DOE/ER/60253--T10

Progress Report

1994

Rangeland - Plant Response to Elevated CO_2

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Summary

Plots of a tallgrass prairie ecosystem were exposed to ambient and twice-ambient CO_2 concentrations in open-top chambers and compared to unchambered ambient CO_2 plots during the entire growing season from 1989 through 1993. Dominant species were Andropogon gerardii, A. scoparius, and Sorghastrum nutans (C_4) and Poa pratensis (C_3). Aboveground biomass and leaf area were estimated by periodic sampling throughout the growing season in 1989 and 1990. In 1991, 1992, and 1993, peak biomass and leaf area were estimated by an early August harvest. Relative root production among treatments was estimated using root ingrowth bags which remained in place throughout the growing season. Latent heat flux was simulated with and without water stress. Botanical composition was estimated annually in all treatments. Compared to ambient CO_2 levels, elevated CO_2 increased production of C_4 grass species in 1989-1991,but in 1992 and 1993, wet years, there was no difference in C_4 biomass production among treatments. Biomass production of C_3 grass species did not differ among treatments any year. Species composition of C_4 grasses did not change, but Poa pratensis (C_3) declined, and C_3 forbs increased in the stand with elevated CO_2 compared to ambient. Open-top chambers reduced latent heat flux and increase water use efficiency similar to elevated CO_2 when water stress was not severe, but under severe water stress, chamber effect on water use efficiency was limited. Whole chamber NCE was higher under elevated CO_2, and whole chamber evapotranspiration was lower under elevated CO_2. In natural ecosystems with periodic moisture stress, increased water use efficiency under elevated CO_2 apparently would have a greater impact on productivity than photosynthetic pathway. Root ingrowth biomass was greater in 1990 and 1991 on elevated CO_2 plots compared to ambient or chambered-ambient plots. In 1992 and 1993, there was no difference in root ingrowth biomass among treatments.

Nitrogen and phosphorus concentrations in Ange, Popr, and forb aboveground biomass were estimated by periodic sampling throughout the growing season in 1989 and 1990. In 1991 and 1992, N and P concentrations in peak biomass were estimated by an early August harvest. N and P concentration in root production among treatments was estimated using root ingrowth bags which remained in place throughout the growing season. Above- and belowground biomass total N and P were calculated as a product of N concentration and peak biomass by

groups. As a rule, N concentration in 1989-1991 of Ange and forb aboveground biomass was lower and total N higher in elevated CO_2 plots than in ambient CO_2 plots. In 1992 and 1993, N concentration and total N did not differ in Ange and forb biomass. N concentration in 1989-1993 of Popr aboveground biomass was lower in elevated CO_2 plots than in ambient, but total N did not differ among treatments. In 1990, N concentration in root ingrowth bag biomass was lower and total N greater in elevated CO_2 than in ambient CO_2 plots. Root ingrowth bag biomass N concentration did not differ among treatments in 1991, 1992, and 1993, but total N was greater in elevated CO_2 plots than in ambient CO_2 plots. In all years, total P in aboveground Ange and root ingrowth bag biomass was greater under elevated CO_2 than ambient. P concentration and total P in Popr usually was similar among treatments. Increased biomass production of C_4 plants under elevated CO_2 compared to ambient likely diluted the available N, but it is likely that carboxylation enzyme may have been responsible for a part of the reduction in N concentration. Rubisco and PEPc concentration during 1993 was lower at certain dates. Increased carbon allocation below ground appeared to increase P uptake, probably mediated through increased mycorrhizal activity. Reduced N concentration in above- and belowground biomass will influence herbivory and reduce litter decomposition rates.

Forage quality was estimated on samples collected for biomass production and on samples collected using esophageally-fistulated sheep. Samples from elevated CO_2 treatments were higher in acid detergent fiber (ADF) and lower in in vitro dry matter digestibility (IVDMD) than samples collected from ambient CO_2 plots. Diet samples collected by esophageally-fistulated sheep were lower in ADF and higher in IVDMD than those hand-clipped, but diet selection by the sheep did not affect the relative differences in forage quality among treatments. Modeled livestock performance was lower under elevated CO_2 than under ambient. Therefore, we conclude that diet quality for ruminants will be reduced under elevated CO_2.

Ange plants exposed to elevated CO_2 had a higher photosynthetic rate at internal CO_2 levels from 150 to 800 ppm than plants exposed to ambient CO_2 in 1990,a dry year, but in 1992 and 1993 did not differ. The increased photosynthesis in 1990 appeared to be from a more efficient photosynthetic system, since photosynthetic rate was higher under elevated than ambient CO_2 at light intensities from 500 to 1750 μmol m-2 s-1 when exposed to 350 and 700 ppm CO_2 atmospheres. Dynamic stomatal response of Ange stomates to sun/shade events was altered by elevated CO_2. Ange stomates tended to open and close more rapidly under elevated CO_2, thereby imparting an increased water use efficiency. We estimated that there was an 8% increase in water use efficiency due to the more rapid response of stomates of Ange. Midday and diurnal xylem pressure potentials indicated that there was less water stress for Ange plants exposed to elevated CO_2 compared to ambient CO_2.

Soil microbial biomass carbon and nitrogen were higher under elevated CO_2 early and late in the growing season when carbon translocation was greatest in the tallgrass prairie ecosystem. Soil respiration was much higher under elevated CO_2 than ambient, indicating a significant increase in carbon allocation below ground under elevated CO_2.

CENTURY ecosystem model output using data collected during the first three years of the study to parameterize the model indicated that soil carbon will likely increase, N mineralization decrease, and litter decay rates decrease with elevated CO_2. Ecosystem sensitivity to the temporal and regional resolution of climate change (changes in annual mean climate vs. seasonally varying changes) was evaluated by driving a regional ecosystem model with two different general circulation model (GCM) climate outputs, Canadian Climate Center and the Geophysical Fluid Dynamics Laboratory models as described in the 1990 IPCC report (Houghton et al., 1990). The grassland model of CENTURY (Parton et al., 1987, Parton et al submitted), was used for the simulations of aboveground net primary productivity (NPP) and soil organic carbon (SOC) for 31 sites across the globe. CENTURY simulations for each site were run to equilibrium (approx. 5000 model years) based on current climatologies. We tested the sensitivity of grassland ecosystems to the following global change effects:

- climate change effects (+CC, i.e., alternations to temperature and precipitation);
- double CO2 response (+CO2, i.e., modified plant production response by increasing plant production rates due to changes in potential evapotranspiration rates and nitrogen use efficiency to increased atmospheric CO2 concentrations;
- combined effect of climate change and doubling of atmospheric CO2 (+CC+CO2)

We modified the plant production parameters under a 2 X CO2 climate by changing production relative to potential evapotranspiration PET and to nitrogen use efficiency (NUE). The magnitude of the effect is to cause a 20% increase in plant production with a change in atmospheric CO_2 concentration from 350 to 700 ppm. The effect of modified NUE and PET on plant production is a simple linear effect on these processes. In addition, with changes in NUE, litter quality of the resulting plant material produced is lessened. This results in a slower decomposition of this material under a given temperature and moisture conditions. The net result of the CO_2 and climate change impacts will depend on the increase in decomposition rates with climate derived changes, the effect on decomposition rates due to biotic feedbacks of lower litter quality material, changes to decomposition and plant production due to altered soil water dynamics due to plant mediated ET, and net change in plant inputs into the soil system.

Future research plans include a more detailed analysis of the GRASS model developed by Dr. Michael Coughenour linked with CENTURY to evaluate the CO_2 impact of grassland dynamics. The modelling activities will further investigate the sensitivity of different grassland communities (e.g., C_3 communities relative to C_4 communities). This will entail refinements in the species level parameterizations relative to the CO_2 impact on plant C fluxes. This will be conducted in conjunction with Drs. Coughenour, Parton and Ojima using both CENTURY and GRASS.

Below is a listing of the papers that have been written on research completed on the project. Recent papers that are in press or review from work completed on the project are printed in their entirety.

Publications

Kirkham, M.B., H. He, T.P. Bolger, D.J. Lawlor, and E.T. Kanemasu. 1991. Leaf photosynthesis and water use of big bluestem under elevated carbon dioxide. Crop Sci. 31:1589-1594.

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Owensby, C.E., P.I. Coyne, J.M. Ham, L.M. Auen, and A.K. Knapp. 1992. Biomass production in a tallgrass prairie ecosystem exposed to ambient and elevated levels of CO_2. Ecological Applications (in press)

Owensby, C. E., P.I. Coyne, and L.M. Auen. 1992. Nitrogen and phosphorus dynamics of a tallgrass prairie ecosystem exposed to elevated carbon dioxide. Plant, Cell, and Environment (in press)

Owensby, C.E., P.I. Coyne, and L.M. Auen. 1992. Nitrogen and phosphorus dynamics of a tallgrass prairie ecosystem exposed to elevated carbon dioxide. Plant Cell Environ. (in press)

Kemp, P.R., N. Adam, C. E. Owensby, and J.F. Reynolds. 1992. Effects of elevated atmospheric CO_2 and soil nitrogen on canopy leaf area distribution in a tallgrass prairie. Ecological Appl. (submitted)

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De-Xing, Chen, M.B. Coughenour, C.E. Owensby, and A.K. Knapp. 1992. Mathematical simulation of C4 grass photosynthesis in ambient and elevated atmospheric CO_2.. Ecological Modeling (in review)

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Knapp, A.K., J.T. Fahnestock, and C.E. Owensby. 1993. Elevated atmospheric CO_2 alters stomatal response to sunlight in a C_4 grass. Plant, Cell, and Environ (in review)

Knapp, A.K., E.P. Hamerlynck, and C.E. Owensby. 1993. Photosynthetic and water relations responses to elevated CO_2 in the C_4 grass, Andropogon gerardii. Experimental Botany(in press)

Owensby, Clenton E. 1993. Potential impacts of elevated CO_2 and above- and belowground litter quality of a tallgrass prairie. Water, Air and Soil Pollution (in press).

Owensby, Clenton E. 1993. Climate Change and Grasslands: Ecosystem-level responses to elevated carbon dioxide. Proc. 17th International Grassland Congress. (in press)

Nie, D., M.B. Kirkham, L.K. Ballou, D.J. Lawlor, and E.T. Kanemasu. 1993. Changes in prairie vegetation under elevated carbon dioxide and tow moisture regimes. J. Vegetation Sci. (in press)

Mo, G., D. Nie, M.B. Kirkham, H. He, L.K. Ballou, F.W. Caldwell, and E.T. Kanemasu. 1992. Root and shoot weight in a tallgrass prairie under elevated carbon dioxide. Environ. Exp. Bot. 32:193-201.