Effects of Elevated Atmospheric CO\textsubscript{2} on Biomass Production and C Sequestration: Conventional and Conservation Cropping Systems

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Abstract: Increasing atmospheric CO\textsubscript{2} concentration may impact production agriculture’s role in sequestering carbon (C). This study was initiated (fall 1997) to compare the effects of elevated CO\textsubscript{2} on two cropping systems (conventional and conservation). The experiment was a split-plot design replicated three times with two cropping systems as main plots and two CO\textsubscript{2} levels (ambient and twice ambient) as subplots using open top field chambers on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults). The conventional system consisted of a grain sorghum \textit{[Sorghum bicolor (L.) Moench.]} and soybean \textit{[Glycine max (L.) Merr.]} rotation using conventional tillage practices and winter fallow. In the conservation system, sorghum and soybean were rotated and three cover crops (also rotated) were used [crimson clover \textit{(Trifolium incarnatum L.)}, sunn hemp \textit{(Crotalaria juncea L.)}, and wheat \textit{(Triticum aestivum L.)}] using no-tillage practices. The conservation system had either cash or cover crops grown throughout the year with no fallow periods (in order of: clover, sorghum, sunn hemp, wheat, and soybean). Biomass responses over two complete 2-year cropping cycles (total of 4 years) and the effect of these two contrasting management systems on C sequestration were evaluated. In the conservation system, cover crop residue production (clover, sunn hemp, and wheat) was increased by high CO\textsubscript{2}, but CO\textsubscript{2} effects on weed residue were variable in the conventional system. Elevated CO\textsubscript{2} had a greater effect on increasing soybean residue compared to sorghum. Grain yield increases due to added CO\textsubscript{2} were greater for soybean followed by wheat and sorghum. Differences in sorghum and soybean residue production within the different management systems were small and variable. Cumulative non-yield residue inputs (both 2 yr cycles) were increased by elevated CO\textsubscript{2} and conservation management. Greater inputs resulted in a substantial increase in soil C concentration at the 0-5 cm depth increment in the conservation system under CO\textsubscript{2}-enriched conditions. Conservation management increased soil C concentration at lower depths (5-10 and 15-30 cm) and CO\textsubscript{2}-induced increases also occurred at the 5-10 cm depth (similar trend at 15-30 cm) in both management systems. Results suggest that with conservation management in a high CO\textsubscript{2} environment, greater amounts of crop residue could increase soil C storage as well as increase ground cover, improve water infiltration and soil water retention, and reduce erosion.

Key words: C sequestration, cover crops, conservation tillage, grain crops, soil carbon

INTRODUCTION

The global atmosphere is changing as evidenced by the well documented rise in atmospheric CO\textsubscript{2} concentration, which is expected to continue (Keeling and Whorf, 1994). This global rise can be attributed to fossil fuel burning, land use change associated with population growth, and industrial expansion (Houghton \textit{et al.}, 1992). Since CO\textsubscript{2} is a primary input to crop growth, there is interest in how this rise in CO\textsubscript{2} will impact highly managed agricultural systems.

Over the last decade, numerous studies have demonstrated that elevated atmospheric CO\textsubscript{2} can result in greater biomass production (Amthor, 1995). The effect of elevated CO\textsubscript{2} on the amount of crop residues can influence soil C dynamics in agroecosystems (Rogers \textit{et al.}, 1999; Torbert \textit{et al.}, 2000). Furthermore, soil C storage can be altered by management practices (e.g., fertility practices, tillage methods, and cropping systems including cover crops) (Kern and Johnson, 1993; Potter \textit{et al.}, 1998).
There is, however, a lack of information on how elevated CO₂ will interact with management practices, especially the newer ones being used in conservation systems. Such information is needed to accurately predict shifts in biomass productivity that will impact soil C storage patterns under different residue management schemes. The capability of soil to act as a sink for C storage in CO₂-enriched agroecosystems is a highly relevant issue since the potential for C storage in agricultural soils is of special interest in the current climate change policy debate.

In the current study, crops were grown in a large outdoor soil bin under two different atmospheric CO₂ environments (ambient and twice ambient CO₂ levels) and management conditions (conventional tillage and conservation tillage). The objective was to investigate the effects of increased CO₂ level on biomass production and soil C storage patterns for these different management systems.

MATERIALS AND METHODS

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 conservation) as main plots and two CO₂ levels (365 and 720 ~L/L) as subplots using open top field chambers (Rogers et al., 1983) on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults).

This report covers two of three, two-year cycles in an ongoing 6-year study comparing two management systems. In the conventional system, grain sorghum and soybean were rotated each year with spring tillage after winter fallow. In the conservation 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 using "no-tillage" practices. 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 spacings. Extension recommendations were used in managing the crops; fertilizer rates were based on standard soil tests.

At final harvest, all 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°C) and total residue was determined by calculation using the fresh weight to dry weight ratio for each plot. The remaining residue material was returned to each plot. For grain crops (sorghum, soybean, and wheat), fresh weights and grain moisture of threshed grain were determined; total yields were determined following correction for moisture. In the conventional system (following the fallow period), aboveground weed dry weight was measured as described above and residue was returned to plots prior to tillage.

Soil samples were collected (4 cores per plot) at the end of the second cropping cycle (4th year) using procedures as described by Prior and Rogers (1992). Cores (3.8 cm diameter) were partitioned into 0-5, 5-10, 10-15, 15-30, and 30-40 cm depth increments, sieved (2 mm), and oven dried (55 °C). Subsamples were ground to pass a 0.15 mm sieve and analysed for total C and total N on a LECO CN 2000 (LECO Corp., Saint Joseph, MI). Statistical analyses were performed using mixed model procedures (Proc Mixed) of the Statistical Analysis System (Littell et al. 1996). A significance level of P < 0.10 was established a priori.

RESULTS

As expected, positive biomass responses to CO₂ enrichment were often noted in the first cropping cycle (Figure 1). This cycle began with an evaluation of clover (conservation system) and weed (conventional system) production prior to sorghum planting. A significant CO₂ x management interaction was noted; elevated CO₂ increased clover residue production by 23%, but had no detectable impact on the weeds. The following sorghum crop was unaffected by management; however, the main effect of CO₂ was significant and residue production was increased by ~14%. Sorghum grain

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yield was not affected by CO$_2$ level. Yield was slightly increased (6%) due to conservation management. The following legume cover crop, sunn hemp, was used to fill a two month gap which is usually left fallow until wheat planting. Elevated CO$_2$ resulted in a 32% increase in sunn hemp residue in the conservation system, but there was no weed production in the conventional system due to previous herbicide application. At the next sampling, significant main effects of CO$_2$ and management indicated that high CO$_2$ increased residue production and that the conservation system produce more residue (wheat) compared to the conventional system (weeds). Wheat grain yield was increased (32%) by high CO$_2$. For soybean, significant main effects of CO$_2$ and management were also noted. Elevated CO$_2$ increased soybean residue (49%) and grain production (40%), but conservation management only resulted in a small increase in residue (4%) and grain (6%).

In the second cropping cycle (Figure 2), a significant CO$_2$ x management interaction was also noted; elevated CO$_2$ increased production of clover residue by 22%, but had no impact on weeds. For sorghum, the main effects of CO$_2$ and management were significant for residue and grain production. Elevated CO$_2$ increased sorghum residue (24%) and grain (22%), while conservation management resulted in ~13% increase in these variables. Elevated CO$_2$ resulted in a 61% increase in sunn hemp residue in the conservation system, but there was no weed production in the conventional system due to previous herbicide application. As observed in the first cycle for wheat, significant main effects of CO$_2$ and management indicated that high CO$_2$ increased residue production and that the conservation system produced more residue (wheat) compared to the conventional system (weeds). For soybean, significant main effects of CO$_2$ and management were noted for residue production. Elevated CO$_2$ increased soybean residue by 49%. Conservation management resulted in a small (9%) decrease in residue. For soybean grain, only the main effect of CO$_2$ was significant; elevated CO$_2$ increased grain yield by 52%.

Cumulative non-yield residue inputs to the soil were increased by elevated CO$_2$ and the use of conservation management (Figs. 1F and 2F). Across both cropping cycles, CO$_2$ level increased cumulative residue production by ~30% regardless of management practice. Use of conservation practices led to an increase in cumulative residue production of ~90% (both 2 yr cycles). Increases in cumulative inputs resulted in changes in soil C and N concentration (Figure 3); changes in soil N concentration followed a similar pattern as observed with soil C concentration over the depth increments evaluated. The most notable difference attributable to management practice was observed at the top depth increment (0-5 cm). Clearly, increased inputs combined with lack of tillage (conservation management) resulted in a higher soil C concentration. A significant CO$_2$ x management interaction was noted for the surface increment, 0-5 cm. In this case, a dramatic increase in soil C concentration (44%) occurred in the conservation treatment under CO$_2$ enrichment. The mean for the elevated CO$_2$-conventional treatment was higher, but not significant. The main effects of CO$_2$ and management were significant for other depth increments. Conservation management increased soil C concentration at lower depths (5-10 and 15-30 cm) and CO$_2$-induced increases also occurred at the 5-10 cm depth (similar trend at 15-30 cm). Results suggest that in a high CO$_2$ environment, crop residue could increase soil C storage. However, the potential to store soil C will be greater in conservation systems compared to conventional.
Figure 1. Biomass production (residue and/or grain) for weeds/clover (A), sorghum (B), sunn hemp (C), weeds/wheat (D), soybean (E), and total residue inputs (F) under ambient and elevated CO₂ conditions and two management systems (conventional and conservation) for the first 2-year cropping cycle are shown.

Figure 2. Biomass production (residue and/or grain) for weeds/clover (A), sorghum (B), sunn hemp (C), weeds/wheat (D), soybean (E), and total residue inputs (F) under ambient and elevated CO₂ conditions and two management systems (conventional and conservation) for the second 2-year cropping cycle are shown.
CONCLUSIONS

Aboveground biomass production was often stimulated by elevated atmospheric CO₂ and conservation management. Increased amounts of cover crop residue production can be expected under CO₂ enrichment in conservation systems. But, the variable response of weeds to CO₂ in the conventional system indicates that further work is required to clarify management implications. Rising CO₂ levels can be expected to increase soybean residue more than that of sorghum. Likewise, yield will likely be increased (due to high CO₂) for soybean followed by wheat and sorghum. Differences in residue production (for both sorghum and soybean) between management systems may not be great under elevated CO₂. Cumulative residue production is likely to be increased by CO₂ enrichment and conservation management. Larger residue inputs were associated with increased soil C and vertical stratification of C within the soil profile. These results indicate that in a future elevated CO₂ world, agroecosystems could potentially store more C, especially with conservation management. Furthermore, results suggest that with conservation management in a high CO₂ environment, greater amounts of crop residue will increase ground cover (thereby improving water infiltration and soil water retention, and reducing soil erosion). Future efforts will assess CO₂ effects on other belowground processes in these management systems; soil C content, root dynamics (minirhizotrons), distribution of nutrients in the soil profile, soil water holding capacity, and soil physical properties (e.g. water stable aggregates, hydraulic conductivity, and bulk density) will be considered.
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References