Ecosystem Processes

Composition and Decomposition of Soybean and Sorghum Tissues Grown under Elevated Atmospheric Carbon Dioxide

F. P. Henning, C. W. Wood,* H. H. Rogers, G. B. Runion, and S. A. Prior

ABSTRACT

It has been hypothesized that changes in both quantity and quality of plant residue inputs to soils as atmospheric carbon dioxide (CO_2) concentration increases may alter carbon (C) and nitrogen (N) turnover rates and pool sizes. We determined the effect of elevated atmospheric CO_2 on plant tissue quality, and how modifications in tissue quality affect C and N mineralization. Soybean [C_3; *Glycine max* (L.) Merr. cv. Stonewall] and sorghum [C_4; *Sorghum bicolor* (L.) Moen. cv. Savanna 5] were grown under elevated (704.96 ± 0.33 μmol CO_2 mol^{-1}) and ambient (357.44 ± 0.12 μmol CO_2 mol^{-1}) atmospheric CO_2 in open-top chambers. Leaf and stem tissues were separated from harvested plants and analyzed for C, N, lignin, and cellulose. Tissues were applied to Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult) and aerobically incubated for 70-d to determine C and N mineralization, C turnover, relative N mineralization, and C/N mineralized. Elevated CO_2 had no effect on plant residue C concentration, but N concentration of soybean leaves and stems and sorghum stems was reduced; however, CO_2 enrichment increased C/N ratio and lignin concentration for only sorghum stems and soybean leaves, respectively. Source of plant residue (i.e., produced under either elevated or ambient CO_2) had no impact on soil C turnover, relative N mineralization, cumulative C and N mineralization, and C/N mineralized. These data suggest that increasing atmospheric CO_2 will have little effect on composition or decomposition of field crop residues. Thus, since CO_2 enrichment results in increased photosynthetic C fixation, the possibility exists for increased soil C storage under field crops in an elevated CO_2 world.

THE CONCENTRATION of carbon dioxide (CO_2) in the atmosphere is rising rapidly. In fact, many scientists predict that current atmospheric concentration will double within the next century (Gribbon, 1981; Bolin et al., 1986; Keeling et al., 1989). There is little doubt that elevated CO_2 will increase net primary production (Kimball, 1983); but, due to already high concentrations of CO_2 ($>10^3$ μmol CO_2 mol^{-1}) that are commonly observed in soil, it is unlikely that a doubling of atmospheric CO_2 will directly affect soil processes (van Veen et al., 1991). It is, however, possible that CO_2 enrichment will alter quality of organic matter, and thereby indirectly affect the rate at which carbon (C) and nitrogen (N) are cycled within plant soil systems (Zak et al., 1993).

Plant biomass production links aerial CO_2 enrichment with the rate at which C and N are cycled within plant-soil systems (Zak et al., 1993). Photosynthetically fixed C is the main source of organic matter entering most soils. Carbon originating aboveground is transferred to soil via root-derived materials (decaying roots, sloughed root cells, root exudates) and litterfall (van Veen et al., 1991). As the concentration of CO_2 in the atmosphere rises, net primary production (Kimball, 1983) and the quantity of C transferred to the soil also will almost certainly increase (van Veen et al., 1991; Wood et al., 1994).

Whether or not higher inputs of organic matter will increase the content of soil organic matter (SOM) depends largely on soil microbial activity. Soil microbial populations are considered the driving force for SOM turnover. Changes in C inputs into soil, both with respect to quantity and quality, can alter turnover rates and, thus, C pool sizes (Lekkerkerk et al., 1990). Carbon and N stabilization or mobilization processes in soil are usually coupled and are regulated through microbial energy requirements (McGill and Cole, 1981). In addition, N can be an important issue in the C storage question since N can be limiting to both plant and microbial biomass production.

Terrestrial ecosystem structure and function is highly dependent on the relationship between plants and soil systems (Dixon and Turner, 1991). The effects of elevated CO_2 on aboveground physiological processes have been well studied; however, to date, soil ecosystems have received much less attention. The long-term capacity of soil to store C from CO_2 enrichment has not yet been determined (Houghton et al., 1985), and many uncertainties remain regarding the extent to which increased C fixation under elevated CO_2 will alter the degradability of plant material.

One possibility is that increased soil microbial activity due to additional C entering soil in an elevated-CO_2 environment (i.e., *the priming effect*) would lead to increased SOM decomposition. Therefore, CO_2 enrichment might not induce soil organic C accumulation (Lekkerkerk et al., 1990). Alternatively, increased plant residue C/N and lignin/N ratio values in a CO_2-rich environment could retard decomposition (Bazzaz, 1990); as a result, soil C accumulation could be increased and nutrient cycling may be limited by elevated CO_2.

It is reasonable to assume that higher plant productivity in a high-CO_2 environment will result in increased organic residue inputs to soil systems; however, since microbial activity-SOM accumulation is affected by both quantity and quality of organic inputs, we also must

F.P. Henning, Cooperative Ext. Serv., N. Fulton Gov. Annex, Room 203, 7741 Roswell Rd. Dunwoody, GA 30350; C.W. Wood, Dep. of Agronomy and Soils, 202 Funchess Hall, Auburn University, AL 36849-5412; H.H. Rogers, G.B. Runion, and S.A. Prior, USDA-ARS, Natl. Soil Dynamics Lab., P.O. Box 3439, Auburn, AL 36831-3439. Received 17 Apr. 1995. *Corresponding author (wwood@ag.auburn.edu).

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Abbreviations: CO_2, carbon dioxide; C, carbon, N, nitrogen; SOM, soil organic matter; DAP, days after planting; FACE, free-air CO_2 enrichment.

investigate the effects of elevated CO_2 on litter quality. Research has indicated that there are numerous quality factors controlling plant litter decay rates. Among these decay rate factors, C/N ratio (Taylor et al., 1989), initial lignin and N contents (Berg et al., 1986), and lignin/N (Melillo et al., 1982; Taylor et al., 1989) are considered good predictors of plant litter degradability.

The objectives of this study were to determine the effects of elevated CO_2 on plant tissue quality, and to determine the effects of modifications in tissue quality on the mineralization of C and N.

MATERIALS AND METHODS

Field Setup and Sample Collection

Throughout the 1992 growing season soybean and sorghum were continuously exposed to two levels of atmospheric CO_2 within an open top field chamber system similar to that described by Rogers et al. (1983). The study site was an outdoor soil bin (2 m deep, 7 m wide, and 76 m long) located at the National Soil Dynamics Laboratory on the campus of Auburn University, AL (32° 36′N, 85° 29′E). The bin is filled with a uniform, experimentally constructed profile of Blanton loamy sand topsoil (loamy, siliceous, thermic Grossarenic Paleudult).

The field portion of this study was arranged as a two factor experiment (split plot) in a randomized complete block design having three replications. Plant species was designated as the main plot, and subplot CO_2 treatments were randomly arranged within each main-plot. Subplot treatments consisted of CO_2 at either an ambient or elevated level of CO_2 maintained within open top field chambers.

Soybean and sorghum were planted in rows across the 7 m width of the bin. Soybean seed was sown on 2 June, and sorghum was sown on 3 June 1992. Row spacing was 75 cm for both soybean and sorghum. Following emergence, chambers were installed so that two middle rows and two smaller outer rows were centered within each chamber. Carbon dioxide dispensing and monitoring began on 12 June. The seasonal daytime (0700–1500 h) mean CO_2 concentration was 704.96 ± 0.33 (standard error, SE) μmol CO_2 mol^{-1} for elevated plots and 357.44 ± 0.12 μmol CO_2 mol^{-1} for ambient plots.

Cultivation simulated standard no-till agricultural practices. Plants were irrigated by a low volume micro-irrigation system only when visible drought stress symptoms were apparent. Following chamber placement, plants were thinned to a uniform density of 30 plants m^{-2} for soybean and 26 plants m^{-2} for sorghum. At physiological maturity (i.e., R7 stage; Ritchie et al., 1992) for soybean and Stage 9 (Vanderlip, 1979; for sorghum), six plants were randomly harvested from each of the two center rows of each chamber for analysis. Soybean was harvested on 9 September, 99 days after planting (DAP), and sorghum was harvested on 10 September in 1992, 97 DAP.

Root mass typically accounts for <15% of production in annual grain crop species (Gardner et al., 1985). Consequently, in agronomic systems SOM replenishment primarily comes from plant-shoot residues retained on the surface or mixed into the soil profile (Wood et al., 1991). Therefore, only component leaf and stem litter-tissues were separated from harvested plants and oven dried (to a constant mass) for at least 72 h at 55 ± 5°C for further analysis.

In order to quantify C and N concentrations, tissue samples were ground to pass a 0.2 mm mesh screen and analyzed using a LECO CHN-600 (LECO Corp., St. Joseph, MI). For cellulose and lignin quantification, tissue samples were ground to pass a 1 mm mesh screen and lignin and cellulose analyses were performed using standard permanganate lignin, cellulose procedures described by Goering and Van Soest (1970). Tissue C, N, lignin, and cellulose concentrations are expressed as grams of C or N per kilogram basis. Ratio values for tissue C/N and lignin/N were calculated on a gram per gram basis.

Laboratory Incubation Study

The effects of elevated CO_2 on C and N mineralization/release were investigated in a laboratory incubation using the procedure of Nadelhoffer (1990). The soil series (Norfolk loamy sand) used in the incubation portion of this study was chosen because it is representative of soil commonly found in agricultural production in Alabama. A composite of 20 randomly collected soil cores (75 mm diam. of Norfolk loamy sand was taken from a field used for a corn–soybean [*Zea mays* L.–*Glycine max* (L.) Merr.] rotation at the E.V. Smith Research Center, Shorter, AL (32° 24′N, 85° 56′E). Soil was collected to a depth of 15 cm, immediately cooled to approximately 5°C, sieved to pass a 2-mm mesh screen, and thoroughly mixed (>24 h) using an air-tight drum mixer.

In order to determine pretreatment soil organic C and total N, five subsamples of mixed field moist soil were oven dried to a constant mass (72 h at 55 ± 5°C), ground to pass a 0.2-mm mesh screen, and analyzed using a LECO CHN-600. Soil organic C concentration was 4.1 ± 0.15 (SE) g kg^{-1}, and soil total N concentration was 0.68 ± 0.02 (SE) g kg^{-1}.

Dried soybean and sorghum leaf and stem tissues from the field portion of this study were ground to pass a 2.0-mm mesh screen and individually surface applied to mixed field moist soil. Tissue application rates were calculated based on plant tissue yield, and soil bulk density field data. Leaf tissue was applied to soil at a rate of 2 Mg ha^{-1}, and stem tissue was applied at a 4 Mg ha^{-1} rate. Consequently, 50 g of field moist soil (46.4 g dry weight), and 0.05 g leaf or 0.1 g stem residue tissue from each elevated and ambient plot/treatment were weighed into micro-lysimeters for aerobic incubation in the dark at 25°C. Soil (50 g) subsamples without applied plant residue also were weighed into microlysimeters, maintained under identical conditions, and used as controls.

The micro-lysimeters were Falcon Filter units (Model no. 1702, Becton Dickinson Labware, Lincoln Park, NJ) modified to permit nondestructive long-term measurements of microbial mineralized C and N (Nadelhoffer, 1990). The Falcon Filter units consist of upper and lower chambers fitted with ports that allow gas sampling from the upper chamber and solution extraction from the lower chamber.

Carbon dioxide efflux (C mineralization) was measured by purging CO_2 from the micro-lysimeter headspace with CO_2-free air until CO_2 could not be detected. A valve was used to relieve pressure within chamber headspace, which allowed chambers to be sealed at atmospheric pressure. Efflux rates were determined by measuring CO_2 accumulation in the headspace of micro-lysimeters that were sealed for <3 h. At the end of the respiration period, headspace CO_2 concentrations were measured on representative samples obtained by drawing 15 mL gas samples into syringes attached to an upper chamber port. Carbon dioxide concentration was analyzed by immediately injecting the 15 mL gas samples into a stream of CO_2-free air of known flow rate that was passed to an infrared gas analyzer (LI-6251 CO_2 analyzer, LI-COR, Lincoln, NE). Signals from the gas analyzer were output as mV as a function of time (s), which were collected by a data logger connected to a personal computer. Output voltage was converted to micromole of CO_2 per mole of air via use of a machine specific regression equation relating CO_2 concentration and mV output.

Table 1. Leaf tissue C and N concentrations, C/N ratio, lignin concentration, lignin/N ratio, and cellulose concentration as affected by plant species and atmospheric CO_2 concentration.

Treatment	C	N	C/N	Lignin	Lignin/N	Cellulose
	g kg^{-1}	g kg^{-1}	g g^{-1}	g kg^{-1}	g g^{-1}	g kg^{-1}
				Soybean		
Elevated	497	34.3	14.5	72.8	2.1	156
Ambient	504	37.9	13.3	58.5	1.5	152
Mean	500	36.1	13.9	65.6	1.8	154
				Sorghum		
Elevated	479	9.3	51.4	49.8	5.4	329
Ambient	480	9.7	49.9	49.7	5.2	320
Mean	479	9.5	50.7	49.8	5.3	325
				Species mean		
Elevated	488	21.8	33.0	61.3	3.7	243
Ambient	492	23.8	31.6	54.1	3.4	236
Mean	490	22.8	32.3	57.7	3.6	240
				Analyses of variance ($P > F$)		
Source of Variation						
Species	0.033	0.001	0.004	0.040	0.016	0.002
CO_2	0.588	0.029	0.508	0.007	0.103	0.098
Species × CO_2	0.634	0.052	0.941	0.008	0.331	0.401
Soybean E vs. A†	0.502	0.013	0.671	0.002	0.086	0.441
Sorghum E vs. A	0.928	0.690	0.600	0.939	0.519	0.095

† E, elevated CO_2; A, ambient CO_2.

Table 2. Stem tissue C and N concentrations, C/N ratio, lignin concentration, lignin/N ratio, and cellulose concentration as affected by plant species and atmospheric CO_2 concentration.

Treatment	C	N	C/N	Lignin	Lignin/N	Cellulose
	g kg^{-1}	g kg^{-1}	g g^{-1}	g kg^{-1}	g g^{-1}	g kg^{-1}
				Soybean		
Elevated	474	15.8	30.1	158.7	10.0	402
Ambient	475	17.1	27.8	148.4	8.7	388
Mean	475	16.5	28.9	153.6	9.4	395
				Sorghum		
Elevated	463	4.1	113.1	86.9	21.2	388
Ambient	456	5.1	90.1	80.8	16.0	372
Mean	460	4.6	101.6	83.9	18.6	380
				Species mean		
Elevated	468	10.0	71.6	122.8	15.6	395
Ambient	466	11.1	58.9	114.6	12.4	380
Mean	471	10.6	65.3	118.7	14.0	388
				Analyses of variance ($P > F$)		
Source of variation						
Species	0.053	0.003	0.008	0.005	0.024	0.044
CO_2	0.562	0.013	0.030	0.183	0.044	0.108
Species × CO_2	0.378	0.537	0.053	0.697	0.167	0.904
Soybean E vs. A†	0.812	0.026	0.694	0.225	0.436	0.243
Sorghum E vs. A	0.315	0.066	0.013	0.448	0.031	0.196

† E, elevated CO_2; A, ambient CO_2.

Concentration in the 15 mL gas samples were calculated by integrating the area under mV vs. time curves. Efflux rates over the measurement period were determined, and mg CO_2-C kg^{-1} soil mineralized were calculated from an average rate between two sampling dates. Measurement of CO_2 efflux rates were made 1, 3, 7, 14, 28, 42, and 70 d following initiation of incubation. Cumulative milligram of CO_2-C per kilogram mineralized from soil was calculated by summation.

Nitrogen mineralization was determined by equilibrating soil samples in the upper chamber with 100 mL of 0.01 *M* $CaCl_2$ for 30 min. A vacuum of −43 kPa was applied to draw the extractant through the filters into the lower chamber where it was collected for analysis. A low level of vacuum was chosen in order to maintain soil samples near field capacity over the course of the study. Nitrate–N and NH_4–N were measured in extracts using standard colorimetric procedures (Keeney and Nelson, 1982) on a Lachat autoanalyzer (Lachat Instruments, Milwaukee, WI).

Carbon turnover and relative N mineralization were calculated as the fraction of C or N mineralized from total pools of C or N respectively (Burke et al., 1989). Carbon/N mineralization was calculated by dividing the cumulative amount of C mineralized by the cumulative amount of N mineralized. Carbon turnover, relative N mineralization, and C:N mineralized were all calculated on a milligram per kilogram per milligram per kilogram basis.

Statistical Analyses

Analyses of variance were performed using the SAS package (SAS Institute, 1982), testing for all main effects and their interactions. Tissue quality data were analyzed by plant tissue using a split-plot model under the GLM procedure (SAS Institute, 1982). Contrasts were used to separate and compare species × CO_2 interactions. Cumulative mineralization data from the incubation study were analyzed by species and plant tissue. Treatment (CO_2) differences were determined using the GLM procedure. Analysis of variance on incubation-treatment versus control differences were performed using contrast statements, and a 2 × 2 × 2 factorial design. Modeling cumulative mineralization was performed by regression of cumulative C or N and time (d) for individual species/tissue combinations. Unless noted otherwise, treatments and their interactions were considered statistically different at the $\alpha = 0.10$ level.

RESULTS AND DISCUSSION

Litter Quality

Carbon dioxide enrichment had no effect on plant residue C concentration (Tables 1 and 2). Nitrogen concentration of soybean leaf and stem tissues and sorghum stem tissues was reduced by aerial CO_2 enrichment (Tables 1 and 2); however, only C/N ratio of sorghum stem tissue was increased by CO_2 enrichment (Tables 1 and 2). Lignin concentration was increased by elevated CO_2 only for soybean leaf tissue (Tables 1 and 2). Lignin: N ratios increased with CO_2 enrichment only for soybean leaf and sorghum stem tissues (Tables 1 and 2). Cellulose concentration in soybean and sorghum residues was relatively unaffected by elevated CO_2.

Many studies addressing changes in plant tissue C, N, and lignin concentrations owing to elevated atmospheric CO_2 indicate increasing C/N and lignin/N with CO_2 enrichment (Bazzaz, 1990), leading to predictions of reduced litter decomposition rates in high CO_2 environments (Williams et al., 1988). However, in this study CO_2 had limited effects on factors that would affect soybean and sorghum residue decomposition, i.e., only sorghum stems and soybean leaves were consistently impacted. Other studies (Curtis et al., 1989; Kemp et al., 1994) indicate little to no effect of CO_2 enrichment on plant tissue C/N or lignin/N.

Carbon and Nitrogen Mineralization

Carbon turnover and cumulative mineralization (CO_2 efflux) were generally higher in soils amended with tissue than in controls containing similar soils without tissue (Tables 3 and 4; Fig. 1 and 2); exceptions include sorghum leaf tissue, sorghum stem tissue grown under ambient CO_2, and soybean leaf tissue grown under ambi-

Table 3. Carbon turnover, relative N mineralization, C/N mineralized, and cumulative C and N mineralization during laboratory incubation from soil amended with plant residues grown under ambient or elevated atmospheric CO_2.

Tissue	Treatment	C Turnover	Relative N mineralization	C/N mineralized	Cumulative C mineralized	Cumulative N mineralized
		mg kg^{-1} (mg kg^{-1})$^{-1}$			mg kg^{-1}	
Soybean						
Leaf	Elevated	0.157	0.047	21.6	734	33.5
	Ambient	0.101	0.041	16.0	473	29.6
	Mean	0.129	0.044	18.8	604	31.6
Stem	Elevated	0.177	0.026	50.6	912	18.2
	Ambient	0.190	0.026	54.4	977	18.6
	Mean	0.184	0.026	52.5	944	18.4
Sorghum						
Leaf	Elevated	0.102	0.023	29.3	473	15.9
	Ambient	0.108	0.025	29.7	500	16.9
	Mean	0.105	0.024	29.5	486	16.4
Stem	Elevated	0.144	0.016	66.2	728	11.1
	Ambient	0.099	0.013	57.2	508	8.8
	Mean	0.122	0.015	61.7	618	10.0
Control	–	0.082	0.028	18.5	337	18.6
			Analyses of variance ($P > F$)			
Soybean						
Leaf	E vs. A†‡	0.275	0.463	0.167	0.275	0.478
	E vs. C†§	0.040	<0.001	0.748	0.031	<0.001
	A vs. C§	0.572	<0.001	0.790	0.432	<0.001
Stem	E vs. A	0.816	0.832	0.818	0.815	0.794
	E vs. C	0.012	0.531	0.004	0.004	0.836
	A vs. C	0.006	0.624	0.002	0.002	0.975
Sorghum						
Leaf	E vs. A	0.793	0.409	0.944	0.790	0.407
	E vs. C	0.561	0.165	0.268	0.431	0.215
	A vs. C	0.454	0.348	0.251	0.347	0.431
Stem	E vs. A	0.089	0.221	0.272	0.075	0.228
	E vs. C	0.085	0.002	<0.001	0.030	0.003
	A vs. C	0.611	<0.001	0.001	0.325	0.003

† E, elevated CO_2; A, ambient CO_2; C, control (no residue).
‡ E vs. A comparisons were made using a split plot model.
§ E vs. C, and A vs. C comparisons made using a model with a 2 × 2 × 2 factorial design.

ent CO_2. Composition of added tissues (Tables 1 and 2) does not explain lack of response of C turnover and cumulative mineralization when sorghum leaf tissue, sorghum stem tissue grown under ambient CO_2, and soybean leaf tissue grown under ambient CO_2 treatments are compared with controls, i.e., soybean leaf tissues and sorghum stem tissues represented end-members in regard to N concentration, C/N and lignin/N. Variability in the data may have contributed to lack of a statistically significant response for C turnover and cumulative C mineralization to the three aforementioned plant residues, because trends towards increased cumulative C mineralization were evident for all treatments in comparison to controls (Fig. 1 and 2).

Relative N mineralization and cumulative N mineralization were affected only by soybean leaf and sorghum stem tissues, i.e., end-members with regard to tissue composition (Tables 1 and 2), in comparison to controls (Tables 3 and 4; Fig. 3 and 4). For soil amended with sorghum stem tissues relative N mineralization and cumulative N mineralization were depressed in comparison to controls, as could be predicted from their relatively low N concentration and high C/N and lignin/N. These data suggest that N was immobilized by application of sorghum stem residues. The opposite was true for soils treated with soybean leaf tissues; relative N mineralization and cumulative N mineralization were greater for soils amended with soybean leaf tissue than for controls. Soybean leaf residue was of much higher quality (i.e., higher N concentration coupled with lower C/N) than other residues explaining increased N mineralization in comparison to controls.

In general, C turnover, relative N mineralization, cu-

Table 4. Regression models for soil amended with soybean leaf and stem tissues grown under ambient or elevated atmospheric CO_2. Models relate C and N mineralization to time (day) during the laboratory incubation. Y = cumulative CO_2-C (mg kg^{-1} soil), x = day, and U = cumulative inorganic-N (mg kg^{-1} soil).

Species	Tissue		Regression equation	R^2
			Cumulative C mineralized	
Soybean	Leaf	Elevated	$Y = 85.6 + 11.5x - 0.035x^2$	0.84
		Ambient	$Y = 67.0 + 10.2x - 0.064x^2$	0.83
	Stem	Elevated	$Y = 56.2 + 22.4x - 0.15x^2$	0.91
		Ambient	$Y = 49.2 + 22.9x - 0.14x^2$	0.86
Sorghum	Leaf	Elevated	$Y = 48.8 + 8.3x - 0.034x^2$	0.78
		Ambient	$Y = 35.5 + 11.6x - 0.072x^2$	0.88
	Stem	Elevated	$Y = 27.9 + 15.7x - 0.083x^2$	0.83
		Ambient	$Y = 34.3 + 12.4x - 0.081x^2$	0.79
Control†	–	–	$Y = 28.7 + 5.3x - 0.013x^2$	0.97
			Cumulative N mineralized	
Soybean	Leaf	Elevated	$U = 2.66 + 0.87x - 0.0062x^2$	0.95
		Ambient	$U = 1.73 + 0.89x - 0.0070x^2$	0.98
	Stem	Elevated	$U = 3.28 + 0.32x - 0.0015x^2$	0.99
		Ambient	$U = 3.84 + 0.37x - 0.0023x^2$	0.97
Sorghum	Leaf	Elevated	$U = 1.14 + 0.33x - 0.0017x^2$	0.98
		Ambient	$U = 1.30 + 0.37x - 0.0021x^2$	0.99
	Stem	Elevated	$U = 1.46 + 0.21x - 0.0010x^2$	0.84
		Ambient	$U = 1.10 + 0.16x - 0.00073x^2$	0.90
Control	–	–	$U = 1.93 + 0.58x - 0.0049x^2$	0.94

† Control = soil without plant residue.

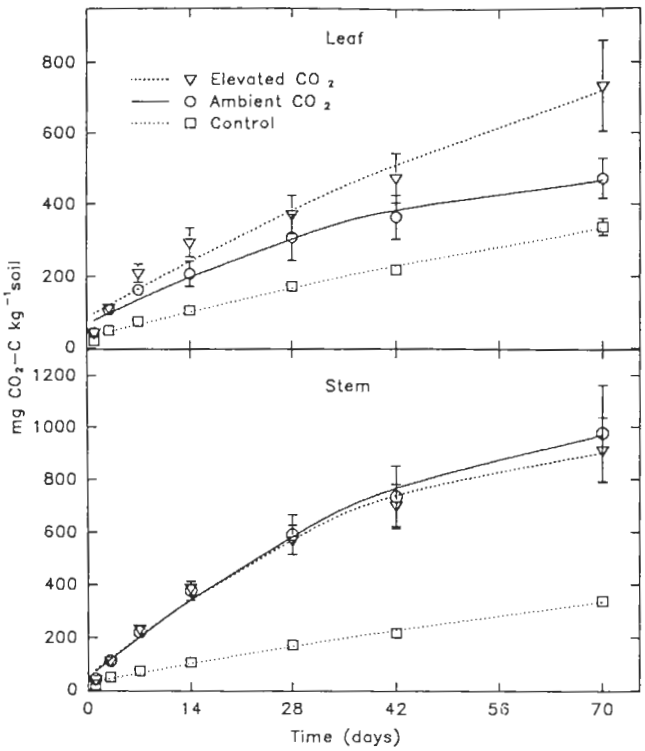

Fig. 1. Cumulative C mineralization during laboratory incubation from soil amended with soybean leaf and stem tissues grown under ambient or elevated atmospheric CO_2. Symbols are means of actual data; lines are predictions from regression equations; bars are standard error.

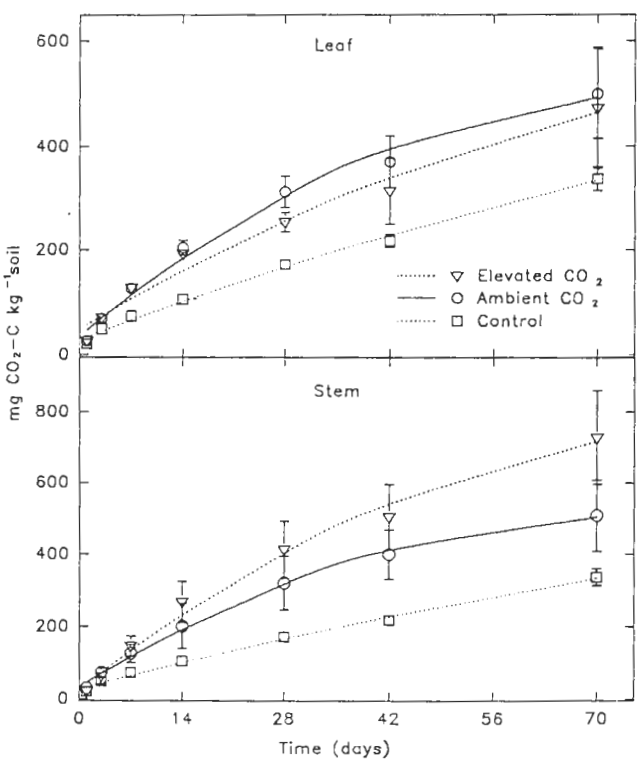

Fig. 2. Cumulative C mineralization during laboratory incubation from soil amended with sorghum leaf and stem tissues grown under ambient or elevated atmospheric CO_2. Symbols are means of actual data; lines are predictions from regression equations; bars are standard error.

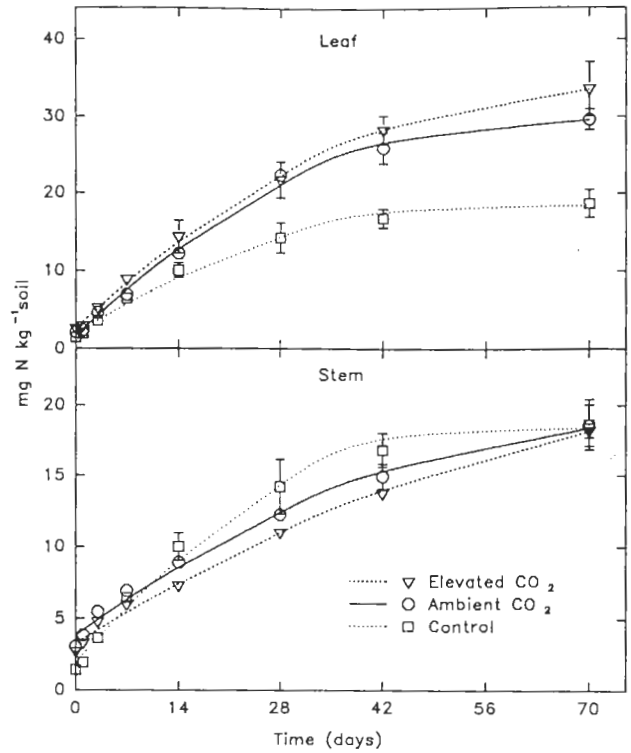

Fig. 3. Cumulative N mineralization during laboratory incubation from soil amended with soybean leaf and stem tissues grown under ambient or elevated atmospheric CO_2. Symbols are means of actual data; lines are predictions from regression equations; bars are standard error.

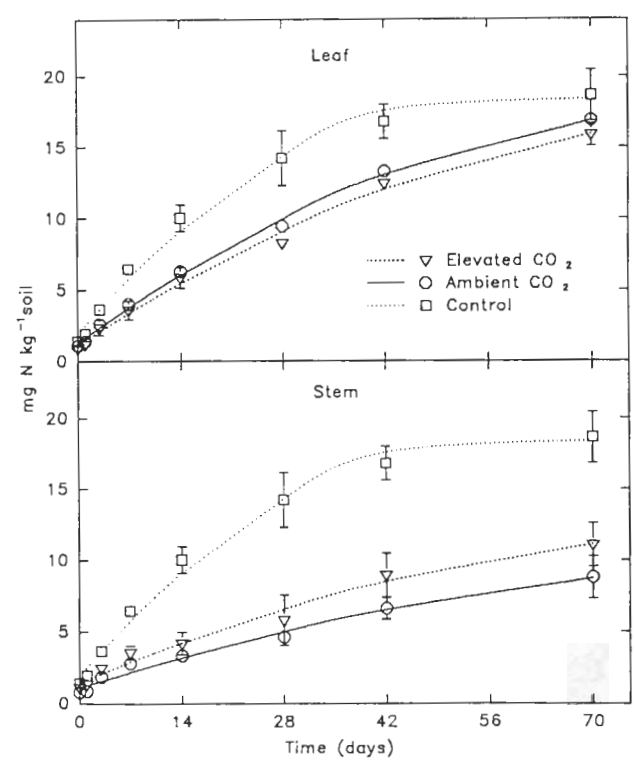

Fig. 4. Cumulative N mineralization during laboratory incubation from soil amended with sorghum leaf and stem tissues grown under ambient or elevated atmospheric CO_2. Symbols are means of actual data; lines are predictions from regression equations; bars are standard error.

mulative C and N mineralization, and C/N mineralized did not differ between soils amended with crop residues grown under elevated and ambient CO_2 (Tables 3 and 4; Fig. 1 to 4). Only sorghum stem residue grown under elevated CO_2, which had a lower N concentration and higher C/N and lignin/N than sorghum stem residue grown under ambient CO_2 (Table 2), increased C turnover and cumulative C mineralization above that observed for sorghum stem residue grown under ambient CO_2 (Tables 3 and 4; Fig. 2).

CONCLUSIONS

Our data indicate that increasing atmospheric CO_2 concentration will have little effect on composition and decomposition of crop residues. Our results are in agreement with a recent study by Torbert et al. (1995) that showed no differences in C mineralization for soils amended with cotton (*Gossypium hirsutum* L.) tissues grown under either elevated or ambient CO_2 conditions in the field. Our data are further supported by the aforementioned Curtis et al. (1989) and Kemp et al. (1994) studies. Thus, since crop plants show increased photosynthesis and growth under elevated CO_2 (Kimball, 1983), and crop residue composition and decomposition remain unaffected by elevated CO_2, our data seemingly indicate that elevated atmospheric CO_2 concentration could result in a net increase in soil C storage under field crops. This conclusion is in agreement with findings of previous field research at the free-air CO_2 enrichment (FACE) site at Maricopa, AZ (Wood et al., 1994), where we observed small increases in surface soil (0- to 20-cm) owing to elevated atmospheric CO_2.

REFERENCES

Bazzaz, F.A., 1990. The response of natural ecosystems to the rising global CO_2 levels. Annu. Rev. Ecol. Syst., 21:167–196.

Berg, B., 1986. Nutrient release from litter and humus in coniferous forest soils - a mini review. Scand. J. For. Res. 1:359–369.

Bolin, B., B.R. Doos, J. Jager, and R.A. Warrick. 1986. Scope 29 – The greenhouse effect, climatic change, and ecosystems. John Wiley & Sons, Chichester.

Burke, I.C., W.A. Reiners, and D.S. Schimel. 1989. Organic matter turnover in a sagebush steppe landscape. Biogeochem. 7:11–13.

Curtis, P.S., B.G. Drake, and D.F. Whigham. 1989. Nitrogen and carbon dynamics in C_3 and C_4 estuarine marsh plants grown under elevated CO_2 in situ. Oecologia 78:297–301.

Dixon, R.K., and D.P. Turner. 1991. The global carbon cycle and climate change: Responses and feedbacks from below-ground systems. 1991. Environ. Pollut. 73:245–262.

Gardner, F.P., R.B. Pearce, and R.L. Mitchell. 1985. Physiology of crop plants. Iowa State Univ. Press, Ames, IA.

Goering, H.K., and P.J. Van Soest. 1970. Forage fiber analyses: Apparatus, reagents, procedures, and some applications. USDA Agric. Handb. 379. U.S. Gov. Print. Office, Washington, DC.

Gribbon, J., 1981. The politics of carbon dioxide. New Sci. 90:82–84.

Houghton, R.A., W.H. Schlesinger, S. Brown, and J.F. Richards. 1985. Carbon dioxide exchange between the atmosphere and terrestrial ecosystems. p. 114–140. *In* J.R. Trabalka (ed.) Atmospheric carbon dioxide and the global carbon cycle. U.S. Dep. of Energy DOE/ER-0239. U.S. Dep. of Energy, Washington, DC.

Keeling, C.D., R.B. Bacastow, A.F. Carter, S.C. Piper, T.P. Whorf, M. Heimann, W.G. Mook, and H. Roeloffzen. 1989. A three dimensional model of atmospheric CO_2 transport based on observed winds: Observational data and preliminary analysis. In aspects of climate variability in the Pacific and western Americas. Vol. 55. Am. Geophys. Union, Washington, DC.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. p. 643–698. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Kemp, P.R., D.G. Waldecker, C.E. Owensby, J.F. Reynolds, and R.A. Virginia. 1994. Effects of elevated CO_2 and nitrogen fertilization pretreatments on decomposition on tallgrass prairie leaf litter. Plant Soil 165:115–127.

Kimball, B.A. 1983. Carbon dioxide and agricultural yield: an assemblage of 770 prior observations. WCL Rep. 14. USDA-ARS, Washington, DC.

Lekkerkerk, L.J.A., S.C. van de Geijn, and J.A. van Veen. 1990. Effects of elevated atmospheric CO_2-levels on the carbon economy of a soil planted with wheat. p. 423–429. *In* A.F. Bouwman (ed.) Soil and the greenhouse effect. John Wiley & Sons, New York.

McGill, W.B., and C.V. Cole. 1981. Comparative aspects of cycling C, N, S and P through soil organic matter. Geoderma 26:267–286.

Melillo, J.M., J.D. Aber, and J.F. Mutatore. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63:621–626.

Nadelhoffer, K.J. 1990. Microlysimeter for measuring nitrogen mineralization and microbial respiration in aerobic soil incubations. Soil Sci. Soc. Am. J. 54:411–415.

Ritchie, S.W., J.J. Hanway, H.E. Thompson, and G.O. Benson. 1992. How a soybean plant develops. Iowa State Univ. Coop. Ext. Serv. Spec. Rep. no. 53. Iowa State Univ., Ames.

Rogers, H.H., W.W. Heck, and A.S. Heagle. 1983. A field technique for the study of crop responses to elevated carbon dioxide in the field. J. Air Pollut. Control Assoc. 33:42–44.

SAS Institute. 1982. SAS users guide. Statistics. SAS Inst., Cary NC.

Taylor, B.R., D. Parkinson, and W.F. Parson. 1989. Nitrogen and lignin content as predictor of litter decay rates: A microcosm test. Ecology 70:97–104.

Torbert, H.A., S.A. Prior, and H.H. Rogers. 1995. Elevated atmospheric carbon dioxide effects on cotton plant residue decomposition. Soil Sci. Soc. Am. J. 59:1321–1328.

Vanderlip, R.L. 1979. How a sorghum plant develops. Kansas State Univ. Coop. Ext. Serv. Bull. no. S-3. Kansas State Univ., Manhattan.

van Veen, J.A., E. Liljeroth, and L.J.A. Lekkerkerk. 1991. Carbon fluxes in plant-soil systems at elevated atmospheric CO_2 levels. Ecol. Appl. 1(2):175–181.

Williams, W.E., K. Garbutt, and F.A. Bazzaz. 1988. The response of plants to elevated CO_2 IV. Two deciduous-forest tree communities. Oecologia 69:454–459.

Wood, C.W., G.A. Peterson, D.G. Westfall, C.V. Cole, and W.O. Willis. 1991. Nitrogen balance and biomass production of newly established no-till dryland agroecosystems. Agron. J. 83:519–526.

Wood, C.W., H.A. Torbert, H.H. Rogers, G.B. Runion, and S.A. Prior. 1994. Free-Air CO_2 enrichment effects on soil carbon and nitrogen. Agric. For. Meteor. 70:103–116.

Zak, D.R., K.S. Pregitzer, P.S. Curtis, J.A. Teeri, R. Fogel, and D.L. Randlett. 1993. Elevated atmospheric CO_2 and feedback between carbon and nitrogen cycles. Plant Soil 151:105–117.