Two Years of Carbon Dioxide Enrichment on the Shortgrass Steppe of Colorado

J.A. Morgan, D.R. LeCain, A.R. Mosier, D.G. Milchunas, W.J. Parton and D.S. Ojima
USDA/ARS and Colorado State University, Fort Collins, CO, USA

ABSTRACT

This study assessed how doubling the CO_2 concentration over present levels affects the growth and physiology of shortgrass steppe vegetation in eastern Colorado. In March, 1997, six open-top chambers (OTCs) were installed on native shortgrass steppe in NE Colorado, USA. Three grass species make up about 88% of the above-ground biomass of this ecosystem; *Bouteloua gracilis* (C_4), *Pascopyrum smithii* (C_3) and *Stipa comata* (C_3). More than 20 other grass and forb species also occur here. CO_2 was injected into three OTCs to raise the concentration to 720 ppm, approximately twice that in the three ambient chambers. Three non-chambered plots were established to evaluate chamber effects. The air temperature in the chambers averaged 2° C warmer than outside. During 1997 and 1998 significant chamber and CO_2 effects were detected. Averaging over the two years, above-ground production in the ambient chambers was 22% greater than that in unchambered plots, probably due to warmer spring temperatures in the chambers. Production under elevated CO_2 averaged 35% greater than that in ambient OTCs. Significant growth increases occurred for both C_3 and C_4 grasses and forbs in 1998. These CO_2-induced growth increases were primarily due to improved water status. Soil water content was often higher in elevated CO_2 chambers. Leaf water potentials were generally higher in plants grown at elevated CO_2 compared to ambient chambers. Leaf intercellular CO_2 photosynthesis response curves indicated neither *P. smithii* nor *B. gracilis* leaves were saturated with CO_2 at 360 ppm. Photosynthetic capacity of both species was reduced in plants grown at elevated CO_2, although this response was much stronger in the the C_3 species, *P. smithii*. Results suggest that future CO_2 enrichment will lead to growth enhancements in both C_3 and C_4 grasses of the shortgrass steppe.

INTRODUCTION

In North America, the Great Plains represents the largest of the native grasslands, stretching south to north from Mexico into Canada and east to west from the Front Range of the Rocky Mountains to the eastern deciduous forest. Along the western edge of the Great Plains lies the shortgrass steppe, an important grassland of which 50% today remains intact. Growth chamber studies have indicated a doubling of CO_2 concentrations over current ambient levels will enhance growth of the native shortgrass steppe grasses by approximately 20% (Hunt et al. 1996). Growth enhancements from CO_2 have been attributed to improved water status and increased photosynthesis in both C_3 and C_4 grasses (Morgan et al., 1994; Read et al., 1997).

The objective of this experiment was to use open-top chambers (OTCs) to double CO_2 concentrations over native shortgrass steppe to evaluate the effect within an intact grassland on plant production, physiology, soil microbiology, and trace gas exchange (CH_4, N_2O, NO). Herein we report on the first two year's findings for plant responses.

Materials and Methods

Experimental Site:	Shortgrass Steppe of Colorado 42% *Bouteloua gracilis* (C_4) 26% *Stipa comata* (C_3) 21% *Pascopyrum smithii*(C_3) 11% other species (27)
Treatments:	**Control** Plots (non-chambered) **Ambient** CO_2 OTC (360 ppm) **Elevated** CO_2 OTC (720 ppm)
Measurements:	Above-ground phytomass Neutron probe soil water content Pressure chamber leaf water potential Steady-state leaf gas exchange

Results

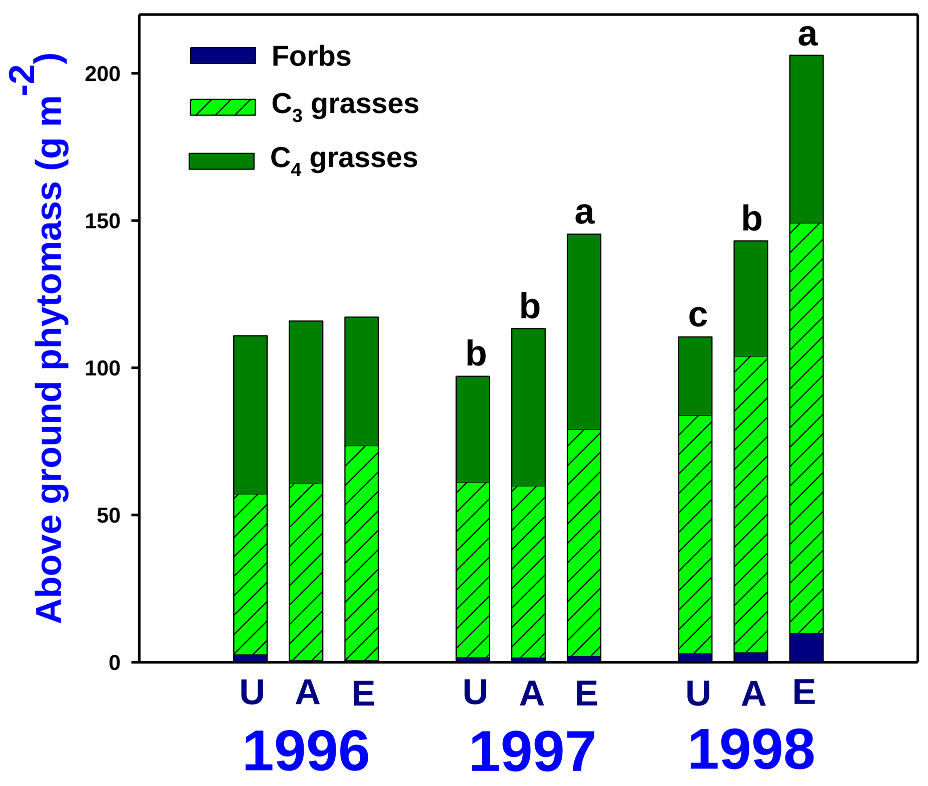

Fig. 1. *Above-ground phytomass.* In 1997 production at peak standing crop was 27% higher in elevated (E) vs. ambient (A) chambers. In 1998 elevated CO_2 improved production by 43% compared to ambient plots, while ambient plots had 29% more phytomass than unchambered (U) plots, probably due to warmer temperatures in the spring (chambers averaged 2° C warmer than outside). Improved growth occurred in C_3 and C_4 grasses and forbs.

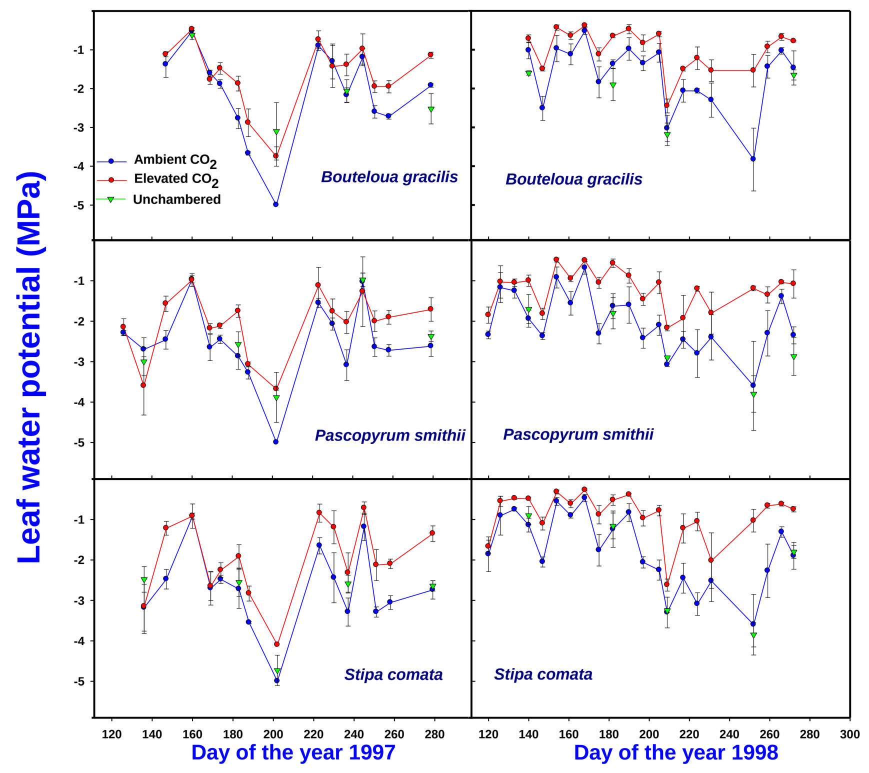

Fig. 3. *Plant water status*. Leaf water potentials largely reflected treatment differences in soil water content, and were often higher in elevated CO_2 plots compared to ambient plots in both C_3 grasses (*P. smithii* and *S. comata*) and the C_4 grass *B. gracilis*.

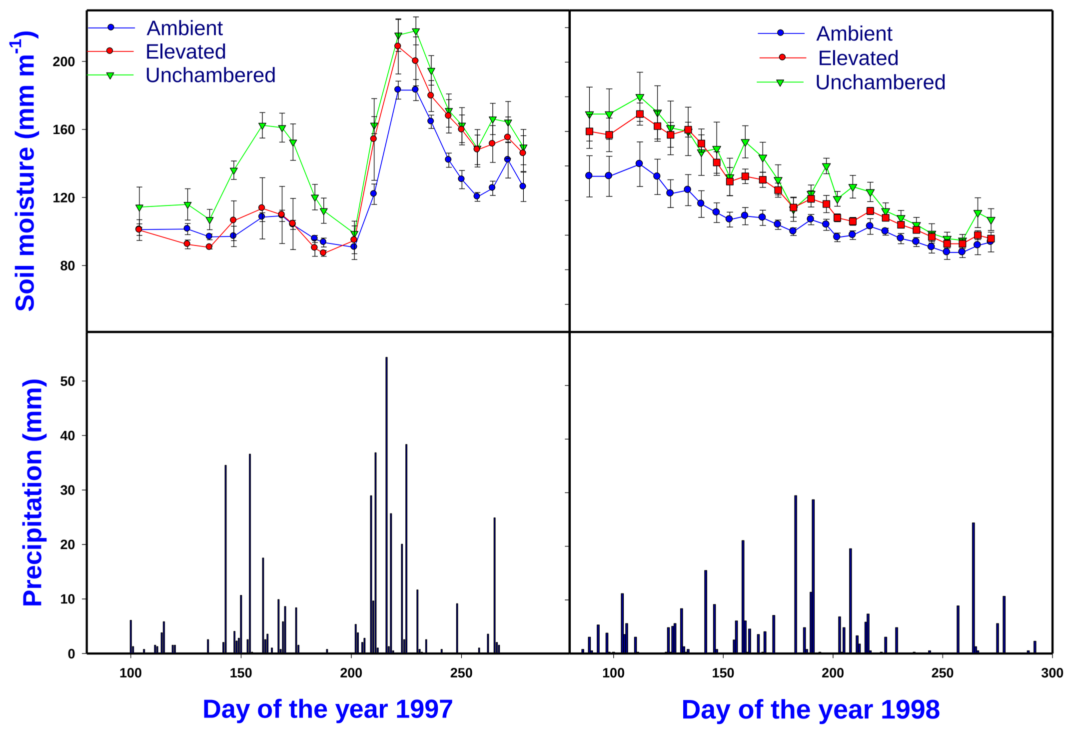

Fig. 2. *Precipitation and soil moisture.* Growing season precipitation was high in the first two years of this study, with 562 and 422 mm in 1997 and 1998, compared with a long-term average of 320 mm. In 1997, after a significant mid-summer drought, an unusual amount of precipitation occurred at the site. This was followed by a separation in soil moisture due to CO_2 treatment, with ambient plots drying out faster than elevated plots. This soil water effect was maintained over the winter and continued until the later part of the 1998 season. Soil moisture in the unchambered plots was higher than the ambient plots indicating a desiccating effect of the chambers.

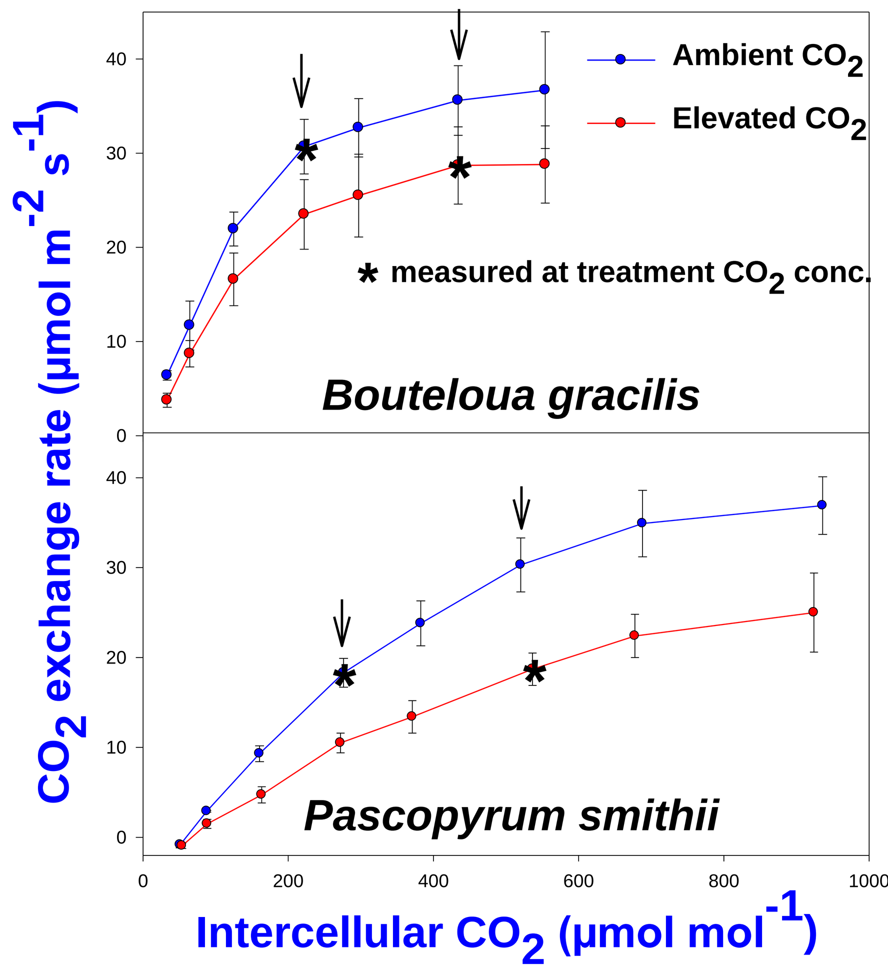

Fig. 4. *Photosynthesis*. Measuring CO_2 exchange rate (CER) over a range of CO_2 concentrations shows that neither *B.gracilis* (C_4) nor *P. smithii* (C_3) were saturated at 360 ppm. CO_2 exchange rate was increased about 72% in *P. smithii* and 20% in *B. gracilis* at 720 vs. 360 ppm (arrows) within each CO_2 treatment. The degree of photosynthetic acclimation that occurred in *P. smithii* was striking, with elevated CO_2 grown plants having much lower rates than ambient CO_2 grown plants. *Bouteloua gracilis* also displayed a small degree of photosynthetic acclimation to high CO_2. Acclimation was so significant on some dates that when we compare CER measured at the growth CO_2 concentration (asterisks) there is little photosynthetic advantage in plants grown at elevated CO_2. On other dates photosynthesis was higher under elevated CO_2.

CONCLUSIONS

1. Doubling CO_2 from 360 to 720 ppm enhanced aboveground production of shortgrass steppe vegetation an average of 35%.

2. No difference was detected in the growth response of C_3 vs. C_4 grasses to elevated CO_2.

3. Warmer spring temperatures in the chambered plots (about 2° C) increased productivity by about 22% over the unchambered plots.

4. CO_2 enrichment reduced soil water usage, and improved leaf water potentials in C_3 and C_4 shortgrass steppe plants. Improved water status was a major factor in the increased productivity in elevated CO_2 plots.

5. In the C_3 grass, *P. smithii*, photosynthetic acclimation under elevated CO_2 consistently reduced leaf photosynthetic rate relative to leaves from ambient chambers. Photosynthetic acclimation was also evident at times in the C_4 grass *B. gracilis*, although to a lesser degree than in *P. smithii*. Acclimation greatly reduced the photosynthetic advantage at elevated CO_2, especially in the C_3 grass.

LITERATURE CITED

Hunt, HW, ET Elliott, JK Detling, JA Morgan and D-X Chen. 1996. Responses of a C_3 and a C_4 perennial grass to elevated CO_2 and temperature under different water regimes. Global Change Biology 2:35-47.

Morgan, JA, WG Knight, LM Dudley and HW Hunt. 1994. Enhanced root system C-sink activity, water relations and aspects of nutrient acquisition in mycotrophic *Bouteloua gracilis* subjected to CO_2 enrichment. Plant and Soil 165:139-146.

Read, JJ, JA Morgan, NJ Chatterton and PA Harrison. 1997. Gas exchange and carbohydrate and nitrogen concentrations in leaves of *Pascopyrum smithii* (C_3) and *Bouteloua gracilis* (C_4) at different carbon dioxide concentrations and temperatures. Ann. Bot. 79:197-206.

ACKNOWLEDGEMENTS. This research was funded by USDA/ARS and funding received from the Terrestrial Ecology and Global Change Program (IBN-9524068), an inter-agency granting program of the United States Government. We thank Dean Ackerman, Scott Andre, Mary Ashby, Susan Crookall, Dennis Mueller, Mary Smith, Larry Tisue, Jeff Thomas and Barry Weaver for their technical contributions to the project, and without whom it would not have been possible.