Can Abundant Summer Precipitation Counter Losses in Herbage Production Caused by Spring Drought?

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Abstract

Drought is an inherent trait of most rangelands and sound management necessitates managers address two fundamental questions when facing a drought situation. The first question is, “what is the probability that a useful amount of precipitation will be received over the period of concern?” and the second question is, “if it does rain, what will the impact be in terms of quantity and quality of herbage produced?” The objective of this study was to address the second question. Our hypothesis was that herbage growth response to above normal summer precipitation (i.e., 2\times in July and August) would be limited in the northern Great Plains because of a general absence of productive warm-season species. Study plots were twelve 5 \times 10-m non-weighing lysimeters. Treatments were: 1) simulated (i.e., rainout shelter imposed), severe spring drought (i.e., 1 May – 1 July) followed by ambient precipitation thereafter; 2) simulated, severe spring drought followed by ambient precipitation thereafter plus summer irrigation (i.e., July and August); 3) ambient precipitation only; and 4) ambient precipitation plus summer irrigation. Results indicated substantial herbage production can be expected in this region during summer when precipitation is well above average because of the positive growth response of blue grama (\textit{Bouteloua gracilis} [H.B.K.] Lag. ex Griffiths), the dominant warm-season grass growing in this region. However, results also showed that level of production in the study situation (i.e., spring drought, wet summer) was only about 50\% of that attained in a normal (i.e., wet spring/dry summer) year. Moreover, long-term weather data shows the probability of receiving 2\times normal precipitation in both July and August (i.e., our irrigation treatments) is < 1\%. Thus, although these rangelands possess the capacity to respond favorably to summer precipitation, the low probability of receiving substantial levels of summer precipitation ensures levels of ecological and economic risk remain high.

Key Words: drought management, forage quality, grassland, primary production, northern Great Plains, soil water, species composition

Resumen

La sequía es una característica inherente de la mayoría de los pastizales y un manejo sensible requiere de que los maneajadores aborden dos cuestiones fundamentales cuando encaran una situación de sequía. La primer cuestión es: “¿cuál es la probabilidad de que una cantidad útil de precipitación sea recibida durante el periodo de preocupación?” y la segunda es: “si llueve, ¿cuál será el impacto en términos de cantidad y calidad del forraje producido?” El objetivo de este estudio fue abordar la segunda cuestión. Nuestra hipótesis fue que el crecimiento de forraje en respuesta a precipitaciones arriba de lo normal en verano (esto es, 2 veces mayor en Julio y Agosto) estaría limitado, en las Grandes Planicies del Norte, por una ausencia general de especies productivas de estación caliente. Las parcelas de estudio fueron lisímetros de no peso de 5 \times 10 m. Los tratamientos evaluados fueron: 1) sequía severa simulada (con protectores de precipitación) en primavera (del 1 de Mayo al 1 de Julio), seguida por un ambiente de precipitación; 2) sequía severa simulada en primavera seguida por un ambiente de precipitación más irrigación en verano (en Julio y Agosto); 3) ambiente de precipitación solamente y 4) ambiente de precipitación más irrigación. Los resultados indican que, en esta región, durante el verano se puede esperar una producción substancial de forraje cuando la precipitación es arriba de lo normal debido a la respuesta positiva de crecimiento del “Blue grama” (\textit{Bouteloua gracilis} [H.B.K.] Lag. Ex Griffiths), el zcate dominante de estación caliente de esta región. Sin embargo, los resultados también mostraron que el nivel de producción en la situación de estudio (es decir primavera con seca y verano húmedo) fue solo aproximadamente 50\% de la obtenida en un año normal (primavera húmeda/veano seco). Más aún, los datos de clima de largo plazo muestran que la probabilidad de recibir 2 veces la precipitación normal en Julio y Agosto (esto es nuestros tratamientos de irrigación) es < 1\%. Así, aunque estos pastizales poseen la capacidad de responder favorablemente a la precipitación de verano, la baja probabilidad de recibir niveles substanciales de precipitación en verano asegura que los niveles de riesgo ecológico y económico permanezcan altos.

Key Words: sequía, pastizales, verano, producción, manejo, forraje, calidad, variedades, granjas, ecología, norte, norteamérica, agua, especies, composición.

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INTRODUCTION

Drought is an inherent trait of most rangelands, and therefore, effective rangeland management must include drought management strategies that minimize ecological and economic risks. But because most rangeland managers are eternal optimists when it comes to rainfall expectations, they often fail to respond to drought in a timely manner, and as such, they often expose themselves to unnecessary risks (Riechers et al. 1989; Holechek 1996; Thurow and Taylor 1999).

There are two fundamental questions rangeland managers need to address when in a drought situation. The first is, “what is the probability that an effective amount of precipitation will be received in the immediate future?” The reason this is a fundamental question is because of the obvious positive linkage between precipitation and herbage production (Sala and Lauenroth 1982, Sala et al. 1988, Mcauliffe 2003, Neilson 2003). Ready access to site, season, and amount specific precipitation probabilities based on long-term weather records (e.g., see http://www.hprcc.unl.edu/wrcc/states/mt.html) provides managers with critical information for improving drought management decisions. But in addition to this information, research throughout the northern Plains region has shown also that herbage production is driven largely by spring precipitation (Sims et al. 1978; Sims and Singh 1978a, 1978b; Singh et al. 1982). More specifically, research at Miles City has shown that 91% ± 16 SD of annual perennial grass production is normally produced by July 1 (Heitschmidt and Vermeire 2005). Thus, we believe that by combining this information with precipitation probability information, regional rangeland management personnel can initiate effective drought management tactics in early July with considerable confidence if the situation so dictates.

But even so, only a limited number of rangeland managers in this region will choose to implement drought management tactics in early July because, “it may rain next week, and if it does . . . .” So the second question is, “if it does rain, what will the impact be on current year’s herbage production?” The answer to this question is key for developing effective drought management strategies across most rangelands because: 1) most rangelands are either arid or semi-arid (i.e., seasonal drought is “normal”); and 2) optimism reigns when considering the probability of receiving significant, fruitful precipitation in the not-too-distant future. The specific objective of this research was to address the second question relative to the northern Great Plains region. Our hypothesis was that the summer production capacity of these grasslands, following spring drought, would be quite limited because of a general absence of productive warm-season perennial grasses. In addition, we hypothesized that quality of forage (i.e., nitrogen content) would vary in direct proportion to the relative amounts of live and dead tissue which in turn would vary largely as a function of precipitation regimen.

METHODS

Study Area

Research was conducted during the 2004 growing season at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, MT (lat 46°22'N, long 105°5'W, elev. 725 m). Regional topography ranges from rolling hills to broken badlands with small intersecting streams that seasonally drain into large permanent rivers meandering through broad, nearly level valleys. The potential natural vegetation on the 22,500-ha station is a grama-needlegrass-wheatgrass (Bouteloua- lonia-Stipa-Agropyron) mixed grass dominant (Küchler 1964). Long-term annual precipitation averages 340 mm with about 60% received during the 150-day, mid-April to mid-September growing season (Fig. 1). Average daily temperatures range from −10°C in January to 24°C in July with daily maximum temperatures occasionally exceeding 37°C during summer and daily minimums occasionally dropping below −40°C during winter.

Study Plots and Treatments

Study plots were 12, 5 × 10-m non-weighing lysimeters constructed in 1992 on a gently sloping (4%) clayey range site (USDA 2003). Soils were Kobase silty clay loam, fine, montmorillonitic, frigid, Aridic Ustochrepts. Lysimeters were arranged perpendicular to the slope along a 65-m transect in two groups of six lysimeters each with a 5-m area between groups. They were created by filling 12-cm wide by 2-m deep perimeter trenches and associated 15-cm tall wooden foundations, with urethane foam insulation. Each lysimeter was equipped with two soil water monitoring access tubes centrally positioned in the upper and lower half of each lysimeter.

An automated rainout shelter was used to develop spring drought conditions, a pre-requisite for the successful conduct of this study, since normal to above normal herbage production during spring would curtail interest and reliance on herbage production during summer. Drought conditions were developed by controlling the amount of precipitation received on six of the 12 lysimeters (Larson et al. 1993). The 12- × 35-m metal-framed “roof” was mounted on 15-cm diameter plastic wheels atop seven 5-cm wide rails extending about 75 cm above the soil surface. Rails extended from top edge (i.e., upslope) to about 15 m below the bottom edge of the lysimeters. Rails were located directly over lysimeter borders. The shelter was equipped with a moisture sensitive conductance plate that when wetted, activated an electric motor and its associated drive system, which moved the shelter across the plots. For a more detailed description of the physical layout of the rainout shelter and lysimeters, see Heitschmidt et al. (1999, 2005).

Randomly assigned, thrice replicated treatments were: 1) simulated spring drought (i.e., no precipitation from 1 May to 1 July) followed by ambient conditions until end of growing season (i.e., 1 October) hereafter referred to as SDNI wherein SD = simulated, severe spring drought, N = no, and I = irrigation; 2) simulated spring drought plus supplemental water during summer (July and August) followed by ambient conditions until end of growing season (SDI); 3) ambient conditions throughout year, hereafter referred to as MDNI wherein MD = moderate drought because ambient precipitation (Fig. 1) during the study resulted in a moderate drought; and 4) ambient conditions during spring and fall plus supplemental water in July and August (MDI).
Irrigated plots were watered in mid- and late July and August 2004. Water was from the Miles City municipal water supply and was applied evenly across plots using a garden hose delivery system and a hand held nozzle. During each of the four irrigation events, 38 mm (1.5") of water was applied resulting in the addition of 76 mm (3.0") during both July and August (i.e., 152 mm total irrigation). This amount is about 225% of the 69-year average precipitation amounts for July (40.4 mm) and August (28.4 mm) and 275% of the 69-year median precipitation for July (32.8 mm) and August (22.6 mm). Rate of application was about 25 mm/hr. Within each event, four applications were made, three late afternoon of the same day and one early the next morning, with each application lasting about 25 minutes, the time required to fully saturate surface soils.

Study plots were located inside a 30-ha enclosure that had not been grazed by livestock since 1988. However, the study plots per se had been grazed infrequently by sheep over the last 11 years depending upon previous research protocols (Heitschmidt et al. 1999, 2005). Study plots were not grazed in this experiment.

Sampling Procedures
Precipitation was monitored on site using three standard rain gauges. Soil water was measured a minimum of once per month from April to October and immediately before and after each irrigation event. Estimates were obtained at depths of 15, 30, 60, and 90 cm using a fully calibrated, dielectric soil water probe (Troxler Sentry 200 AP).

Aboveground standing crop was measured monthly May through October by clipping 10, 250-cm² circular quadrats per lysimeter. Five quadrats each were located randomly along two randomly located transects, one in the up-slope half of the lysimeter and the other in the down-slope half. Permanent records of quadrat locations were used to insure no repeat clipping of any quadrat during the year. Before harvesting standing crops, visual estimates of relative abundance (i.e., abundant, common, or sparse) were assigned to all species within each quadrat. Only the most abundant species were clipped individually with most species combined into functionally similar groups. Species and species groups were: western wheatgrass (Pascopyrum smithii Rydb. [Love]); needle-and-thread grass (Hesperostipa comata [Trin. & Rupr.] Barkworth); warm-season perennial shortgrasses, which was dominated by blue grama (Bouteloua gracilis [H. B. K.] Lag. ex Griffiths) with a scattering of buffalograss (Buchloe dactyloides [Nutt.] Engelm.); other warm-season perennial grasses, of which sand dropseed (Sporobolus cryptandrus [Torr.] A. Gray) and tumblegrass (Schedonnardus paniculatus [Nutt.] Trel.) were the dominant species; Bromus spp., which was principally Japanese brome (Bromus japonicus Thunb. ex Murr.) with a small amount of downy brome (Bromus tectorum L.); other cool-season perennial grasses, of which Sandberg's bluegrass (Poa sandbergii Vasey) was dominant; other cool-season annual grasses, of which sixweeks fescue (Vulpia octoflora [Walt.] Rydb.) and little barley (Hordeum pusillum Nutt.) were dominant, and forbs. Herbage was dried at 60°C for a minimum of 48 hours before weighing. Amounts of live (i.e., green) and dead (i.e., brown) tissue were estimated by hand separation.

Total nitrogen content was estimated by tissue class (i.e., live [green] and dead [brown]) for both western wheatgrass and the pool of warm-season perennial shortgrasses which was dominated by blue grama. Because amounts of harvested herbage within a treatment replication (i.e., lysimeter) were frequently insufficient to conduct C-N laboratory analyses, like samples were pooled across replicates within treatments and dates prior to analyses. Total nitrogen content was determined using a C-N analyzer (Carlo-Erba, C. E. Elantech, Inc., Lakewood, NJ) following grinding to pass through a 1-mm Wiley Mill screen.

Data Analyses
Herbage aboveground net primary production (ANPP) was estimated by summing increases in live herbage within four functional groups: 1) cool-season perennial grasses (CSPG); 2)
cool-season annual grasses (CSAG); 3) warm-season perennial grasses (WSPG); and 4) forbs (FORB). Total production was estimated by summing functional group estimates. Proportional live and dead standing crops were multiplied by live and dead %N, then summed and multiplied by 6.25 to estimate whole plant crude protein (%CP) by replicate.

Data were statistically analyzed using SAS MIXED analysis of variance procedures (Littell et al. 1996). The complete randomized design, repeated measures models included the main effects of water treatment (fixed) and date (random) and their interaction. All data sets were analyzed for normality using the Shapiro-Wilk test. Data sets identified as not normally distributed were FORB primary productivity estimates, soil water at all four (i.e., 15, 30, 60, and 90 cm) depths, and all three (live, dead, and total) standing crop data sets. All non-normal distribution data sets were log-transformed for analyses, but are presented as arithmetic means to facilitate interpretation. Significant interactions were followed by tests of simple effects at $P \leq 0.05$. In addition, PROC GLM regression procedures were used to identify relationships between whole plant %CP (dependent variable) and live/dead ratios (independent variable) (SAS 1990).

**RESULTS**

**Precipitation and Soil Water**

Ambient precipitation throughout this study was 42% below average with a total of 197 mm received during the 12-month period from October 2003 to September 2004 as compared to the long-term average of 340 mm (Fig. 1). Monthly precipitation was at or above average for only 3 months (i.e., October and December 2003, September 2004) during the entire year and below average the remaining 9 months. Even with the 76.2 mm of supplemental water applied in July and August to the SDI and MDI treatments (i.e., SDI = 284 mm, MDI = 324 mm), total water (i.e., precipitation + irrigation) during the study year remained below the long-term average.

Soil water dynamics were closely tied to the various precipitation regimens (Fig. 2). Soil water content at the 15-cm depth steadily declined, regardless of treatment, until mid-July when the first 39 mm of water were applied to the SDI and MDI treatments. Post-irrigation soil water percolation rates tended to be greater in the SDI than MDI treatment as reflected by the greater amounts of soil water present at the 15-cm depth the day after irrigation and by the greater amounts that eventually percolated through to the 30-cm depth. The reasons for this difference were unclear, but we suspect evapotranspiration (ET) rates may have been greater in the MDI than SDI treatment since it had greater amounts of live, actively growing biomass until late August (Fig. 3).

Depletion rates during spring at the 30-cm depth followed the same pattern as at the 15-cm depth although there were some differences ($P < 0.05$) among treatments in soil water content early in the spring. Soil water increases following the mid-July irrigation were neither as dramatic nor as rapid at the 30-cm depth as at the 15-cm depth. There were no significant ($P > 0.12$) differences among treatments in soil water content at the 60- and 90-cm depths. There were significant ($P < 0.01$) date effects at both depths as slight increases in soil water were noted as the growing season progressed and supplemental irrigation was begun in mid-July, but neither the 60- nor 90-cm treatment-by-date interaction effect was significant ($P > 0.20$).

**Aboveground Herbage Dynamics**

Herbage dynamics clearly reflected anticipated treatment effects relative to amounts of live, dead, and total herbage (Fig. 3). Total herbage remained near constant in the severe drought treatments (SDNI and SDI) during spring and was dominated by dead material. This was in contrast to the moderate drought treatments (MDNI and MDI) wherein total herbage increased with the production of live herbage. During summer and early autumn, total herbage in the non-irrigated treatments (SDNI and MDNI) decreased and was dominated by dead material. This is in contrast to the irrigated treatments (SDI and MDI) wherein total herbage increased with the production of live material.

**Aboveground Net Primary Production**

The severe, season-long drought conditions simulated in the SDNI treatment severely limited aboveground net primary production (ANPP) with total ANPP being 267 kg·ha$^{-1}$ which was significantly ($P = 0.049$) less than the average of 892...
kg·ha⁻¹ for the SDI, MDNI, and MDI treatments (Fig. 4). Differences in total ANPP were the result of varying functional group responses to the differing precipitation regimens in that summer irrigation (SDI and MDI) significantly (P < 0.01) increased WSPG of which blue grama was the overwhelming dominant. The other significant difference was in FORB production wherein severe spring drought (SDNI and SDI) significantly suppressed production (P < 0.03), particularly that of the dominant species wooly plaintain (*Plantago patagonica* Jacq.). There were no significant (P > 0.05) differences among treatments in either CSPG or CSAG production.

**Herbage Quality**

Whole-plant western wheatgrass %CP estimates varied significantly (P < 0.02) by treatment, date and their interaction. Temporal trends (Fig. 5) closely followed community level changes in amounts of live and dead tissue (Fig. 3) with average %CP being least during spring in the severe drought treatments (SDNI and SDI) when dead tissue was dominate and greatest in summer in the irrigated treatments (SDI and MDI) when live tissue was dominant. A notable exception to this generalization was the greater than expected %CP estimate for June in the SDI treatment. Close examination of this data point revealed estimated CP concentrations for both live and dead tissue were slightly greater in the SDI than SDNI treatment as were estimates for live:dead ratios. But when these non-significant (P > 0.05) differences were combined to estimate whole plant %CP, a significant (P < 0.05) difference emerged. As expected, the correlation between whole plant %CP and live:dead estimates was significant (P < 0.01, r = 0.33, n = 68). However, the rather low r² value (0.11) indicated that factor(s) other than “greenness” were also affecting %CP estimates.

Whole plant %CP analyses of the pool of warm-season perennial shortgrasses also varied (P < 0.01) by treatment, date, and their interaction effect, and as with western wheatgrass, treatment effects (Fig. 5) mimicked the effects of community level changes in amounts of live and dead tissue (Fig. 3). The resulting effect was that temporal trends tended to mimic those for western wheatgrass except during fall when estimated %CP was greater in the non-irrigated (SDNI and MDNI) than irrigated treatments (SDI and MDI). The reason for this was because October %CP estimates for both live and dead tissue were substantially greater in the non-irrigated than irrigated treatments (live = 20.8% vs. 10.8%, dead = 10.0% vs. 8.0%). We assume this was because the average age of these tissues, particularly the live tissue, was substantially less in the non-irrigated than irrigated treatments. Evidence in support of this explanation is that live tissue standing crop increased in the non-irrigated treatments 55% from early September to early October whereas it declined 47% in the irrigated treatments. In addition, if it is assumed that September precipitation (Fig. 2) spurred equal amounts of growth in all treatments, then it can be reasoned that the greater quality in the non-irrigated treatments was because the small amount of young, high quality, perennial shortgrass tissue added to the small pool of older, live tissue present in the non-irrigated treatments 55% from early September to early October whereas it declined 47% in the irrigated treatments. In addition, if it is assumed that September precipitation (Fig. 2) spurred equal amounts of growth in all treatments, then it can be reasoned that the greater quality in the non-irrigated treatments was because the small amount of young, high quality, perennial shortgrass tissue added to the small pool of older, live tissue present in the non-irrigated treatments 55% from early September to early October whereas it declined 47% in the irrigated treatments.
Similar until supplemental water was added in July and August whereafter both soil water content and herbage production increased significantly in the irrigated treatments (SDI and MDI); and 2) total ANPP was similar among treatments except for the significantly greater amount of warm-season perennial grass production in the irrigated treatments than non-irrigated treatments (Fig. 4). However, the magnitude of differences in warm-season perennial grass production between the simulated severe drought treatments was considerably greater than the magnitude of differences between the moderate drought treatments (Fig. 4). For example, in the moderate drought treatments, irrigation increased warm-season perennial grass production by 251% (176 vs. 443 kg·ha⁻¹) whereas in the severe drought treatments, irrigation increased production by 716% (79 vs. 566 kg·ha⁻¹).

We acknowledge that the severity of the simulated drought was extreme for the northern Great Plains. This is evidenced by: 1) there is > 90% chance that at least 5 mm of precipitation will be received at this location in each of the months of April, May, and June (http://www.hprcc.unl.edu/wrcc/states/mt.html); and 2) total herbage production in the SDNI was only 267 kg·ha⁻¹ or about 33% of total production in the MDNI treatment. Still, the response to summer irrigation was equivalent (P > 0.05) in the severe drought treatment (SDI) to that in the moderate drought treatment (MDI) in terms of both total production and functional group composition (Fig. 4). Presumably, this was because soil water in all treatments was near equal by July 1 (Fig. 2), thus insuring the occurrence of similar post-July 1 production responses to both ambient and supplemental water treatments.

An important question relative to these conclusions is, “do these grasslands have the capacity to produce herbage during summer in an amount equivalent to normal spring production?” To address this question, we examined 8 years of herbage production data from non-manipulated control plots used in previous studies conducted within these same study plots (Heitschmidt et al. 1999, 2005). Estimated ANPP for those 8 years averaged 2072 kg·ha⁻¹ with an average composition of 55% cool-season perennial grasses (1140 kg·ha⁻¹), 25% warm-season perennial grasses (520 kg·ha⁻¹), 10% cool-season annual grasses (207 kg·ha⁻¹), and 10% forbs (207 kg·ha⁻¹). This is in contrast to the current study wherein estimated ANPP for the moderate drought, irrigated treatment (MDI) was 984 kg·ha⁻¹ with a compositional mix of 28% cool-season perennial grasses (273 kg·ha⁻¹), 46% warm-season perennial grasses (443 kg·ha⁻¹), 10% cool-season annual grasses (92 kg·ha⁻¹), and 16% forbs (156 kg·ha⁻¹). Thus, it appears that ample summer precipitation will not enhance annual production to a level that fully off-sets production losses resulting from spring drought. In fact, it is rather surprising that warm-season perennial grass production with ample summer precipitation was essentially the same (443 vs. 520 kg·ha⁻¹) as that in an average, non-drought year.

Although the results of this study are from one specific site, findings are applicable to a relatively broad region of the northern Great Plains. This is because much of the northern Great Plains is dominated by cool-season perennial grasses with an accompanying spring/early summer growing season and associated precipitation pattern (Küchler 1964; Sims et al.
Vermeire (2005) that about 90% of perennial grass production during a "normal" spring. We know from Heitschmidt and the quantity of herbage that would normally be produced. However, the capacity appears to be capped at about 50% of month growing season if growing conditions are favorable. Specifically, results from this study show these grasslands have considerable capacity to produce herbage throughout the 5-month growing season if growing conditions are favorable. However, the capacity appears to be capped at about 50% of the quantity of herbage that would normally be produced during a "normal" spring. We know from Heitschmidt and Vermeire (2005) that about 90% of perennial grass production is completed in this region by 1 July and that the probability of receiving substantial growing season precipitation after July 1 is low. Therefore, we believe ranchers and other rangeland managers can make critical stocking rate decisions in this region with confidence by early July thereby substantially reducing both ecological and economic risks during periods of drought.

LITERATURE CITED


MANAGEMENT IMPLICATIONS

The results of this study, in concert with the findings of Heitschmidt and Vermeire (2005), provide key information necessary to develop effective, proactive drought management strategies for a large region of the northern Great Plains. Specifically, results from this study show these grasslands have considerable capacity to produce herbage throughout the 5-month growing season if growing conditions are favorable. However, the capacity appears to be capped at about 50% of the quantity of herbage that would normally be produced during a "normal" spring. We know from Heitschmidt and Vermeire (2005) that about 90% of perennial grass production...


