Soil Respiration in Relation to Photosynthesis of Quercus mongolica Trees at Elevated CO₂

Yumei Zhou¹, Mai-He Li², Xu-Bing Cheng¹,³, Cun-Guo Wang¹,³, A-Nan Fan⁴, Lian-Xuan Shi⁵, Xiu-Xiu Wang⁶, Shijie Han¹*¹

¹ Department of Forest Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, China, ² Tree Physiology Group, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland, ³ Graduate School of Chinese Academy of Sciences, Beijing, China, ⁴ Dalian Forest Institute, Dalian, China, ⁵ School of Life Science, Northeast Normal University, Changchun, China, ⁶ Research Station of Changbai Mountain Forest Ecosystem, Chinese Academy of Sciences, Erdao, China

Abstract
Knowledge of soil respiration and photosynthesis under elevated CO₂ is crucial for exactly understanding and predicting the carbon balance in forest ecosystems in a rapid CO₂-enriched world. Quercus mongolica Fischer ex Ledebour seedlings were planted in open-top chambers exposed to elevated CO₂ (EC = 500 μmol mol⁻¹) and ambient CO₂ (AC = 370 μmol mol⁻¹) from 2005 to 2008. Daily, seasonal and inter-annual variations in soil respiration and photosynthetic assimilation were measured during 2007 and 2008 growing seasons. EC significantly stimulated the daytime soil respiration by 24.5% (322.4 at EC vs. 259.0 mg CO₂ m⁻² hr⁻¹ at AC) in 2007 and 21.0% (281.2 at EC vs. 232.6 mg CO₂ m⁻² hr⁻¹ at AC) in 2008, and increased the daytime CO₂ assimilation by 28.8% (624.1 at EC vs. 484.6 mg CO₂ m⁻² hr⁻¹ at AC) across the two growing seasons. The temporal variation in soil respiration was positively correlated with the aboveground photosynthesis, soil temperature, and soil water content at both EC and AC. EC did not affect the temperature sensitivity of soil respiration. The increased daytime soil respiration at EC resulted mainly from the increased aboveground photosynthesis. The present study indicates that increases in CO₂ fixation of plants in a CO₂-rich world will rapidly return to the atmosphere by increased soil respiration.

Introduction
The forest carbon balance is the net result of CO₂ fixation by aboveground photosynthesis and CO₂ release, notably the release from the belowground respiration of plant roots, rhizosphere, and soil organisms [1]. Almost 10% of the atmospheric CO₂ is released by soils each year [2], and this emission is more than the CO₂ released from fossil fuel combustion [3]. Soil respiration plays, therefore, a crucial role in the global carbon cycle and may be altered strongly by global environmental change [4–6].

Some studies found that elevated CO₂ had no effects on soil respiration [7,8], or, even suppressed soil respiration [9,10]. However, many studies using open-top chambers (OTCs) or Free-Air CO₂ Enrichment (FACE) experiments suggested that elevated CO₂ led to increased soil respiration rate [4,5,11–20]. For example, in a northern deciduous forest ecosystem, elevated CO₂ (534 μmol mol⁻¹) significantly stimulated soil respiration (+8–+26%) compared to the controls over three growing seasons [19]. Soil respiration rate was significantly stimulated (+10–+19%) by elevated CO₂ (500 μmol mol⁻¹) throughout 7 years of CO₂ enrichment in the Duke Forest FACE [18]. Data from four forest FACE experiments have shown that elevated CO₂ (544 μmol mol⁻¹) increased soil respiration by 16 to 39%, and the stimulation persisted for up to 6 years [5].

The rising concentration of atmospheric CO₂ commonly stimulated both photosynthesis and growth in forest trees [21–27], resulting in increased belowground carbon allocation [28,29]. Increased root biomass and root length stimulated root respiration [15,30,31]. After 6-years of CO₂ enrichment in a mid-successional lowland forest, root biomass and soil respiration increased by 50% and 30%, respectively [32].

There is growing evidence that soil respiration rate is closely correlated with aboveground photosynthesis [1,33–35]. A strong correlation between soil respiration and photosynthesis was observed in a mixed coniferous-deciduous temperate forest [36]. Soe et al. [6] reported that CO₂ respired by roots (rhizosphere) derived from the recently assimilated CO₂ accounted for 70% of the total soil respiration at a FACE facility. A large-scale tree-girdling experiment conducted in boreal forests showed that girdling reduced soil respiration by 54% relative to respiration on ungirdled control plots, indicating that current assimilation to roots is a key driver of soil respiration [1]. However, soil respiration does not respond to aboveground photosynthesis in complete synchrony. In situ radiocarbon labeling experiment in a black spruce forest revealed that the maximum ¹³C values in roots and rhizosphere respiration occurred 4 days after labeling [37]. Evidence from temperate and boreal forest ecosystems showed
that responses of root respiration to canopy photosynthesis lagged for a few hours to three weeks [33,38].

On the other hand, many environmental factors affect soil respiration [9]. Soil temperature has been recognized to be the most important environmental factor leading to seasonal and diurnal variations in soil respiration; and soil water content was considered to be the secondary variable affecting the temporal variation in soil respiration [39]. Soil respiration rate typically increases exponentially with increasing temperatures, and this relationship is often described using a $Q_{10}$ (magnitude of increase in gas efflux over a 10°C change) [16,39–42]. The $Q_{10}$ values varied greatly with vegetation types and environmental conditions [43]. King et al. [5] reported that $Q_{10}$ values ranged from 1.2 to 4.8 in four FACE experiments with developing and established forests exposed to elevated CO$_2$ for 2–6 years. Unlike temperature, there is no common function used to model the relationship between soil respiration and soil moisture. In Siberian tundra systems, soil water significantly affected soil respiration in wet microsites but not in dry microsites [44]. However, the diel variation of soil respiration measured in dry valleys of Antarctica was explained by soil moisture variation [45].

As mentioned above, the responses of soil respiration to elevated CO$_2$ gained from the published data seem to vary with the variations of experimental facilities, duration of CO$_2$ exposure, plant species, soil property, etc. Hence, we investigated the soil surface respiration rate and plant photosynthesis of Quercus mongolica Fischer ex Ledebour plants exposed to elevated CO$_2$ in OTCs for three (2007) and four years (2008). The deciduous Q. mongolica widely distributed in northern China, Japan, Korea, Mongolia, and eastern Siberia, is a dominant tree species of natural forests in northeastern China. We hypothesize that elevated CO$_2$ in deciduous forest ecosystems stimulates soil respiration only during the peak growing season (hypothesis I). The rationale behind this hypothesis is that the photosynthesis of deciduous trees may be significantly affected by elevated CO$_2$ only when leaves are expanded but not yellowed. This means that a stimulation of soil respiration may not be detectable during either the early or the late growing season. Hence, a stimulation of soil respiration at elevated CO$_2$ in deciduous forests would be attributed mainly to the enhanced aboveground photosynthesis (hypothesis II). In addition, we also hypothesize that the seasonal variation of soil respiration is correlated with soil temperature, but not with soil moisture in the study area (hypothesis III), where the yearly precipitation reaches ~700 mm.

**Results**

**Seasonal variation in soil respiration and photosynthesis**

Soil respiration showed distinct temporal variation over time ($P<0.001$ for both year and month time scale, Fig. 1A), with the highest values occurring in the peak growing season from June to August (Fig. 1A), when the soil was warm and the soil water content (SWC) was relatively high (Fig. 2). The lower values of accumulated daytime soil respiration occurred in May and October (Fig. 1A) when both soil temperature and soil moisture were low (Fig. 2). The accumulated daytime soil respiration ranged from 93.3 (EC) and 94.4 (AC) mg CO$_2$ m$^{-2}$ hr$^{-1}$ in October to 514.6 (EC) and 457.8 (AC) mg CO$_2$ m$^{-2}$ hr$^{-1}$ in August 2007. In 2008, the minimum and maximum accumulated daytime soil respiration were 103.9 mg CO$_2$ m$^{-2}$ hr$^{-1}$ in September and 481.3 mg CO$_2$ m$^{-2}$ hr$^{-1}$ in June at EC, 80.2 mg CO$_2$ m$^{-2}$ hr$^{-1}$ in September and 359.9 mg CO$_2$ m$^{-2}$ hr$^{-1}$ in August at AC (Fig. 1). No significant differences in soil respiration between EC and AC were found during the early (May) and late growing season (October) (Fig. 1A; $P>0.05$).

Within each CO$_2$ treatment, no significant inter-annual and seasonal variations in daytime photosynthesis of trees were found ($P>0.05$; Fig. 1B). The average accumulated CO$_2$ assimilation was 624.1 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at EC and 484.6 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at AC across the two growing seasons.

**Effects of elevated CO$_2$ on soil respiration and photosynthesis**

Elevated CO$_2$ increased the overall accumulated daytime soil respiration significantly (Table 1), especially during the peak of the growing season (June to August) when photosynthetic rate was high and environmental factors, including temperature and moisture, were optimal (Fig. 1A, Fig. 2). The overall percentage increase caused by EC reached 24.5% (322.4 at EC vs. 259.0 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at AC) for 2007 and 21.0% (281.2 at EC vs. 232.6 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at AC) for 2008, with marked increase of 79.7% (June 2007), 54.1% (June 2008), and 29.6% (September 2008). The average accumulated daytime soil respiration were 306.0 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at EC and 248.4 mg CO$_2$ m$^{-2}$ hr$^{-1}$ at AC over the two growing seasons (Table 1). However, during the
Soil respiration increased exponentially with $T_s$ for both CO₂ treatments (Fig. 3A). $T_s$ explained $>72\%$ of the variations in soil respiration (Table 2). No significant difference in $Q_{10}$ values between the two CO₂ treatments was detected for both 2007 and 2008 ($P>0.05$; Table 2). Across the two growing seasons, the $Q_{10}$ values were about 1.6 for both CO₂ treatments (Table 2).

Soil respiration increased with increasing SWC during the growing season for both CO₂ treatments, showing a positive correlation between soil respiration and SWC (Fig. 3B, Table 3). SWC at EC exhibited similar seasonal trend to AC and peaked in July and August (Fig. 2). In 2007, SWC ranged from 15.2% in October to 25.4% in July (19.4% on average) at EC and from 13.4% in May to 42.6% in July (24.9% on average) at AC (Table 2). In 2008, the mean SWC was 17.0% at EC with the lowest value of 4.8% in September and the highest value of 26.1% in July, whereas the mean SWC was 22.2% at AC with the lowest value of 7.7% in September and the highest value of 34.6% in August (Table 2). Elevated CO₂ significantly decreased SWC (Table 1) by 11.7% in 2007 and 20.6% in 2008.

Growth responses

The plant height and basal diameter at EC were significantly greater than those at AC across the two growing seasons (Fig. 4, Table 1). The plants stop growing after October until next May; therefore, the height and basal diameter in October 2007 were similar to those in May 2008 (Fig. 3). The plant height increased by 19.2 cm and 17.6 cm at EC and 17.6 cm and 19.6 cm at AC for 2007 and 2008, respectively. Similarly, the mean basal diameter increased by 0.4 cm at EC and 0.3 cm at AC for each year.

Relationships between soil respiration and biotic and abiotic factors

Daytime soil respiration was positively correlated with $T_s$ ($P<0.01$), SWC ($P<0.01$), and photosynthetic assimilation ($P<0.05$) for both AC and EC treatment (Table 3). In addition, positive correlation between $T_s$ and SWC was also found during the two growing seasons (Table 3).

Discussion

The seasonal pattern of soil respiration in our study showed that soil respiration was higher during the middle growing season just when the soil temperature, soil moisture and photosynthesis were also higher. These results are consistent with the findings of Niinisto et al. [16] and Pregitzer et al. [46], who found that the greatest soil respiration in forest ecosystems occurred during the peak growing season, and the lowest soil respiration was measured in spring and autumn when soil temperatures was relatively low and the canopy density was low.

Previous studies found that the increase magnitude of soil respiration caused by elevated CO₂ varied greatly with the tree species or vegetation cover [5,12,19]. The present study with deciduous Q. mongolica under elevated CO₂ showed a monthly increase in soil respiration by 23.0%. Similarly in deciduous forests, elevated CO₂ has been found to stimulate soil respiration by 39% in stands of paper birch and trembling aspen [15], and 8–26% in aspen forests [19]. In evergreen forests, elevated CO₂ stimulated the soil respiration by 24% in loblolly pine (Pinus taeda L.) plantation [18], 50–57% in ponderosa pine [11,12], 23–37% in 20-year-old Scots pines (Pinus sylvestris L.) [16], and 20% in Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings [47].

Consistent with our hypothesis I (see Introduction), the present study found that elevated CO₂ significantly stimulated soil
respiration from June to August (Fig. 1A, Table 1) and this stimulation was significantly correlated with enhanced photosynthesis (Fig. 1, Table 3). Increased plant height and basal diameter under elevated CO2 implied higher root biomass. Thus, the increase in respiring roots and photosynthate availability at elevated CO2 may result in pronounced increase in soil respiration compared to ambient CO2. Increased root biomass and production at elevated CO2 have already been recognized to be the most common reason resulting in increased soil respiration [12,16,19,48–51]. Previous studies indicated that there was a close relationship between aboveground photosynthesis and soil respiration since root respiration consumes recently fixed photosynthates from foliages [1,13,46,52–54]. Andrews and Schlesinger [53] attributed the increase in forest soil respiration to increased root and rhizosphere respiration under elevated CO2. Pregitzer et al. [19] reported that the recently fixed carbon by photosynthesis accounted for 60–80% of soil respiration during the peak growing season. Although there are still uncertainties regarding the relative contribution of roots or rhizosphere to the total soil respiration in the present study, higher soil respiration associated with higher photosynthesis under elevated CO2 may imply a greater carbon input to roots/rhizosphere. Thus, consistent with our hypothesis II (see Introduction), the increase in soil respiration at elevated CO2 is mainly attributed to increased aboveground photosynthesis.

Soil respiration varied significantly with year and month (P, 0.05), which may be a combined result of temporal variation in soil temperature, aboveground photosynthesis, and root growth rate. King et al. [5] found that the inter-annual variation of soil respiration in four FACE systems was determined by changes in soil temperature influencing plant photosynthesis and root growth. Regardless of CO2 treatment, soil respiration increased exponen-

### Table 2. Temperature response functions of soil respiration (μmol m⁻²s⁻¹) to soil temperature (°C); soil temperature and soil water content (%) in quality) during growing seasons in 2007 and 2008.

| Year   | Treatment       | Fitted equation     | R²   | Q₁₀  | Tₛ (Min) | Tₛ (Max) | Tₛ (Mean) | SWC (Min) | SWC (Max) | SWC (Mean) |
|--------|-----------------|---------------------|------|------|----------|----------|-----------|-----------|-----------|------------|
| 2007   | Elevated CO₂    | SR = 0.7096 exp (0.0822 Tₛ) | 0.7776 | 1.62 ± 0.03a | 4.4 ± 2.3 | 23.4 ± 0.6 | 16.6 ± 2.9a | 15.2 ± 0.7 | 25.4 ± 7.1 | 19.4 ± 1.7a |
|        | Ambient CO₂     | SR = 0.8243 exp (0.0641 Tₛ) | 0.7225 | 1.56 ± 0.08a | 2.6 ± 1.6 | 22.8 ± 1.6 | 16.0 ± 3.1a | 13.4 ± 3.2 | 42.6 ± 7.9 | 24.9 ± 4.3b |
| 2008   | Elevated CO₂    | SR = 0.3707 exp (0.1438 Tₛ) | 0.7390 | 1.54 ± 0.16a | 10.8 ± 0.7 | 16.5 ± 0.8 | 14.2 ± 1.4a | 4.8 ± 0.7 | 26.1 ± 4.8 | 17.9 ± 4.3a |
|        | Ambient CO₂     | SR = 0.4506 exp (0.1250 Tₛ) | 0.7736 | 1.57 ± 0.05a | 10.5 ± 0.6 | 17.9 ± 0.9 | 14.2 ± 1.7a | 7.7 ± 2.1 | 34.6 ± 2.4 | 22.2 ± 9.9b |

SR = soil respiration rate, Tₛ = soil temperature, SWC = soil water content.

Different letters between elevated and ambient CO2 within the same year and the same category indicated significant difference at P<0.05 level (n=3).

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Additionally, the results of Table 2 and Fig. 3A,B show that there is a strong linear relationship between soil respiration and temperature, and the relationship is exponential. The fitted curve is given in the figure. The fitted curve shows that the soil respiration rate increases exponentially with increasing temperature and that the relationship is described by the equation: SR = a exp(b Tₛ), where SR is the soil respiration rate, a and b are constants, and Tₛ is the soil temperature. The coefficients of determination (R²) for the fitted curves are shown in Table 2. The values of R² indicate that the models fit the data well, with R² values ranging from 0.72 to 0.77.

### Table 3. The Pearson’s correlation coefficient among soil respiration, photosynthesis, plant height, basal diameter, soil temperature at 5 cm depth and soil water content at elevated and ambient CO₂ during growing seasons in 2007 and 2008.

|          | SR   | PN   | H    | D    | Tₛ   | SWC  |
|----------|------|------|------|------|------|------|
| SR       | 1.00 |      |      |      |      |      |
| PN       | 0.226* | 1.00 |      |      |      |      |
| H        | −0.067 | 0.153 | 1.00 |      |      |      |
| D        | −0.229 | 0.246 | 0.956** | 1.00 |      |      |
| Tₛ       | 0.678** | 0.024 | −0.245 | −0.341 | 1.00 |      |
| SWC      | 0.436** | 0.169 | −0.075 | −0.107 | 0.239* | 1.00 |

SR = soil respiration, PN = photosynthesis, H = plant height, D = basal diameter, Tₛ = soil temperature at 5 cm depth, SWC = soil water content.

*indicates correlation is significant at 0.05 level and **at 0.01 level (2-tailed).

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Figure 3. Soil respiration in relation to soil temperature at 5 cm depth (A) and soil water content (B) at elevated (EC) and ambient CO₂ (AC) during growing seasons. Trend lines were generated for each CO₂ treatment using exponential regression. doi:10.1371/journal.pone.0015134.g003

Table 3. The Pearson’s correlation coefficient among soil respiration, photosynthesis, plant height, basal diameter, soil temperature at 5 cm depth and soil water content at elevated and ambient CO₂ during growing seasons in 2007 and 2008.
Elevated CO2 did not change the temperature sensitivity of soil respiration since no significant difference in Q10 values between elevated and ambient CO2 was found (Table 2). Similarly, King et al. [5] also found that the temperature sensitivity of soil respiration appeared to be unaffected by elevated CO2. However, soil respiration rates were found to be more sensitive to changes in soil temperature at elevated CO2 than at ambient CO2 [9]. For example, the Q10 values were 2.4 in ambient CO2 versus 2.8 in elevated CO2 in a ponderosa pine forest [9], 1.5 to 3.2 at ambient CO2 and 1.2 to 4.8 at elevated CO2 in a Populus plantation [5], 1.9 to 3.3 in a mixed temperate forest [60]. The Q10 values of ~1.6 for both CO2 treatments found in the present study (Table 2) are similar to the values of 1.4 to 1.8 found in a ponderosa pine plantation [61]. The temperature sensitivity of soil respiration has been recognized to be positive with substrate supply [9]. Elevated CO2 increased the carbon allocation to roots, providing additional substrates for root respiration [62,63], and further leading to an increased temperature sensitivity of root respiration and soil respiration. On the other hand, decreased soil moisture resulted from elevated CO2 can result in a decrease in activity and biomass of soil organisms [64], consequently causing reduction in soil microbial respiration and soil respiration. In the present study, no apparent CO2 effects on Q10 were found (Table 2). This result may be resulted from an interaction between elevated CO2 and soil moisture since elevated CO2 increased the aboveground photosynthesis and root respiration (Fig. 1), but decreased the soil moisture (Fig. 2).

The contribution of soil water content to soil respiration was found to depend on vegetation cover and soil properties [39,44,45]. The mathematical relationship between soil respiration and soil moisture is relatively complex if a correlation between them exists [65,66]. In six forest plantations located at Rwanda in African, soil respiration is mainly related to soil water content which explained 36–77% of the temporal variation in soil respiration [67]. The quadratic relationship between soil respiration and soil water content in a tallgrass prairie accounted for 26% of the variation in soil respiration [65]. Soil moisture is also considered as an important factor affecting soil respiration in our study because a significantly positive correlation between soil water content and soil respiration has been detected (Table 3). This finding is consistent with the results gained in a semiarid grassland ecosystem [68], but did not support our hypothesis III (see Introduction). Elevated CO2 decreased soil water content in the present study (Table 1, Fig. 2), probably due to greater water loss caused by greater leaf area. Since the precipitation in the research area mainly occurs during the peak growing season (from June to August) while temperature is also relatively higher, soil water content is then positively correlated with soil temperature in our study (Table 3).

Conclusion
An enhanced photosynthetic assimilation leading to increased plant growth at elevated CO2 implies greater root respiration consuming the recently fixed carbon. Increased photosynthetic assimilation and aboveground growth may create dense canopy to fix more carbon but also stimulate belowground respiration. Hence, the present study indicates that increase in CO2 fixation of plants in a CO2-rich world will rapidly return to the atmosphere by increased soil respiration.

Materials and Methods
Research area and experiment design
The experiment was conducted at the Research Station of Changbai Mountain Forest Ecosystem (42°24'N, 128°05'E, 738 m a.s.l.), Jilin Province, northeastern China. The annual mean air temperature is 3.6°C and annual mean precipitation is 695 mm [69]. The maximum air temperature and over 60% precipitation occurred in June to August. Ten hexagon OTCs (4.0 m in both height and diameter) with clear glass were established nearby the research station. Uniform local forest soil with a total organic carbon of 9.0% was used in OTCs [70]. Three-year-old plants, with similar plant size in height and basal diameter, of Q. mongolica from a nearby plantation were planted at a spacing of 0.5×0.5 m in OTCs in spring 2005.

CO2 fumigation treatments (AC = ambient CO2 concentration of 370 μmol mol−1 CO2 for 4 chambers, and EC = elevated CO2 concentration of 500 μmol mol−1 CO2 for the other 6 chambers) began in 2005. Elevated CO2 was supplied in daytime during each growing season from the beginning of May to the end of October. Elevated CO2 has been supplied to the chambers by pipes connected to industrial CO2 tanks outside the chambers. The concentrated CO2 was pumped into the chambers from a height of 1.6 m and was diffused. The CO2 concentration (500±100 μmol mol−1 CO2) was recorded every 10 min by CO2
Soil respiration measurements

The soil respiration presented in this study is defined as an integrating respiration of all components including root respiration, microbial and soil fauna respiration, and chemical process emission, but excluding the respiration of litter. Soil surface respiration was monitored for a two-hour interval from May to October in 2007 and repeated in 2008, using a LI-6400 portable photosynthesis system (LI-COR, Lincoln, NE, USA) in closed circuit with a LI-6400-09 soil respiration chamber (SRC). The measurements were carried out according to the methods described in detail by Tingey et al. [9]. Soil respiration collars, constructed from PVC pipe, were randomly distributed in the center and on the edge of each OTC. We did not find any significant difference in soil respiration measured on the edge of OTCs compared to that measured in the chamber center. Collars remained in the same measurement locations throughout the measurement. The collars were inserted approximately 2 cm into the soil depth, and matched well with the SRC to avoid possible leakage. All litter and herbs were carefully removed during the experiment period. To ensure parallel measurements and to diminish the effects of environmental variations of temperature and humidity on parameters measured, we selected two points (measurement locations) at each chamber, and three chambers per treatment only.

The T is recorded with soil respiration rate concurrently by a portable temperature probe attached to the analyzer which was inserted into the soil adjacent to the SRC. The 0–5 cm soil layer under each SRC was cored after each measurement. The soil was weighed before and after dried at 100°C for 48h. The SWC was expressed as a percentage of water mass to dry soil mass. The soil respiration rate per treatment for each measurement time was based on the average of the data from the two locations in three OTCs.

The soil respiration was measured only during the daytime from 6 am to 6 pm corresponding to the photosynthesis measurements.

Photosynthesis and growth measurements

The daily course of photosynthesis was also measured concurrently during the daytime from 6 am to 6 pm at a two-hours’ interval on clear days during the growing seasons in 2007 and repeated in 2008. Photosynthetic measurements were conducted using the same system of LI-6400 (LI-COR, Lincoln, NE, USA). All measurements were made in situ on fully sunlit leaves in trees at respective growth CO2 concentrations (AC, EC). Plant height and basal diameter of all individuals in each OTC were measured during early, peak and late growing season each year.

Q10 of soil respiration

Scatter plots were used to determine the relationship between soil respiration and T, for 2007 and 2008, respectively, using the data gained from a complete growing season (May - October) in each year. The scatter plots were fitted by an exponential relationship between measured data of soil respiration rate (y) and T (\( T \)) : \( y = ae^{bx} \), where a and b are coefficients. The Q10 values were then calculated using \( Q_{10} = e^{10b} \).

Estimating accumulated daytime soil respiration and CO2 assimilation

Accumulated daytime soil respiration was obtained by integrating values measured during the daytime for each treatment. Integrated values were calculated by determining the area under each segment of two consecutive measurement points and then summing the segments for a total daytime soil respiration. For a detailed method description, see Vose et al. [12]. The same method was also applied for calculating the daytime CO2 assimilation, using the daily course of net photosynthetic rate.

Statistical analyses

Statistical analyses were performed with SPSS 13.0 software program (SPSS Inc, 2004). The normality test was carried out using P-P test on datasets prior to statistical analyses to verify a normal distribution. We used paired-samples T test to test the differences in soil respiration, photosynthesis, soil temperature at 5 cm depth, soil water content, and plant growth in height and basal diameter between EC and AC within each measurement date. One-way ANOVA was used to compare the difference in Q10 values between EC and AC. The Pearson correlation was used to detect the correlation among soil respiration, photosynthesis, tree growth, and environmental factors.

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Author Contributions

Conceived and designed the experiments: YZ SH. Performed the experiments: YZ X-BC C-GW A-NF L-XS X-XW. Analyzed the data: YZ M-HL. Wrote the paper: YZ M-HL.

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