

FC03-95NV62026

762782

### **Carbon Dioxide and Vegetation Water Use**

J.T. Ball, A.G. Peterson, A.M. Hoylman, Y. Luo, D.A. Sims, D.W. Johnson,  
J.S. Coleman, P.D. Ross, and W. Cheng<sup>1</sup>.

1. The authors are members of the Ecosystem Processes Group, Biological Sciences Center, Desert Research Institute, P.O. Box 60220 Reno, NV. 89506. E-mail: [Error! Bookmark not defined.](#) and through [Error! Bookmark not defined.](#)



## **DISCLAIMER**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

Evapo-transpiration from vegetation, as well as patterns of precipitation are expected to change as the concentration of CO<sub>2</sub> in the atmosphere continues to rise (1). Water modulates the rates of many biogeochemical processes, and it has been estimated that water directly limits plant productivity over two-thirds of the earth's land surface (2). Water quality and availability are increasingly important practical issues as demands by both agricultural and urban users continue to increase. In a recent *Perspective* article (3) Farquhar stated that transpiration (water loss) from terrestrial vegetation will decline by 40 to 50% as the CO<sub>2</sub> concentration in the atmosphere approaches twice present levels. He suggested that "the impending saving of water would be a welcome result of the rising atmospheric CO<sub>2</sub> concentration." We can confirm that large reductions in transpiration are expected by terrestrial physiological ecologists. Examining 35 recent articles that discussed the issue of water use while synthesizing research on ecosystem impacts of doubling atmospheric CO<sub>2</sub> (including reviews and crop/natural ecosystem models), we found that 31 articles suggest that reductions in water use of between 25 and 50% are to be expected.

Experiments by our group are consistently failing to yield large reductions in transpiration at elevated CO<sub>2</sub>. Moreover, some experiments show that dramatic increases in plant water use can occur at elevated CO<sub>2</sub>, even without increases in leaf area.

We have studied water loss by plants growing across a range of atmospheric CO<sub>2</sub> concentrations from sub-ambient to twice present levels; have considered this process at the leaf, whole plant, and canopy scales; and have used

contrasting species: primarily *Pinus ponderosa* (ponderosa pine), *Populus Fremontii* (Fremont Cottonwood), *Tamarisk chenesis* (Salt cedar), *Glycine max* (soybean) and *Helianthus annus* (sunflower). None of our studies lead us to expect 40 to 50% declines in transpiration as the atmospheric CO<sub>2</sub> rises.

Canopy-scale experiments conducted in the naturally-lit EcoCELL (mesocosm) facility at the Desert Research Institute (4) allow partitioning of changes among the several factors that determine ecosystem-level water use. The effect of CO<sub>2</sub> (380 versus 710  $\mu\text{mol mol}^{-1}$ ) on transpiration and its components in developing canopies of sunflower (*Helianthus annus*) is shown in Figure 1. In this experiment total transpiration was 18% higher in the elevated compared to the lower CO<sub>2</sub> treatment. For the daylight hours net photosynthesis was 40% higher and the integrated water use-efficiency was 19% higher at elevated CO<sub>2</sub>.

Canopy conductance to water vapor (dominated by leaf stomatal conductance) was higher in elevated CO<sub>2</sub>. From the perspective that conductance can be described as a function of photosynthesis, humidity, and the inverse of the CO<sub>2</sub> concentration (5) — the increase in transpiration at elevated CO<sub>2</sub> is explained by increased photosynthesis and increased conductance (normalized for the above influences, Figure 1). Factors that can contributed to differences in ecosystem water use — leaf area, leaf to air vapor gradient — were not sufficient to explain the differences in water use between treatments in this experiment. Across seven ambient-versus-twice-ambient-CO<sub>2</sub> experimental comparisons, involving different species and conditions, responses that we have observed have ranged from a 10% decline to the 18% increase in water use

shown here. Increases in photosynthesis and normalized conductance largely off-set the tendency for higher CO<sub>2</sub> to reduce transpiration.

A similar analysis of the factors contributing to literature reports of the CO<sub>2</sub> effect on conductance and transpiration has not proven possible because values of conductance and transpiration usually appear without inclusion of the covariates: photosynthesis, humidity, and measurement CO<sub>2</sub> concentration.

Where these covariates have been reported and conductance has declined 40 to 50% at elevated CO<sub>2</sub>, the plants were being grown in pots and nearly complete down-regulation of photosynthesis had occurred (6). Such results would be expected from the perspective of the empirical relationship between conductance, photosynthesis, and CO<sub>2</sub> concentration (X, Y, Z). Studies conducted where the possibility of pot restriction has clearly been minimized, seem to yield smaller declines in conductance at leveled CO<sub>2</sub>. It is accepted that pot restriction of root activity compromised many studies of the response of photosynthesis to elevated (7). This problem also may have compromised our understanding of the response of conductance and transpiration to elevated CO<sub>2</sub>.

Presently, bases for specific predictions of the response of stomatal conductance, of transpiration, and even of photosynthesis to rising atmospheric CO<sub>2</sub> are lacking. These processes are basic aspects of ecosystem function.

Thus, the need for research on the mechanisms of these CO<sub>2</sub> responses is clear. Much of the past decade's work on terrestrial ecosystem responses to increasing atmospheric CO<sub>2</sub> has focused on carbon sequestration and on the interactions of the nitrogen cycle with carbon processes. Changes in plant water use at elevated CO<sub>2</sub> and modulation of the carbon and nitrogen cycles resulting from changes in water availability need experimental attention.

### References and Notes

1. P.J. Sellers *et al.* Science **275**, 502-506 (1997); P.J. Sellers *et al. ibid* **271**, 1402-1406. (1996).
2. H. Leith, in Primary Productivity of the Biosphere, H. Leith and R.H. Whittaker Eds. (Springer-Verlag, New York, USA, 1975), pp. 237-263.
3. G.D. Farquhar, Science **278**, 1411 (1997)
4. K. Griffin *et al.*, Plant, Cell Environ. **19**, 1210-1221 (1996). In the experiment: presented here: (1) daily air temperature and humidity cycles kept identical in contrasting mesocosms; (2) flux data were recorded as 15 minute averages of data collected at 0.1 Hz and are presented here as the ratio of integrals over the daylight period. (3) diurnal variation in photosynthetic activity was detectable above soil respiration beginning near the halfway point of the 60 day trial; (4) on day 31 the leaf area index (LAI) of both treatments averaged less than 0.1 m<sup>2</sup>m<sup>-2</sup> increased to just over 4 in both treatments by day 60.
5. S.C. Wong, I.R. Cowan, G.D. Farquhar, Nature **282**, 424 (1979); J.T. Ball, I.E. Woodrow, J.A. Berry, in Progress in Photosynthesis Research, J.



- Biggins, ed. Martinus Nijhoff Publishers, Dordrecht, Netherlands. (1987);  
R. Luening, Plant, Cell Environ. **18**, 365-372 (1995).
6. S.C. Wong, I.R. Cowan, G.D. Farquhar, Plant Physiol. **78**:821-825 (1985).
7. R.B. Thomas, B.R. Strain, 1991. Plant Physiol. **96**:627-634 (1991).

Relative Effect of Development at Elevated  $\text{CO}_2$  Concentration on Canopy-level Transpiration, Water Use Efficiency, and their Components

