DOI: 10.1007/s00267-003-9143-0

Elevated Atmospheric CO_2 in Agroecosystems: Residue Decomposition in the Field

STEPHEN A. PRIOR*
H. ALLEN TORBERT
G. BRETT RUNION
HUGO H. ROGERS
National Soil Dynamics Laboratory
US Department of Agriculture-Agricultural Research Service,
411 South Donahue Drive
Auburn 36832, Alabama, USA

ABSTRACT / Elevated atmospheric CO_2 concentration can increase biomass production and alter tissue composition. Shifts in both quantity and quality of crop residue may alter carbon (C) and nitrogen (N) dynamics and management considerations in future CO_2-enriched agroecosystems. This study was conducted to determine decomposition rates of the legume soybean [*Glycine max* (L.) Merr.] and nonlegume grain sorghum [*Sorghum bicolor* (L.) Moench.] residue produced under two levels of atmospheric CO_2 (ambient and twice ambient) on a Blanton loamy sand (loamy siliceous, thermic, Grossarenic Paleudults) in Auburn, Alabama, USA, managed using no-till practices. At maturity, harvested plants were separated into component parts for dry weight determination and tissue analysis. Mass, C, and N losses from residues were determined using the mesh bag method. Biomass production was significantly greater for soybean compared to sorghum and for elevated versus ambient CO_2-grown plants. The CO_2 level had little affect on the C/N ratio of residue (probably because the tissue used was senesced). Elevated CO_2 concentration did not affect percent residue recovery; however, greater biomass production observed under elevated CO_2 resulted in more residue and C remaining after overwintering. The higher total N content of soybean residue, particularly when grown under elevated CO_2, indicated more N may be available to a following crop with lower N inputs required. Results suggest that in a high CO_2 environment, greater amounts of residue may increase soil C and ground cover, which may enhance soil water storage, improve soil physical properties, and reduce erosion losses.

The global rise in atmospheric CO_2 concentration (Keeling and Whorf 1994) has raised questions concerning the dynamics of carbon (C) in terrestrial ecosystems (Houghton and others 1990, 1992). Studies have demonstrated that CO_2 enrichment can increase aboveground (Kimball 1983, Rogers and Dahlman 1993, Wittwer 1995, Kimball and others 2002) and belowground biomass production (Prior and others 1994, Rogers and others 1994) and induce changes in residue quality (Amthor 1995, Poorter and others 1997, Torbert and others 2000, Norby and Cotrufo 1998). Lower tissue nitrogen (N) concentration in conjunction with other shifts in the chemical makeup of plant tissue (e.g., lignin) due to high CO_2 can be important factors influencing residue C and N dynamics in highly managed agricultural systems (Torbert and others 2000). However, the impact of these CO_2-induced changes on residue decomposition can be species dependent (Wood and others 1994, Torbert and others 1995, 1998, Prior and others 1997b); differential changes in the quantity and quality of plant tissue may affect nutrient turnover and soil C storage as well as soil properties. Consideration of these factors along with farm residue management practices may become important in predicting future soil C dynamics in agroecosystems (Follett 1993, Kern and Johnson 1993, Potter and others 1998, Lal and others 1998a). This will be especially true as more farms adopt conservation tillage systems that not only promote more soil C sequestration (Follett 1993, Kern and Johnson 1993, Paustian and others 1997, Lal and others 1998b), but can also improve soil structure (Blevins and others 1984, Campbell and Zentner 1993) and water storage (Hudson 1994) while decreasing erosional losses (Unger and McCalla 1980, Phillips and others 1980, Griffith and others 1986). The fate of residue C in CO_2-enriched agroecosystems is a highly relevant issue since the potential for C storage in agricultural systems is of special interest in the current climate change policy debate.

Improved predictions on how changes in the global environment will impact agroecosystems will depend on obtaining realistic field data. More CO_2 research with major crops is required to accurately determine if shifts in the quantity and quality of residue will influence decomposition processes in highly managed agricultural systems. Furthermore, the amount of crop res-

KEY WORDS: Global change; Soybean; Sorghum; Litter; Leaves; Stems; Roots

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*Author to whom correspondence should be addressed, *email:* sprior@acesag.auburn.edu idue left in the field may depend on the differential response of crop species to CO_2 level. In the current study, soybean (a N-fixing C_3 crop) and grain sorghum (a C_4 crop) were grown outdoors under two atmospheric CO_2 concentrations; these two photosynthetic types are known to respond differently to elevated CO_2 both with regard to C metabolism and water use (Rogers and others 1983b, Amthor 1995, Drake and Gonzalez-Meler 1997, Dugas and others 1997). The study design allows for a direct statistical comparison of the decomposition of C_3 and C_4 crop residue (produced under elevated CO_2 conditions) using the mesh bag method during an overwintering period in the field.

Materials and Methods

Soybean (Stonewall) and grain sorghum (Savanna 5) were selected to provide legume and nonlegume test crops that are widely produced (FAO 1996). Plants were grown from seed to maturity in open top field chambers (Rogers and others 1983a) at two atmospheric CO_2 concentrations (360 and 720 $\mu l\ l^{-1}$). The experiment was conducted on a soil bin (Batchelor 1984) located at the USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama, USA (32.6°N, 85.5°W); the soil was a Blanton loamy sand (loamy, siliceous, thermic Grossarenic Paleudult) that had been fallow for over 25 years. This fallow period was followed by three seasons of soybean and sorghum grown under no-tillage conditions. Here we report results of a litter bag study using senescent crop residue collected at the of end of the third growing season.

The experiment was conducted using a split-plot design with three replicate blocks. Whole-plot treatments (crop species) were randomly assigned to half of each block. Subplot treatments (CO_2 levels) were randomly assigned to two chambers (3 m diameter) within each whole plot. Statistical analyses of data were performed using the Mixed procedure of the Statistical Analysis System (Littell and others 1996). A significance level of $P < 0.10$ was established a priori.

The open-top field chambers were constructed of a structural aluminum frame (3 m diameter × 2.4 m high) covered with a PVC film panel (0.2 mm thickness) similar to those described in detail by Rogers and others (1983a). Carbon dioxide was supplied from a 12.7 Mg liquid CO_2 receiver through a high volume dispensing manifold and the atmospheric CO_2 concentration was elevated by continuous injection of CO_2 into plenum boxes. Air was introduced into each chamber through the bottom half of each chamber cover, which was double-walled; the inside wall was perforated with 2.5-cm-diameter holes to serve as ducts to distribute air uniformly into the chamber. Three chamber volumes were exchanged every minute. Carbon dioxide concentrations were continually monitored (24 hr day^{-1}) using a time-shared manifold with samples drawn through solenoids to an infrared CO_2 analyzer (Model 6252, Li-Cor, Inc., Lincoln, Nebraska, USA). Values were continuously recorded every 15–30 min for each chamber, depending upon whether or not an additional CO_2 study was on line.

Soybean seeds were inoculated with commercial *Rhizobium* (Lipha Tech, Inc., Milwaukee, Wisconsin, USA) and seeds were sown in 6-m rows oriented across the width of the soil bin. The distance between rows was 0.76 m. Plants were thinned for uniformity to a final density of 30 or 26 plants m^{-2} for soybean and sorghum, respectively. To ensure adequate plant establishment, fertilizer N was broadcast at a rate of 34 kg N ha^{-1} shortly after planting. In the grain sorghum, an additional 67 kg N ha^{-1} was applied 30 days after planting. All plots received ambient rainfall and were irrigated only when necessary to prevent drought-induced mortality; a drip irrigation system was used to uniformly distribute water throughout the bin. Weed control was done by hand and/or by use of glyphosate (N-[phosphonomethyl] glycine).

Plots were harvested at maturity for determination of dry mass production. Subsamples of leaves, stems, and roots for the litter bag study were separated, dried (55° C), and shredded (< 7.5 cm size). The remaining material, including 10% (by weight) of the seed yield, was added back to the appropriate study plots to simulate normal farm operations. Following the final harvest, chambers were removed but their locations remained fixed and were delineated by permanent 3-m aluminum rings. Bird netting (1.6-cm × 1.9-cm openings; Dalen Products, Inc., Knoxville, Tennessee, USA) was placed over the entire soil bin to prevent movement of aboveground residue into or out of plots.

Nylon litter bags (15 × 20 cm with a 1-mm mesh) were filled with either leaf, stem (10 g), or root residue (4 g). In October, seven bags of each residue type were randomly placed within each plot. Leaf and stem bags were placed on the soil surface while root bags were placed in the plow layer. One bag of each residue type was collected two weeks after placement and on a monthly basis thereafter; the last sample was collected in May prior to planting the next crop. Dry weights (55°C) of residue from bags were determined, and all weights were corrected for soil contamination by the ash procedure (450°C for 24 hr). The initial residue material was ground (0.2 mm mesh) and analyzed for lignin (Runion and others 1999); initial residue and residue of each part at each sampling were also analyzed for N and C using a LECO CHN-600 carbon/nitrogen analyzer (Leco Corp., Augusta, Georgia, USA).

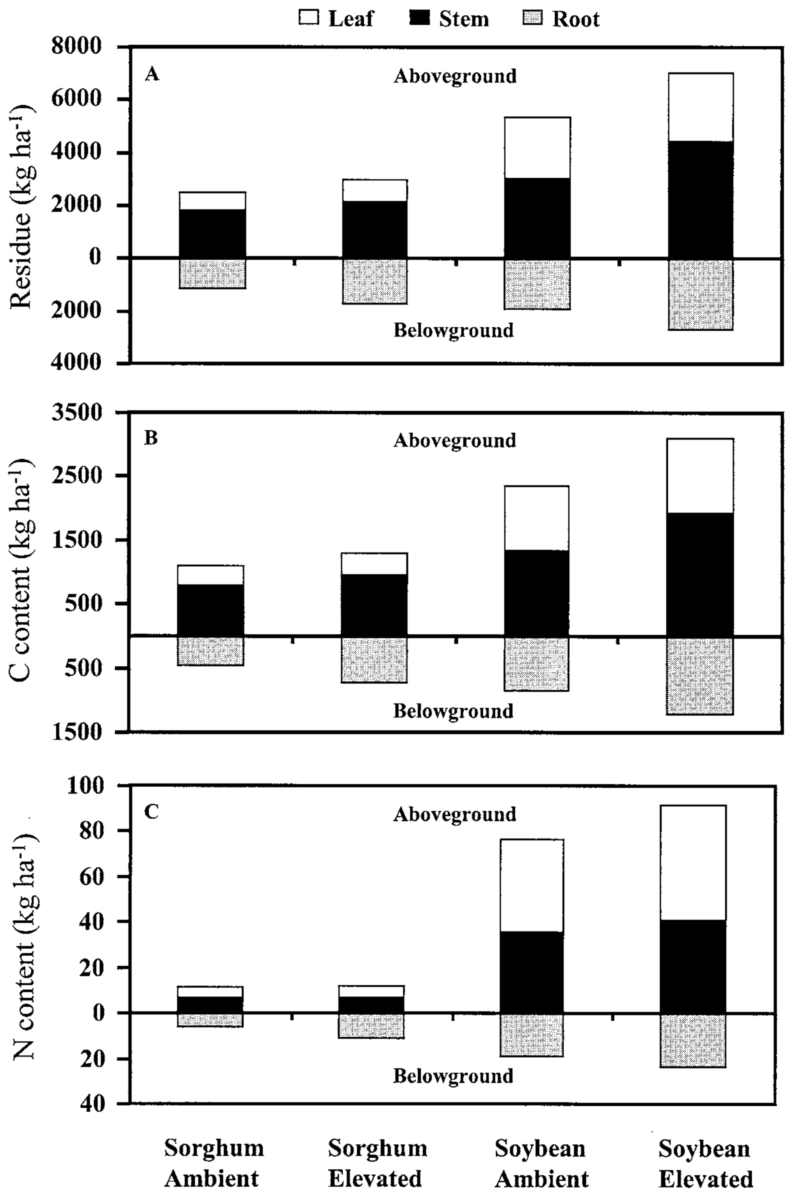

Figure 1. Leaf, stem, and root residue mass (A), total C content (B), and total N content (C) at grain maturity for ambient and elevated CO_2-produced soybean and sorghum.

Results

Residue Production

Significant main effects of crop species for leaf ($P =$ 0.001), stem ($P <$ 0.0001), and root ($P =$ 0.050) parts indicated that the mass of all soybean residues was greater than respective sorghum residue parts (Figure 1A). For leaf residue, a significant CO_2 species interaction was noted (P = 0.091); there was a significant percentage increase in leaf residue for the C_3 soybean ($P =$ 0.007) and a trend for increase for C_4 sorghum (P = 0.116) under CO_2 enrichment. A significant CO_2 species interaction also occurred for stem residue ($P =$ 0.0001); there was a greater percentage increase in stem residue for soybean (46%) relative to sorghum (18 %) under CO_2-enriched conditions. For roots, both crops responded to changing CO_2 levels in similar ways (P = 0.01); no CO_2 species interaction was detected. Under elevated CO_2, soybean root mass was increased by 55% and sorghum by 42%.

Initial Residue Analysis

Analysis of crop material used for litter bags indicated that N and C contents of soybean residues were higher than sorghum residues, but CO_2 effects were more variable (Figure 1 B and C). For leaf residue N

Table 1. Effect of atmospheric CO$_2$ concentration on leaf, stem, and root residue C/N ratio and lignin for sorghum and soybean at the maturity harvest[a]

Treatment[b]	Leaf C/N	Leaf lignin (mg/g)	Stem C/N	Stem lignin (mg/g)	Root C/N	Root lignin (mg/g)
Ambient SG	63.1	153.2	118.6	131.1	77.6	187.7
Elevated SG	71.8	146.8	137.6	143.7	65.0	183.8
Ambient SB	24.8	135.0	43.6	185.6	45.8	227.4
Elevated SB	22.7	154.5	48.0	198.5	52.0	233.9
Significance levels						
Species	0.0001	0.510	0.012	<0.0001	0.007	0.011
CO$_2$	0.269	0.279	0.240	0.014	0.624	0.871
CO$_2$ species	0.094	0.071	0.439	0.969	0.170	0.774

[a] Means and probabilities shown. [b] Carbon dioxide treatments were ambient (360 µl/liter) and elevated (720 µl/liter). Crop species were soybean (SB) and sorghum (SG).

content, the main effects of CO$_2$ ($P < 0.0001$) and crop species were significant ($P = 0.002$). A significant CO$_2$ species interaction was also noted ($P = 0.002$); only the soybean leaf N content was increased by CO$_2$ enrichment. The N content of soybean stem residue was significantly greater than sorghum ($P = 0.001$), but no main effect of CO$_2$ or interaction was noted. For root residue, the main effect of crop species ($P = 0.035$) and CO$_2$ were significant ($P = 0.018$); no CO$_2$ species interaction was detected. Soybean root N content was higher than sorghum, and roots of both crops exhibited increases in N content due to CO$_2$ enrichment. For residue C content, significant species effects were noted for leaf ($P < 0.0001$), stem ($P < 0.0001$), and roots ($P = 0.035$); the C content was higher for soybean residues. For this same variable, the main effect of CO$_2$ was significant for leaf ($P < 0.0001$), stem ($P = 0.0001$), and roots ($P = 0.017$). In all cases, soybean residue C content was higher than sorghum, and residues of both crops exhibited higher C content due to CO$_2$ enrichment. No CO$_2$ species interactions occurred for this variable.

Residue C/N ratio and lignin data indicated differences between crop species while the effect of CO$_2$ was less common (Table 1). For C/N ratio, the main effects of species were significant for all residue types; C/N ratio of soybean residues was always lower than sorghum residues. No significant main effects of CO$_2$ were seen, but a CO$_2$ species interaction was noted with leaf residue; only the sorghum C/N ratio was increased by elevated CO$_2$. For lignin, the main effects of species were significant for stem and root residues; values for these same soybean residues were higher than those of sorghum. The main effect of CO$_2$ was only significant for stem residue, suggesting that lignin for both crops had increased under elevated CO$_2$. There was a significant CO$_2$ species interaction with leaf residue; lignin in the soybean leaf component was increased under high CO$_2$.

Treatment Effects on Residue Mass Recovery

Generally, lower percentages of leaf and higher percentages of stem and root residue were recovered for soybean relative to sorghum during the course of this study (Figure 2). Percent recovery of leaf residue was often significantly influenced by crop species ($P = 0.006$–0.03) except for the first sampling date ($P = 0.14$; Figure 2A). Leaf residue recovery was affected by CO$_2$ concentration in a few cases (8 weeks, $P = 0.097$; 24 weeks, $P = 0.004$); at both periods, a higher percentage of leaf residue was recovered from the elevated CO$_2$ treatment. At two sample periods (4 and 12 weeks), a significant CO$_2$ species interaction ($P = 0.067$ and 0.012, respectively) was noted; a higher percentage of soybean leaf residue from the elevated CO$_2$ treatment was recovered at 4 weeks ($P = 0.083$), whereas more CO$_2$-enriched sorghum leaf residue was recovered at 12 weeks ($P = 0.013$).

For stem residue, percent recovery was significantly influenced by crop species ($P = 0.001$–0.043), except for week 20, where a similar trend was seen ($P = 0.106$; Figure 2B). Overall, percent recovery of stem residue was greater for soybean compared to sorghum. Percent recovery of stem residue was not significantly influenced by CO$_2$ level, nor were any significant CO$_2$ species interactions detected during the study.

Like other tissue types, the main effect of crop species was usually significant for percent recovery of root residue ($P = 0.001$–0.075) except at 4 weeks ($P = 0.126$; Figure 2C). As noted with stems, percent recovery of root residue was greater for soybean compared to sorghum. Root residue recovery was affected by CO$_2$ concentration at a few sample periods (4 weeks, $P = 0.068$; 8 weeks, $P = 0.035$; 20 weeks, $P = 0.071$) and at

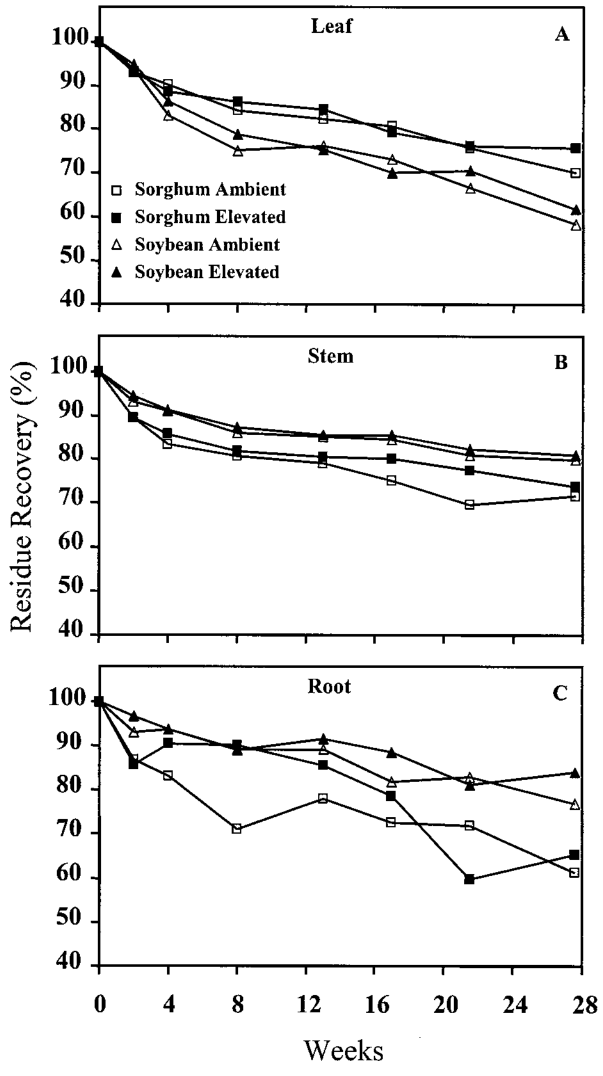

Figure 2. Percent recovery of mass from ambient and elevated CO_2-produced soybean and sorghum leaf (A), stem (B), and root (C) residue during during an overwintering period.

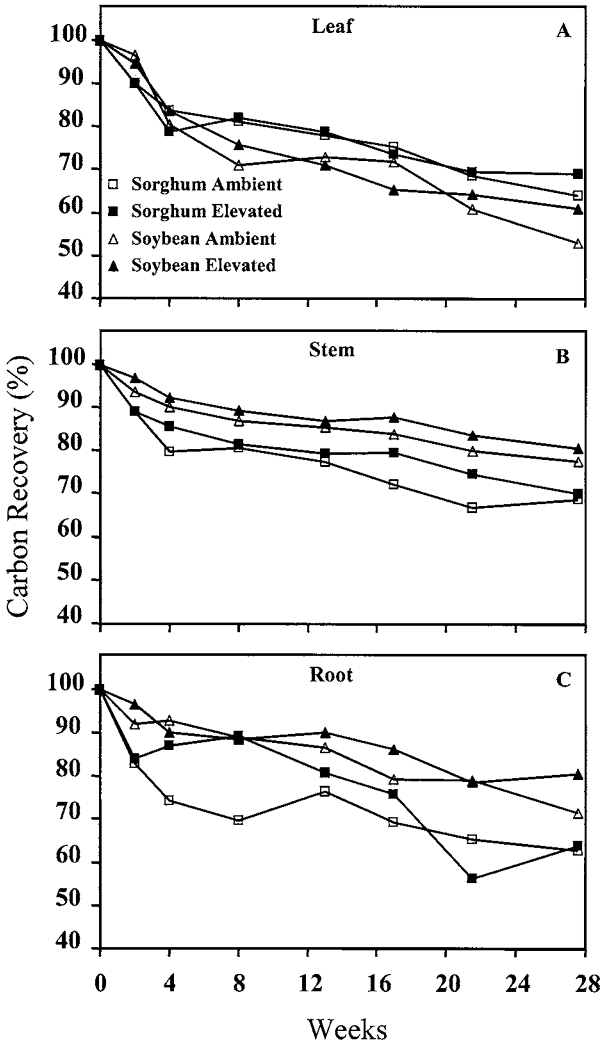

Figure 3. Percent recovery of carbon from ambient and elevated CO_2-produced soybean and sorghum leaf (A), stem (B), and root (C) residue during an overwintering period.

two of these periods (4 and 8 weeks), a significant CO_2 species interaction (P = 0.076 and 0.031, respectively) occurred. In these cases, a higher percentage of sorghum root residue from the elevated CO_2 treatment was recovered at both the 4-week (P = 0.026) and 8-week (P = 0.007) sample periods. At 20 weeks, a lower percentage of root residue was recovered from the elevated CO_2 treatment.

Treatment Effects on Residue Carbon Recovery

Percent C recovery from the three residues types followed somewhat similar patterns as observed with percent residue recovery, but treatment effects were more variable (Figure 3). At three sampling dates (weeks 8, 12, and 28), the percent recovery of leaf C was significantly influenced by crop species ($P < 0.0001$–0.085; Figure 3A). In these cases, less leaf C was recovered from soybean relative to sorghum residue. Leaf C recovery was only affected by CO_2 at the last sampling period (28 weeks, $P < 0.0001$); a higher percentage of leaf C was recovered from the elevated CO_2 treatment. For this variable, no significant CO_2 x species interaction was observed.

For stem residue, percent C recovery was often significantly influenced by crop species (P = 0.003–0.092) except for week 8 where a similar trend was noted (P = 0.107; Figure 3B). Overall, percent recovery of C from stem residue was greater for soybean compared to sorghum. Percent recovery of stem residue was significantly affected by CO_2 level at 16 weeks ($P = 0.032$), and a similar trend ($P = 0.101$) was noted at 4 weeks; at both dates a higher percentage of stem C was recovered from the elevated CO_2 treatment. For this variable, no significant CO_2 species interaction was seen.

The main effect of crop species was significant for percent recovery of C from root residue ($P = 0.001$–0.081) except at 2 ($P = 0.118$) and 8 weeks ($P = 0.218$; Figure 3C). As noted with stem C, percent recovery of root C was greater for soybean relative to sorghum. The main effects of CO_2 were not significant at any date. However, a significant CO_2 species interaction was noted at 4 weeks ($P = 0.098$). In this case, a higher percentage of sorghum root C was found from the elevated CO_2 treatment; a similar trend was also observed at 8 weeks.

Treatment Effects on Residue Nitrogen Recovery

Percent recovery of N from leaf residue was significantly influenced by crop species at a few sample periods (4 and 24 weeks); a higher percentage of soybean leaf N was recovered at 4 weeks ($P = 0.045$), whereas more sorghum leaf N was recovered at 24 weeks ($P = 0.039$; Figure 4A). In general, percent N recovery from leaf residue declined initially before leveling off (~80%). Percent recovery of N from leaf residue was not affected by CO_2 and there was no notable CO_2 species interaction.

For stem residue, percent N recovery was often significantly affected by crop species ($P = 0.001$–0.067) except for week 8 ($P = 0.16$; Figure 4B). Overall, percent recovery of N from stem residue was greater for sorghum than soybean. In general, soybean stem N recovery declined before leveling off (~50%) while sorghum stem N recovery varied throughout the study and remained relatively high (~90%). Overall, the main effects of CO_2 and CO_2 species interaction were not significant.

Percent recovery of N from root residue was variable, and few species effects were noted (8 weeks, $P = 0.058$; Figure 4C). In this case, percent recovery of N from root residue was greater for soybean than sorghum. In general, values declined initially before leveling off (~70%). For the most part, CO_2 level had little affect on N recovery. The main effects of CO_2 were not significant at any date. Nevertheless, significant CO_2 species interactions were noted at 8 ($P = 0.071$), 16 ($P = 0.046$), and 20 ($P = 0.060$) weeks. A lower percentage of sorghum root N was found in under elevated CO_2 at 8 ($P = 0.067$) and 20 ($P = 0.063$) weeks, whereas at 16 weeks, N recovery from soybean residue was higher under elevated CO_2 ($P = 0.083$).

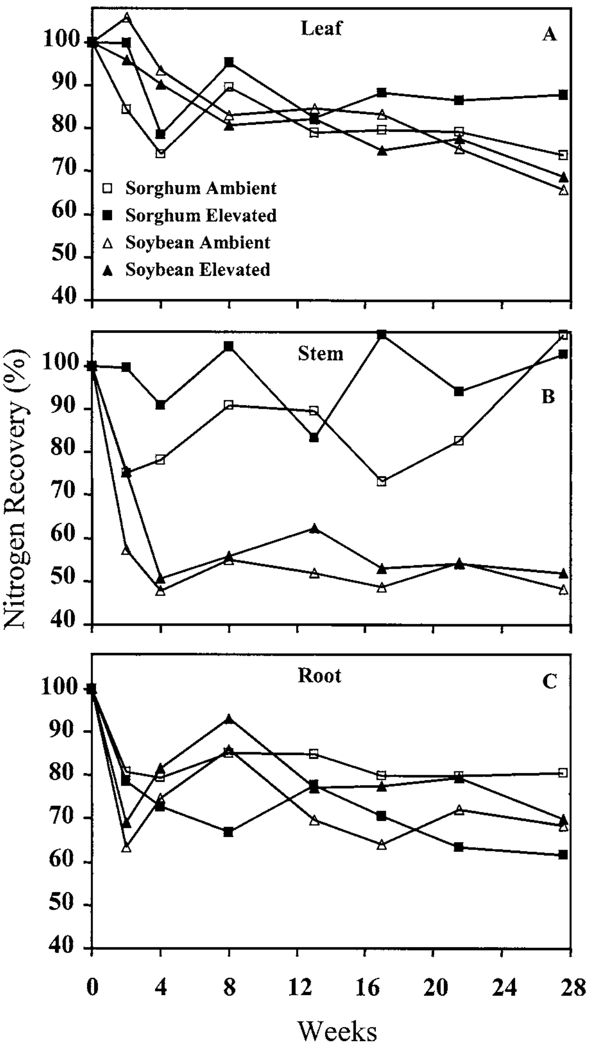

Figure 4. Percent recovery of nitrogen from ambient and elevated CO_2-produced soybean and sorghum leaf (A), stem (B), and root (C) residue during an overwintering period

Residue Mass and Carbon Remaining After Overwintering

Using baseline production from the maturity harvest and litter bag results (i.e., percent residue recovery) from the last sampling, estimations of residue mass remaining after the overwintering period were calculated (Figure 5A). In general, remaining residue was greater for soybean compared to sorghum. Overall, treatment effects followed the same pattern as observed for the maturity residue. For all residue types, the main effects of CO_2 ($P \leq 0.001$) and crop species were significant ($P \leq 0.002$) for remaining residue. For remaining leaf residue, a significant CO_2 species interaction was noted ($P = 0.018$); soybean was increased by 20%

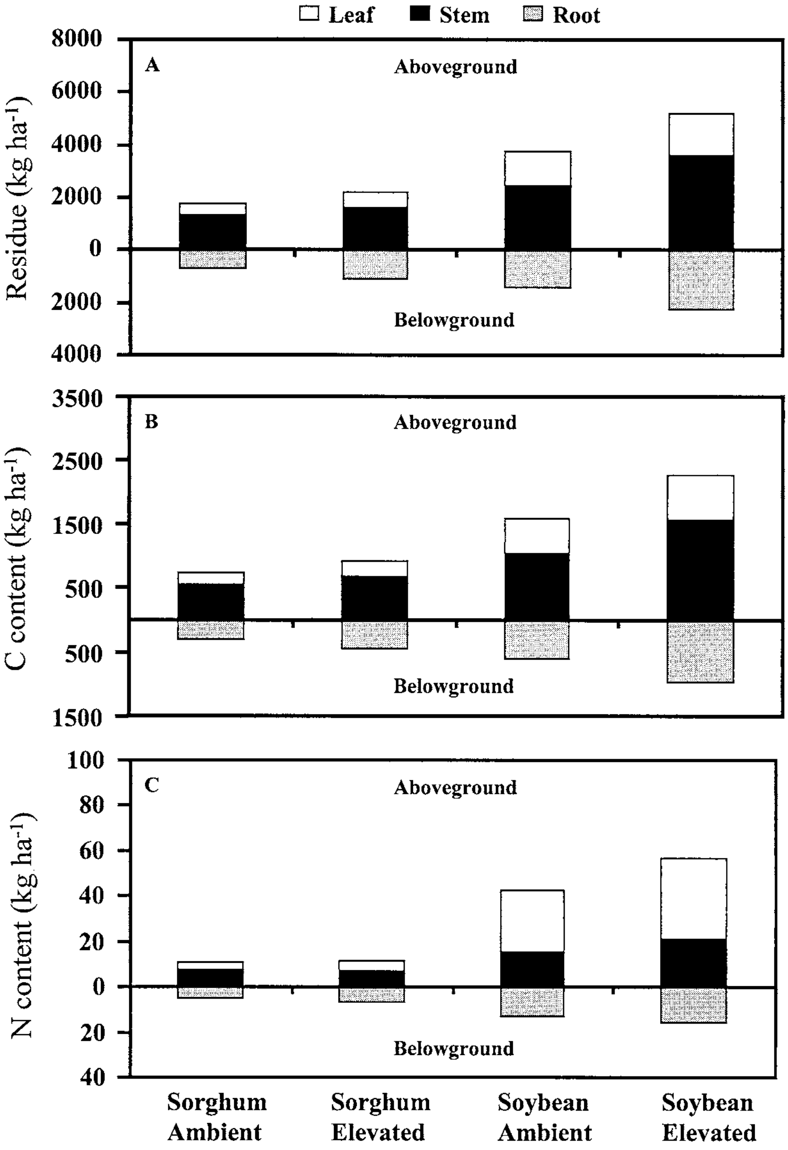

Figure 5. Leaf, stem, and root mass (A), total C content (B), and total N content (C) remainnig after the overwintering period for ambient and elevated CO_2-produced soybean and sorghum.

and sorghum by 27% under CO_2-enriched conditions. A significant CO_2 species interaction also occurred for remaining stem residue ($P < 0.0001$); there was a greater percentage increase in remaining stem residue for soybean (48%) relative to sorghum (22%) under elevated CO_2. For the remaining root residue, the main effect of crop species ($P < 0.001$) was significant and both crops responded to changing CO_2 in similar ways ($P = 0.002$). There was no CO_2 species interaction ($P = 0.112$). Under elevated CO_2 conditions, the remaining root mass for both soybean and sorghum was increased by 55%.

Treatment effects on remaining residue C (Figure 5B) were similar to those described above (Figure 5A). For all residue types, the main effects of CO_2 and crop species were significant ($P \leq 0.001$) for remaining residue C. In general, remaining residue C was greater for soybean compared to sorghum. For remaining leaf residue C, a significant CO_2 species interaction was noted ($P = 0.001$); soybean was increased by 31% and sorghum by 27% under high CO_2. A significant CO_2 species interaction also occurred for remaining stem residue C ($P = 0.0003$); there was a greater percentage increase in remaining stem residue C for soybean (50%) relative to sorghum (22%) under CO_2 enrichment. For remaining residue root C, a CO_2 species interaction was detected ($P = 0.036$); soybean was increased by 61% and sorghum by 47% under CO_2-enriched conditions.

Residue Nitrogen Remaining After Overwintering

For all residue types, the main effects of crop species were significant for remaining residue N ($P \leq 0.008$; Figure 5C). In all cases, remaining residue N was greater for soybean than sorghum. For leaf and roots, the main effects of CO$_2$ were significant ($P \leq 0.018$) for remaining residue N. For remaining leaf residue N, a significant CO$_2$ species interaction was noted ($P = 0.0003$); sorghum was unaffected by CO$_2$ ($P = 0.147$) whereas soybean residue N was 30% higher with high CO$_2$. No CO$_2$ species interaction was detected for remaining stem ($P = 0.145$) or root residue N ($P = 0.453$). For remaining root residue N, soybean was increased by 25% and sorghum by 37% under CO$_2$-enriched conditions.

Discussion

The effect of changing CO$_2$ level on crops in this study supports other findings concerning the positive effects on aboveground (Kimball 1983, Rogers and Dahlman 1993, Wittwer 1995, Kimball and others 2002) and belowground (Prior and others 1994, Rogers and others 1994) biomass production. In our study, end-of-season residue production was often significantly greater for soybean, and the positive effects of CO$_2$ favored soybean over sorghum. This differential crop response (C$_3$ vs C$_4$) was not surprising due to their inherent differences (Rogers and others 1983b, Amthor 1995, Drake and Gonzalez-Meler 1997). Crops with a C$_3$ photosynthetic pathway often exhibit a greater CO$_2$-growth response. The CO$_2$-concentrating mechanism (at the site of ribisco) for C$_4$ species often limits the CO$_2$ response, but increases in biomass production can occur primally due to increased water use efficiency. Despite these differences, it is clear that residue inputs to both cropping systems are increased under elevated CO$_2$. At this site in previous years, increased end-of-season residue inputs were accompanied by increased percent ground cover (both soybean and sorghum plots) under elevated CO$_2$ following a overwintering period (Prior and others 1997a).

During the overwintering period, the species effect on percent residue recovery was very consistent, and this response varied based on tissue type. Generally, less leaf and more stem and root residue were recovered for soybean relative to sorghum. The pattern of residue recovery was attributed to differences in tissue quality. The N content of soybean residues was consistently higher than sorghum, presumably because soybean fixes atmospheric N. The lower tissue N concentration of sorghum residues resulted in higher C/N ratios compared to soybean residues. Legume residues often have lower C/N ratios versus nonlegume species). Previous decomposition work has shown that the level of N mineralization of crop residue occurs in the order: alfalfa > peanut > soybean > oat ≥ sorghum > wheat > corn (Smith and Sharpley 1990). Since the C/N of soybean was lower, it was expected that decomposition would proceed more rapidly, as was observed with leaf residue. However, the opposite pattern was seen with soybean stem and root residues despite these tissue types having much lower C/N ratios. These results suggest that other tissue quality factors such as lignin may be influencing decomposition; lignin was found to be higher for both soybean stem (29%) and root residue (24%) relative to the same sorghum parts. In comparison, lignin levels for leaf residue were similar for both crops. These findings highlight the importance of considering specific tissue characteristics in predicting the fate of residues in agroecosystems.

It has been hypothesized that CO$_2$-induced shifts in residue quality indicators (e.g., C/N ratio) may alter decomposition processes (Melillo 1983, Strain and Bazzaz 1983). The literature indicates that CO$_2$ enrichment can often increase tissue C/N ratio, but not in all cases (Rogers and others 1994, Norby and Cotrufo 1998, Amthor 1995). Divergent results are probably related to a number of factors (biotic and abiotic) such as differences in species response, age/length of study, soil fertility, or nutrient/water supplying characteristics of a given soil type and other experimental attributes. This variable response may also be related to differences between the analysis of green tissue vs senescent tissue (Amthor 1995). In the current study, senescent plant material was used. Sorghum leaf residue exhibited increased C/N ratio while the other residue types were not significantly affected by CO$_2$ level. In comparison, the C/N ratio for soybean leaf residue was not affected by CO$_2$, but lignin was found to be higher under elevated CO$_2$. Carbon dioxide-induced increases in lignin were also observed for stem residue of both crops, but not for root residue. In terms of percent recovery of residue mass, CO$_2$-induced shifts in leaf residue quality could help explain why more elevated than ambient CO$_2$-produced leaf residue was recovered at the final sampling. As previously stated, this may be due to changes in the C/N ratio for sorghum and in lignin for soybean leaf residue. The relationship between tissue quality changes and the decomposition of stem and root residue was less clear since recovery patterns for these residue types tended to be unaffected by CO$_2$. In comparison, residue C recovery patterns for the various tissue parts had patterns similar to those observed with residue mass recovery.

The results from this study support the contention of others that predicting decomposition rates of plant material produced under elevated CO_2 based solely on C/N ratio could be difficult and unreliable (Norby and Cotrufo 1998, Hom 2002). The resident times of crop residue in agroecosystems are dependent on several interacting abiotic (e.g., soil moisture, soil temperature) and biotic (e.g., plant age, lignin content, residue C/N ratio) factors (Ghidey and Alberts 1993, Parr and Papendick 1978) that govern the rate and extent of organic C turnover in terrestrial ecosystems (Van Veen and others 1991). Predictions of decomposition processes in agroecosystems are further complicated if the contribution of specific plant parts are not considered collectively. Evaluation of field studies following multiple years of natural inputs of above- and belowground residue produced under elevated CO_2 conditions have determined (through soil C analysis and laboratory soil incubation studies) that agroecosystems could sequester C in the soil (see review by Torbert and others 2000). In FACE experiments, a cotton production system was shown to more likely exhibit increases in soil C under nonlimiting soil water conditions (Wood and others 1994), whereas in a wheat system the potential for more C storage could occur under both irrigated and non-irrigated conditions (Prior and others 1997b). These findings suggested that, aside from CO_2-induced increases in residue inputs, a differential effect of CO_2 and irrigation treatment on residue structure/composition could have affected decomposition patterns. Use of stable isotope and fractionation techniques suggested that differences in C storage for sorghum and soybean systems may have been related to residue quality (Torbert and others 1997). Results from these studies suggest that biodegradability of crop residue is not only influenced by the environment under which they were produced, but also by crop species, both factors contributing to differences in soil C storage patterns.

The complex nature of residue decomposition was also reflected in the pattern of percent N recovery from the various residue types. Residues are an important N pool that serve as sources and sinks for N. These N pools help sustain productivity in agroecosystems. Residue N can also contribute to environmental degradation (i.e., due to N losses from leaching and/or runoff) if not managed correctly (Torbert and others 1996). Patterns of percent N recovery over time were similar for leaf and root residue but different than stem residue. Differences between crop species were sporadic except for stem residue, where sorghum had a higher percent N recovery than soybean residue. The initial declines in N recovery were probably attributable to losses from easily decomposable components, and fluctuations over time (especially for stem residue) reflect dynamic changes in residue biodegradability related to microbial activity or colonization. Although CO_2 effects on percent N recovery showed no consistent pattern, estimations of total N content at the end of the overwintering period indicated that elevated CO_2 increased total N content in the remaining soybean residue. The greater total N content of soybean residue indicates that a larger N pool may be available to the following crop. However, this would not be the case for sorghum. The existence of a larger N pool suggests that lower N inputs may be required, thereby imparting an advantage for legume over non-legume crops under CO_2-enriched conditions. Our study does not allow prediction of decomposition (i.e., N mineralization) nor the synchronization of N release and crop uptake since the litter bag experiment was terminated prior to planting the next crop.

Results from this study clearly demonstrated that residue production can be expected to increase in a CO_2-enriched environment, and despite some CO_2-induced shifts in residue quality, decomposition of this high CO_2 residue followed patterns similar to those noted for ambient CO_2 produced material. Thus, the greater production observed under elevated CO_2 resulted in more residue and C remaining after the overwintering period. This work also indicates that the species effect on residue remaining varied with tissue type. The effect of CO_2 on aboveground residue remaining will be greater for soybean, while positive effects of CO_2 on remaining root residue will be similar for both crops. Despite differences, findings suggest a potential for these CO_2-enriched agroecosystems to store more C due to greater aboveground and belowground C inputs. This additional crop residue may lead to an overall increase in soil quality and protection of soil resources (especially on eroded areas). In a high CO_2 environment, greater amounts of crop residue would increase ground cover and promote more favorable soil surface characteristics which may increase soil water holding capacity, improve soil physical properties, and reduce erosion losses. It is important to note that the extent of these changes will likely depend on crop species, regional conditions, and management practices.

Acknowledgements

The authors thank Barry G. Dorman, Tammy K. Dorman, and Robert F. Chaison for technical assistance. Support from Biological and Environmental Research Program (BER), U.S. Department of Energy

(Interagency Agreement No. DE-AI02-95ER62088) is gratefully acknowledged.

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