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# Changes in Carbon and Nitrogen Mineralization in Soil Organic Matter Under High $CO_2$ Concentrations

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# Abstract

To investigate the effects of different organic materials on soil organic carbon accumulation and carbon and nitrogen mineralization under different $CO_2$ concentrations, field topsoil was used as the test soil and chicken manure, cow manure, and straw were mixed with soil samples as organic materials. The changes in organic carbon, carbon and nitrogen mineralization, and utilization of carbon sources by soil microorganisms were measured under high $CO_2$ (800–1000 ppm) and low $CO_2$ (400–500 ppm) concentrations. The results showed that adding organic material to soil can accelerate the mineralization of organic carbon and reduce the mineralization of nitrogen. While the addition of chicken manure and cow manure reduced the content of total organic carbon and active organic carbon in soil, straw increased the content of total organic carbon and active organic carbon in soil and reduced carbon utilization by the soil microbial community. Collectively, our findings revealed that, under high $CO_2$ concentrations, adding organic material to soil can accelerate the mineralization of organic carbon and reduce the mineralization of nitrogen.


# Highlights

1: Content of total and active organic C was reduced by adding chicken or cow manure.

2: Content of total and active organic C was increased by adding straw.

3: Utilization of C sources by soil microorganisms differed under the $CO_2$ enrichment.

# Introduction

The soil carbon and nitrogen cycles are an important part of the global carbon and nitrogen cycles, and deficiencies in carbon and nitrogen limit the quality and productivity of many soils (Katsaliroua et al., 2010; Lee et al., 2009). The mineralization of carbon is the process in which soil organic carbon is mineralized into inorganic carbon by microbial decomposers, resulting in $CO_2$ emission (Pires et al., 2017); furthermore, nitrogen mineralization is the process in which soil organic N is mineralized to inorganic forms, including $NH^{4+}$ and $NO^{3-}$(Manzoni and Porporato, 2009; Xia et al., 2010). Essentially, the mineralization of soil organic carbon (SOC) and nitrogen through the decomposition of soil organic matter are fundamental biogeochemical processes that underpin soil fertility and crop production. Moreover, an increasing number of studies have investigated the effects of straw biochar on carbon mineralization (Junna et al., 2014; Zavalloni et al., 2011).Hence, in order to improve the management of soil fertility, which contributes to food security and climate change mitigation, a better understanding of SOC and N mineralization in soils is necessary.

It is well known that the global concentration of atmospheric $CO_2$ is steadily increasing. Especially, as an important source of atmospheric greenhouse gases, the amount of soil organic carbon is 2–3 times the amount present in the total atmospheric carbon pool; moreover, due to its role as a carbon source and

sink, the ability of soil to store carbon has also been controversial (Cookson et al., 2007; Lal, 2004; Rhodes, 2014). It has been shown that slight changes in the soil organic carbon pool lead to significant changes in atmospheric $CO_2$ concentrations (Haei et al., 2012). Consequently, $CO_2$ generation and emission caused by soil organic carbon mineralization has been regarded as an important basis for evaluating the soil greenhouse effect (Phillips et al., 2011). Several studies have reported a relationship between increased $CO_2$ concentration and the accumulation of soil organic carbon (Hagedorn et al., 2010; Johannes and Saran, 2008). Elevated $CO_2$ and temperature have been found to enhance the temperature sensitivity of SOM decomposition (Chen et al., 2015). Moreover, it has been reported that with elevated atmospheric $CO_2$, the rate of plant residue decomposition may be limited by N and the release of N from decomposing plant material may be slowed (Torbert et al., 2000). However, research on the mineralization of organic materials under increased $CO_2$ concentrations is still limited.

The interactions between microbial communities and their local environment not only have significant effects on microbial community structure, but also regulate many of the soil functions carried out by microorganisms (Chaparro et al., 2012; Sleutel et al., 2012). Interestingly, an increasing number of studies have explored the soil carbon mineralization responses to alterations in microbial diversity and soil structure. For example, it has been reported that biochar in soil can stimulate bacterial biomass in the short term (Prayogo et al., 2014) and soil microbial diversity may exert more control on SOC dynamics than soil structure, at least under these conditions and when the levels of diversity are very low (Juarez et al., 2013). All these data suggest that soil microorganisms may play an important role in the mineralization of organic materials. In addition, increased $CO_2$ concentration could affect the structure of soil microbial communities. Presently, there are many methods to study soil microbial diversity, including Biolog microplate technology. This technique is simple to operate, rich in data, and can intuitively reflect the overall activity of a microbial population; therefore, it can clearly identify the functional diversity of microorganisms in the environment. In addition, the Biolog ECO microplate method can be used to determine the differences in the degree of utilization of different carbon sources by microorganisms, which is a common currently used method for studying microbial community diversity (Demoling et al., 2009).

Therefore, in this study, to investigate the effect of different organic fertilizers on soil organic carbon accumulation as well as carbon and nitrogen mineralization, indoor culture experiments were carried out. Natural conditions were simulated using the surface soil from a field as test soil, and chicken manure, cow manure, or straw were used as organic materials. Moreover, the Biolog ECO method was used to study soil microbial diversity and the microbial utilization of different carbon sources.

# Materials And Methods

## Study area and experiment design

The surface soil samples (0–20 cm) were collected from Dongyang field, Shanxi province, China. The tested soil was clay loam with nutrient content as follows: 15.2 $g \cdot kg^{-1}$ organic matter, 0.65 $g \cdot kg^{-1}$ total nitrogen, 5.7 $mg \cdot kg^{-1}$ nitrate nitrogen, 6.43 $mg \cdot kg^{-1}$ available phosphorus, 105 $mg \cdot kg^{-1}$ available potassium, pH 8.47, and 162 $s \cdot cm^{-1}$ electrical conductivity. After multi-point mixing, the soil samples were transported to the laboratory, dried, and passed through a 2-mm sieve for use in the experiments.

Treatments with high $CO_2$ (800–1000 ppm) and low $CO_2$ (400–500 ppm) concentrations were utilized for the soil-only group (H1 and L1, respectively), the mixture of soil and chicken manure group (32 g/kg; H2 and L2, respectively), the mixture of soil and cow manure group (37 g/kg; H3 and L3, respectively), the mixture of soil and corn straw group (16.3 g/kg; H4 and L4, respectively). All experiments were repeated 10 times.

# Chemo-physical analysis

The content of organic carbon and nitrogen in soil and organic materials (chicken manure, cow manure, and straw) were determined by dichromate oxidation and Kjeldahl digestion, respectively (Nelson et al., 1996). Briefly, for soil organic carbon analysis, 0.5 g of air-dried soil or soil organic materials was sieved through 0.15-mm sieves and placed in conical flasks. Next, 10 mL of $K_2Cr_2O_7$-$H_2SO_4$ solution was added, and the wetted soil samples were then baked for 30 min in an oven at 170–180℃. o-Phenanthroline was used as an indicator. For organic nitrogen analysis, 1-g (< 0.15 mm) soil samples were placed in a rigid test tube, and 10 mL $H_2SO_4$ was added. The N concentration of soil was measured using a 2300 Kjeltec Analyzer Unit (FOSS, Sweden).

# Organic carbon and nitrogen mineralization

Organic carbon mineralization was measured using the lye absorption method (Ribeiro et al., 2010). Briefly, 300 g of soil was adjusted to 60–80% of field capacity with deionized water and incubated in a dark incubator at 25°C. Carbon dioxide and soil moisture were added regularly during the experiment, and NaOH solution was used to absorb $CO_2$ at 1, 9, 15, 30, 60, 90, 120, 150, and 180 days. After adding 3 mL of 1 $mol \cdot L^{-1}$ $BaCl_2$ solution and 2 drops of phenolphthalein indicator, the samples were titrated to a colorless solution with 0.1 mol $L^{-1}$ HCl. The cumulative mineralization amount of organic carbon was calculated based on the amount of $CO_2$ released during the culture period.

Meanwhile, the amount of active organic carbon in the soil was determined after incubation for 180 days based on the potassium permanganate method. First, a soil sample of 1.50 g was placed in a 100-mL tripod bottle, and 25 mL of 33 mmol/L potassium permanganate solution was added and incubated in the dark for 24 h. Next, 0.5 mL of the supernatant was collected, and the volume was fixed in a 250-mL volumetric flask. Colorimetric analysis was performed at a wavelength of 565 nm. Assuming that every 1 mmol of potassium permanganate consumes 9 mg or 0.75 mmol of carbon, the soil sample organic matter oxidized by 33 mmol / L potassium permanganate solution was defined as highly active organic carbon; the soil sample organic matter oxidized by 167 mmol/L potassium permanganate solution was

defined as medium active organic carbon; and the soil sample organic matter oxidized by 333 mmol/L potassium permanganate solution was defined as active organic carbon.

Soil nitrogen mineralization is the process in which N is mineralized into inorganic forms. After the pre-incubation period at 1, 30, 60, and 180 d, 5-g samples of the soil mixture (< 2 mm) were extracted with 50 mL of 2 mol/L KCl to examine the initial nitrate ($NO^{3-}$) concentrations, which were quantified using an automatic discontinuous chemical analyzer (SMART CHEM 200).

# Microbial community structure analysis

To determine the soil microbial community composition, 10 g of freeze-dried soil samples that were collected at 1, 30, and 180 d during the incubation period, were placed into 90 mL of sterile 0.85% NaCl solution. Diluted supernatant fluid was put into a Biolog ECO board and then incubated at 25–28℃. Every 24 h, the absorbance values of each ECO plate were recorded on the Biolog instrument. To determine the utilization of carbon sources by soil microorganisms, the average rate of color change (AWCD) was recorded.

# The activation effect of $CO_2$ on soil organic carbon mineralization

The excitation effect value was calculated as follows (Luo et al., 2014):

PE (%) = (C1-C2)/C2×100%,

where, C1 is the amount of $CO_2$ from original organic carbon mineralized in the soil under high $CO_2$ concentrations and C2 is the amount of $CO_2$ from soil organic carbon under low $CO_2$ concentrations. A PE value > 0 means that the addition of $CO_2$ causes a positive excitation effect on soil organic carbon. A PE value < 0 indicates that the addition of $CO_2$ causes a negative excitation effect on soil organic carbon and inhibits the mineralization of bulk organic carbon.

# Statistical analysis

Statistical analyses were performed using SPSS 13.0, Microsoft Excel 2007, and Croeldraw X4. GPS package was used to draw a heatmap. All statistical data are described using mean ± standard deviation (SD). A P value less than 0.05 was considered to be statistically significant.

## Results

# Basic soil properties

The initial organic ingredients in soil and the mixture of soil and materials are summarized in Table 1. The content of C and N and C/N ratio were higher in the soil samples mixed with organic materials than in the soil-only group.

Table 1
The basic chemical compositions of soil and organic amendments

| Content | Soil | Chicken manure | Cow manure | Corn straw |
|---|---|---|---|---|
| C(g/kg) | 8.77 | 285.64 | 256.08 | 560.90 |
| N(g/kg) | 0.65 | 13.85 | 5.58 | 6.10 |
| C/N | 13.49 | 20.62 | 45.89 | 91.95 |

# Soil C and N mineralization

The cumulative $CO_2$ release and release rate of different groups under different culture times were investigated. According to data shown in Fig. 1A–1B, the cumulative $CO_2$ release and release rate differed among soil samples in which different organic materials were added, in descending order, as corn straw > chicken manure > cow manure. Moreover, the cumulative $CO_2$ release and release rate were higher in high $CO_2$ concentrations than in groups treated with low $CO_2$ concentrations. During the culture period, the $CO_2$ release rate of each group gradually decreased and essentially stabilized after 60 days, which suggests that high $CO_2$ concentrations can accelerate the mineralization of organic carbon in soil containing with organic materials. More importantly, the effects of high $CO_2$ concentration on the levels of different organic materials are summarized in Fig. 1C–1F.

Meanwhile, as illustrated in Table 2, the content of total organic carbon and active organic carbon in soil increased after 180 days of incubation upon addition of chicken manure, cow manure, or corn straw. In addition, high $CO_2$ concentration resulted in less total organic carbon and active organic carbon in chicken manure or cow manure groups, respectively. Inversely, the total organic carbon and active organic carbon in the cow manure group treated with high $CO_2$ concentrations were significantly higher than those in group treated with low $CO_2$ concentration (both, $P < 0.05$).

Table 2
Organic carbon contents in soil under different treatments

| Groups | Total organic carbon (mg/kg) | High active organic carbon (mg/kg) | Middle active organic carbon (mg/kg) | Active organic carbon (mg/kg) |
|---|---|---|---|---|
| L1 | 7.00 ± 0.27a | 0.68 ± 0.09a | 0.28 ± 0.15a | 0.75 ± 0.41a |
| H1 | 7.41 ± 0.19a | 0.45 ± 0.13b | 0.45 ± 0.24a | 0.75 ± 0.23a |
| L2 | 10.25 ± 0.70a | 0.83 ± 0.05a | 0.98 ± 0.34a | 1.55 ± 0.19a |
| H2 | 9.29 ± 0.07a | 0.85 ± 0.03a | 0.85 ± 0.24a | 1.12 ± 0.18b |
| L3 | 10.12 ± 0.10a | 0.90 ± 0.13a | 1.40 ± 0.10a | 1.67 ± 0.56a |
| H3 | 8.22 ± 0.04b | 0.75 ± 0.05a | 1.05 ± 0.30a | 2.70 ± 0.09a |
| L4 | 15.79 ± 0.25a | 1.85 ± 0.11a | 2.73 ± 0.21a | 2.67 ± 0.24a |
| H4 | 17.34 ± 0.10b | 1.65 ± 0.16b | 2.93 ± 0.60a | 3.74 ± 0.09b |
| Note: Values with different letters in the same column of group are significantly different at P < 0. 05 | | | | |

As shown in Table 3, when compared with the groups treated with low $CO_2$ concentration, the $NO^{3-}$-N levels were significantly lower in groups treated with high $CO_2$ concentration (all, $P < 0.05$). The order of $NO^{3-}$-N content was chicken manure > cow manure > corn straw. During the culture period, the content of $NO^{3-}$-N in the control soil group and groups treated with chicken or cow manure increased gradually. On the contrary, the content of $NO^{3-}$-N in the soil with straw added was lower than that in the control soil, indicating that the addition of straw can reduce the $NO^{3-}$-N levels in soil. Collectively, high $CO_2$ concentrations can reduce the mineralization of organic N in soil with added organic materials.

Table 3
Nitrate nitrogen content in soil under different treatments

| Groups | 1 | 30 | 60 | 180 |
|---|---|---|---|---|
| L1 | 11.95 ± 0.64a | 21.10 ± 0.77a | 35.68 ± 1.60a | 55.51 ± 0.78a |
| H1 | 10.20 ± 0.27b | 19.92 ± 0.60b | 29.26 ± 0.13b | 43.51 ± 0.11b |
| L2 | 153.88 ± 3.18a | 213.04 ± 12.30a | 221.57 ± 7.96a | 259.72 ± 1.34a |
| H2 | 160.03 ± 13.86a | 162.98 ± 15.45b | 183.58 ± 1.67b | 229.31 ± 1.32b |
| L3 | 45.86 ± 3.82a | 45.29 ± 0.79a | 61.83 ± 1.59a | 135.81 ± 0.69a |
| H3 | 37.44 ± 2.16a | 42.20 ± 0.56b | 37.69 ± 2.80b | 78.31 ± 0.41b |
| L4 | 8.66 ± 0.52a | 6.22 ± 0.31a | 6.56 ± 0.10a | 5.49 ± 0.53a |
| H4 | 9.54 ± 0.56a | 5.82 ± 0.11a | 6.20 ± 0.07b | 4.64 ± 0.75b |
| Note: Values with different letters in the same column of group are significantly different at P < 0. 05 | | | | |

# Microbial community composition

In order to detect the carbon source utilization by soil microorganisms, the AWCD of soil microorganisms was determined after 1, 30, and 180 d of incubation. Under high $CO_2$ concentrations at the early stages of culture (1 and 30 d), the utilization of carbon sources by the microbial community was increased compared with that under conditions of low $CO_2$ concentration (Fig. 2A and 2B). However, in addition to the corn straw group, the utilization of carbon sources by the microbial communities in soils was decreased at 180 days upon adding chicken manure or cow manure under high $CO_2$ concentrations (Fig. 2C).

Additionally, the results of soil microbial community diversity analysis showed that under high $CO_2$ concentrations at 30 d, the soil microbial community diversity index and richness index were increased compared with that under low $CO_2$ concentrations (Table 4). Principal component analyses (PCA) showed that the H1 and the H2 treatments were close to each other; whereas H3 and H4 treatments clustered separately (Fig. 2D–2F). Moreover, the heatmaps of microbial carbon source utilization showed that the utilization of 31 carbon sources by soil microbial communities differed among the experimental groups (Fig. 3). All these data indicate that high $CO_2$ concentrations can change the characteristics of the soil microbial community.

Table 4
The indexes of soil microbial community diversity under different treatments

| Days | Treats | Diversity index (U) | Diversity index (H') | Simpson index | Shannon evenness | Carbon source utilization richness index(s) |
|---|---|---|---|---|---|---|
| | L1 | 4.24 ± 0.22 | 2.34 ± 0.12 | 0.87 ± 0.02 | 1.02 ± 0.01 | 10.00 ± 1.00 |
| | H1 | 5.10 ± 0.35 | 2.38 ± 0.08 | 0.89 ± 0.01 | 0.98 ± 0.01 | 11.33 ± 0.88 |
| | L2 | 8.03 ± 0.42 | 3.04 ± 0.02 | 0.95 ± 0.01 | 1.00 ± 0.01 | 21.00 ± 0.01 |
| 1d | H2 | 8.51 ± 0.31 | 3.03 ± 0.02 | 0.95 ± 0.01 | 0.99 ± 0.01 | 21.67 ± 0.67 |
| | L3 | 8.58 ± 0.30 | 3.10 ± 0.02 | 0.95 ± 0.01 | 0.97 ± 0.01 | 24.67 ± 0.33 |
| | H3 | 5.49 ± 0.40 | 2.96 ± 0.04 | 0.93 ± 0.01 | 0.99 ± 0.02 | 20.00 ± 1.53 |
| | L4 | 8.81 ± 0.41 | 3.24 ± 0.04 | 0.96 ± 0.01 | 0.96 ± 0.01 | 29.33 ± 0.88 |
| | H4 | 9.56 ± 0.20 | 3.26 ± 0.02 | 0.96 ± 0.01 | 0.97 ± 0.01 | 28.67 ± 0.33 |
| | L1 | 1.69 ± 0.09 | 1.30 ± 0.23 | 0.65 ± 0.07 | 1.39 ± 0.16 | 3.00 ± 1.00 |
| | H1 | 3.65 ± 0.33 | 2.19 ± 0.11 | 0.86 ± 0.02 | 1.06 ± 0.05 | 8.00 ± 0.58 |
| | L2 | 5.09 ± 0.43 | 2.55 ± 0.06 | 0.90 ± 0.01 | 0.99 ± 0.01 | 13.33 ± 0.88 |
| 30d | H2 | 5.34 ± 0.32 | 2.88 ± 0.01 | 0.93 ± 0.01 | 0.98 ± 0.02 | 19.00 ± 1.00 |
| | L3 | 4.65 ± 1.09 | 2.55 ± 0.08 | 0.91 ± 0.01 | 0.99 ± 0.02 | 13.33 ± 1.20 |
| | H3 | 4.88 ± 0.16 | 2.51 ± 0.16 | 0.90 ± 0.02 | 1.02 ± 0.02 | 12.33 ± 2.33 |
| | L4 | 9.49 ± 0.20 | 2.89 ± 0.02 | 0.94 ± 0.01 | 0.97 ± 0.01 | 20.00 ± 0.01 |
| | H4 | 9.87 ± 0.15 | 2.96 ± 0.07 | 0.94 ± 0.01 | 0.96 ± 0.01 | 21.67 ± 0.88 |
| | L1 | 1.81 ± 0.43 | 1.45 ± 0.23 | 0.67 ± 0.08 | 1.55 ± 0.29 | 3.33 ± 1.33 |

| Days | Treats | Diversity index (U) | Diversity index (H') | Simpson index | Shannon evenness | Carbon source utilization richness index(s) |
|---|---|---|---|---|---|---|
| | H1 | 0.13 ± 0.01 | 2.02 ± 0.13 | 0.79 ± 0.05 | 0.01 ± 0.01 | 0.11 ± 0.01 |
| | L2 | 4.17 ± 0.17 | 2.18 ± 0.01 | 0.87 ± 0.01 | 1.06 ± 0.04 | 8.00 ± 0.58 |
| | H2 | 3.28 ± 0.20 | 1.93 ± 0.09 | 0.82 ± 0.02 | 1.14 ± 0.07 | 5.67 ± 0.88 |
| 180d | L3 | 2.87 ± 0.69 | 2.45 ± 0.19 | 0.89 ± 0.03 | 1.14 ± 0.10 | 10.33 ± 3.53 |
| | H3 | 2.22 ± 0.35 | 1.49 ± 0.20 | 0.70 ± 0.07 | 1.37 ± 0.27 | 3.67 ± 1.20 |
| | L4 | 6.79 ± 0.60 | 2.84 ± 0.05 | 0.93 ± 0.01 | 0.97 ± 0.02 | 19.00 ± 2.00 |
| | H4 | 8.53 ± 0.19 | 3.00 ± 0.04 | 0.94 ± 0.01 | 0.96 ± 0.01 | 22.67 ± 0.33 |

# The activation effect of $CO_2$ on soil organic carbon mineralization

As illustrated in Fig. 4, at the initial culture stage, soil microbial activity increased under high $CO_2$ concentrations, which led to increased soil organic carbon mineralization. However, as culture time increased, soil microbial activity gradually decreased, and the microbial activity in soil gradually decreased after 50 days of culture in high $CO_2$ conditions.

Correlation analysis showed that cumulative $CO_2$ release was positively correlated with AWCD value, diversity index, and richness index (Table 5).

Table 5
Correlation analysis of soil microbial diversity index with AWCD value and carbon dioxide cumulative release

| | CO2 cumulative release | AWCD value | Diversity index (U) | Diversity index (H) | Simpson index | Evenness |
|---|---|---|---|---|---|---|
| AWCD value | 0.823** | | | | | |
| Diversity index (U) | 0.844** | 0.977** | | | | |
| Diversity index (H) | 0.610** | 0.835** | 0.783** | | | |
| Simpson index | 0.512* | 0.691** | 0.679** | 0.933** | | |
| Evenness | 0.192 | -0.005 | 0.099 | -0.328 | -0.370 | |
| Richness index of C source utilization | 0.813** | 0.967** | 0.955** | 0.871** | 0.744** | 0.023 |

# Discussion

Previous studies have suggested that accelerated SOM decomposition rates will result in greater quantities of $CO_2$ being emitted into the atmosphere, thus exacerbating the greenhouse effect; whereas the higher availability of other nutrients due to SOM decomposition can facilitate photosynthesis and growth, leading to enhanced sequestration of atmospheric $CO_2$ (Erhagen et al., 2013; Wang et al., 2015). Moreover, Chen et al. (Chen et al., 2015) revealed that elevated $CO_2$ and temperature greatly enhance the temperature sensitivity of SOM decomposition. However, data on the effects of $CO_2$ on the mineralization of SOM is limited. In our study, under high $CO_2$ conditions, the cumulative $CO_2$ release and $CO_2$ release rate of soil containing chicken manure, cow manure, or corn straw were higher than those under low $CO_2$ concentrations, suggesting the increased $CO_2$ promotes SOC mineralization. Additionally, the content of total organic carbon and active organic carbon in soil containing chicken manure or cow manure was reduced under the conditions of high $CO_2$ but was increased in soil containing corn straw under the same conditions. We speculated that this occurred because straw contains high levels of easily decomposed organic matter, which is conducive to the growth and activity of microorganisms, thus accelerating the transformation of organic carbon in straw and increasing the content of soil organic carbon.

As one of the essential nutrients for plant growth, nitrogen is mineralized into inorganic forms, including $NH^{4+}$-N and $NO^{3-}$N, by microbial decomposition (Hu et al., 2019; Xia et al., 2010; Yuan et al., 2016); Gai et al. (Gai et al., 2019) found that long-term manure application and straw incorporation are beneficial for soil NO-N content retention. Additionally, Xie et al. (Xie et al., 2019) reported that management with an organic fertilizer can markedly reduce the levels of ammonium nitrogen (NH-N) and nitrate nitrogen (NO-N) (TK) in runoff water. Our data revealed that, compared with the groups exposed to low $CO_2$ concentrations, the content of $NO^{3-}$-N was significantly decreased in groups treated with high $CO_2$

concentrations, indicating that high $CO_2$ concentration can reduce the mineralization of organic N in soil with added organic materials. Moreover, a previous study suggested that increased $NO^{3-}$ concentrations in soil are due to the nitrogenization of $NH^{4+}$ (Jien et al., 2017); however, the content of $NH^{4+}$-N was not detected in the present study, it will be evaluated in future experiments.

Given that microbial biomass is generally C-limited in agricultural soil, the application of organic fertilizers presumably stimulates the growth and activity of microorganisms by increasing SOC labile fractions, which can lead to the changes in the mineralization rate of soil organic matter (Luo et al., 2014). Accumulating evidence suggests that the stimulatory effect of organic materials on SOM mineralization is determined by carbon stability and pore structure characteristics (Chen et al., 2018; Luo et al., 2011; Sun et al., 2014); Generally, the properties of organic materials containing different types of raw materials are quite different, which leads to different effects on soil microorganisms and enzyme activities (Lehmann et al., 2011; Lu et al., 2014). However, to date, the effect of biodiversity on soil carbon and nitrogen mineralization remains controversial (Hol et al., 2010; Johannes et al., 2009; Naidoo et al., 2008; Philippot et al., 2013). Results of the present study showed that soil microbial diversity was significantly correlated with soil carbon accumulation and mineralization. In particular, increased $CO_2$ concentration increased soil microbial diversity during the early incubation period, but in later stages of incubation, the soil microbial diversity decreased, which was in line with previous reports related to functional redundancy (Kelly et al., 2016; Loreau, 2010; Moya and Ferrer, 2016). Functional redundancy studies suggest that different species can perform the same function, and the loss of one species can be replaced by another species; therefore, reduced biodiversity does not have significant impact on the function of the ecosystem. Our study confirmed that increasing $CO_2$ concentration only affected soil microbial diversity during a certain period of time. We speculate that the microbial species in the soil were restored and adjusted after a period of time, and although the diversity was reduced, the community's functions were not affected, since species play redundant roles.

In conclusion, our results showed that adding organic materials to soil can accelerate the mineralization of organic carbon and reduce the mineralization of nitrogen under high $CO_2$ concentrations. Briefly, the content of total organic carbon and active organic carbon in soil could be reduced by adding chicken manure or cow manure, or increased by adding straw under high $CO_2$ concentrations. Moreover, after the addition of different organic materials, the utilization of carbon sources by soil microorganisms differed because under the conditions of $CO_2$ enrichment, soil microbial activity increased, which accelerated the mineralization of soil organic carbon and caused a positive excitation effect in the short term. However, with the extension of culture time, soil microbial activity decreased gradually, and a negative excitation effect occurred in the soil.

# Declarations


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### Competing Interests

The authors declare that they have no competing interests.

# References

1. Chaparro, J.M., Sheflin, A.M., Manter, D.K., Vivanco, J.M., 2012. Manipulating the soil microbiome to increase soil health and plant fertility. Biology and Fertility of Soils 48, 489-499.
2. Chen, Y., Liu, Y., Chen, Z., Lv, H., Wang, Y., He, L., Yang, S., 2018. Research progress on the activation effect of biochar on soil organic carbon mineralization and its mechanism. Journal of applied ecology 29, 314-320.
3. Chen, Z., Wang, B., Wang, J., Pan, G., Xiong, Z., 2015. Contrasting effects of elevated CO2 and warming on temperature sensitivity of soil organic matter decomposition in a Chinese paddy field. Environmental monitoring and assessment 188, 545.
4. Cookson, W.R., Osman, M., Marschner, P., Abaye, D.A., Clark, I., Murphy, D.V., Stockdale, E.A., Watson, C.A., 2007. Controls on soil nitrogen cycling and microbial community composition across land use and incubation temperature. Soil Biology & Biochemistry 39, 744-756.
5. Demoling, L.A., Bååth, E., Greve, G., Wouterse, M., Schmitt, H., 2009. Effects of sulfamethoxazole on soil microbial communities after adding substrate. Soil Biology and Biochemistry 41, 840-848.
6. Erhagen, B., Öquist, M., Sparrman, T., Haei, M., Ilstedt, U., Hedenström, M., Schleucher, J., Nilsson, M., 2013. Temperature response of litter and soil organic matter decomposition is determined by chemical composition of organic material. Global Change Biology 19, 3858-3871.
7. Gai, X., Liu, H., Liu, J., Zhai, L., Wang, H., Yang, B., Ren, T., Wu, S., Lei, Q., 2019. Contrasting impacts of long-term application of manure and crop straw on residual nitrate-N along the soil profile in the North China Plain. The Science of the total environment 650, 2251-2259.
8. Haei, M., Ilstedt, U., Laudon, H., 2012. The influence of soil frost on the quality of dissolved organic carbon in a boreal forest soil: combining field and laboratory experiments. Biogeochemistry 107, 95-106.
9. Hagedorn, F., Spinnler, D., Bundt, M., Blaser, P., Siegwolf, R., 2010. The input and fate of new C in two forest soils under elevated CO2. Global Change Biology 9, 862-872.
10. Hol, W.H., De, B.W., Termorshuizen, A.J., Meyer, K.M., Schneider, J.H., van Dam, N.M., van Veen, J.A., Wh, V.D.P., 2010. Reduction of rare soil microbes modifies plant-herbivore interactions. Ecology Letters 13, 292-301.
11. Hu, T., Hu, H., Li, F., Zhao, B., Wu, S., Zhu, G., Sun, L., 2019. Long-term effects of post-fire restoration types on nitrogen mineralisation in a Dahurian larch (Larix gmelinii) forest in boreal China. The

Science of the total environment 679, 237-247.

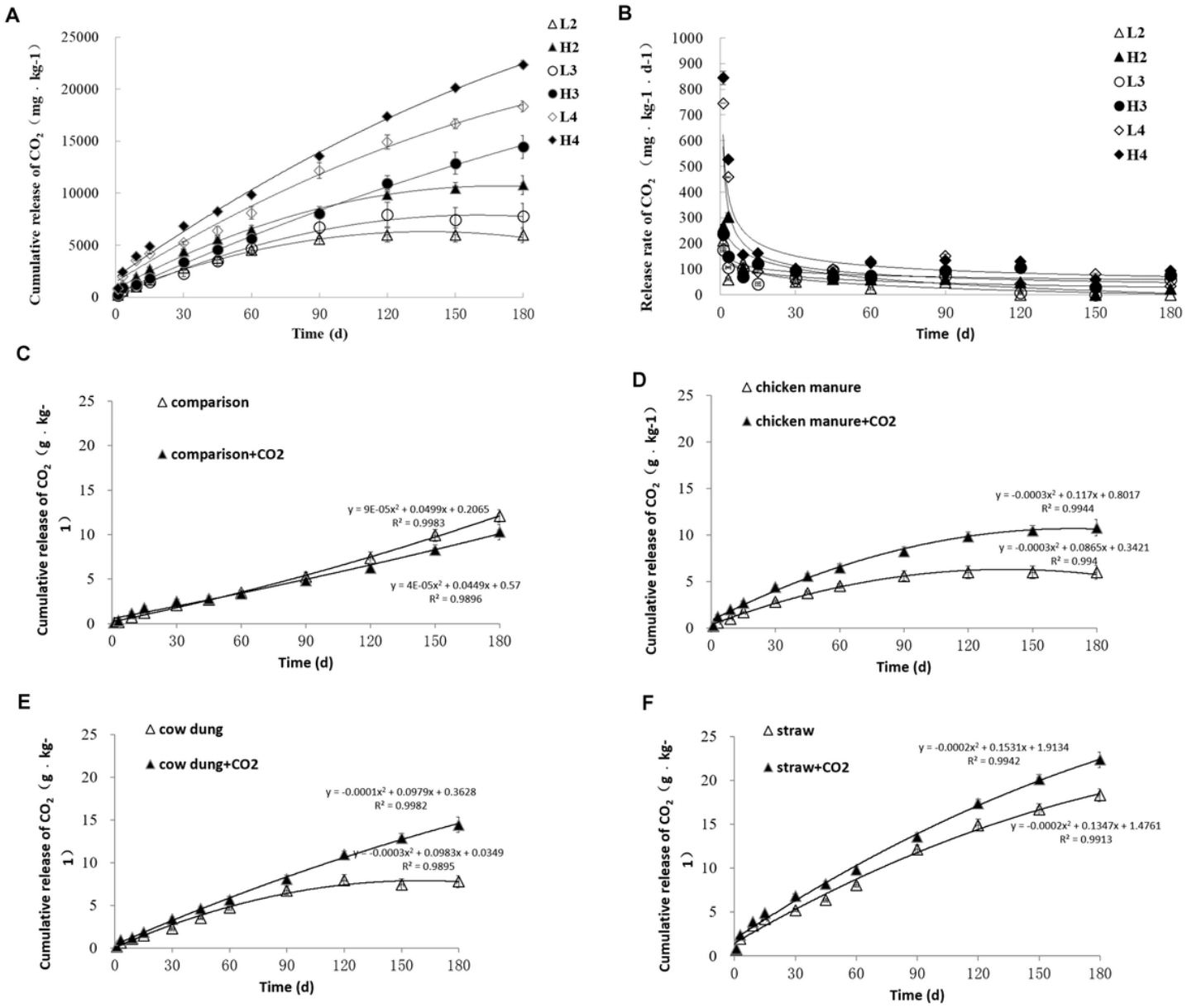
12. Jien, S.H., Chen, W.C., Yong, S.O., Awad, Y.M., Liao, C.S., 2017. Short-term biochar application induced variations in C and N mineralization in a compost-amended tropical soil. Environmental Science & Pollution Research, 1-11.
13. Johannes, L., Saran, S., 2008. Comment on "Fire-derived charcoal causes loss of forest humus". Science 321, 1295; author reply 1295.
14. Johannes, R., Brookes, P.C., Erland, B.T., 2009. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. Applied & Environmental Microbiology 75, 1589-1596.
15. Juarez, S., Nunan, N., Duday, A.-C., Pouteau, V., Chenu, C., 2013. Soil carbon mineralisation responses to alterations of microbial diversity and soil structure. Biology and Fertility of Soils 49, 939-948.
16. Junna, S., Bingchen, W., Gang, X., Hongbo, S., 2014. Effects of wheat straw biochar on carbon mineralization and guidance for large-scale soil quality improvement in the coastal wetland. Ecological Engineering 62, 43-47.
17. Katsaliroua, E., Nofziger, D.L., Gerakis, A., 2010. Long-term management effects on organic C and N pools and activities of C-transforming enzymes in prairie soils. European Journal of Soil Biology 46, 335-341.
18. Kelly, E.L.A., Eynaud, Y., Clements, S.M., Gleason, M., Sparks, R.T., Williams, I.D., Smith, J.E., 2016. Investigating functional redundancy versus complementarity in Hawaiian herbivorous coral reef fishes. Oecologia 182, 1-13.
19. Lal, R., . 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304, 1623-1627.
20. Lee, S.B., Chang, H.L., Jung, K.Y., Park, K.D., Lee, D., Kim, P.J., 2009. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. Soil & Tillage Research 104, 227-232.
21. Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., Crowley, D., 2011. Biochar effects on soil biota – A review. Soil Biology & Biochemistry 43, 1812-1836.
22. Loreau, M., 2010. Does functional redundancy exist? Oikos 104, 606-611.
23. Lu, W., Ding, W., Zhang, J., Li, Y., Luo, J., Bolan, N., Xie, Z., 2014. Biochar suppressed the decomposition of organic carbon in a cultivated sandy loam soil: A negative priming effect. Soil Biology & Biochemistry 76, 12-21.
24. Luo, Y., Durenkamp, M., Nobili, M.D., Lin, Q., Brookes, P.C., 2011. Short term soil priming effects and the mineralisation of biochar following its incorporation to soils of different pH. Soil Biology & Biochemistry 43, 2304-2314.
25. Luo, Y., Zhao, X., Li, G., Zhao, L., Zhao, H., Lin, Q., 2014. Characteristics and differences of activation effects of miscanthus biomass charcoal in acidic and alkaline soils. Journal of soil, 90-95.

26. Manzoni, S., Porporato, A., 2009. Soil carbon and nitrogen mineralization: Theory and models across scales. Soil Biology & Biochemistry 41, 1355-1379.
27. Moya, A., Ferrer, M., 2016. Functional Redundancy-Induced Stability of Gut Microbiota Subjected to Disturbance. Trends in Microbiology 24, 402-413.
28. Naidoo, R., ., Balmford, A., ., Costanza, R., ., Fisher, B., ., Green, R.E., Lehner, B., ., Malcolm, T.R., Ricketts, T.H., 2008. Global mapping of ecosystem services and conservation priorities. Proceedings of the National Academy of Sciences of the United States of America 105, 9495-9500.
29. Nelson, D.W., Sommers, L.E., Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E., 1996. Total carbon, organic carbon, and organic matter. Methods of Soil Analysis 9, 961-1010.
30. Philippot, L., Spor, A., Hénault, C., Bru, D., Bizouard, F., Jones, C.M., Sarr, A., Maron, P.A., 2013. Loss in microbial diversity affects nitrogen cycling in soil. Isme Journal Multidisciplinary Journal of Microbial Ecology 7, 1609-1619.
31. Phillips, R.P., Finzi, A.C., Bernhardt, E.S., 2011. Enhanced root exudation induces microbial feedbacks to N cycling in a pine forest under long-term CO2 fumigation. Ecology Letters 14, 187-194.
32. Pires, C., Schaefer, C., Hashigushi, A., Thomazini, A., Filho, E., Mendonça, E., 2017. Soil organic carbon and nitrogen pools drive soil C-CO2 emissions from selected soils in Maritime Antarctica. The Science of the total environment null, 124-135.
33. Prayogo, C., Jones, J.E., Baeyens, J., Bending, G.D., 2014. Impact of biochar on mineralisation of C and N from soil and willow litter and its relationship with microbial community biomass and structure. Biology and Fertility of Soils 50, 695-702.
34. Rhodes, C., 2014. Soil erosion, climate change and global food security: challenges and strategies. Science progress 97, 97-153.
35. Ribeiro, H.M., Fangueiro, D., Alves, F., Vasconcelos, E., Coutinho, J., Bol, R., Cabral, F., 2010. Carbon-mineralization kinetics in an organically managed Cambic Arenosol amended with organic fertilizers. Journal of Plant Nutrition & Soil Science 173, 39-45.
36. Sleutel, S., Bouckaert, L., Buchan, D., Van Loo, D., Cornelis, W., Sanga, H.G., 2012. Manipulation of the soil pore and microbial community structure in soil mesocosm incubation studies. Soil Biology and Biochemistry 45, 40-48.
37. Sun, J., Wang, B., Gang, X., Shao, H., 2014. Effects of wheat straw biochar on carbon mineralization and guidance for large-scale soil quality improvement in the coastal wetland. Ecological Engineering 62, 43-47.
38. Torbert, H., Prior, S., Rogers, H., Wood, C., 2000. Review of elevated atmospheric CO2 effects on agro-ecosystems: residue decomposition processes and soil C storage. Plant and Soil 224, 59-73.
39. Wang, G., Jia, Y., Li, W., 2015. Effects of environmental and biotic factors on carbon isotopic fractionation during decomposition of soil organic matter. Scientific reports 5, 11043.
40. Xia, J., Niu, S., Wan, S., 2010. Response of ecosystem carbon exchange to warming and nitrogen addition during two hydrologically contrasting growing seasons in a temperate steppe. Global

Change Biology 15, 1544-1556.

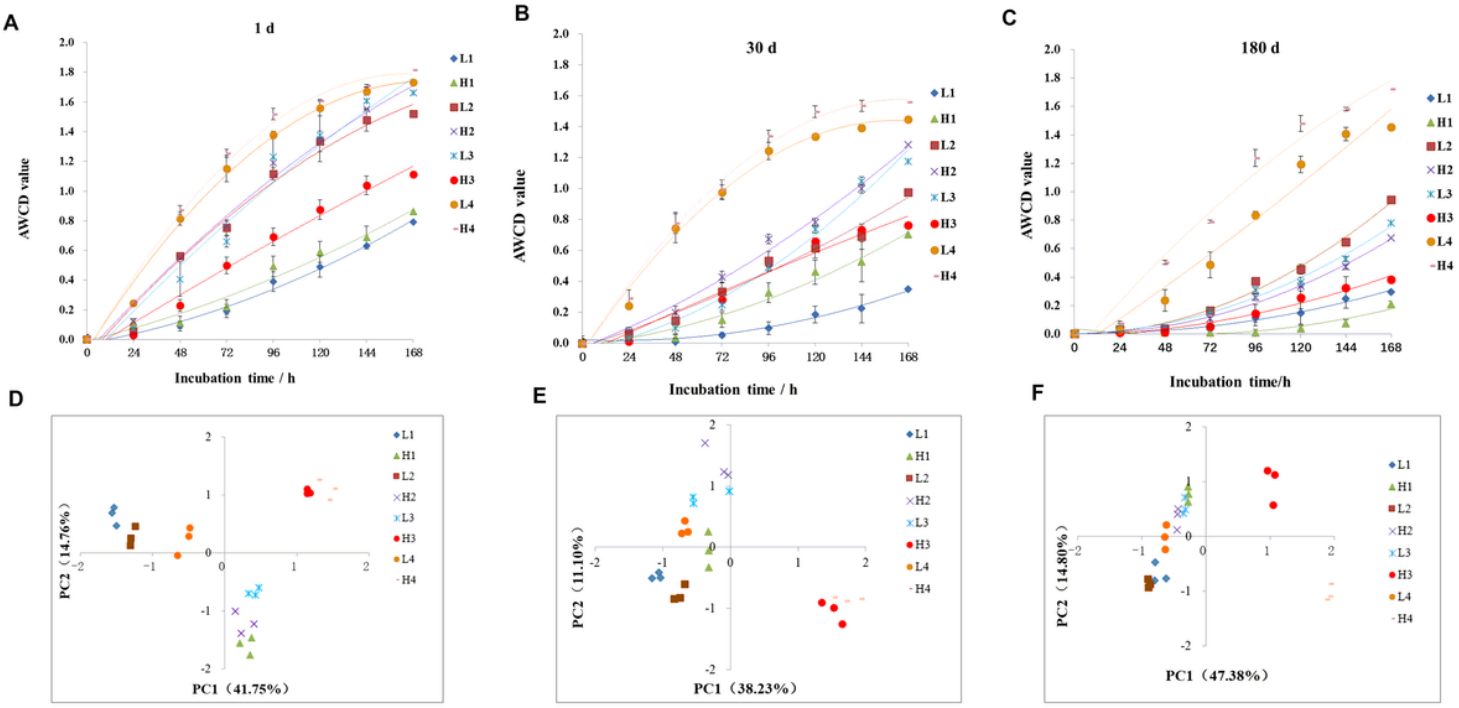
41. Xie, S., Feng, H., Yang, F., Zhao, Z., Hu, X., Wei, C., Liang, T., Li, H., Geng, Y., 2019. Does dual reduction in chemical fertilizer and pesticides improve nutrient loss and tea yield and quality? A pilot study in a green tea garden in Shaoxing, Zhejiang Province, China. Environmental science and pollution research international 26, 2464-2476.
42. Yuan, L., He, N., Wen, X., Yu, G., Yang, G., Jia, Y., 2016. Patterns and regulating mechanisms of soil nitrogen mineralization and temperature sensitivity in Chinese terrestrial ecosystems. Agriculture Ecosystems & Environment 215, 40-46.
43. Zavalloni, C., Alberti, G., Biasiol, S., Delle Vedove, G., Fornasier, F., Liu, J., Peressotti, A., 2011. Microbial mineralization of biochar and wheat straw mixture in soil: a short-term study. Applied Soil Ecology 50, 45-51.

# Figures



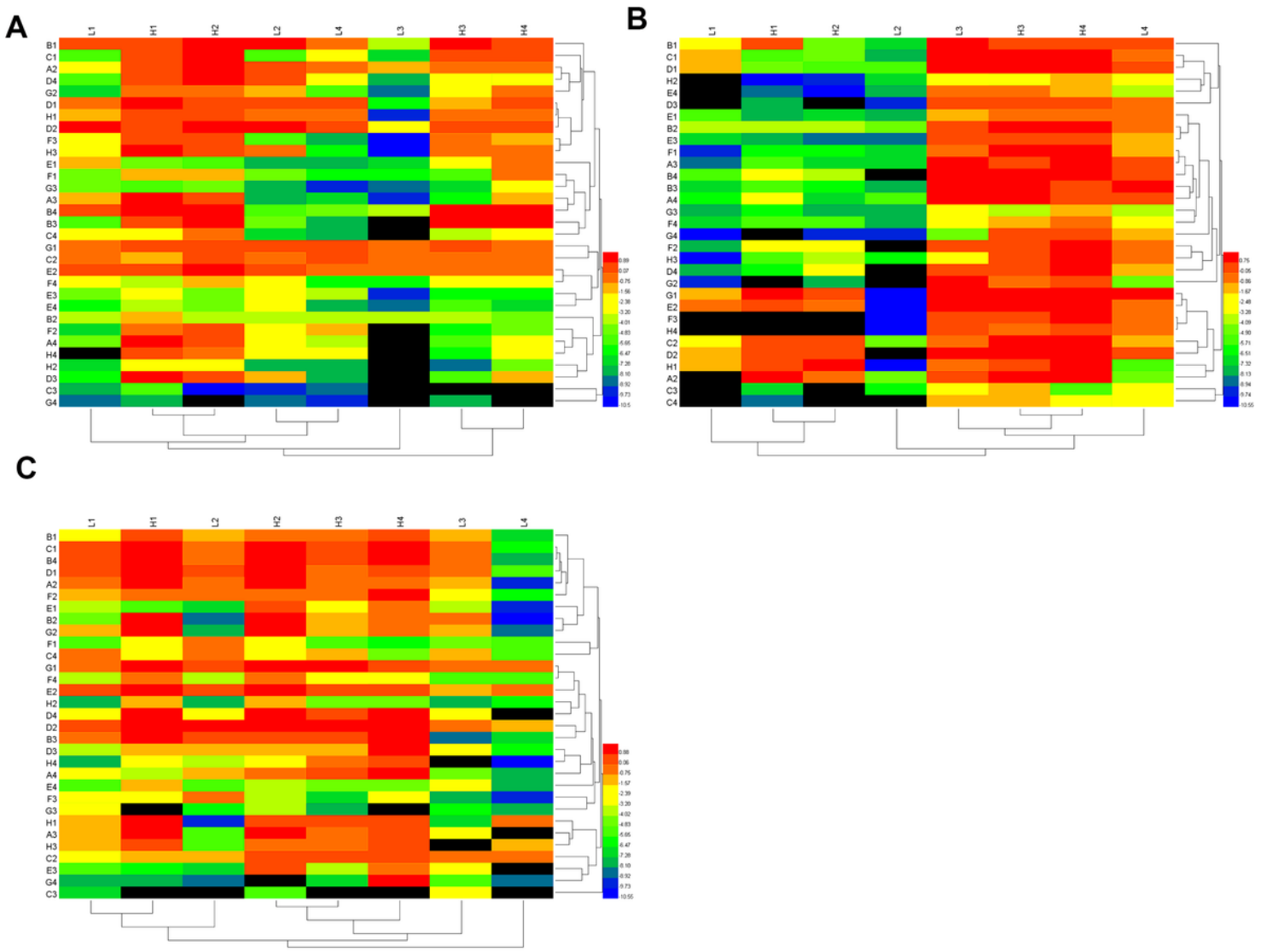

## Figure 1

The cumulative release (A, C–F) and the release rate of CO2 (B).




## Figure 2

Utilization of carbon sources by soil microorganisms, and principal component analysis of soil microbial community metabolism under different treatment conditions. (A) The average rate of color change (AWCD) values after incubation for 1, 30, and 180 days, respectively. Soil microbial community structure and carbon source utilization pattern were changed by adding different organic materials and taking samples at different culture times (B).




## Figure 3

The heatmaps of carbon source utilization rate of soil microorganisms cultured for 1, 30, and 180 d under different treatment conditions. B1, methyl pyruvate; C1, twain 40; D1, twain 80; E1, a-cyclodextrin; F1, glycogen; G1, d-fibrodisaccharide; H1, a-d-lactose; A2, ss-methyl d-glucoside; B2, D-xylose; C2, i-alginol; D2, d-mannitol; E2, n-acetyl-d-glucosamine; F2, d-glucosamine; G2, glucose-1-phosphate; H2, D, l-a-glycerin; A3, d-galactonate; B3, d-galacturonic acid; C3, 2-hydroxybenzoate; D3, 4-hydroxybenzoate; E3, r-hydroxybutyric acid; F3, itaconic acid; G3, a-butanoic acid; H3, d-malic acid; A4, l-arginine; B4, L-asparaginic acid; C4 l-phenylalanine; D4, l-serine; E4, l-threonine; F4, glycyl-l-glutamate; G4, phenylethylamine; H4, putamine.

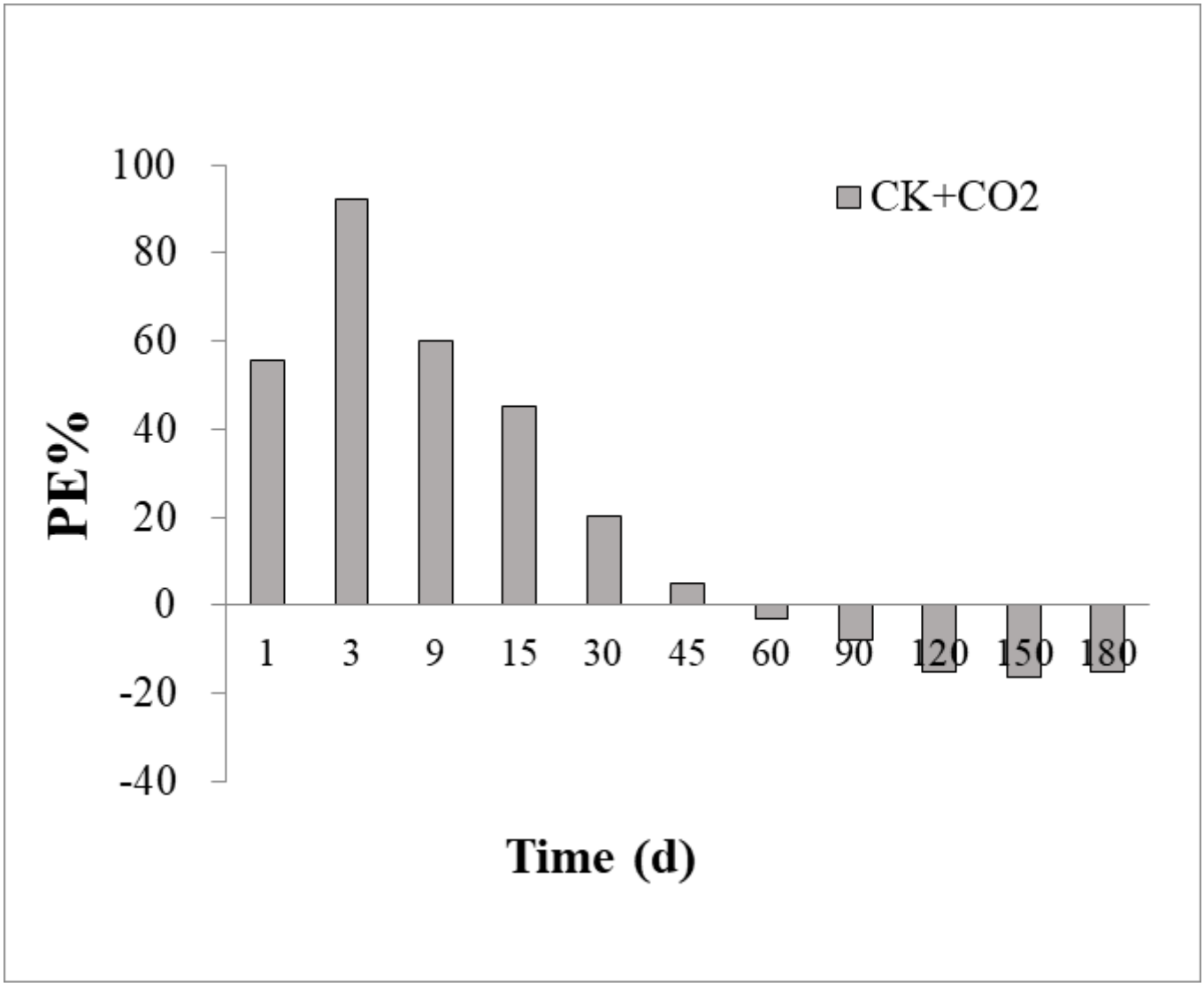



**Figure 4**

Stimulatory effect of CO2 on soil organic carbon mineralization.