# Effect of Elevated $CO_2$ and Temperature on Soil C and N Cycling

## 4.11

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## Introduction

One potential and highly debated implication of global change is an alteration in the dynamics of soil C in terrestrial ecosystems (Rogers *et al.*, 1999). This potential change in soil C dynamics is important not only because of a possible mitigating effect on rising atmospheric $CO_2$ concentration, but also because of its influence on quality of soil organic matter. Ultimately, the rate and extent of turnover of organic C produced in an elevated $CO_2$ environment will control C storage in terrestrial ecosystems (Van Veen *et al.*, 1991).

The decomposition of crop residue inputs is a fundamental component in the turnover of soil organic C which is dependent on several crop, soil, management (i.e. tillage practices) and climatic factors (Potter *et. al.*, 1998). Plant factors controlling decomposition such as age, size, chemical composition and residue C : N ratio (Ghidey and Alberts, 1993) may be affected by changing $CO_2$ level (Torbert *et al.*, 1995; Prior *et al.*, 1997a). Research considering the effect of elevated $CO_2$ on crop residue decomposition suggests that $CO_2$-enriched cropping systems may store more soil C (Torbert *et al.*, 1995, 1998; Prior *et al.*, 1997b). Even if decomposition rates of plant components (produced under elevated $CO_2$) are not changed, residue decomposition products may impact soil N dynamics (Torbert *et al.*, 1995, 1996, 1998).

Residue decomposition is a microbial-driven process and soil temperature is an important factor controlling decomposition, thereby influencing soil C dynamics. Thus, potential changes in soil temperature due to global

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warming could have important effects on soil C cycling (Smith *et al.*, 1999). Studies have shown that increased soil temperature will affect soil nutrient cycling in agroecosystems (Buyanovsky *et al.*, 1986). Also, temperature was shown to be the climatic factor that most closely explained the rate of soil C accumulation due to removal of soil tillage in agroecosystems (Potter *et al.*, 1998). Few studies have examined the interaction of elevated $CO_2$ with changes in soil temperature. Our objective was to conduct an incubation study to evaluate how changes in soil temperature influence C and N cycling of soil collected from soybean and grain sorghum cropping systems after 5 years of elevated $CO_2$ treatment.

## Materials and Methods

Soil samples were collected from a 5-year $CO_2$ enrichment study conducted in an outdoor soil bin at the USDA-ARS National Soil Dynamics Laboratory in Auburn, Alabama, USA. The bin was 2 m deep, 7 m wide and 76 m long, and was filled uniformly with surface soil of a Blanton loamy sand (loamy, siliceous, thermic Grossarenic Paleudult) that had been fallow continuously for > 25 years. Fertilizer and lime additions were used to maintain soil conditions within a normal range for crop production. To ensure adequate plant growth, fertilizer N was broadcast applied at a rate of 34 kg N $ha^{-1}$ to the grain sorghum (*Sorghum bicolor* (L.) Moench) and soybean (*Glycine max* (L.) Merr.) crop shortly after planting. An additional 67 kg N $ha^{-1}$ was applied to grain sorghum 30 days after planting. All plots were managed under no-tillage conditions.

This study had a split plot design with main plots of two crop species and two $CO_2$ levels as sub-plots replicated three times. Soybean and grain sorghum were chosen to provide legume and non-legume species that are widely produced in agroecosystems. Open-top field chambers (Rogers *et al.*, 1983) were used to impose $CO_2$ regimes (365 and 720 $\mu l\ l^{-1}$). Harvests consisted of grain sorghum head and soybean pod removal and threshing with a plot combine. Plant stalks were cut (15 cm length) using hedge clippers and uniformly applied to plots.

To determine soil C and N cycling, sieved soil samples were weighed (25 g dry mass basis) and placed in plastic containers; deionized water was then added to adjust soil water content (soil water content equivalent to −20 kPa at a bulk density of 1.3 mg $m^{-3}$). Sample containers were placed in sealed glass jars with 20 ml of water (humidity control) and a 15 ml vial of 1 M NaOH ($CO_2$ trap), then incubated in the dark at temperatures of 20, 25, and 30°C. Treatment samples were removed after 30 and 60 days. Carbon dioxide in NaOH traps was determined by titrating excess base with 1 M HCl in the presence of $BaCl_2$. The cumulative $CO_2$ emissions after 30 and 60 days incubation were calculated by the difference between

$CO_2$-C captured in sample traps and in blanks (glass jars with no soil). The $CO_2$ emissions divided by total soil organic C were used to calculate C turnover. Soil inorganic N ($NO_3$-N and $NH_4$-N) was extracted with 2 M KCl and measured by standard colorimetric procedures using a Technicon Autoanalyzer II (Technicon Corp., Tarrytown, New York). The net N mineralization was the difference between the final and initial inorganic N contents for the incubation.

Statistical analyses of data were performed using the mixed procedure of the Statistical Analysis System at an established *a priori* level of $P \leq 0.10$ (SAS, 1996). The term 'trend' is used to designate appreciable, but non-significant, treatment effects which differed at the $0.10 < P < 0.20$ level.

## Results and Discussion

For both crop species, elevated $CO_2$ resulted in a significant increase in the residue mass returned to plots (Torbert *et al.*, 1997), resulting in a significant increase in total C and total N (0–5 cm soil depth) after 5 years (Table 4.11.1). At the 5–10 cm depth, a similar trend for an increase in total N was observed under elevated $CO_2$, but not with total C. The increased retention of N in the soil system in the elevated $CO_2$ treatment resulted in a significant reduction in the C : N ratio for soil under soybeans at the 0–5 cm depth, and for both the sorghum and the soybean at the 5–10 cm depth (Table 4.11.1). The high C : N ratio at both depths and the significant difference between treatments indicated that the soil C was in an unsteady state (Table 4.11.1).

**Table 4.11.1.** Effect of plant species and atmospheric $CO_2$ level on soil total C (g $kg^{-1}$), total N (g $kg^{-1}$) and C : N ratio[1].

| | Total C | | Total N | | C : N ratio | |
|---|---|---|---|---|---|---|
| $CO_2$ level | Sorghum | Soybean | Sorghum | Soybean | Sorghum | Soybean |
| 0–5 cm | | | | | | |
| Ambient | $3.7^a$ | $4.1^a$ | $0.21^a$ | $0.25^a$ | $17.3^a$ | $16.1^a$ |
| Elevated | $4.2^b$ | $5.4^b$ | $0.24^b$ | $0.36^b$ | $17.3^a$ | $14.9^b$ |
| 5–10 cm | | | | | | |
| Ambient | $2.3^a$ | $2.4^a$ | $0.13^a$ | $0.13^a$ | $18.7^a$ | $18.2^a$ |
| Elevated | $2.4^a$ | $2.2^a$ | $0.14^a$ | $0.14^a$ | $17.9^b$ | $15.7^b$ |

[1] Values represent means of three replicates. Means within a column followed by the same letter do not differ significantly (0.10 level).

During the soil incubation, $CO_2$ emission, N mineralization and C turnover were greatly affected by both time and soil depth (Table 4.11.2). While plant species had little significant effect on $CO_2$ emission, N mineralization was much higher with soybean compared with sorghum at both time periods and soil depths.

Increasing temperature increased soil $CO_2$ emission, N mineralization and C turnover at 30 days for both soil depths (Table 4.11.3). Likewise, at 60 days, increasing temperature increased soil $CO_2$ emission, N mineralization and C turnover at the 0–5 cm depth and the N mineralization at the

**Table 4.11.2.** Effect of plant species and soil depth on $CO_2$ emission, N mineralization and C turnover[1].

| | C mineralized (mg $kg^{-1}$) | | N mineralized (g 100 $g^{-1}$) | | C turnover (g 100 $g^{-1}$) | |
|---|---|---|---|---|---|---|
| Crop | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm |
| 30 days | | | | | | |
| Sorghum | $154^{a}$ | $92^{a}$ | $4.6^{a}$ | $0.8^{a}$ | $4.0^{a}$ | $3.9^{a}$ |
| Soybean | $174^{a}$ | $102^{a}$ | $12.6^{b}$ | $1.6^{b}$ | $3.8^{a}$ | $4.5^{a}$ |
| 60 days | | | | | | |
| Sorghum | $394^{a}$ | $297^{a}$ | $11.4^{a}$ | $2.8^{a}$ | $10.1^{a}$ | $12.5^{a}$ |
| Soybean | $401^{a}$ | $294^{a}$ | $23.0^{b}$ | $4.8^{b}$ | $8.7^{b}$ | $12.9^{a}$ |

[1] Values represent means of three replicates. Means within a column followed by the same letter do not differ significantly (0.10 level).

**Table 4.11.3.** Effect of temperature and soil depth on $CO_2$ emission, N mineralization and C turnover[1].

| Temperature | C mineralized (mg $kg^{-1}$) | | N mineralized (g 100 $g^{-1}$) | | C turnover (g 100 $g^{-1}$) | |
|---|---|---|---|---|---|---|
| (°C) | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm |
| 30 days | | | | | | |
| 20 | $135^{a}$ | $91^{a}$ | $4.8^{a}$ | $0.2^{a}$ | $3.1^{a}$ | $3.9^{a}$ |
| 25 | $159^{b}$ | $92^{a,b}$ | $6.3^{a,b}$ | $1.6^{a,b}$ | $3.8^{b}$ | $4.0^{b}$ |
| 30 | $199^{c}$ | $108^{b}$ | $14.7^{b}$ | $1.8^{b}$ | $4.7^{c}$ | $4.7^{c}$ |
| 60 days | | | | | | |
| 20 | $304^{a}$ | $299^{a}$ | $11.6^{a}$ | $2.4^{a}$ | $7.2^{a}$ | $12.8^{a}$ |
| 25 | $360^{b}$ | $308^{a}$ | $14.9^{b}$ | $3.8^{b}$ | $8.4^{b}$ | $13.2^{a}$ |
| 30 | $528^{c}$ | $280^{a}$ | $16.7^{c}$ | $5.1^{c}$ | $12.6^{c}$ | $11.9^{a}$ |

[1] Values represent means of three replicates. Means within a column followed by the same letter do not differ significantly (0.10 level).

5–10 cm depth. No interaction between soil temperature and elevated $CO_2$ was observed.

No significant difference was observed for N mineralization at the 0–5 cm depth between the $CO_2$ treatments, but elevated $CO_2$ resulted in a significant reduction in N mineralization at the 5–10 cm depth for the 30-day period (Table 4.11.4). No significant difference was observed between ambient $CO_2$ and elevated $CO_2$ treatments for $CO_2$ emission at the different time periods and soil depths. However, because of the increased level of soil total C present under elevated $CO_2$, a significant reduction was observed with elevated $CO_2$ for C turnover at both time periods for the 0–5 cm soil depth, compared with ambient $CO_2$ (Table 4.11.4).

Our findings indicated that the effects of elevated $CO_2$ on plant decomposition processes observed with isolated plant material (i.e. little difference observed between $CO_2$ emission, but a reduction in N mineralization with elevated $CO_2$ (Torbert *et al.*, 1995, 1998)) could be observed with soil samples collected following a 5-year elevated $CO_2$ field experiment. Nitrogen cycling within the plant–soil system will probably be altered with elevated $CO_2$ and may be the controlling factor for C storage in these systems.

Results from this study indicate that nutrient cycling may be increased in these agroecosystems with an increase in soil temperature and, since there was no observed temperature by $CO_2$ treatment interaction, changes in residue quality will not greatly reduce nutrient availability to growing plants and may reduce the impacts predicted from global warming. Furthermore, increased biomass production with elevated $CO_2$ will probably result in increased soil C storage since no significant increase in $CO_2$ emission was observed and a significant reduction in C turnover was

**Table 4.11.4.** Effect of atmospheric $CO_2$ and soil depth on $CO_2$ emission, N mineralization and C turnover[1].

| | C mineralized (mg $kg^{-1}$) | | N mineralized (g 100 $g^{-1}$) | | C turnover (g 100 $g^{-1}$) | |
|---|---|---|---|---|---|---|
| $CO_2$ level | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm | 0–5 cm | 5–10 cm |
| 30 days | | | | | | |
| Ambient | $158^a$ | $104^a$ | $8.6^a$ | $1.5^a$ | $4.1^a$ | $4.4^a$ |
| Elevated | $171^a$ | $91^a$ | $8.5^a$ | $0.9^b$ | $3.6^b$ | $4.0^a$ |
| 60 days | | | | | | |
| Ambient | $387^a$ | $306^a$ | $16.7^a$ | $3.9^a$ | $10.0^a$ | $12.9^a$ |
| Elevated | $407^a$ | $285^a$ | $17.7^a$ | $3.7^a$ | $8.8^b$ | $12.5^a$ |

[1] Values represent means of three replicates. Means within a column followed by the same letter do not differ significantly (0.10 level).

found under conditions of elevated $CO_2$. The potential impact of elevated $CO_2$ on soils of agroecosystems may be important for the future management and productivity of these systems because small improvements in soil organic C can have important positive influences on soil physical properties such as soil hydraulic conductivity, soil bulk density, soil porosity, soil aggregate stability, soil water retention and rainfall infiltration.

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