Impact of Increasing Atmospheric CO_2 on Crop Gas Exchange under Different Tillage Practices

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Abstract: Increasing atmospheric CO_2 concentration may impact production agriculture. In the fall of 1997, a study was initiated to examine the response of different tillage systems to changing atmospheric CO_2 level. The study used a split-plot design (three replications) with two tillage systems (conventional tillage and no-tillage) as main plots and two atmospheric CO_2 levels (ambient and twice ambient) as sub-plots using open top chambers on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults). The conventional tillage system was a grain sorghum [*Sorghum bicolor* (L.) Moench.] and soybean [*Glycine max* (L.) Merr.] rotation with winter fallow and spring tillage practices. In the no-tillage system, sorghum and soybean were rotated and three cover crops were used [crimson clover (*Trifolium incarnatum* L.), sunn hemp (*Crotalaria juncea* L.), and wheat (Triticum aestivum L.)] under no-tillage practices. Over multiple growing seasons (three for each crop), the effect of management and CO_2 level on leaf level gas exchange during row crop reproductive growth were evaluated. Findings were fairly consistent across years with higher photosynthetic rates being observed under high CO_2 (more so with soybean) regardless of management practice. Further, elevated CO_2 led to decreased stomatal conductance and transpiration, and increased water use efficiency. Results suggest that better soil moisture conservation and high rates of photosynthesis can occur in both tillage systems in CO_2-enriched environments during reproductive growth.
Key words: global change, conservation tillage, photosynthesis, transpiration.

INTRODUCTION and LITERATURE REVIEW

Over the last decade, numerous studies have demonstrated that elevated atmospheric CO_2 often enhances plant water use efficiency, net photosynthesis, and biomass production (Amthor, 1995). The effect of elevated CO_2 on crop residue production can influence soil C dynamics in agroecosystems (Rogers et al., 1999; Torbert et al., 2000). Furthermore, C dynamics can be altered by management practices (Kern and Johnson, 1993; Potter et al., 1998). There is a lack of information on how elevated CO_2 will interact with management practices, especially the newer ones being used in conservation systems. Systems that maintain high levels of residue can help mitigate problems by enhancing soil C storage and soil water holding capacity, reducing evaporative soil water loss, and improving soil water infiltration. Crop growth is often reduced under soil water deficits owing to decreases in photosynthesis, stomatal aperture, and water potential (Boyer, 1982) during critical reproductive stages when demand for water is high. The effect of elevated CO_2 in the field may depend on the crop species utilized; C_3 and C_4 crops such as soybean and sorghum represent two photosynthetic types which are known to respond differentially to elevated CO_2 both with regard to carbon metabolism and water use (Rogers et al., 1983b; Amthor, 1995).

In the current study, crops were grown in a large outdoor soil bin under two different atmospheric CO_2 environments (ambient and twice ambient) and management conditions (conventional tillage and no-tillage). The objective was to investigate the effect of management and CO_2 level on leaf level gas exchange during row crop (sorghum and soybean) reproductive growth over multiple growing seasons.

MATERIAL and METHOD

This study was initiated in the fall of 1997 using an outdoor soil bin (7m x 76 m) at the USDA-ARS National Soil Dynamics Laboratory in Auburn, Alabama, USA (Batchelor, 1984). A split-plot design replicated three times was used with two cropping systems (conventional and no-tillage) as main plots and two CO_2 levels (ambient and twice ambient) as subplots using open top field chambers (Rogers et al., 1983a) on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults).

In the conventional system, grain sorghum and soybean were rotated each year with spring tillage after winter fallow. In the no-tillage system, grain sorghum and soybean were also rotated, but with three winter cover crops (crimson clover, sunn hemp, and wheat) which were also rotated; all were grown without tillage. The wheat served as cover as well as being harvested for grain. Cover crops were broadcast planted while row crop seeds were planted on 0.38 m row spacing. Extension recommendations were used in managing the crops.

At final harvest, plants were removed and total fresh weights recorded. A subsample of the non-yield material (residue) was taken and its fresh weight recorded; the subsample was dried (55 ^{o}C) and total residue was calculated using the fresh weight to dry weight ratios (Prior et al., 2005). The remaining residue material was returned to each plot. For grain crops (sorghum, soybean, and wheat), yields were determined following correction for moisture. In the conventional system (after fallow period), weed dry weight was measured as described above and residue was returned to plots prior to tillage.

During reproductive growth, leaf level measurements [i.e., photosynthesis, stomatal conductance (data not shown), and transpiration) were made twice a week using a LI-6400 Portable Photosynthesis System (LI-COR, Inc., Lincoln, NE). Measurements were taken at midday on three different randomly chosen leaves (fully expanded, sun exposed leaves at the canopy top) per plot and were initiated at the start of reproductive growth. Soil water status was also monitored at two depths (20 and 40 cm) using time domain reflectometry (Topp et al., 1980), but only the 20 cm data are presented.

RESULTS and DISCUSSION

The rise in atmospheric CO_2 concentration may alter future responses. Past work has clearly shown that elevated atmospheric CO_2 often enhances plant biomass production and subsequently the amount of residue returned to the soil surface and belowground (Torbert et al., 2000). A review of the literature indicated that the fate of crop residue and soil carbon dynamics are highly influenced by management practices under current atmospheric CO_2 conditions (Kern and Johnson, 1993). Currently, there is a lack of information on how elevated CO_2 will interact with no-till management practices. Advantages of no-till management is that maintaining high levels of residue can help mitigate problems by enhancing soil C storage and soil water holding capacity, reducing evaporative soil water loss, and improving soil water infiltration.

Although previous work has shown that total residue inputs were higher under no-till, especially under elevated CO_2 conditions (Prior et al., 2005), the impact of no-till management on enhancing crop yields was small relative to conventional tillage in our study. Dry matter data across all seasons for both crops are shown in Figure 1. In general, benefits of no-till altering yield and stover production was more notable in sorghum compared to soybean. In comparison, the benefits of additional CO_2 was clearly evident in all years of study. Soybean exhibited a greater response to elevated CO_2 across all growing seasons relative to sorghum. The greater response of soybean to CO2 are in general agreement with reviews of the literature (Rogers et al., 1983b; Rogers and Dahlman, 1993; Amthor, 1995).

Likewise, management had little effect on gas exchange measurements reported here (Figs. 2 and 3). Response patterns to imposed treatment across the various years were consistent in that elevated CO_2 had a greater impact on reported measurement. C_3 and C_4 crops such as soybean and sorghum represent two photosynthetic types which are known to respond differentially to elevated CO_2 both with regard to carbon metabolism and water use (Rogers et al., 1983b; Amthor, 1995). Multiple years of observations in our study clearly illustrated this pattern of response. Seasonal averages indicated that elevated CO_2 increased soybean photosynthesis approximately 50% regardless of the management system used for all years. In comparison, sorghum photosynthesis increased about 15% across years for both systems. The photosynthetic field response of these two crops were in the range previously reported in a review by Rogers and Dahlman (1993). Soybean transpiration was more variable than photosynthesis. Elevated CO_2 decreased transpiration around 17% across years for both systems. Sorghum transpiration decreased more consistently—approximately 26%. Dugas et al. (1997) reported a CO_2-induced decrease in whole plant transpiration for soybean and sorghum in a field study using stem flow gauges. Overall, changes in photosynthesis and transpiration led to elevated CO_2-induced increases in water use efficiency of 86% for soybean and 51% for sorghum. These shifts in water use efficiency are in general agreement with reviews of the literature (Rogers et al., 1983b; Rogers and Dahlman, 1993; Amthor, 1995).

In general, management had little effect on gas exchange measurements. These results suggest that in a future CO_2-enriched environment better soil moisture conservation and high rates of photosynthesis can lead to increased productivity in both conventional and conservation tillage systems.

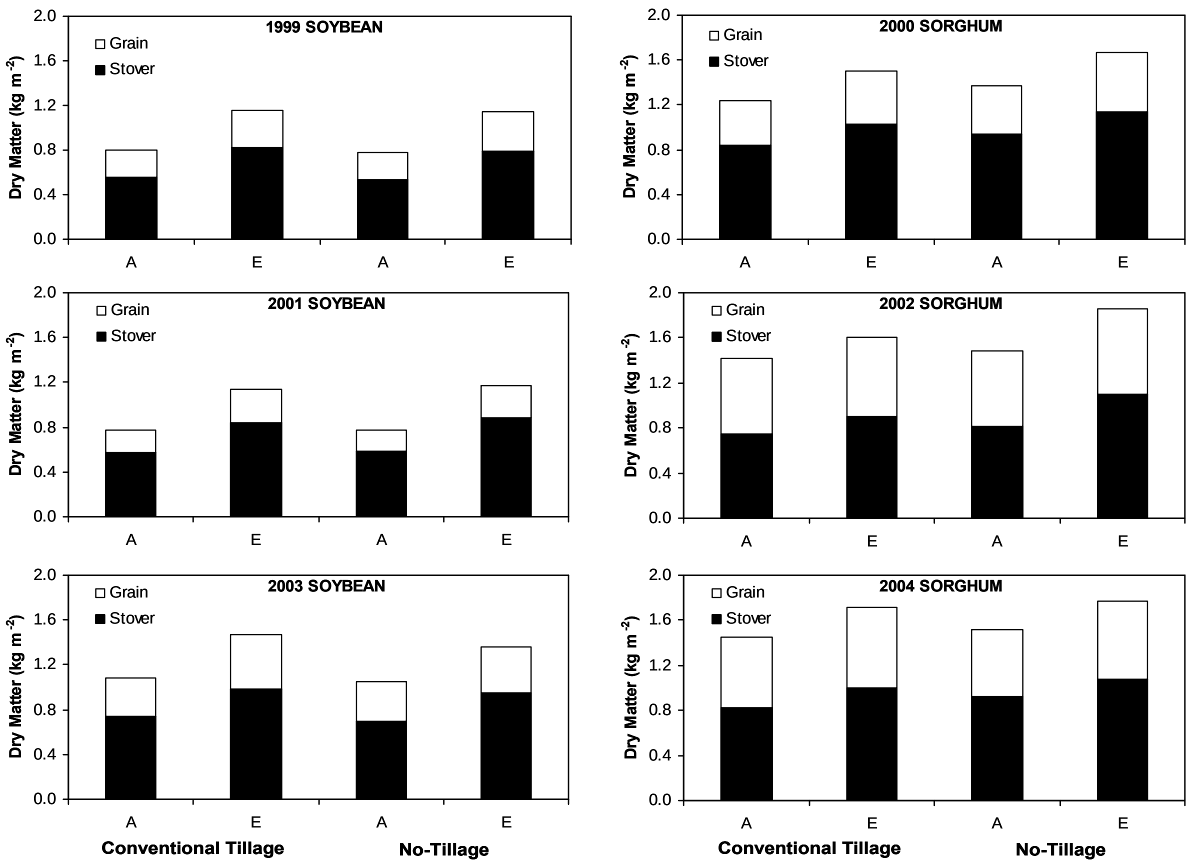

Figure 1. Dry production (stover and grain) for soybean (1999, 2001, 2003) and sorghum (2000, 2002, 2004) under ambient (A) and elevated (E) atmospheric CO2 conditions and two management systems (conventional tillage and no-tillage) are shown.

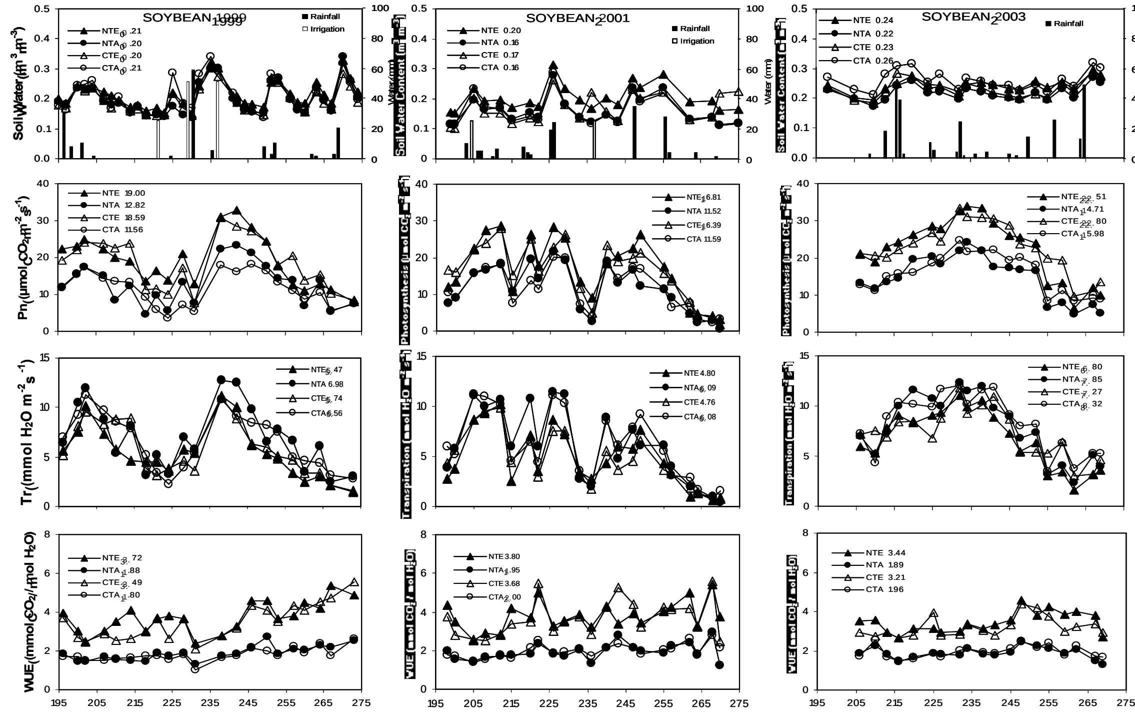

Figure 2. Three seasons (1999, 2001, 2003) of gas exchange measures (Pn=photosynthesis; Tr=Transpiration; WUE= water use efficiency) during reproductive growth for soybean grown under conventional tillage (CT) or no-tillage (NT) and exposed to ambient (A) or elevated (E) atmospheric CO2; means within graphs are seasonal averages. Corresponding seasonal rainfall and volumetric soil water measurements are also shown.

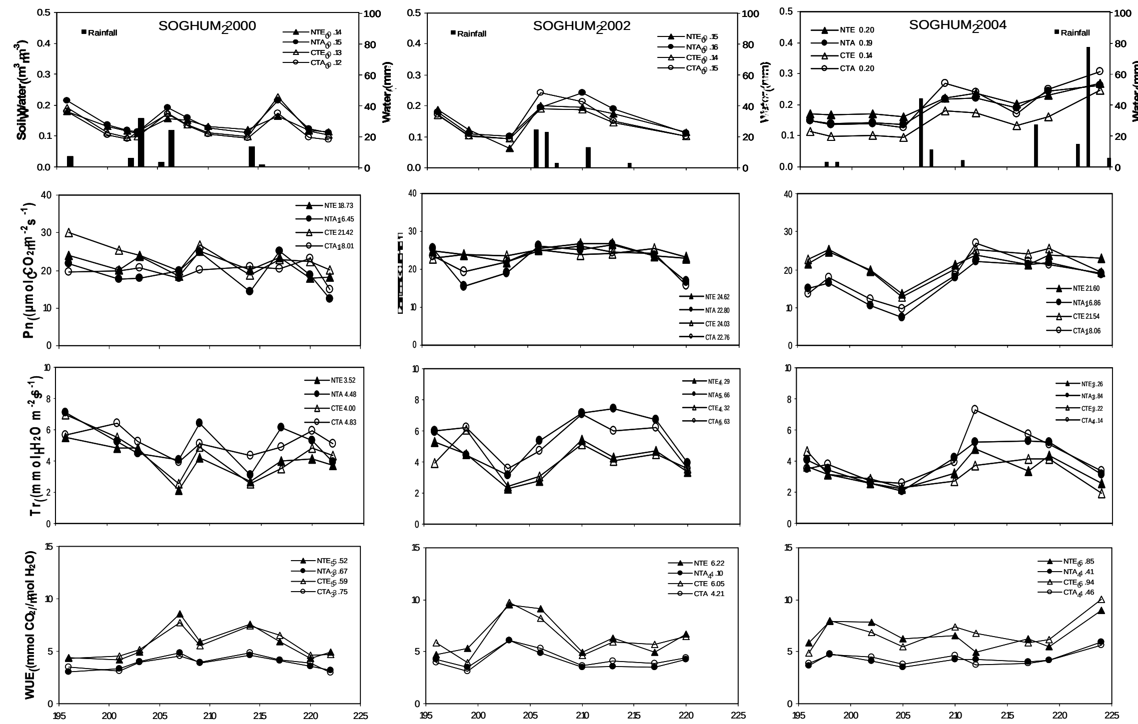

Figure 3. Three seasons (2000, 2002, 2004) of gas exchange measures (Pn=photosynthesis; Tr=Transpiration; WUE= water use efficiency) during reproductive growth for sorghum grown under conventional tillage (CT) or no-tillage (NT) and exposed to ambient (A) or elevated (E) atmospheric CO2; means within graphs are seasonal averages. Corresponding seasonal rainfall and volumetric soil water measurements are also shown.

ACKNOWLEDGMENTS The authors thank B.G. Dorman and J.W. Carrington for technical assistance. This research was supported by the Biological and Environmental Research Program (BER), U.S. Department of Energy, Interagency Agreement No. DE-AI02-95ER62088.

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