Increasing Atmospheric Carbon Dioxide and Water- Use Efficiency

M.B. Kirkham, Kansas State University – Manhattan, KS

Introduction

The Evapotranspiration (ET) Laboratory at Kansas State University was the first to carry out experiments with sorghum [*Sorghum bicolor* (L.) Moench] and winter wheat (*Triticum aestivum* L.) under elevated carbon dioxide (CO_2) in the field (Chaudhuri et al., 1986; Chaudhuri et al., 1990a, b). The experiments were started in 1984, when the CO_2 concentration in the atmosphere was 330 ppm. In 2008, the concentration of CO_2 in the atmosphere was 385 ppm (Dugokencky, 2009), 55 ppm more than in 1984. In the early experiments, the first increment of CO_2 that we used was 485 ppm (155 ppm above the then ambient). Because we are only 100 ppm from that first increment (485 ppm – 385 ppm = 100 ppm), we can use these early results to see what is happening now to plants in the field under a CO_2 concentration that is elevated compared to 1984. In particular, we focus on water-use efficiency.

Water-use efficiency (WUE) is the biomass produced divided by the water consumed, or
WUE = biomass produced/water consumed (Eq.1), where biomass produced and water consumed to produce that biomass each can be expressed in grams (e.g., g dry matter/g H_2O). The WUE may be based on either the total dry matter production (vegetative yield) or the marketable yield (e.g., grain yield).. The reciprocal of WUE is the "water requirement" (WR) of plants, or
WR = water consumed/biomass produced (Eq.2), and the units of WR are g H_2O/g dry matter. Again, WR can be based on total dry matter production or the marketable yield.

The goal in semi-arid regions like Kansas is to increase water-use efficiency or decrease the water requirement. Elevated CO_2 offers an opportunity to increase water-use efficiency of plants, because under elevated CO_2, stomata close, reducing water lost by transpiration. Also, under elevated CO_2, photosynthesis is often increased. So both the numerator and denominator in Equations (1) and (2) are changed under elevated CO_2, causing an increase in WUE or a decrease in WR.

Materials and Methods

We grew the sorghum or winter wheat under elevated levels of CO_2 in closed top chambers at a rhizotron facility near Manhattan, Kansas (Figure 1).

Figure 1. Rhizotron Facility

Figure 2. Pulley System

The plants grew in 16 underground boxes with a Muir silt loam.

Sorghum was kept well-watered during its growth. For wheat, water in half of the boxes was maintained at field capacity (0.38 m^3/m^3 or the high-water level) and in the other half between 0.14 and 0.25 m^3/m^3 (about half field capacity or the low-water level).

We had four CO_2 concentrations: 330 ppm (ambient), 485 ppm, 660 ppm, and 795 ppm.

The underground boxes could be pulled out of the ground by a pulley system (Figure 2).

Materials and Methods cont.

Boxes then could be pulled to a load-cell balance, where they were weighed. At the end of the season, above-ground weight was determined. Wheat was grown for three seasons (1984-1985; 1985-1986; 1986-1987), and the water requirement was determined for the wheat grain at the end of each year. Water requirement of the dry matter of the wheat (vegetative production) was not determined. Sorghum was grown for one season (1984), and water requirement was determined for the sorghum dry matter and the sorghum grain.

Results

The water requirement for winter-wheat grain production decreased as CO_2 concentration increased (Figure 3).

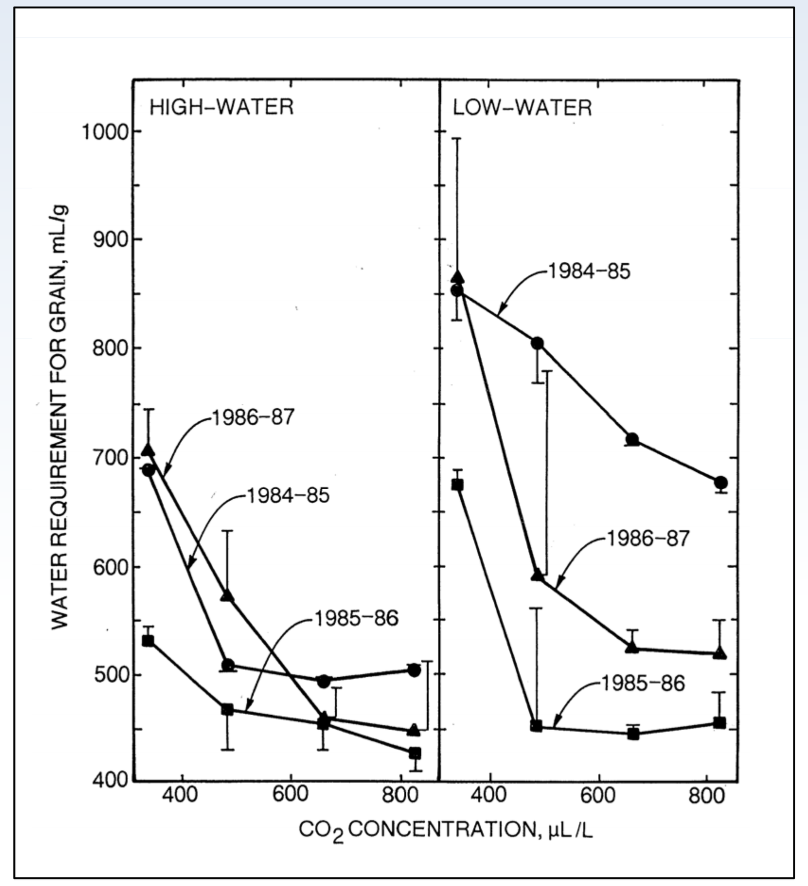

Figure 3. Water Requirement for Wheat as Affected by Carbon Dioxide

During the three-years of the study (1984-1987), water required to produce a gram of grain under high CO_2 (825 ppm) and low-water-level conditions was less (547 mL/g) than that required to produce a gram of grain under high-water level conditions at ambient CO_2 (642 mL/g). Under high-water levels, the water requirement for wheat grain was reduced by 29% when the CO_2 level was raised from ambient (3-year average = 642 mL/g) to 825 ppm (WR = 458 mL/g). Under low water levels, the water requirement for wheat grain was reduced by 31% when the CO_2 level was raised from ambient (WR = 797 mL/g) to 825 ppm (WR = 547 mL/g).

Table 1. Water used to produce a gram of dry matter or grain of sorghum (g H_2O/g) as affected by ambient (330 ppm) and enriched atmospheric CO_2 concentrations (ppm).

CO_2	Vegetative dry matter	Grain
330	525	1090
485	430	961
660	388	826
795	395	776

The water requirement for the dry matter of sorghum, as well as the water requirement for grain of sorghum, are shown in Table 1. As the CO_2 level increased, the water requirement decreased.

Results cont.

I have calculated what the water requirement of wheat and sorghum now is, when atmospheric CO_2 concentration is 385 ppm, based on the 1984-1987 experiments. Wheat and sorghum are now using 41 mL and 43 mL, respectively, less water to produce a gram of grain than they were in the 1984-1987 period. If we assume the water requirement of wheat grain under well-watered conditions is 642 mL/g, then 41/642 = 0.06, or the water requirement to produce a gram of wheat grain has been reduced by 6% due to the 55 ppm increase in CO_2 since the mid-1980's.

If we assume the water requirement of sorghum grain under well-watered conditions is 1090 mL/g, then 43/1090 = 0.04, or the water requirement to produce a gram of sorghum grain has been reduced by 4% due to the 55 ppm increase in CO_2 since the mid-1980s.

These may seem like small percentages. But spread over the large acreage of wheat and sorghum grown in Kansas, the more efficient use of water now (2009) compared to the mid-1980's should have a large impact. In 2009: 8,800,000 acres of wheat were harvested in Kansas and 2,700,000 acres of sorghum were harvested in Kansas (Kansas Department of Agriculture, 2009).

Conclusion

Data collected between 1984 and 1987 suggest that the increase in atmospheric CO_2 since then (55 ppm) has allowed production of more wheat grain and sorghum grain for the same amount of water applied.

The water requirements for wheat and sorghum have been reduced 6% and 4%, respectively, due to the 55 ppm increase in CO_2 in the air in the past quarter century.

References

Chaudhuri, U.N., R.B. Burnett, M.B. Kirkham, and E.T. Kanemasu. 1986. Effect of carbon dioxide on sorghum yield, root growth, and water use. Agricultural and Forest Meteorology 37:109-122.

Chaudhuri, U.N., M.B. Kirkham, and E.T. Kanemasu. 1990a. Carbon dioxide and water level effects on yield and water use of winter wheat. Agronomy Journal 82:637-641.

Chaudhuri, U.N., M.B. Kirkham, and E.T. Kanemasu. 1990b. Root growth of winter wheat under elevated carbon dioxide and drought. Crop Science 30:853-857.

Dlugokencky, E.J. 2009. Carbon dioxide. Bulletin of the American Meteorological Society 90 (No. 8, Supplement): S34-S35.

Kansas Department of Agriculture. 2009. Kansas Agricultural Statistics. Crops, Vol. 9, No. 7, Page 1 and 3. Kansas Dept. Agric., U.S. Dept. Agric., Topeka, KS.