Experimental Design

This study was arranged in a randomized complete block, split-plot design with fall moisture regimes applied to main plots and defoliation treatments applied to subplots. At each site, we constructed a 1.0-ha exclosure to exclude cattle. Within each exclosure, we established six 4.0×4.0 m main plots based on uniform distribution of needle-and-thread and threadleaf sedge. At each site, three main plots were randomly selected to receive treatments in 2002 and three to receive treatments in 2003. Each main plot contained three rows of three 1.0×1.0 m subplots, each surrounded by a 30-cm buffer strip. All main plots included three nondefoliated controls (one per row and column of subplots). Clipping treatments were applied to the entire subplot. Main plot dimensions were constrained by the size of the water application systems. All main plots and subplots were permanently marked. Within each treatment year, main plot and subplot treatments were randomly assigned.

Defoliation and Moisture Treatments

Spring Defoliation. Treatments were a combination of defoliation times and intensities, in conjunction with fall moisture regime (Table 1). Two sets of main plots in each treatment year were defoliated in the spring only. Defoliation treatments were composed of a factorial array of three spring clipping dates (early May, late May, and mid-June) and three levels of defoliation (0%, 40%, and 80%). In the fall, one set of plots experienced ambient moisture conditions resulting in continued senescence of needle-and-thread and threadleaf sedge, whereas the other set received 10 cm of supplemental water in mid-August to stimulate fall growth. During 2002, supplemental water was applied using a boom system with

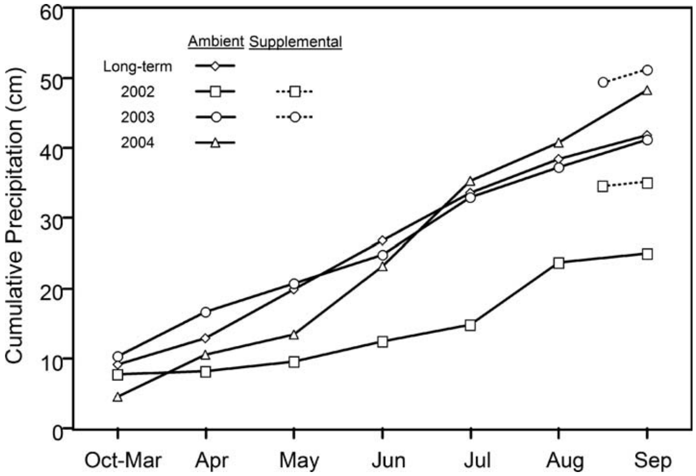

Figure 1. Cumulative plant-year (October–September) moisture (cm) during 2002, 2003, 2004, and the long-term average at Potter, Nebraska. Values for the ambient moisture regime include only ambient precipitation. Those for the supplemental water regime include 10 cm of water applied in mid-August.

nozzles (Whisenhunt 2006). Water was applied in 16 passes at intervals (based on the terrain and soil properties) to allow infiltration and avoid runoff. During 2003, a passive application watering system involving a network of soaker hoses was used (Reece et al. 2007b). All plots received ambient precipitation during the subsequent year.

Spring and Fall Defoliation. A third combination of treatments was composed of the supplemental water regime and an array of a single spring clipping date (late May), a single fall clipping date (late September, after regrowth), and three levels of defoliation (0%, 40%, 80%). All treatments were applied within individual calendar years. This combination of treatments allowed us to explore potential interactions between spring and fall defoliations.

Calibration of Defoliation

Clipping treatments were designed to remove 40% or 80% of current-year herbage by weight from needle-and-thread and threadleaf sedge. Just prior to each clipping event at each site, we determined species-specific clipping heights for needle-and-thread and threadleaf sedge. All other species within a subplot were clipped to the same height as needle-and-thread. We determined clipping heights using regression lines developed from independently collected samples. For each species, we clipped tillers at ground level and tied them into bundles with stem bases flush. Bundles were balanced on a ruler edge to determine the balance point, an estimate of the stubble height at which 50% of the herbage by weight would be removed. Bundles were cut at the point of balance and the resulting two bundle portions were balanced and measured to estimate stubble height for 25% and 75% defoliation. We fit regression lines to these data and used them to determine clipping heights.

Subsequent-Year Yield

Yield data were collected in each subplot in mid-June of the year following treatment. This timing corresponds with the period of peak cool-season graminoid standing crop (Northup 1993). In an average-precipitation year, needle-and-thread would be headed and threadleaf sedge would have cast seed. All current-year herbage within each subplot was clipped at ground level, separated into needle-and-thread, threadleaf sedge, other graminoids, and forbs, dried at 60°C, and weighed. Residual growth was hand-separated from current-year herbage during clipping.

Statistical Analysis

Data were analyzed using the Mixed Model Procedure (SAS Institute 2007). When significant effects were detected, the Differences of Least Squares Means Procedure (SAS Institute 2007) was used to separate means. In all analyses, differences were considered significant at $P \leq 0.05$. Because defoliation treatments differed among treatment regimes, data for Spring/Ambient, Spring/Supplemental, and Spring+Fall/Supplemental main plots were analyzed separately. Separate analyses were also performed by treatment year to enhance our ability to discern treatment effects under drought (2002) and average (2003) precipitation conditions (Fig. 1). For Spring/Ambient and Spring/Supplemental main plots, spring defoliation treatment was a fixed effect. Site and spring defoliation treatment×site were random effects.

For the analysis of the Spring+Fall/Supplemental main plots, we included the two late May defoliation treatments (40% and 80%) from the adjacent Spring/Supplemental main plots (September 0%) to complete the factorial array of spring and fall defoliation treatments. In these analyses, spring defoliation treatment, fall defoliation treatment, and their interaction were fixed effects. Site was a random effect.

To further explore the response to drought, we conducted additional analyses using the 2002 spring defoliation data. For each species, we evaluated the response to ambient versus supplemental fall moisture. Moisture regime and defoliation treatment were fixed effects and site, site×moisture regime, and defoliation treatment×site×moisture regime were random effects. We also compared the response of needle-and-thread versus threadleaf sedge. Defoliation treatment and species were fixed effects, and site, site×species, and defoliation treatment×site×species were random effects.

RESULTS

Precipitation Regimes

The 56-yr–average total plant-year precipitation was 41.9 cm. Total plant-year precipitation was 40% below average during 2002, near average during 2003, and 15% above average during 2004 (Fig. 1). Thus, Spring/Ambient main plots initiated in 2002 experienced drought conditions during the treatment year and average conditions during the subsequent year. Spring/Ambient main plots initiated in 2003 received average precipitation throughout the treatment year. In the subsequent year (2004), cumulative precipitation was below average during the dormant season and early growing season; however, total plant-year precipitation was about 15% above average.

With moisture addition to stimulate fall regrowth, total plant-year moisture in Spring/Supplemental and Spring+Fall/

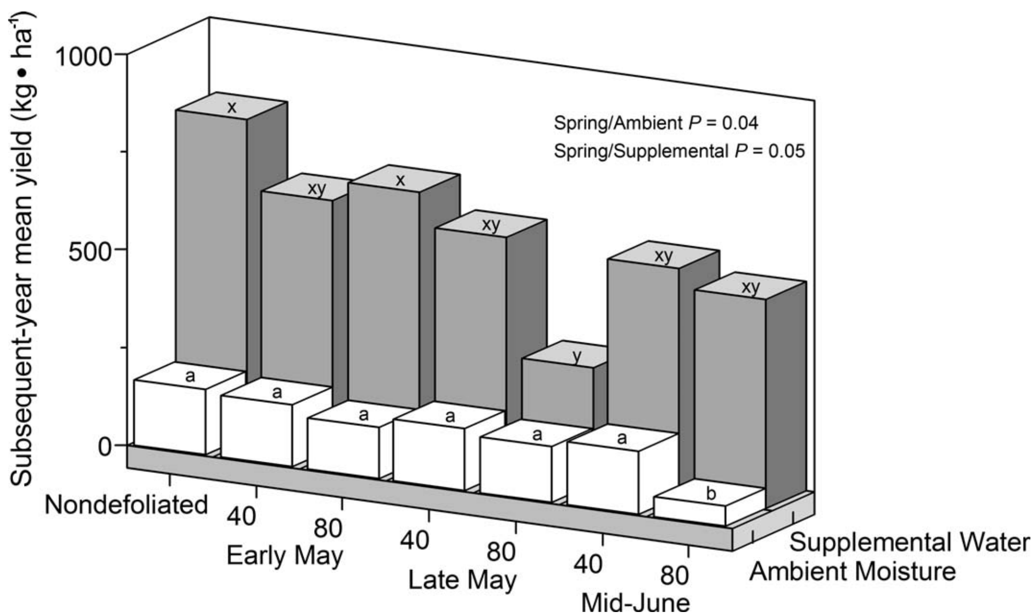

Figure 2. Subsequent-year yield (kg · ha^{-1}) of needle-and-thread in response to seven spring defoliation treatments following ambient or supplemental water moisture regimes during drought in 2002. Within fall moisture regimes, columns with different letters are significantly different ($P \leq 0.05$). In comparisons between fall moisture regimes, subsequent-year yield was lower in plots receiving ambient moisture than in those receiving supplemental water, except those experiencing 80% defoliation in late May. Standard errors ranged from 15 to 56 under the ambient moisture regime and from 115 to 249 under the supplemental moisture regime. The study was located 21 km north of Potter, Nebraska.

Supplemental main plots was 16% below average during 2002 and 22% above average during 2003 (Fig. 1).

Many graminoid species are particularly susceptible to defoliation during their respective periods of rapid growth (Pearson 1964; Reece et al. 2007a). In the northern and central Great Plains, the period of rapid growth of cool-season graminoids typically occurs during April through June, which overlaps with the timing of our defoliation treatments. During 2002, precipitation was 73% below average during this critical period, providing an additional stress. In contrast, April–June precipitation was 18% below average during 2003 and 5% above average during 2004.

Needle-and-Thread

Spring-Only Defoliation. The response of needle-and-thread to defoliation was influenced by moisture conditions during the treatment year. Subsequent-year yield varied with spring defoliation treatment under the drought conditions of 2002 ($P_{\text{Spring/Ambient}}=0.04$, $P_{\text{Spring/Supplemental}}=0.05$) (Fig. 2), but not under the average precipitation conditions of 2003 ($P_{\text{Spring/Ambient}}=0.58$, $P_{\text{Spring/Supplemental}}=0.33$) (data not shown). Among Spring/Ambient main plots, subsequent-year yield was less for plots receiving 80% defoliation in June than for nondefoliated plots and all other spring defoliation treatments (Fig. 2). Among Spring/Supplemental main plots, subsequent-year yield was less for plots receiving 80% defoliation in late May than for nondefoliated plots and those receiving 80% defoliation in early May (Fig. 2). Fall moisture regime influenced the response to defoliation under the drought conditions of 2002 ($P=0.03$). Subsequent-year yield in ambient plots was lower than in plots receiving supplemental water, except in those plots experiencing 80% defoliation in late May (Fig. 2).

Spring and Fall Defoliation. Needle-and-thread yield was influenced by moisture conditions during the treatment year. Subsequent-year yield varied with spring defoliation treatment under drought conditions ($P_{2002}=0.02$) (Fig. 3), but not under average precipitation conditions ($P_{2003}=0.85$) (data not shown). Under drought conditions, subsequent-year yield was less for plots receiving 80% defoliation in late May than for

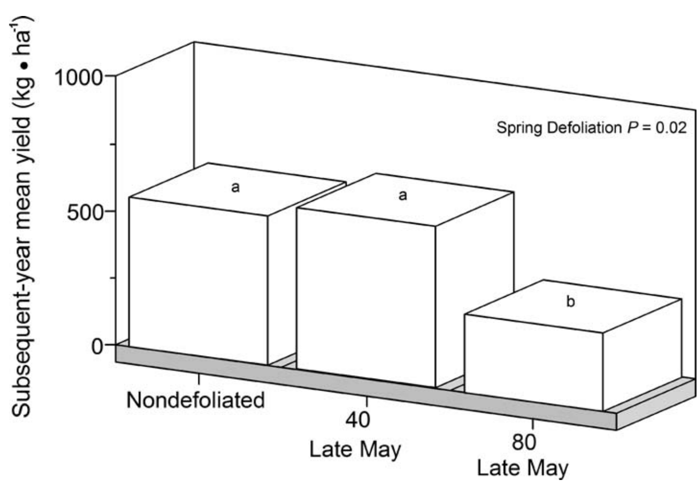

Figure 3. Subsequent-year yield (kg · ha^{-1}) of needle-and-thread in response to three levels of spring defoliation. Spring and fall defoliation treatments were applied during the same growing season in 2002. Columns with different letters are significantly different ($P \leq 0.05$). Standard errors ranged from 62 to 82. The study was located 21 km north of Potter, Nebraska.

nondefoliated plots or those receiving 40% defoliation in late May. Fall defoliation did not affect subsequent-year yield of needle-and-thread (P_{2002}=0.74, P_{2003}=0.29) and spring defoliation did not increase the likelihood of fall defoliation effects (P_{2002}=0.66, P_{2003}=0.45).

Threadleaf Sedge

Spring-Only Defoliation. In contrast to needle-and-thread, subsequent-year yield of threadleaf sedge did not vary with spring defoliation treatment ($P_{2002\ Spring/Ambient}$=0.38, $P_{2002\ Spring/Supplemental}$=0.21, $P_{2003\ Spring/Ambient}$=0.28, $P_{2003\ Spring/Supplemental}$=0.29) (data not shown). Although drought conditions prevailed during 2002, subsequent-year yield of threadleaf sedge did not differ between the ambient and supplemental moisture regimes (P_{2002}=0.27) (data not shown). Interestingly, yield of threadleaf sedge (mean=400 $kg \cdot ha^{-1}$, SE=18) exceeded that of needle-and-thread (mean=148 $kg \cdot ha^{-1}$, SE=14) following the season-long (summer and fall) drought conditions under the ambient fall moisture regime during 2002 ($P_{2002\ Spring/Ambient}$=0.02).

Spring and Fall Defoliation. Fall defoliation did not affect subsequent-year yield of threadleaf sedge (P_{2002}=0.10, P_{2003}=0.15) (data not shown). Spring defoliation did not affect subsequent-year yield of threadleaf sedge (P_{2002}=0.30, P_{2003}=0.66), nor did it increase the likelihood of fall defoliation effects (P_{2002}=0.30, P_{2003}=0.72).

DISCUSSION

The response of needle-and-thread was influenced by the amount of precipitation received during the growing season. Subsequent-year yield of needle-and-thread was not reduced by defoliation under average precipitation conditions; however, yield of needle-and-thread was reduced by heavy (80%) late-spring (late May or June) defoliation during a drought year. The latter is consistent with our hypothesis that defoliation effects would be greatest with later, heavier defoliation treatments. In contrast, we did not detect defoliation effects on subsequent-year herbage production of threadleaf sedge under either fall moisture regime.

Several studies have documented that sedges and cool-season grasses are susceptible to spring defoliation. Mid- to late-spring (May) grazing on upland Nebraska Sandhills range sites reduced yield of cool-season graminoids, including needle-and-thread and sedges, decreasing forage availability later in the season (Volesky et al. 2005). Similarly, Fassett (2003) reported that subsequent-year threadleaf sedge production during April, May, and June was lower in grazed (season-long) than in nongrazed plots in western Nebraska. Total current-year herbage production (Ganskopp 1988, 1998) and root mass (Ganskopp 1988) of Thurber needlegrass (*Achnatherum thurberiana* [Piper] Barkworth) was reduced by spring defoliation, particularly during the early boot stage. Wright (1967) observed a moderately severe reduction in subsequent-year yield of squirreltail (*Elymus elymoides* [Raf.] Swezey) and needle-and-thread following defoliation in late May or early June.

Fall defoliation effects on cool-season graminoids are less studied and rarely involve fall regrowth initiated with the return of favorable moisture conditions. Wright (1967) found that late-season clipping of dormant squirreltail mildly impacted subsequent-year yield, whereas defoliation of non-dormant needle-and-thread in July, August, and to a lesser degree late September, severely reduced yield. We did not detect any effects of fall defoliation on subsequent-year yield of either species. This is consistent with our hypothesis that the soil moisture needed to enable fall growth would reduce potential adverse effects of fall defoliation.

Needle-and-thread was more responsive to soil moisture levels than threadleaf sedge. Drought conditions alone had a greater impact on subsequent-year yield of needle-and-thread compared to threadleaf sedge under ambient conditions. In spite of its lower growth form, threadleaf sedge was more productive than needle-and-thread following the drought conditions of 2002. The addition of supplemental water partially alleviated drought conditions in 2002 and, with one exception, needle-and-thread responded with greater herbage production the following year, compared to ambient conditions. Among plots receiving supplemental moisture in 2002, plots with the lowest subsequent-year production of needle-and-thread (80% defoliation in late May) had some of the highest production of threadleaf sedge. Although not evaluated in this study, this finding suggests that interspecific competition may have been a factor in the response of these species, particularly under drought conditions. Stubbendieck and Foster (1978) found that threadleaf sedge yielded well when precipitation was below average, accounting for 86% and 80% of total herbage production when precipitation was 10% and 27% below average, respectively. Similarly, Olson et al. (1985) reported that basal area of needle-and-thread was directly related to the amount of precipitation, whereas threadleaf sedge responded well under extreme or fluctuating precipitation conditions.

Contrasting responses of threadleaf sedge and needle-and-thread to defoliation may reflect differences in phenology and life history. Threadleaf sedge is very cold tolerant and initiates growth much earlier than needle-and-thread. Pollination typically begins in March and ends in April. Thus, most seedhead production likely occurred before the spring defoliation treatments were applied. Needle-and-thread develops later than threadleaf sedge. The boot stage typically occurs during the first three weeks of May. During the boot stage, the growing point elevates and becomes susceptible to removal, particularly during late May. Defoliation in June limits the time available for plants to recover prior to senescence. During this study, most cool-season graminoids entered summer dormancy by the end of June under the drought conditions of 2002 and by late July under the average conditions of 2003 (Whisenhunt 2006). Fall growth did not occur in either species under ambient conditions in either treatment year (Whisenhunt 2006).

Whether drought breaks in the fall or the following spring has management implications for needle-and-thread. During 2002, the application of 10 cm of water to supplemental-water main plots in mid-August was enough to break the drought and stimulate fall growth after summer senescence (though total moisture was still 16% below average). In contrast, ambient main plots experienced season-long drought. With average precipitation during the following growing season, plots previously receiving favorable fall moisture (supplemental moisture regime) generally had relatively high yields, whereas ambient plots had greatly reduced yields. This suggests that limited grazing of needle-and-thread may be possible the following spring if drought breaks in the fall, but not if drought continues throughout the growing season.

It is important to remember that these results reflect the impact of a single year of defoliation followed by average precipitation during the subsequent growing season. How these species would respond to consecutive years of spring and/or fall defoliation or to drought conditions during the subsequent year is unknown. Given the importance of treatment-year precipitation patterns during this study, we suspect that the effect of defoliation treatments would have been more severe under subsequent-year drought.

IMPLICATIONS

On semiarid rangelands, ranchers often consider fall growth of cool-season species to be a windfall nutrient resource for livestock and wildlife. Our results suggest fall growth can be grazed at moderate to heavy levels in a single year without reducing subsequent-year yield of needle-and-thread and threadleaf sedge if average precipitation occurs during the growing season. Fall growth could be grazed in spring-deferred pastures during a drought year, though not at heavy (80%) rates of defoliation.

Reductions in subsequent-year yield of needle-and-thread following season-long drought suggests a need for conservative grazing of needle-and-thread–dominated pastures the year after drought. However, if drought is broken by late-season precipitation, there would be less concern the following year, though heavy spring defoliation during the drought year may limit subsequent-year herbage production. Monitoring average levels of defoliation after spring grazing may provide some indication of subsequent-year herbage production potential. Because it is difficult to predict when drought will occur, and drought may not become evident until after pastures have been grazed, it would be prudent to avoid heavy late-spring grazing in needle-and-thread–dominated pastures in consecutive years. In addition to conservative use, flexible grazing strategies are important to adapt to growing conditions.

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LITERATURE CITED

BURLESON, W. H., AND G. B. HEWITT. 1982. Response of needle-and-thread and western wheatgrass to defoliation by grasshoppers. *Journal of Range Management* 35:223–226.

COUPLAND, R. T. 1992. Mixed prairie. *In*: R. T. Coupland [ED.]. Ecosystems of the world 8A: natural grasslands, introduction and Western Hemisphere. New York, NY, USA: Elsevier. p. 151–182.

EPSTEIN, H. E., W. K. LAUENROTH, I. C. BURKE, AND D. P. COFFIN. 1997. Productivity patterns of C_3 and C_4 functional types in the U.S. Great Plains. *Ecology* 78:722–731.

EPSTEIN, H. E., W. K. LAUENROTH, I. C. BURKE, AND D. P. COFFIN. 1998. Regional productivities of plant species in the Great Plains of the United States. *Plant Ecology* 134:173–195.

FASSETT, J. A. 2003. Seed production, herbage yield, and quality of *Carex filifolia* [thesis]. Lincoln, NE, USA: University of Nebraska. 58 p.

GANSKOPP, D. 1988. Defoliation of Thurber needlegrass: herbage and root responses. *Journal of Range Management* 41:472–476.

GANSKOPP, D. 1998. Thurber needlegrass: seasonal defoliation effects on forage quantity and quality. *Journal of Range Management* 51:276–281.

HIGH PLAINS REGIONAL CLIMATE CENTER. 2004. Classic online services. Available at: http://www.hprcc.unl.edu/services. Accessed 26 October 2004.

NORTHUP, B. K. 1993. Utilization of native forages of the Nebraska Sandhills by yearling cattle [dissertation]. Lincoln, NE, USA: University of Nebraska. 328 p.

OLSON, K. C., R. S. WHITE, AND B. W. SINDELAR. 1985. Response of vegetation of the northern Great Plains to precipitation amount and grazing intensity. *Journal of Range Management* 38:357–361.

PEARSON, L. C. 1964. Effect of harvest date on recovery of range grasses and shrubs. *Agronomy Journal* 56:80–82.

PETERSON, R. A. 1962. Factors affecting resistance to heavy grazing in needle-and-thread grass. *Journal of Range Management* 15:183–189.

REECE, P. E., A. E. KOEHLER, W. D. WHISENHUNT, J. D. VOLESKY, AND W. H. SCHACHT. 2007b. A passive application watering system for rangeland plots. *Rangeland Ecology & Management* 60:203–207.

REECE, P. E., J. E. BRUMMER, R. K. ENGEL, B. K. NORTHUP, AND J. T. NICHOLS. 1996. Grazing date and frequency effects on prairie sandreed and sand bluestem. *Journal of Range Management* 49:112–116.

REECE, P. E., R. P. BODE, AND S. S. WALLER. 1988. Vigor of needle-and-thread and blue grama after short duration grazing. *Journal of Range Management* 41:287–291.

REECE, P. E., W. H. SCHACHT, AND J. D. VOLESKY. 2007a. Skillful grazing management on semiarid rangelands. Lincoln, NE, USA: University of Nebraska–Lincoln, Extension Circular EC162. 8 p.

SAS INSTITUTE. 2007. SAS® OnlineDoc, 9.1.3 release. Cary, NC, USA: SAS Institute, Inc. Available at: http://support.sas.com/onlinedoc/913/docMainpage.jsp?_topic=statug.hlp/intro_index.htm. Accessed 22 June 2013.

STUBBENDIECK, J., AND M. A. FOSTER. 1978. Herbage yield and quality of threadleaf sedge. *Journal of Range Management* 31:290–292.

[USDA-NRCS] UNITED STATES DEPARTMENT OF AGRICULTURE, NATURAL RESOURCE CONSERVATION SERVICE. 2012. The PLANTS database. Available at: http://plants.usda.gov. Accessed 4 October 2012.

TRLICA, M. J., M. BUWAI, AND J. W. MENKE. 1977. Effects of rest following defoliations on the recovery of several range species. *Journal of Range Management* 30:21–27.

VOLESKY, J. D., W. H. SCHACHT, P. E. REECE, AND T. J. VAUGHN. 2005. Spring growth and use of cool-season graminoids in the Nebraska Sandhills. *Rangeland Ecology & Management* 58:385–392.

WEAVER, J. E., AND F. W. ALBERTSON. 1956. Grasslands of the Great Plains. Lincoln, NE, USA: Johnsen Publishing Company. 395 p.

WHISENHUNT, W. D. 2006. Subsequent-year yield of mixed-grass prairie as affected by defoliation and precipitation [thesis]. Lincoln, NE, USA: University of Nebraska. 57 p.

WRIGHT, H. A. 1967. Contrasting responses of squirreltail and needle-and-thread to herbage removal. *Journal of Range Management* 20:398–400.