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Critical decision dates for drought management in Central and Northern Great Plains rangelands

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Forum: Critical Decision Dates for Drought Management in Central and Northern Great Plains Rangelands☆

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ABSTRACT

Ranchers and other land managers of central and northern Great Plains rangelands face recurrent droughts that negatively influence economic returns and environmental resources for ranching enterprises. Accurately estimating annual forage production and initiating drought decision-making actions proactively early in the growing season are both critical to minimize financial losses and degradation to rangeland soil and plant resources. Long-term forage production data sets from Alberta, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming demonstrated that precipitation in April, May, and June (or some combination of these months) robustly predict annual forage production. Growth curves from clipping experiments and ecological site descriptions (ESDs) indicate that maximum monthly forage growth rates occur 1 mo after the best spring month (April to June) precipitation prediction variable. Key for rangeland managers is that the probability of receiving sufficient precipitation after 1 July to compensate for earlier spring precipitation deficits is extremely low. The complexity of human dimensions of drought decision-making necessitates that forage prediction tools account for uncertainty in matching animal demand to forage availability, and that continued advancements in remote sensing applications address both spatial and temporal relationships in forage production to inform critical decision dates for drought management in these rangeland ecosystems.

Introduction

Predicting forage production for the upcoming growing season is an important aspect of rangeland and pasture management, specifically for proactive and adaptive grazing management decisions (Derner and Augustine 2016; Kelley et al. 2016). Climatic variability in intrinsically high interannual and intra-annual variable environments with substantial spatial variability in precipitation (Augustine 2010) magnifies rancher vulnerability to

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matching animal demand to forage availability (Eakin and Conley 2002; Scasta et al. 2015) and impacts economic returns (Bastain et al. 2012; Hamilton et al. 2016; Irisarri et al. 2019). Drought occurs about 30% of the time in the northern Great Plains (Smart et al. 2005). During drought, livestock producers are concerned with 1) having adequate forage for grazing livestock and hay harvest, 2) stockpiling forage for late fall/winter grazing, and 3) the persistence of current drought effects into the next growing season (Kachergis et al. 2014). These concerns emphasize the complexity of human dimensions of drought decision making (Wilmer and Fernández-Giménez 2015). This paper is a synthesis by rangeland management extension specialists and researchers attending a drought management symposium at the 72nd annual meeting of the Society for Range Management. We collected published, long-term forage production data sets from Alberta, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Wyoming (Fig. 1 and Table 1) to demonstrate a broad, regional understanding of spring precipitation relationships to annual forage production, accumulated monthly forage growth (growth curves), and the significance and probability of relying on summer rainfall to compensate for spring drought in the central and northern Great Plains.

Precipitation Drives Forage Production

Precipitation is the primary driver of plant growth and soil moisture (Engda et al. 2016) and is typically the first limiting factor for forage growth in most grassland ecosystems of North America (Lauenroth and Sala 1992; Khumalo and Holechek 2005), including the Great Plains (Mowll et al. 2015). Additional factors, such as plant community (Smart et al. 2007; Derner et al. 2008), prior grazing history (stocking rate) (Launchbaugh 1967; Derner et al. 2007; Irisarri et al. 2016), time of grazing (Reece et al. 1996; Stephenson et al. 2015), topoedaphic position (Bork et al. 2001; Nippert et al. 2011; Stephenson et al. 2019), prior year precipitation (Petrie et al. 2018), and sea surface temperature anomalies (Chen et al. 2017) all have effects on forage production. For managers to make adaptive grazing management decisions for the upcoming grazing season, they need forage production predictions now available such as Grass-Cast (Peck et al. 2019) and remote sensing applications to handle both spatial and temporal relationships (Hermance et al. 2015; Gaffney et al. 2018); this information will assist managers in decision making related to drought (Dunn et al. 2005).

Substantial precipitation and temperature gradients exist in the Great Plains (Lauenroth et al. 1994). Precipitation increases more than threefold from west to east (Burke et al. 1991; Anadón et al. 2014), and temperature increases from the northwest to the southeast (Epstein et al. 1996). Forage production increases nearly fourfold west to east (Heisler-White et al. 2009) due to precipitation (Lane et al. 1998) rather than with the temperature gradient (Epstein et al. 1996; Mowll et al. 2015).

In contrast to the precipitation-driven, large-scale, west-to-east influence on forage production (see earlier), smaller-scale (ranch-to county-level) forage production patterns are driven by soil water holding capacity (Sala et al. 1988), which combines local precipitation and soil characteristics. Foundational studies (Albertson and Weaver 1944; Dahl 1963) established this relationship at the smaller scales across several sites in the central Great Plains.

Precipitation and Plant Community Relationships

Growing season temperature and precipitation in the shortgrass prairie ecoregion have considerable overlap (Fig. 2), so forage production is robustly predicted using May–June precipitation (see Table 1). Seasonal distributions of precipitation and temperature have greater overlap in the mixed-grass prairie (see Figs. 2 and 3), with forage production predicted well by April–June precipitation across multiple locations in the northern and central Great Plains (see Table 1). The greater abundance of warm-season grasses in the tallgrass prairie shifts the influential months of precipitation to May–July for accurately predicting forage production (see Table 1).

Forage production of seeded perennial grasses and native rangeland vegetation display similar responses to seasonal precipitation. Variation in April and May precipitation explained > 90% of the variation in forage production of several seeded switchgrass (*Panicum virgatum* [L.]) cultivars, a native warm-season grass, in central South Dakota (Lee and Boe 2005). In eastern Montana, forage production of Russian wildrye (*Psathyrostachys juncea* [Fisch.] Nevski]), a non-native cool-season grass, was correlated with May and June precipitation (White 1985). Similar results were observed for the cool-season, non-native crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.) in Colorado (Currie and Peterson 1966).

Climate change projections to 2050 have indicated that climate may trend greater temperatures, greater winter precipitation, and increased variability in growing season precipitation

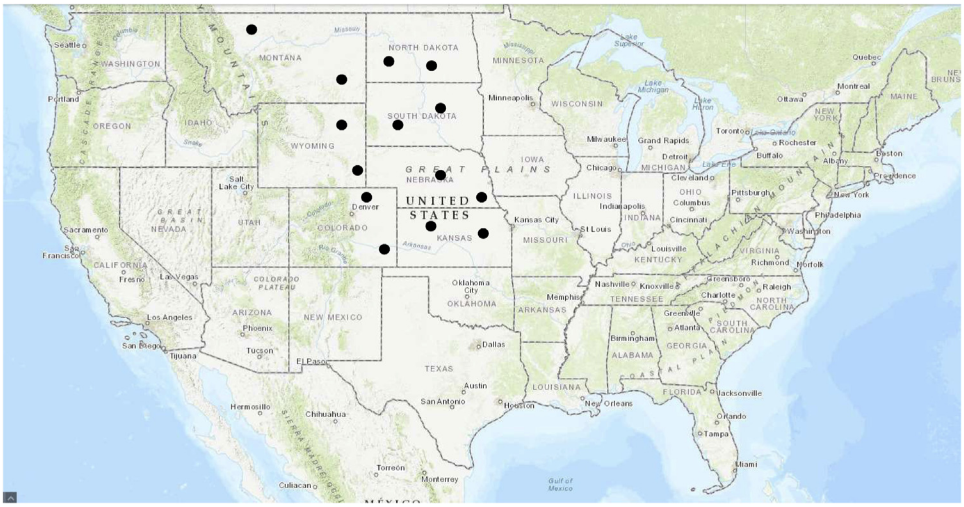

Figure 1. The enclosed circles represent the locations of the climate diagrams in Figures 2 and 3 (USDI-USGS 2019).

Table 1
Precipitation months that are important predictors and correlation coefficients (*r*) of annual forage production from grassland ecosystems in the central and northern Great Plains.

State/Province	Precipitation mo	Correlation coefficient (*r*)	Reference
Alberta	May-June	0.86	Smoliak 1956
Alberta	April-June	0.71	Kruse et al. 2007
Alberta	April-July	0.74	Smoliak 1986
Kansas	May-June	0.52	Hulett and Tomanek 1969
Kansas	May-July	0.68	Shiflet and Dietz 1974
Montana	April-May	0.92	Vermeire et al. 2008
Montana	April-May	0.83	Wiles et al. 2011
Nebraska	April-mid-Aug	0.70	Stephenson et al. 2019
North Dakota	May-June	0.88	Wiles et al. 2011
South Dakota	April-June	0.72	Smart et al. 2007
Wyoming	April-August	0.89	Engda et al. 2016
Wyoming	April-June	0.74-0.82	Derner and Hart 2007
Wyoming	April-June	0.81	Wiles et al. 2011
Wyoming	May-June	0.68	Rauzi 1964

(Polley et al., 2013). These changes in climate may influence species composition in the central and northern Great Plains with more favorable conditions (e.g., earlier spring warm-up and increased winter precipitation) for cool-season grass production (Derner et al. 2018). Additionally, greater variability in precipitation events (e.g., more large and fewer small events) may affect total production

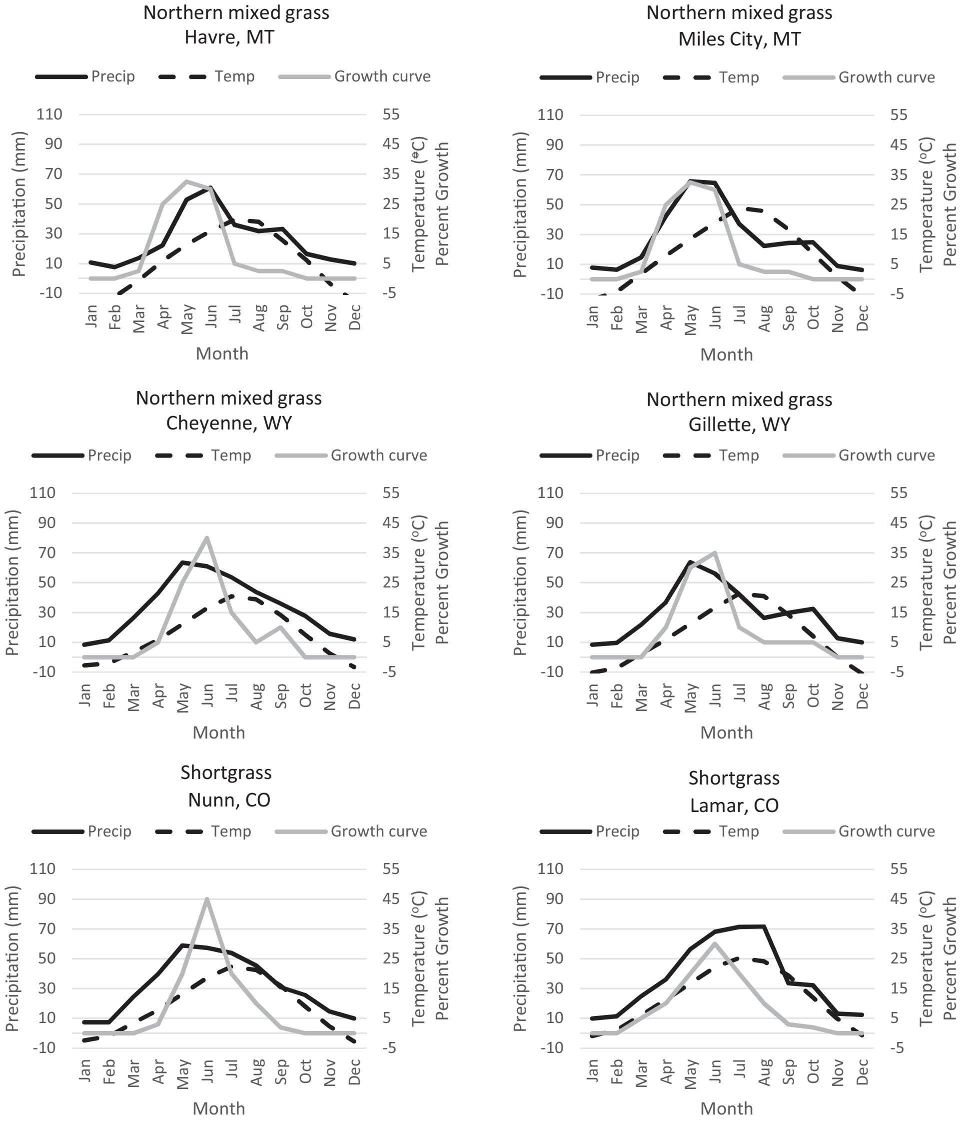

Figure 2. Climate diagrams using 30-yr average (1981–2010) county data for Colorado, Montana, and Wyoming (HPRCC 2019). Growth curves are from ecological site descriptions (ESD) of the most common rangeland ecological site at each location (USDA-NRCS 2019).

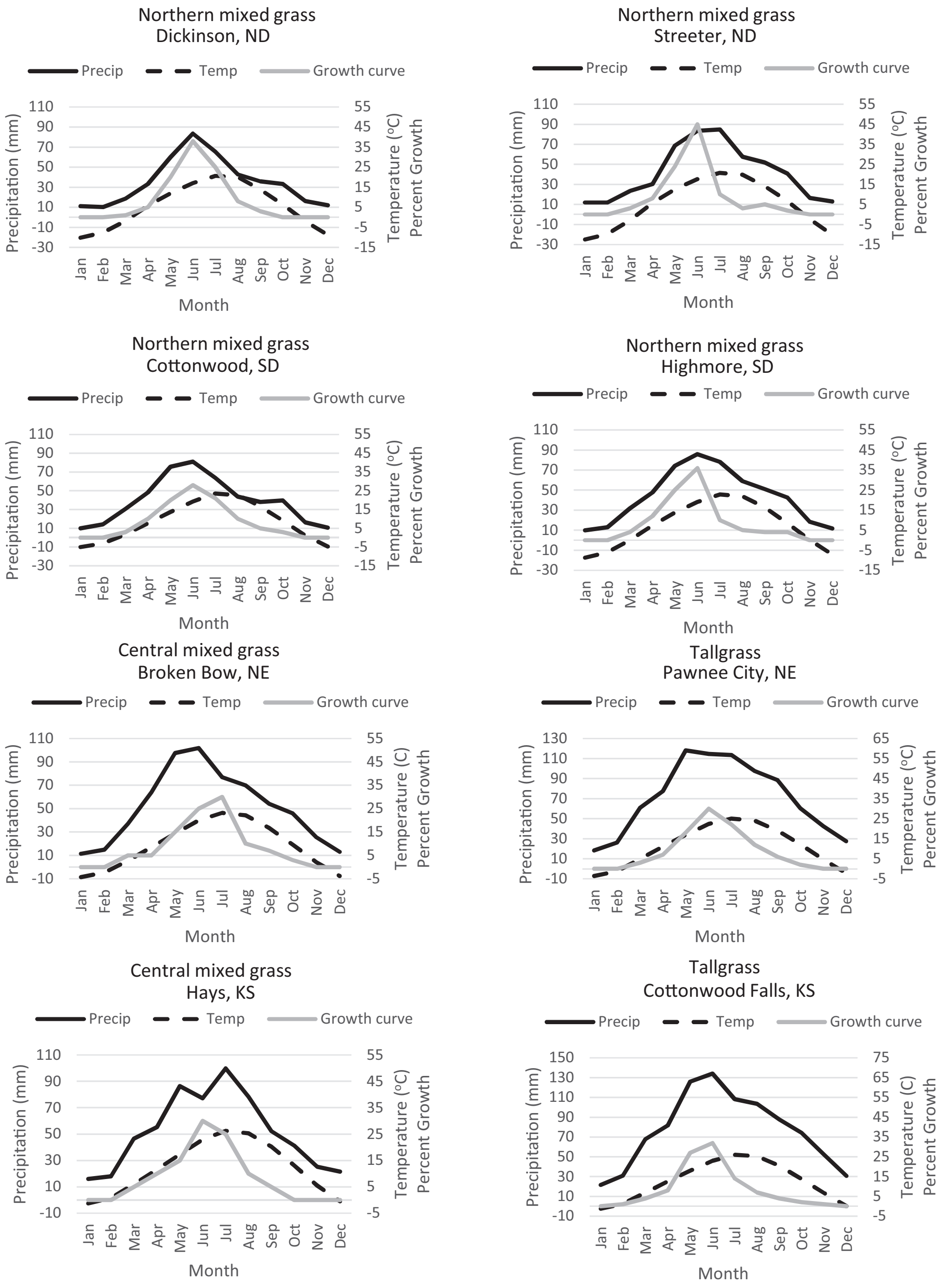

Figure 3. Climate diagrams using 30-yr average (1981–2010) county data for Kansas, Nebraska, North Dakota, and South Dakota (HPRCC 2019). Growth curves are from ecological site descriptions of the most common rangeland ecological site at each location (USDA-NRCS 2019).

differently based on grassland differences in the Great Plains. For example, growing season precipitation apportioned into a few large precipitation event sizes compared to many small event sizes increases aboveground net primary productivity in shortgrass and mixed-grass prairie (Heisler-White et al., 2009), but precipitation event size has less of an influence on primary production in tallgrass prairie systems (Wilcox et al., 2015). As such, long-term plant production data sets are critical for the continued tracking, evaluation, and understanding of potential changes in plant biomass shifts and how that may affect forage production growth patterns into the future. We hypothesize that precipitation received earlier in the year (e.g., March) will influence forage growth more in the future than it does now if, as predicted by Derner et al. (2018), warmer temperatures arrive earlier in spring and forage plants break winter dormancy earlier in the calendar year.

Decision-Making Conundrums With Drought: The Need For Early Detection

Drought occurs quite regularly in the Great Plains as evidenced by the long-term datasets used in this analysis (Table 2). According to climate change projections for the region, the occurrence of drought is expected to increase (USGCRP 2018). Some regions in the Great Plains experience drought more often than others (see Table 2) making it especially important for managers and resources specialists to understand their local climate. Matching animal demand to forage availability becomes increasingly difficult as

Table 2
Frequency of occurrence of receiving < 75% of the mean (i.e., drought yr), 75–125% of the mean (i.e., average yr), and > 125% of the mean (i.e., wet yr) April–June precipitation and the percent of the median for the first and fourth quartiles at several locations in the central and northern Great Plains (HPRCC 2019).

State	Location	Yr	Frequency of occurrence (%)			Percent of the median	
			Drought yr	Average years	Wet yr	First quartile (drought yr)	Fourth quartile (wet yr)
Colorado	Nunn	80	29	51	20	64	132
	Lamar	124	35	37	28	53	151
Kansas	Hays	151	26	49	25	57	149
	Cottonwood Falls	112	26	51	23	67	153
Montana	Havre	95	31	42	27	68	129
	Miles City	82	28	49	23	65	158
Nebraska	Broken Bow	124	19	57	24	63	146
	Pawnee City	98	32	47	21	62	141
North Dakota	Dickinson	120	26	48	26	64	146
	Streeter	31	26	48	26	61	156
South Dakota	Cottonwood	104	32	44	24	57	154
	Highmore	120	27	47	27	61	156
Wyoming	Gillette	99	29	47	24	64	146
	Cheyenne	42	29	55	17	62	136

drought conditions emanate (Andales et al. 2006; Derner and Augustine 2016). Uncertainty about the likelihood of receiving precipitation and associated forage availability can delay making or implementing drought-related decisions (Haigh et al. 2019). Ranchers with limited flexibility and adaptive capacity in their operations (Kachergis et al. 2014) or without written drought plans with clearly identified trigger dates and associated predetermined decisions (Reece 2012) often make reactive rather than proactive decisions that have negative economic consequences (Dunn et al. 2005). These include reduced animal performance, purchasing supplemental feed, moving animals to a different location, and liquidating livestock during a depressed market because of high livestock supplies (Holechek 1996; Scasta et al. 2015; Scasta et al. 2016). The impacts of these negative consequences for ranching operations increase with increasing drought severity (Haigh et al. 2019). Delays in drought-related destocking influence economic returns and negatively impact rangeland productivity, health, and diversity (Haigh et al. 2019). The cumulative financial losses and mental stress from decision-making conundrums with drought impact emotional and social dynamics of ranching families and communities (Wilmer and Fernández-Giménez 2016).

Differences in resources and opportunities among ranching operations (locally and regionally) add to the complexity of determining which management strategies are best suited for adaptation to drought challenges (Wilmer et al. 2016). Each ranch has its own unique environmental, financial, and social conditions; therefore, optimal responses to drought vary among ranch businesses. As a result, the conceptual method of systems thinking, or examining linkages and interactions between different components of a ranch operation, may help producers better visualize, discuss, and apply drought management strategies for the whole operation rather than just being focused on drought alone (Rhoades et al. 2014). For example, increasing the proportion of stockers on a ranch may provide management flexibility and other beneficial opportunities (Kachergis et al. 2014). Dry spring conditions may allow producers to capitalize on enhanced spring individual stocker performance due to higher forage protein content (Harmoney and Jaeger 2011; Harmoney and Jaeger 2013; Owensby and Auen 2018) yet retain the ability to sell animals early in a drought to reduce forage demand. This strategy can provide more forage to the remaining cow herd and reduce the need to sell breeding stock. However, raising yearlings may require different marketing and management skills, and ranch goals and objectives may need to be refocused to include a yearling enterprise, thus altering other aspects of the whole ranch system. In an eastern New Mexico scenario, flexible grazing management with an equal forage allocation between cow-calf and yearling enterprises provided optimal opportunities for producers in this region to manage low and high forage production during dry and wet years, respectively (Torell et al. 2010).

Regardless of which strategies may be appropriate to help producers plan and adapt to drought conditions, early detection of drought is one of the most important variables in the decision-making process. Early drought detection can assist producers in making timely management choices and avoiding reactionary or forced decisions later in the growing season when fewer, and often less desirable, options are available. Producers can make early detection decisions by considering monthly forage growth expectations, long-term climate information, and short-term weather predictions. While other factors (e.g., livestock and hay markets) introduce uncertainty into decision making as well, stronger, clearer guidelines on forage production thresholds may help lessen this one key source of uncertainty, leading to increased confidence and more timely decision making.

Forage Growth Expectations

On the basis of the predictive relationships of spring precipitation and annual forage production (see Table 1), we used the growth curves of cool-season grasses and warm-season grasses grown in Hettinger, North Dakota and Ft. Pierre, South Dakota, respectively, as an example to understand the monthly forage growth expectation for a given year (Sedivec et al. 2009; Sedivec et al. 2010). Cool-season grasses, such as green needlegrass (*Nassella viridula* [Trin.] Barkworth), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve), and western wheatgrass (*Pascopyrum smithii* [Rydb.] Barkworth & D. R. Dewey), had a majority of their growth in June (48%) (Fig. 4a). Warm-season grasses, such as little bluestem (*Schizachyrium scoparium* [Michx.] Nash), blue grama (*Bouteloua gracilis* [Kunth] Lag. ex Griffiths), and sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), had a majority of their growth in July (36%) (see Fig. 4b). The Ecological Site Description (ESD) growth curves shown in Figures 2 and 3 were obtained from the US Department of Agriculture–Natural Resources Conservation Services (USDA-NRCS) (2019) ESD online database for 14 locations throughout the central and northern Great Plains based on the most common ecological site at each location. Growth curves are derived from a combination of field data and expert observation. The peak forage production month for a vast majority of the locations is June (see Figs. 2 and 3). Three exceptions to this were Havre, Montana; Miles

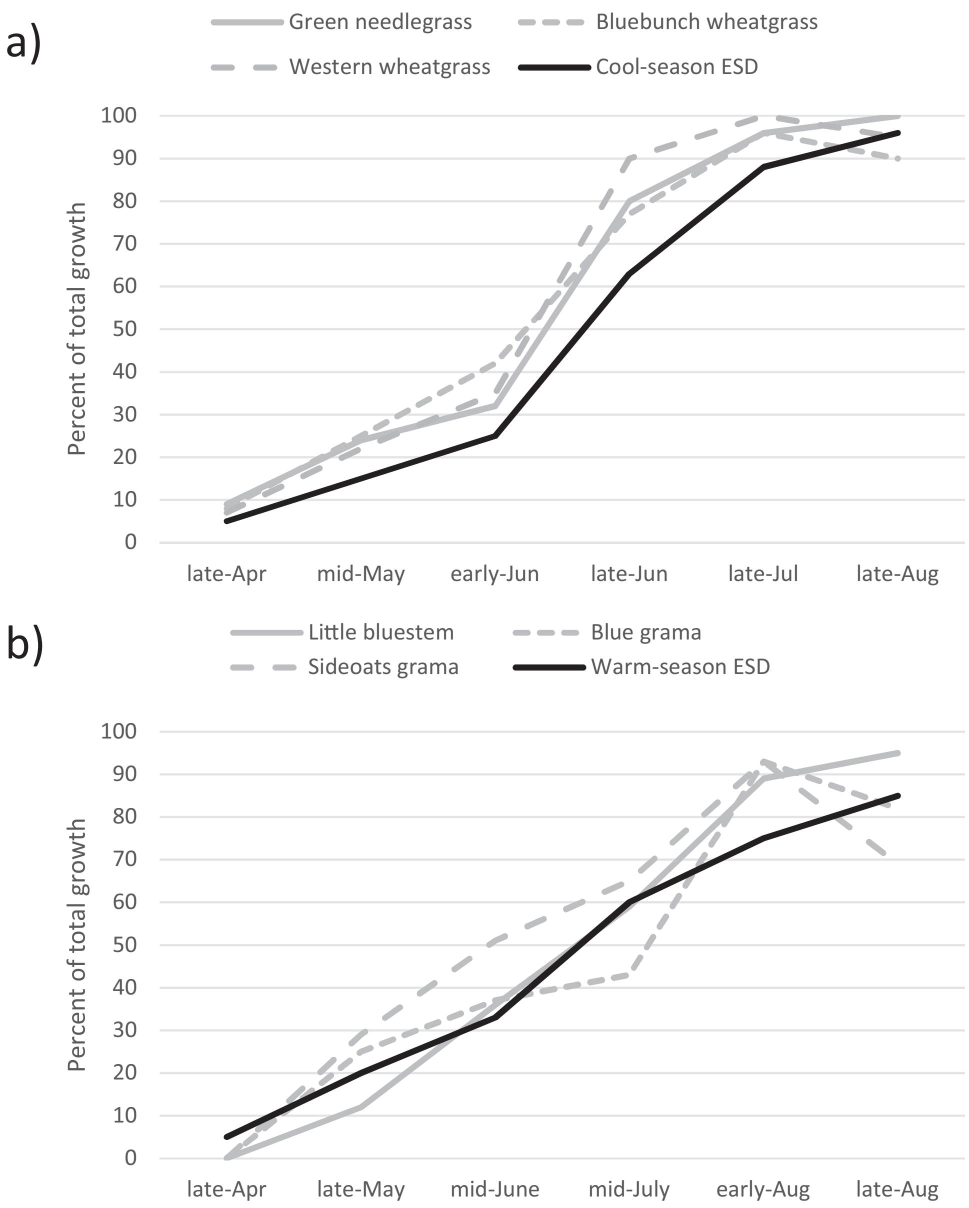

Figure 4. Growth curves for **a**, cool-season grasses and **b**, warm-season grasses grown at Hettinger, North Dakota and Ft. Pierre, South Dakota. In addition, the growth curve for a cool season–dominated ecological site description (ESD) and a warm season–dominated ESD were included (adapted from Sedivec et al. 2009; Sedivec et al. 2010; USDA-NRCS 2019).

City, Montana; and Broken Bow, Nebraska. The two locations in Montana had peak forage production in May, but June was important as well. The peak occurred in July for Broken Bow, Nebraska because the central mixed-grass prairie is dominated by warm-season grasses and has a longer growing season than northern mixed-grass prairie (see Fig. 3). The two locations in MT have a shorter growing season and a lower precipitation to temperature ratio in July and August, and they are dominated by cool-season grasses (see Fig. 2). In Montana, 75% of production occurs by early June and 90% by 1 July (see Table 2; Kruse et al. 2007; Vermeire et al. 2009). Adding water at a rate of 275% of the long-term median during July and August increased production following severe spring drought by < 2% of the median (Heitschmidt and Vermeire 2006). These data clearly indicate the importance of April–May precipitation and the futility of hoping for significant amounts of additional forage production in Montana after 1 July. In more central and eastern locations within the Great Plains, less of the annual production occurs by 1 July (Table 3), likely due to a longer growing season and a greater percentage composition of warm-season species (Stephenson et al. 2019).

We use contingent probabilities, or the likelihood of an outcome given the current conditions, to illustrate interpretations of the forage growth expectations for Miles City, Montana (Table 4). Here, we assume that 13 mm was received in April 2019; thus, 147 mm must be received in May + June to achieve the median 160 mm of total April + May + June precipitation. Over the past 30 yr, 147 mm or more precipitation in May + June was achieved 12 times (including a 146 mm amount in 1993). Therefore, a contingent probability of 40% chance (or 12/30) exists for median spring precipitation to total 160 mm if only 13 mm is received in April. Probabilities of receiving late spring or early summer precipitation to overcome spring deficits are greater in eastern portions of the Great Plains compared with western locations. Low probabilities of receiving the needed precipitation and the potential growth remaining after a dry spring period greatly increase the risk that average forage production will not be achieved after 1 July.

Table 3
Percent annual growth by 1 July and date of 90% annual growth for locations in the Great Plains. Data for growth curves were obtained from Ecological Site Descriptions (USDA-NRCS 2019).

State	Location	Annual growth by July 1 (%)	Date of 90% annual growth
Colorado	Nunn	68	Aug 1
	Lamar	65	Aug 15
Kansas	Hays	60	Aug 15
	Cottonwood Falls	72	Aug 15
Montana	Havre	90	July 1
	Miles City	90	July 1
Nebraska	Broken Bow	50	Sep 1
	Pawnee City	58	Sep 1
North Dakota	Dickinson	64	Aug 1
	Streeter	80	Aug 1
South Dakota	Cottonwood	61	Aug 15
	Highmore	77	Aug 15
Wyoming	Gillette	75	Sep 1
	Cheyenne	70	Sep 1

Another way to analyze the probability of receiving late spring or summer precipitation to compensate for spring precipitation deficits is to use the Standardized Precipitation Index Explorer Tool (https://uaclimateextension.shinyapps.io/SPItool/). The Standardized Precipitation Index (SPI) divides the difference between actual and median precipitation by the standard deviation of that distribution (McClaran and Wei 2014). SPI values of < -1 and > 1 each have a probability of occurring at ~16%, and SPI values −1 to 0 and 0 to 1 each have probabilities of ~34%. At Miles City, Montana (Table 5), there was never a case of a very wet July (> 1 SPI) after a very dry (< −1 SPI) April–June between 1980 and 2010. A wet (0 to 1 SPI) July occurred 60% of the time following a very dry (< minus 1 SPI) April-June. More important, however, is whether the 31 to 68 mm in a "wet" July is enough to pull out of a deficit of < 103 mm between April and June. The answer, of course, is "not likely" because artificial watering experiments showed little increase in forage production (Heitschmidt and Vermeire 2006).

Table 4
30-yr precipitation (mm) records for Miles City, Montana (HPRCC 2019). Cells highlighted are months and years where above-normal precipitation is needed to make up for spring moisture deficits outlined in the case scenario discussion.

Yr	April	May	June	July	May + June	April + May + June
1989	97	36	71	33	107	204
1990	72	27	45	23	71	144
1991	101	69	164	7	232	333
1992	62	29	63	74	92	155
1993	56	26	120	161	146	202
1994	35	31	25	16	57	91
1995	29	75	75	40	150	179
1996	24	123	21	15	144	168
1997	39	33	38	67	71	110
1998	16	21	73	58	93	109
1999	66	43	54	14	97	162
2000	19	34	38	54	71	90
2001	27	30	119	141	149	176
2002	27	59	30	34	89	116
2003	34	58	62	6	119	154
2004	1	33	45	39	78	80
2005	41	89	132	7	221	262
2006	66	49	26	17	74	140
2007	34	115	58	3	172	207
2008	1	88	67	22	155	157
2009	32	26	78	23	105	137
2010	50	133	57	93	189	240
2011	51	237	79	29	317	368
2012	24	26	9	20	35	59
2013	32	170	64	28	233	266
2014	8	89	109	2	198	206
2015	11	46	68	23	114	126
2016	111	62	18	34	79	190
2017	25	11	19	0	30	55
2018	78	106	113	25	220	298
Median	34	47	62	24	111	160

Short-Term Weather Prediction Tools

We have demonstrated that April–June are the critical precipitation months affecting forage production in the northern and central Great Plains. We have also demonstrated that short-term climate predictions during this period can help ranchers and others to estimate upcoming precipitation events and make timelier and better informed drought management decisions. The National Oceanic Atmospheric Administration's (NOAA) Climate Prediction Center provides 6–10-d, 10–14-d, 3-wk, 1-mo, and 3-mo outlooks on its website https://www.cpc.ncep.noaa.gov/. The website provides probability maps of above-normal and below-normal precipitation and temperature for the United States. If a rancher normally turns out livestock in May, he or she already knows if April precipitation met the long-term median. Thus, the rancher only needs to "look forward 2 mo."

Another useful prediction tool is Grass-Cast (http://grasscast.agsci.colostate.edu/). This collaborative effort by the USDA Agricultural Research Service (ARS), Colorado State University, National Drought Mitigation Center, University of Arizona, and USDA Northern Plains Climate Hub provides forage productivity estimate maps at the 10-km spatial scale for the Great Plains. The maps start in early April and are updated every 2 wk. Productivity estimates are provided for three options or "what if" (above-normal, near-normal, and below-normal) precipitation scenarios, with the estimates relative to a 34-yr average. The maps produced on 29 April 2019 shown in Figure 5 give equal chances (33%) for each scenario. The red, orange, and yellow colors on the map indicate below-average forage production. Green, teal, blue, and dark blue colors indicate above-average forage production maps. A helpful feature on the website is the "Maps Archive" tab. Here, the previous prediction maps can be viewed and compared with the most current set of maps.

Implications

Long-term studies of forage production have been used to develop predictive models using monthly precipitation. Our synthesis of the literature shows precipitation in April, May, and June (or some combination of these months) accurately predicted annual forage production in the central and northern Great Plains. This brief period at the beginning of the growing season represents an opportunity for ranchers and others to assess forage production

Table 5
Standardized Precipitation Index (SPI) Explorer Tool (https://uaclimateextension.shinyapps.io/SPItool/) showing the probabilities for transitioning from Period 1 (April–June) and Period 2 (July) for four categories (very dry, dry, wet, and very wet) for Miles City, Montana using the 30-yr period (1980–2010).

Period 1 (April–June)	Precipitation (April–June)	Period 2 (July)			
		Very dry (< 12 mm)	Dry (12-31 mm)	Wet (31-68 mm)	Very wet (> 68 mm)
		(< −1 SPI)	(−1 to 0 SPI)	(0 to 1 SPI)	(> 1 SPI)
		Probability			
Very wet (> 1 SPI)	> 250 mm	0	75	25	0
Wet (0 to 1 SPI)	159-250 mm	15.4	46.2	23.1	15.4
Dry (−1 to 0 SPI)	103-159 mm	0	22.2	44.4	33.3
Very dry (< −1 SPI)	< 103 mm	20	20	60	0
Null or random expectations		16	34	34	16

and to make better informed drought management decisions ahead of market price signals. Forage growth curves for most of the central and northern Great Plains peak in June with a few locations peaking in July. This means that most (60–90%) of the annual forage production occurs by 1 July for cool season–dominated sites and 90% occurs by 1 September in warm season–dominated sites. The probability of receiving precipitation to make up for spring deficits decreases as the summer progresses. Ranchers and others can use short-term precipitation and forage prediction tools in the spring to evaluate the potential of developing drought conditions. By 1 July, drought coping strategies should be enacted or at least planned. While many ranchers wait until later in the summer or fall to respond to drought, drought response strategies should be enacted earlier. Waiting for July and August precipitation to make up for spring precipitation deficits to produce more forage is ill-advised because the probabilities are very low (usually < 20%) and the peak growth period has already occurred for most locations in the central and northern Great Plains. We suggest ranchers and others assess weekly precipitation, beginning in April each year, and make drought management preparations no later than late June or early July in the central and northern Great Plains.

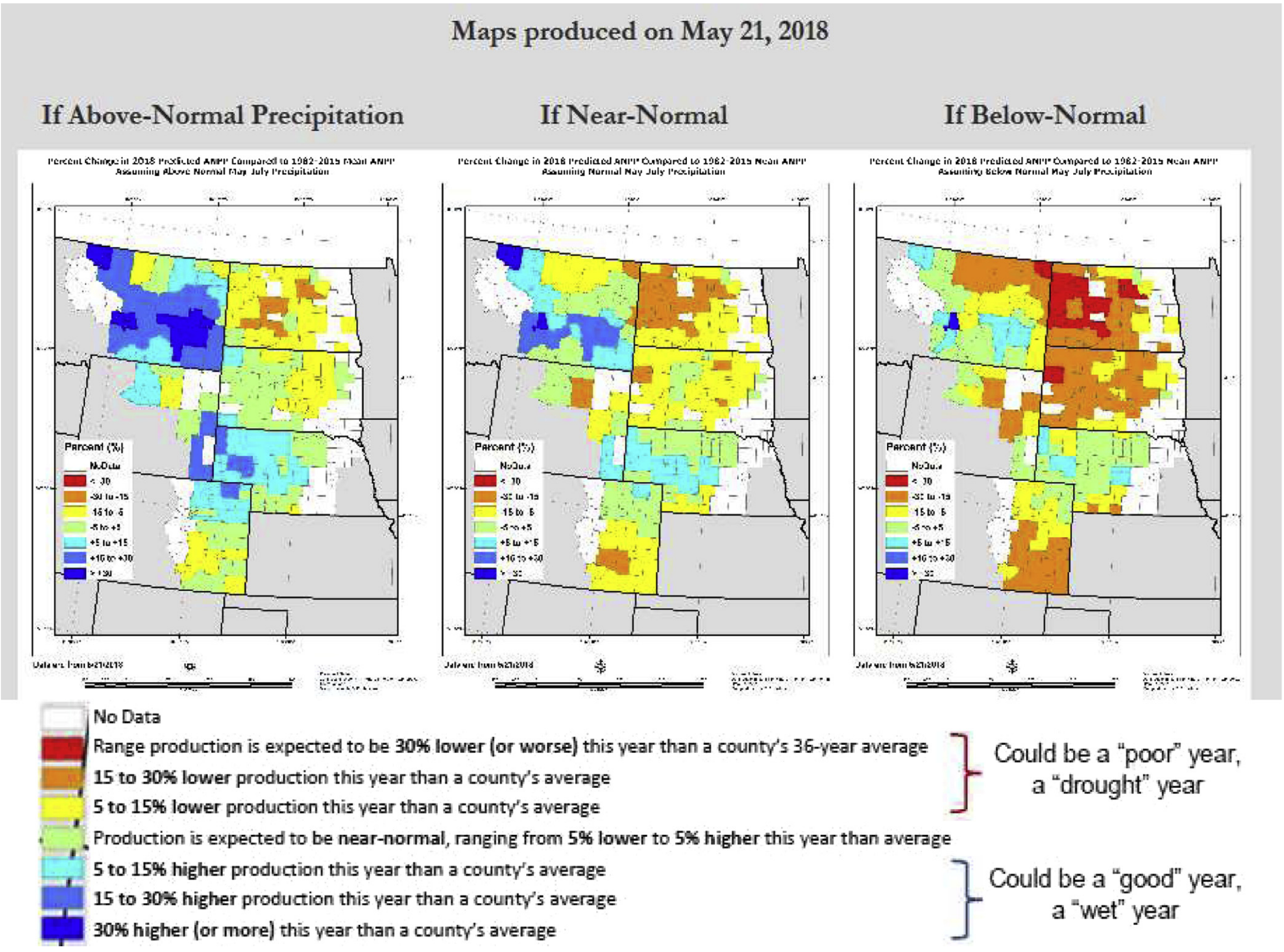

Figure 5. Grass-Cast map produced on 29 April 2019 (http://grasscast.agsci.colostate.edu/).

References

Albertson, F.W., Weaver, J.E., 1944. Nature and degree of recovery of grassland from the Great Drought of 1933 to 1940. Ecological Monographs 14, 393–479.

Anadón, J.D., Sala, O.E., Turner, B.L., Bennett, E.M., 2014. Effect of woody-plant encroachment on livestock production in North and South America. Proceedings of the National Academy of Sciences 111, 12948–12953.

Andales, A.A., Derner, J.D., Ahuja, L.R., Hart, R.H., 2006. Strategic and tactical prediction of forage production in northern mixed-grass prairie. Rangeland Ecology & Management 59, 576–584.

Augustine, D.J., 2010. Spatial versus temporal variation in precipitation in a semiarid ecosystem. Landscape Ecology 25, 913–925.

Bastian, C.T., Peck, D.E., Smith, M.A., Jacobs, J.J., 2012. Sagebrush control: at what canopy cover is it economically justified? Rangeland Ecology & Management 65, 351–361.

Bork, E.W., Thomas, T., McDougall, B., 2001. Herbage response to precipitation in central Alberta boreal grasslands. Journal of Range Management 54, 243–248.

Burke, I.C., Kittel, T.G.F., Lauenroth, W.K., Snook, P., Yonker, C.M., Parton, W.J., 1991. Regional analysis of the Central Great Plains. BioScience 41, 685–692.

Chen, M., Parton, W.J., Del Grosso, S.J., Hartman, M.D., Day, K.A., Tucker, C.J., Derner, J.D., Knapp, A.K., Smith, W.K., Ojima, D.S., Gao, W., 2017. The signature of sea surface temperature anomalies on the dynamics of semiarid grassland productivity. Ecosphere 8 (12), e02069.

Currie, P.O., Peterson, G., 1966. Using growing-season precipitation to predict crested wheatgrass yields. Journal of Range Management 19, 284–288.

Dahl, B.E., 1963. Soil moisture as a predictive index to forage yield for the sandhills range type. Journal of Range Management 16, 128–132.

Derner, J.D., Augustine, D.J., 2016. Adaptive management for drought on rangelands. Rangelands 38, 211–215.

Derner, J.D., Hart, R.H., 2007. Grazing-induced modifications to peak standing crop in northern mixed-grass prairie. Rangeland Ecology & Management 60, 270–276.

Derner, J.D., Hess, B.W., Olson, R.A., Schuman, G.E., 2008. Functional group and species responses to precipitation in three semi-arid rangeland ecosystems. Arid Land Research and Management 22, 81–92.

Derner, J., Briske, D., Reeves, M., Brown-Brandl, T., Meehan, M., Blumenthal, D., Travis, W., Augustine, D., Wilmer, H., Scasta, D., Hendrickson, J., Volesky, J., Edwards, L., Peck, D., 2018. Vulnerability of grazing and confined livestock in the northern Great Plains to projected mid- and late-twenty-first century climate. Climatic Change 146, 19–32.

Dunn, B., Smart, A., Gates, R., 2005. Barriers to successful drought management: why do some ranchers fail to take action? Rangelands 27, 13–16.

Eakin, H., Conley, J., 2002. Climate variability and the vulnerability of ranching in southeastern Arizona: a pilot study. Climate Research 21, 271–281.

Engda, T.A., Kelleners, T.J., Paige, G.B., Hild, A.L., 2016. Rainfall, evapotranspiration, and soil moisture as herbage production predictors for Wyoming rangelands. Arid Land Research and Management 30, 445–459.

Epstein, H.E., Lauenroth, W.K., Burke, I.C., Coffin, D.P., 1996. Ecological responses of dominant grasses along two climatic gradients in the Great Plains of the United States. Journal of Vegetation Science 7, 777–788.

Gaffney, R., Porensky, L.M., Gao, F., Irisarri, J.G., Durante, M., Derner, J.D., Augustine, D.J., 2018. Using APAR to predict aboveground plant productivity in semi-aid rangelands: spatial and temporal relationships differ. Remote Sensing 10, 1474.

Haigh, T.R., Schacht, W., Knutson, C.L., Smart, A.J., Volesky, J., Allen, C., Hayes, M., Burbach, M., 2019. Socio-ecological determinants of drought impacts and coping strategies for ranching operations in the Great Plains. Rangeland Ecology & Management 72, 561–571.

Hamilton, T.W., Ritten, J.P., Bastian, C.T., Derner, J.D., Tanaka, J.A., 2016. Economic impacts of increasing seasonal precipitation variation on southeast Wyoming cow-calf enterprises. Rangeland Ecology & Management 69, 465–473.

Harmoney, K.R., Jaeger, J.R., 2011. Animal and vegetation response to modified intensive-early stocking on shortgrass rangeland. Rangeland Ecology & Management 64, 619–624.

Harmoney, K., Jaeger, J., 2013. Precipitation effects on shortgrass rangeland: vegetation production and steer gain. Kansas State University, Agricultural Experiment Station. Report of Progress, Manhattan, KS, USA, p. 1086.

Heisler-White, J.L., Blair, J.M., Kelly, E.F., Harmoney, K., Knapp, A.K., 2009. Contingent productivity responses to more extreme rainfall regimes across a grassland biome. Global Change Biology 15, 2894–2904.

Heitschmidt, R.K., Vermeire, L.T., 2006. Can abundant summer precipitation counter losses in herbage production caused by spring drought? Rangeland Ecology & Management 59, 392–399.

Hermance, J.F., Augustine, D.J., Derner, J.D., 2015. Quantifying characteristic growth dynamics in a semi-arid grassland ecosystem by predicting short-term NDVI phenology from daily rainfall: a simple four parameter coupled-reservoir model. International Journal of Remote Sensing 36, 5637–5663.

Holechek, J.L., 1996. Drought and low cattle prices: hardship for New Mexico ranchers. Rangelands 18, 11–13.

HPRCC (High Plains Regional Climate Center), 2019. 1981-2010 climate summaries. Available at: http://www.hprcc.unl.edu/data/historical/. Accessed 6 March 2019.

Hulett, G.H., Tomanek, G.W., 1969. Forage production on a clay upland range site in western Kansas. Journal of Range Management 22, 270–276.

Irisarri, J.G., Derner, J.D., Porensky, L.M., Augustine, D.J., Reeves, J.L., Mueller, K.E., 2016. Grazing intensity differentially regulates ANPP response to precipitation in North American semiarid grasslands. Ecological Applications 26, 1370–1380.

Irisarri, J.G., Derner, J.D., Ritten, J.P., Peck, D.E., 2019. Beef production and net revenue variability from grazing systems on semiarid grasslands of North America. Livestock Science 220, 93–99.

Kachergis, E., Derner, J.D., Cutts, B.B., Roche, L.M., Eviner, V.T., Lubell, M.N., Tate, K.W., 2014. Increasing flexibility in rangeland management during drought. Ecosphere 5, 1–14.

Kelley, W.K., Scasta, J.D., Derner, J.D., 2016. Advancing knowledge for proactive drought planning and enhancing adaptive management for drought on rangelands: introduction to a special issue. Rangelands 38, 159–161.

Khumalo, G., Holechek, J., 2005. Relationships between Chihuahuan Desert perennial grass production and precipitation. Rangeland Ecology & Management 58, 239–246.

Kruse, R.E., Tess, M.W., Heitschmidt, R.K., 2007. Livestock management during drought in the northern Great Plains. I. A practical predictor of annual forage production. The Professional Animal Scientist 23, 224–233.

Lane, D.R., Coffin, D.P., Lauenroth, W.K., 1998. Effects of soil texture and precipitation on above-ground net primary productivity and vegetation structure across the central grassland region of the United States. Journal of Vegetation Science 9, 239–250.

Lauenroth, W.K., Sala, O.E., 1992. Long-term forage production of North American shortgrass steppe. Ecological Applications 2, 397–403.

Lauenroth, W.K., Milchunas, D.G., Dodd, J.L., Hart, R.H., Heitschmidt, R.K., Rittenhouse, L.R., 1994. Effects of grazing in ecosystems of the Great Plains. p 69–100. In: Vavra, M., Laycock, W.A., Pieper, R.D. (Eds.), Ecological implications of livestock herbivory in the west. Society for Range Management, Denver, CO, USA, p. 297.

Launchbaugh, J., 1967. Vegetation relationships associated with intensity of summer grazing on a clay upland range site in the Kansas 20-24-inch precipitation zone. Kansas State University, Agricultural Experiment Station. Technical Bulletin, Manhattan, KS, USA, p. 154.

Lee, D., Boe, A., 2005. Biomass production of switchgrass in central South Dakota. Crop Science 45, 2583–2590.

McClaran, M.P., Wei, H., 2014. Recent drought phase in a 73-year record at two spatial scales: implications for livestock production on rangelands in the southwestern United States. Agricultural and Forest Meteorology 197, 40–51.

Mowll, W., Blumenthal, D.M., Cherwin, K., Smith, A., Symstad, A.J., Vermeire, L.T., Collins, S.L., Smith, M.D., Knapp, A.K., 2015. Climatic controls of aboveground net primary production in semi-arid grasslands along a latitudinal gradient portend low sensitivity to warming. Oecologia 177, 959–969.

Nippert, J.B., Ocheltree, T.W., Skibbe, A.M., Kangas, L.C., Ham, J.M., Shonkwiler, K.B., Brunsell, N.A., 2011. Linking plant growth response across topographic gradients in tallgrass prairie. Oecologia 166, 1131–1142.

Owensby, C.E., Auen, L.M., 2018. Steer and pasture productivity influenced by intensive early stocking plus late season grazing. Crop Forage &Turfgrass Management 4, 170011.

Peck, D., Derner, J., Parton, W., Hartman, M., Fuchs, B., 2019. Flexible stocking with Grass-Cast: a new grassland productivity forecast to translate climate outlooks for ranchers. Western Economics Forum 17, 24–39.

Petrie, M.D., Peters, D.P., Yao, J., Blair, J.M., Burruss, N.D., Collins, S.L., Derner, J.D., Gherardi, L.A., Hendrickson, J.R., Sala, O.E., Starks, P.J., Steiner, J.L., 2018. Regional grassland productivity responses to precipitation during multiyear above-and below-average rainfall periods. Global Change Biology 24, 1935–1951.

Polley, H.W., Briske, D.D., Morgan, J.A., Wolter, K., Bailey, D.W., Brown, J.R., 2013. Climate change and North American rangelands: trends, projections, and implications. Rangeland Ecology & Management 66, 493–511.

Rauzi, F., 1964. Late-spring herbage production on short-grass rangeland. Journal of Range Management 17, 210–212.

Reece, P. E. 2012. Writing your drought plan. Proceedings of the 2012 Nebraska Grazing Conference. August 14–15, Kearney, NE, USA. p. 81–96.

Reece, P.E., Brummer, J.E., Engel, R.K., Northrup, B.K., Nichols, J.T., 1996. Grazing date and frequency effects on prairie sandreed and sand bluestem. Journal of Range Management 49, 112–116.

Rhoades, R.D., McCuistion, K.C., Mathis, C.P., 2014. A systems thinking approach to ranching: finding leverage to mitigate drought. Rangelands 36, 2–6.

Sala, O.E., Parton, W.J., Joyce, L.A., Lauenroth, W.K., 1988. Primary production of the central grassland region of the United States. Ecology 69, 40–45.

Scasta, J.D., Windh, J.L., Smith, T., Baumgartner, B., 2015. Drought consequences for cow-calf production in Wyoming: 2011—2014. Rangelands 37, 171–177.

Scasta, J.D., Lalman, D.L., Henderson, L., 2016. Drought mitigation for grazing operations: matching the animal to the environment. Rangelands 38, 204–210.

Sedivec, K.K., Tober, D.A., Duckwitz, W.L., Dewald, D.D., Printz, J.L., Craig, D.J., 2009. Grasses for the Northern Plains: growth patterns, forage characteristics and wildlife values, volume ii—warm-season. Circ. R-1390, Fargo, ND, USA, p. 67.

Sedivec, K.K., Tober, D.A., Duckwitz, W.L., Dewald, D.D., Printz, J.L., 2010. Grasses for the Northern Plains: growth patterns, forage characteristics and wildlife values, volume I—cool-season. Circ. R-1323, 2nd Ed. North Dakota State University Extension Service, Fargo, ND, USA, p. 89.

Shiflet, T.N., Dietz, H.E., 1974. Relationship between precipitation and annual rangeland herbage production in southeastern Kansas. Journal of Range Management 27, 272–276.

Smart, A.J., Dunn, B., Gates, R., 2005. Historical weather patterns: a guide for drought planning. Rangelands 27, 10–12.

Smart, A.J., Dunn, B.H., Johnson, P.S., Xu, L., Gates, R.N., 2007. Using weather data to explain herbage yield on three Great Plains plant communities. Rangeland Ecology & Management 60, 146–153.

Smoliak, S., 1956. Influence of climatic conditions on forage production of shortgrass rangeland. Journal of Range Management 9, 89–91.

Smoliak, S., 1986. Influence of climatic conditions on production of Stipa-Bouteloua prairie over a 50-year period. Journal of Range Management 39, 100–103.

Stephenson, M.B., Schacht, W.H., Volesky, J.D., Eskridge, K.M., Bauer, D., 2015. Time of grazing effect on subsequent-year standing crop in the eastern Nebraska Sandhills. Rangeland Ecology & Management 68, 150–157.

Stephenson, M.B., Volesky, J.D., Schacht, W.H., Lawrence, N.C., Soper, J., Milby, J., 2019. Influence of precipitation on plant production at different topographic positions in the Nebraska Sandhills. Rangeland Ecology & Management 72, 103–111.

Torell, L.A., Murugan, S., Ramirez, O.A., 2010. Economics of flexible versus conservative stocking strategies to manage climate variability risk. Rangeland Ecology & Management 63, 415–425.

USDA-NRCS, 2019. Ecological Site Description System. Available at: https://esis.sc.egov.usda.gov/Welcome/pgReportLocation.aspx?type=ESD. Accessed 6 March 2019.

USDI-USGS, 2019. The National Map. Available at: https://viewer.nationalmap.gov/advanced-viewer/. Accessed 6 March 2019.

USGCRP. 2018: Impacts, risks, and adaptation in the United States: fourth national climate assessment, volume II. *In:* Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L. M., Maycock, T. K., and Stewart, B. C. [eds.]. Washington, DC, USA: US Global Change Research Program. 1515 p. doi:10.7930/NCA4.2018

Vermeire, L.T., Heitschmidt, R.K., Haferkamp, M.R., 2008. Vegetation response to seven grazing treatments in the Northern Great Plains. Agriculture, Ecosystems and Environment 125, 111–119.

Vermeire, L.T., Heitschmidt, R.K., Rinella, M.J., 2009. Primary productivity and precipitation-use efficiency in mixed-grass prairie: a comparison of northern and southern US sites. Rangeland Ecology & Management 62, 230–239.

White, L.M., 1985. Stand age, precipitation, and temperature effects on forage yield. Journal of Range Management 38, 39–43.

Wilcox, K.R., Von Fischer, J.C., Muscha, J.M., Peterson, M.K., Knapp, A.K., 2015. Contrasting above- and belowground sensitivity of three Great Plains grasslands to altered rainfall regimes. Global Change Biology 21, 335–344.

Wiles, L.J., Dunn, G., Printz, J., Patton, B., Nyren, A., 2011. Spring precipitation as a predictor for peak standing crop of mixed-grass prairie. Rangeland Ecology & Management 64, 215–222.

Wilmer, H., Fernández-Giménez, M.E., 2015. Rethinking rancher decision-making: a grounded theory of ranching approaches to drought and succession management. The Rangeland Journal 37, 517–528.

Wilmer, H., Fernández-Giménez, M.E., 2016. Some years you live like a coyote: gendered practices of cultural resilience in working rangeland landscapes. Ambio 45, 363–372.

Wilmer, H., York, E., Kelley, W.K., Brunson, M.W., 2016. In every rancher's mind": effects of drought on ranch planning and practice. Rangelands 38, 216–221.