Management Implications of Global Change for Great Plains Rangelands

Jack A. Morgan, *Justin D. Derner, Daniel G. Milchunas, and Elise Pendall*

Authors are Research Leader and Plant Physiologist (Morgan), US Department of Agriculture-Agricultural Research Service (USDA-ARS), Fort Collins, CO 80526-2083; Rangeland Scientist (Derner), USDA-ARS, Cheyenne, WY 82009; Research Scientist (Milchunas), Forest, Rangeland and Watershed Stewardship Department, and Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO 80523; and Assistant Professor (Pendall), Department of Botany, University of Wyoming, Laramie, WY 82071.

Correspondence: Jack Morgan, USDA-ARS, Fort Collins, CO 80526. Email: Jack.Morgan@ars.usda.gov

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One table, two figures

Great Plains Rangeland Resources. The Great Plains of North America encompass approximately 85 million hectares (210 million acres) consisting of shortgrass, mixed-grass and tallgrass prairie[1] with about 60% of this area converted to row-crop agriculture and the remainder used primarily for livestock production[2]. Large-scale gradients of precipitation (west to east, <30 to >100 cm; 12 to > 40 inches) and mean annual temperature (north to south, 2 to 18° C; 36 to 64 ºF) determine vegetation patterns. For example, the precipitation gradient influences biomass production[3] (1,000 to 6,200 kg/ha; 900 to 5,500 lbs/ac), canopy height[4] (<20 to >200 cm; 8 to > 80 inches), and overall resource limitations governing plant-soil interactions[5]. Both soil carbon and nitrogen increase from west to east[6,7], whereas root:shoot ratios decrease[7,8] (18-25:1 to 3-5:1). The temperature gradient influences the distribution of cool- (C_3) and warm-season (C_4) species[9], with C_3 species more prevalent in northern latitudes, and C_4 species more abundant in the southern half of the Great Plains.

We expect that global change will impact Great Plains rangelands largely through changes in the master environmental variables of moisture and temperature. However, the combined impacts of global change will vary across the region. Herein we summarize the latest findings and implications in global change research pertinent to rangelands of the Great Plains. A summary of the following major points can be found in Table 1.

Current Global Change Predictions. Our analysis of global change and its impacts on primarily plant responses in Great Plains rangelands will focus on three main factors about which we have a fair amount of fundamental knowledge: temperature, precipitation, and carbon dioxide (CO_2). Changes in temperature and precipitation have obvious consequences for vegetation. Most vegetation responds directly to CO_2, and CO_2 is a major driver of climate change.

The average global surface air temperature has already increased 1° C (2 ºF) in the past century. A doubling of atmospheric concentration of CO_2 from levels experienced in the late 20th-century to levels expected near the end of the 21st century[10] is predicted to result in an additional average 3° C (6 ºF) temperature increase. Along with rising global temperatures are predicted more frequent and longer lasting heat waves, higher atmospheric humidity, more intense storms, and fewer and less severe cold periods. Warming in North America[11] is expected to be greater than for the planet (Figure 1). Precipitation will tend to increase in Canada and northeast USA, and decrease in southwest USA. Seasonality of precipitation is also predicted to change, with relatively more precipitation falling in winter and less in summer (Figure 1). The desiccating effect of higher temperatures is expected to more than offset the benefit of higher precipitation, resulting in lower soil water content and increased drought throughout most of the Great Plains[12].

Plant Production Sensitivity to Global Changes. If soil nutrients, water and space are not limiting, increasing CO_2 has the potential on its own to enhance photosynthesis and productivity of most plant species[13]. More importantly for semi-arid rangelands, increasing CO_2 also reduces plant water loss[13], thereby increasing plant water use efficiency[14]. In the northern Great Plains and in high altitude rangelands where seasonal cold temperatures limit plant production, combined warming and higher CO_2 may continue to enhance plant production, at least for the next few decades or so. However, in the southern Great Plains, production may eventually decline if the positive effects of CO_2 on water savings and plant production are countered by the negative effects of warming-induced desiccation and more variable precipitation patterns[15,16]. The final outcome of these global changes on plant productivity will depend on local conditions and the degree to which each of these environmental factors change. As a result, the current positive effect of rising CO_2 on plant production which has been underway for well over a century now (since the beginning of the Industrial Revolution) is likely to become increasingly modified in coming decades as climate change becomes more pronounced.

Plant Species Will Respond Unpredictably to Global Change.

The alteration of plant community species composition due to differential plant species or functional group sensitivities to global change is a matter of concern for rangelands, where the economic value of the land depends in large part on plant community composition. However, our ability to predict how global change will impact composition of future rangeland plant communities is limited. While precipitation and temperature have formerly been reliable predictors of relative abundances and distributions of plant groups like cool-season C_3 grasses, warm-season C_4 grasses, forbs and shrubs in the Great Plains[17-19], those patterns may be complicated in the future due to the effects of rising CO_2 on plants. For instance, warmer temperatures and drier conditions should continue to favor C_4 grasses[17,20], but rising CO_2 should benefit C_3 plant photosynthesis and growth rates[13, 21-26]. Further, CO_2 is known to enhance other plant attributes that are important in determining plant community dynamics like seedling recruitment[24,25], tap root growth[13,23,26], and N fixation[22,25,26]. There is very little information on how these various plant characteristics will respond to multiple global changes over time to affect changes in species composition in native plant communities. Nevertheless, cumulative experimental evidence is beginning to reveal some trends which suggest that rising CO_2 and temperature plus increased winter precipitation may favor herbaceous forbs, legumes and woody plants in many Great Plains rangelands[13, 23-27]. These plant community shifts add to concerns about uncertain contributions of global change to exotic weed invasion. Most invasive weeds are in the C_3 functional group, and if they have woody stems or deep taproots, are especially likely to gain dominance on rangelands as CO_2 concentrations rise.

Altered Fire Regimes. Fire is an important feature of many Great Plains rangelands, and its frequency, intensity and seasonality are likely to be affected by changes in climate, productivity and species composition. Fire was an important factor in maintaining grass dominance in the more productive rangelands of the eastern Great Plains. In more recent times, the removal of fire and/or changes in its seasonality along with rising CO_2 have encouraged woody plant encroachment in many of these productive rangelands (Figure 2). However, predicted changes in precipitation patterns may encourage more frequent and intense fires in the future, with increased winter precipitation driving early-season plant growth, and warmer, drier summers desiccating vegetation, increasing the probability of fire.

Feedbacks Involving Soil Nitrogen. The ability of rangeland soils to provide adequate concentrations of essential nutrients is important in understanding plant species and community responses to global change. For instance, the potential of CO_2 to enhance plant growth depends on the ability of soil to release more available nitrogen (N) to meet increased demand[28]. Experimentally increasing CO_2 over native grasslands of Texas and Minnesota initially enhanced plant productivity, but after 3 years, soil N became depleted and production declined[29,30]. By contrast, in the more arid shortgrass steppe of Colorado, enhanced soil moisture availability under elevated CO_2 appeared to stimulate N mineralization, maintaining enhanced production even after 5 years[31]. Interactions of soil moisture and temperature complicate predictions of long-term rangeland nutrient availability. While warmer temperatures may stimulate nutrient mineralization and plant productivity in tallgrass prairie[32], warming may reduce N availability in the drier portions of the Great Plains if soil drying decreases mineralization rates[33].

Effects of global change on nutrient cycling may also be mediated by changes in species composition. Nutrient availability may be enhanced if N-fixing legumes increase in abundance under higher CO_2[25,26], or reduced if low-quality forage species are instead stimulated[34]. Grazing animals can also influence nutrient cycling by diet selection and N return to the ecosystem, thereby mediating direct CO_2 or warming effects on N cycling[35]. Thus, nutrient availability for livestock in grazed systems will be dependent on the interaction of plant species composition and soil N availability, plus N cycling by the livestock.

Forage Quality. Quality of vegetation can be as important as its abundance for animal performance. Changes in N cycling often lead to lower total N or crude protein in plants as CO_2 increases, although this is less evident in senescent vegetation[34,36]. Increasing CO_2 tends to increase soluble carbohydrates, but has small or no effects on compounds like hemi-cellulose and cellulose which are more slowly and less fully digested or like lignin which impedes digestion. However, responses can be species and/or organ dependent. In general, crude protein appears to be consistently negatively affected by CO_2 than concentrations of carbon compounds[34]. In Great Plains rangelands, digestibility of affected plant tissues tends to decrease with higher CO_2[34,36].

Temperature can also affect forage quality. Soluble sugars tend to accumulate below optimal growth temperatures. Increases above optimal growth temperatures can increase cell wall constituents along with stem tissues, reduce soluble sugar content, and result in a lowering of forage quality. A classic study of differences in forage quality across a latitude gradient showed an approximate 1% decrease in digestibility per 1^0C (2^0F) increase in temperature[37] moving from temperate to tropical regions. Warming may tend to worsen problems of low forage quality caused by CO_2 in rangelands of the southern Great Plains, but counteract them in more temperate northern rangelands.

Changes in species composition of plant communities may also impact forage quality. Higher CO_2 may enhance production of C_3 over C_4 plants, and C_3 plants tend to have higher quality and forage digestibility[38]. However, two C_3 species in the shortgrass steppe that showed strong production responses to CO_2, needle-and-thread (*Hesperostipa comata)* and fringed sage (*Artemisia frigida*)[23,24], are both relatively low forage quality species.

Management and Policy Implications. Evidence from experiments, computer modeling exercises and long-term observations provide strong evidence that rangelands are changing, and that many of those changes are linked to global change. While there is still considerable uncertainty concerning how quickly climate and other global changes are developing, which regions will be affected most, and the particulars of exactly how plant communities and animals will be impacted by climate, there is a strong consensus that weather is becoming more extreme, climate more unpredictable, and droughts more common. What, then, are the management and policy implications for Great Plains rangelands?

As climate and atmospheric CO_2 concentrations continue to change, stocking rates and systems will need to be modified to optimize livestock use in regions where the seasonality, amount, and quality of forage production are altered[39]. Greater production in northern and high altitude rangelands in the near future may initially allow greater stocking rates, although not if soil N levels become depleted and forage quality declines. Increased occurrence and severity of drought in the southern and central Great Plains may reduce stocking rates or season of grazing in the next thirty years or so. The same may eventually happen in the north. Throughout the region, ranchers and land managers will need to be flexible and proactive in dealing with a more variable forage supply, with greater dependence on grass banks and hay supplies, and tolerance for greater fluctuations in herd size and components (cow calf, yearlings). Decision support systems which specifically address drought response strategies will become increasingly helpful to ranchers in dealing with a more variable and drought-prone climate.

Management practices are certain to shift substantially where global change results in significant alterations in plant and soil resources. Changes in the plant community or nutrient cycling that result in lower forage quality will mean greater expenditures on non-grazing season supplementation. A change in breed or in animal species, from cattle to sheep or goats, may eventually be needed in some regions to better match animals to a drier and/or warmer climate[39], or where grassland transitions to a savanna or woodland. Fire may become more or less important as a natural event and/or management tool, depending on the combined effects of global change on the plant community. For rangelands in which livestock grazing becomes economically marginal, management may focus more on ecosystem services like ecotourism, hunting, open space, wind energy, or C sequestration.

In general, future management for Great Plains rangelands will need to address an increasingly foreign landscape as our environment changes in unprecedented ways, and as a result, new plant communities arise. Such non-analog communities may present a challenge as they are likely to differ from those previously studied[40]. Our present notions of best management practices which draw heavily on our past ecological knowledge may be inadequate for future planning. As an example, state-and-transition models are recommended as decision support tools for individuals and agencies to prevent the occurrence of undesirable states and to promote the occurrence of desirable states. These conceptual tools provide a means of organizing our current understanding of management influences on states of vegetation and transitions, including ecological resilience (capacity to return to a previous condition) and thresholds of change, or the amount of energy required to move from one state to another[41-43]. However, presently-configured models may not be well-suited for the future as they are based in large part on knowledge gained from research conducted in past environments, environments which are becoming increasingly scarce. Our notions of how rangelands respond to management need to incorporate the latest information on the effects of projected warming, altered precipitation regimes, and rising CO_2 if we hope to be successful in applying those concepts in future environments.

As we transition into climates that are more variable and extreme, and rangelands change in ways not previously experienced, monitoring[44] will take on increased importance. Monitoring, combined with decision support systems which incorporate the latest advancements in weather forecasting with models of plant production[45] will be essential for developing informed, tactical (within-year) management decisions that are based on the latest weather and environmental information, and which have the necessary ecological information to predict future rangeland performance in an increasingly uncertain environment. Public land management agencies and conservation programs may need to consider policy changes that allow for more tactical responses to an increasingly variable climate. Long-term strategic planning (across years), which incorporates the vagaries of economics and agriculture policy, will become the standard for successful land managers, and will require collaborations among all interested parties, including society.

In summary, we are fairly certain that climate change is already underway and having impacts on the ecology, sustainability and utility of Great Plains rangelands. Despite an incomplete picture of exactly how those changes will unfold in the next few decades, we know that the future will not look like the past, and uncertainty concerning the climate and general ecology of the region is increasing. Management of these lands has always been a critical factor in affecting their condition and use, and that will continue in the future. Our challenge today is to understand how Earth’s changing climate is influencing the outcome of our management practices, and to develop innovative and sustainable practices and tools based on that information to continue managing these lands in a responsible manner.

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Table 1. Global Change and Consequences for Great Plains Rangelands

- Predictions of Global Changes[11,12]
  - Atmospheric CO_2 increasing, predicted to continue far into future
  - Mean surface air temperatures rising in region over 6 ºF this century
  - More intense and less predictable hydrologic cycle
  - Mid-continental drying

- Vegetation Productivity and Community Responses
  - Increased plant production in northern latitude and high altitude Great Plains Rangelands
  - Possible decreased plant productivity in southern Great Plains
  - Plant species changes are likely already underway
  - Forbs, woody plants and legumes may increase
  - Changes in balance between cool- and warm-season perennial grasses unknown
  - Invasive species may be promoted by global change

- Soil Nutrients and Forage Quality
  - Possible long-term decline in available forms of soil N
  - Possible reduction in forage N and quality
  - Species changes will impact forage quality

- Management/Policy Implications
  - Changes in plant community, productivity, seasonality of plant growth and forage quality will require adjustments in management (stocking rate, animal breeds and species, changes in enterprise)
  - Improved monitoring and understanding of vegetation dynamics in state-and-transition models will be critical for optimizing resources, minimizing potential downside of global changes, and developing sustainable and realistic future management scenarios

Figure Captions.

Figure 1. Temperature and precipitation changes over North America from the MMD-A1B simulations. Top row: Annual Mean, DJF (December, January and February) and JJA (June, July and August) temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increased in precipitation. From Christensen et al., 2007, Figure 11.12.

Figure 2. Tree islands in the tallgrass prairie of Kansas (photograph courtesy of Alan K. Knapp). Although the invasion of woody plants into rangelands is due to complex combinations of management (grazing and fire) and a host of environmental factors, evidence is accumulating that rising CO_2 and climate may be involved in these transitions.

Fig. 1

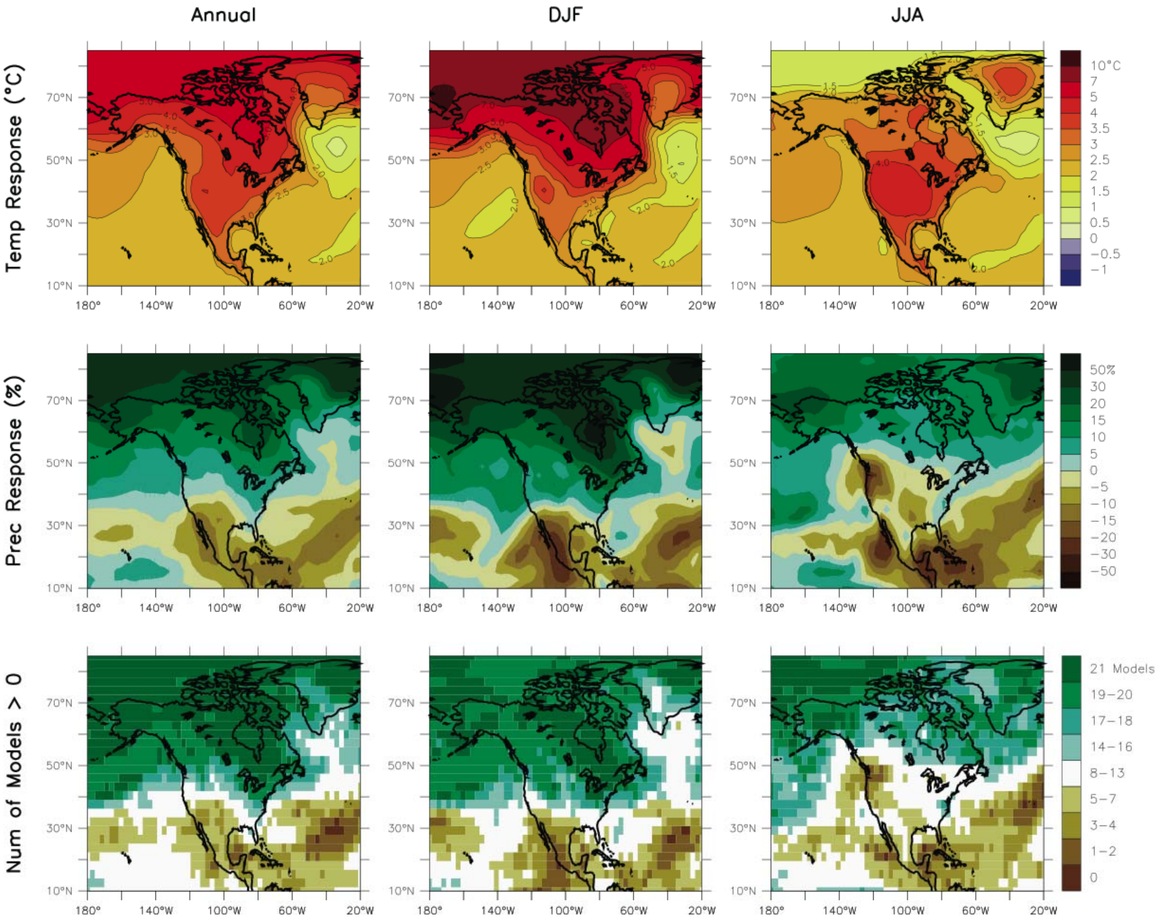
Annual
DJF
JJA
Temp Response (°C)
Prec Response (%)
Num of Models > 0
10°C
7
5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
−1
50%
30
20
15
10
5
0
−5
−10
−15
−20
−30
−50
21 Models
19−20
17−18
14−16
8−13
5−7
3−4
1−2
0
10°N
30°N
50°N
70°N
180°
140°W
100°W
60°W
20°W

Fig. 2