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Spatial Characteristics of Stem Respiration of Abies fabri on Mount Gongga and Its Response to Temperature (Postprint)

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Abstract

Using the infrared gas analyzer-horizontal soil respiration chamber method (HOSC), we conducted in-situ monitoring of the trunk CO efflux rate (Es) of Abies fabri on the eastern slope of Gongga Mountain, and analyzed the relationship between trunk Es and trunk temperature (Tstem). The spatial variation patterns of trunk Es and Tstem in Abies fabri were distinct, with trunk temperature at different measurement heights following the order of 0.3m > 1.3m > 2.3m, and Es being highest at 1.3m; both Es and Tstem exhibited a south > north orientation. The Es of Abies fabri ranged between 0.51–0.99 mol m ^{2} s ^{1} during the growing season and 0.14–0.22 mol m ^{2} s ^{1} during the non-growing season. The variation trend of Es was consistent with Tstem, and the two showed a significant exponential relationship ($P<0.01$). The Q of trunk respiration in Abies fabri during the non-growing season was significantly higher than that during the growing season ($P<0.01$), ranging between 1.9–3.0 in the growing season and 4.6–6.8 in the non-growing season, implying that estimation of trunk CO efflux at individual or community levels should take into full consideration the spatial characteristics of trunk Es and Q variations.

Full Text

Spatial Variations in the Stem CO Efflux Rate of *Abies fabri* and Its Response to Temperature in the Gongga Mountains

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Abstract

Using an infrared gas analyzer (IRGA) with a horizontally oriented soil chamber (HOSC) technique, we conducted in situ measurements of stem CO efflux rate (E) of *Abies fabri* on the eastern slope of Gongga Mountain from September to December 2014. Our objectives were to examine spatial variations in E and explore its response to stem temperature. The results revealed distinct spatial patterns in *A. fabri* stem respiration. At different measurement heights, E ranked as 0.3 m > 1.3 m > 2.3 m, with maximum values appearing at 1.3 m. The E on the south face of the stem was consistently higher than that on the north face. Monthly average E values during the growing season (September and October) and non-growing season (November and December) were 0.51–0.99 and 0.14–0.22 mol m ^{2}s ^{1}, respectively. The trend in *A. fabri* E was consistent with stem temperature, showing a significant exponential relationship ($p < 0.01$). The temperature coefficient (Q) during the non-growing season (4.6–6.8) was significantly higher than that in the growing season (1.9–3.0). We conclude that spatial variations in E and Q should be considered when estimating individual- and community-level stem CO efflux fluxes.

Keywords: *Abies fabri*; stem CO efflux rate; spatial variations; temperature sensitivity coefficient (Q)

Introduction

Forest ecosystems play a crucial role in the global carbon cycle, with forest carbon balance depending on both carbon fixation and metabolic processes within the system. Stem respiration represents 25–50% of aboveground respiration and constitutes an important component of carbon metabolism in forest ecosystems. Accurate assessment of stem respiration is essential for constructing carbon cycle models between forests and the atmosphere. Previous studies have shown that stem CO efflux rate (E) is influenced by environmental factors such as air temperature, humidity, and CO concentration, as well as biological factors including tree species, stem nitrogen content, and diameter class. Most earlier research measured E at breast height and scaled up to whole-tree or community levels using diameter or sapwood volume. However, significant inter- and intra-specific variations and pronounced spatiotemporal dynamics have been reported. For instance, studies on temperate tree species in northeastern China found that diameter was the main factor causing intra-specific variation, while inter-specific differences were closely related to species-specific characteristics such as bark tightness and xylem porosity.

Temperature is the primary driver of temporal variation patterns, manifesting as diurnal and seasonal changes, which has been extensively documented. Temperature affects E by influencing enzyme activity, substrate and adenylate availability, and transport of respiratory products. However, reports on vertical distribution patterns of E remain limited, and studies examining how stem direction and height affect spatial variation patterns are scarce, which greatly

constrains the development of stem respiration flux models. The exponential equation is the most widely used model for describing the relationship between respiration and temperature, from which the temperature coefficient Q (the factor by which respiration rate changes with a 10°C temperature increase) is derived as an important parameter in ecosystem carbon cycle models. Reported Q values for stem respiration range from 1.5–2.0, with 90% falling between 1.0–3.0. However, Q is not constant but varies with measurement temperature range, season, and other factors. Most ecosystem models use a constant Q value (2.0), which can lead to substantial estimation errors and reduced model accuracy.

Research on stem respiration in China has focused on cold-temperate and temperate species in northeastern China, as well as subtropical and tropical species, but studies on southwestern forest regions and subalpine dark coniferous forests are lacking. The southwestern forest region, located on the southeastern edge of the Tibetan Plateau, features mountainous dark coniferous forests dominated by *Abies* species as the main component of subalpine forests. With typical alpine-gorge landforms and significant vertical climate zonality, this region' s unique geological conditions and varying soil and vegetation development stages make plant individuals and ecosystems highly sensitive to climate change. While research on carbon cycling responses to climate change in southwestern subalpine forests has concentrated on forest biomass and net primary productivity, studies on temporal and spatial variation of stem respiration and its temperature response are urgently needed. Given the lack of research on stem E in *Abies fabri* and the study area, this paper aims to elucidate the spatial and temporal patterns of stem respiration and its response to temperature, providing fundamental data for improving the accuracy of individual- and community-level stem E estimates and for constructing carbon cycle models in subalpine forest ecosystems.

1. Study Site Description

Gongga Mountain is located on the southeastern edge of the Tibetan Plateau, along the central-southern section of the Daxue Mountains. The region features complex geological structures, diverse landform types, and dramatic ridge-valley elevation differences, with a relative relief of 6450 m from the Dadu River valley to the main peak over a horizontal distance of only 29 km. Climatically, it lies in a transitional zone between the subtropical humid monsoon region of eastern China and the cold climate region of the Tibetan Plateau. Annual precipitation ranges from 1000–3000 mm, and the area has developed a complete vertical zonation from subtropical to frigid zones, including evergreen broad-leaved forest, mixed coniferous-broadleaved forest, dark coniferous forest, shrub meadow, and sparse cold desert zones.

The experimental site was located at the *Abies* forest experimental field of the Gongga Mountain Alpine Ecosystem Observation and Experiment Station, Chinese Academy of Sciences, at 3000 m elevation (29°34 21 N, 102°59 42 E). The

climate type is cold temperate, with mean annual temperature of 4°C, January mean temperature of -4.5°C, July mean temperature of 12.7°C, mean annual precipitation of 1900 mm, mean relative humidity of 88%, and mean annual sunshine hours of 880 h. The representative *A. fabri* middle-aged forest selected in the dark coniferous forest zone had an average DBH of 23.4 cm and average height of 24.3 cm. *A. fabri* was the dominant species in the tree layer, accompanied by other species such as *Acer maximowiczii*, *Populus simonii*, and *Sorbus multijuga*. The soil was typical mountain dark brown soil with well-developed profiles (1–1.2 m), obvious humus characteristics, and organic carbon content of 39.2 g/kg.

2. Measurement of Stem CO Efflux Rate

We used an infrared gas analyzer (Li-6400, Li-Cor Inc., Lincoln, NE, USA) connected to a soil respiration chamber (Li-6400-09, Li-Cor Inc.) to measure stem E using the horizontally oriented soil chamber (HOSC) technique. Two representative trees in an immature forest stand were selected for measurement. Opaque PVC collars (10.7 cm inside diameter and 5 cm high) were cut to match the approximate curvature of the stem, with the other end cut flat. Custom-built PVC collars were fastened to the south face of the stem at heights of 0.3, 1.3, and 2.3 m, and to the north face at 1.3 m height, using 100% silicone sealant 24 hours before measurement. Loose bark and moss were carefully removed from the stem surface within the collar area using a hairbrush without damaging the underlying cambium before installing the collars.

Measurements were conducted over three cycles at each sampling point, every 2 hours from 8:00 to 18:00 on the same day each month. To objectively quantify spatial and temporal variation patterns of stem E , all measurements at different stem heights and directions were performed on the same day, with each monitoring period lasting no more than 0.5 hours to minimize the influence of diurnal variation. We selected only two representative sample trees because measuring more individuals would be impossible to complete in a single day, and previous research in this forest indicated no significant differences in E among trees of similar DBH. Based on phenological observations of *A. fabri* at the study site, September–October were designated as the growing season and November–December as the non-growing season. The basic characteristics of different measurement positions are shown in Table 1 and Table 2 .

3. Data Processing

Because custom-built respiration collars were used, stem respiration rates required correction using the following formula:

E = E × (V / V) × (S / S)

where E is the corrected stem respiration rate (mol m $^{-2}$s $^{-1}$), E is the rate recorded by the measurement system, V is the measured collar volume (99.1 cm^3), V is the system default chamber volume (71.6 cm^3), S is the

system default chamber surface area (99.1 cm^2), S is the actual measured stem surface area, D is the stem diameter at the measurement point (10.7 cm), and h is the collar height.

The temperature response of stem respiration was modeled using the exponential equation:

E = × e^(T)

where E is the stem respiration rate (mol $m^{-2}s^{-1}$), T is stem temperature (°C), and and are constants. The temperature coefficient Q was calculated as:

Q = e^(10)

Statistical analysis was performed using one-way ANOVA in SPSS 20.0, with least significant difference (LSD) tests to compare differences among measurement positions. Data processing and graphing were conducted using Excel 2007 and Origin 8.0.

4. Results and Analysis

4.1 Seasonal Variation Characteristics The monthly average E of *A. fabri* during the measurement period ranged from 0.14–0.22 mol $m^{-2}s^{-1}$ in the non-growing season to 0.51–0.99 mol $m^{-2}s^{-1}$ in the growing season, showing significantly higher values during the growing season ($p < 0.05$). Stem temperature (T) exhibited similar seasonal trends, with amplitude decreasing with increasing month and measurement height. The amplitude of E variation increased with month but decreased with height, being greatest at 0.3 m and higher on the south than north face.

4.2 Spatial Variation Characteristics Stem E showed distinct spatial patterns with measurement height and direction. At different heights, E ranked as 0.3 m > 1.3 m > 2.3 m, with significant differences between months ($p < 0.05$). The E on the south face was consistently higher than on the north face, with significant differences observed in all measurement months ($p < 0.05$). To eliminate temperature effects and objectively compare E among positions, we analyzed normalized respiration rates (E). The results showed that E at 1.3 m height was significantly higher than at other positions ($p < 0.05$), and south-face values exceeded north-face values.

4.3 Temperature Response Characteristics Both stem E and T showed highly significant exponential relationships at all measurement positions ($p < 0.01$; Figure 4 [Figure 4: see original paper] and Figure 5 [Figure 5: see original paper]). The coefficient of determination (R^2) ranged from 0.69–0.88, indicating that temperature explained 69.4–89.5% of the variation in E . The Q values differed significantly between seasons and positions ($p < 0.05$), ranging from 1.9–3.0 during the growing season and 4.6–6.8 during the non-growing season. Across positions, Q ranked as: 1.3 m (north) > 1.3

m (south) > 2.3 m (south) > 0.3 m (south) (Figure 6 [Figure 6: see original paper]).

5. Discussion

5.1 Spatial Variation Patterns Accurate estimation of individual-tree respiration is fundamental for scaling to stand-level carbon release. Most forest carbon cycle models assume constant temperature and Q within trees, using measurements from one or a few points to estimate whole-stem or stand-level respiration. However, research has shown significant differences in stem temperature at different heights and aspects, which can substantially affect carbon release estimates at individual or stand levels. Our results demonstrate clear spatial variation in *A. fabri* stem E , with values decreasing with measurement height (0.3 m > 1.3 m > 2.3 m) and being higher on the south than north face. This pattern differs from some temperate and tropical studies where canopy-level xylem temperature and E exceed those at breast height, likely due to the unique environmental conditions at our site. The Gongga Mountain region experiences frequent cloud cover and fog, with minimal direct solar radiation reaching the *A. fabri* forest. Additionally, soil temperature at 0–60 cm depth exceeds air temperature, warming the lower stem portion in contact with soil and creating a temperature gradient that decreases with height. However, E did not show a consistent gradient with temperature, suggesting that factors beyond temperature—such as internal CO transport via xylem sap, bark thickness, and physiological activity of cambial tissues—influence vertical variation in respiration.

5.2 Seasonal Variation and Temperature Response The significant seasonal difference in E , with growing-season values substantially higher than non-growing-season values, aligns with findings from other studies. During the growing season, trees exhibit higher physiological activity, growth rates, and carbon/nitrogen supply, all requiring respiratory support for energy and carbon skeletons. The exponential relationship between E and temperature was strong at all positions, with temperature explaining 69–89% of respiration variation. However, the Q values showed clear seasonal patterns, being significantly higher during the non-growing season (4.6–6.8) than during the growing season (1.9–3.0). This seasonal difference in Q is consistent with previous research and supports the concept of thermal acclimation, where plants adjust their respiratory metabolism to long-term temperature conditions. The higher Q values during the non-growing season likely reflect the predominance of maintenance respiration, which is more temperature-sensitive than growth respiration. The lower Q values during the growing season (1.9–3.0) are closer to the commonly assumed constant value of 2.0, but still show considerable variation among measurement positions.

5.3 Implications and Limitations Our findings demonstrate that both spatial position and season significantly affect stem respiration rates and tempera-

ture sensitivity in *A. fabri*. The variation in Q among positions (north > south, mid-height > lower/upper heights) suggests that using a single Q value for scaling respiration estimates would introduce substantial errors. The temperature acclimation phenomenon observed here, where Q varies with season and environmental conditions, highlights the need for more sophisticated models that incorporate these variations. However, this study had limitations, including measurements limited to only two sample trees and a maximum height of 2.3 m due to methodological constraints. Future research should examine whole-tree respiration patterns and develop better mechanistic models for stem respiration. The current reliance on soil respiration measurement systems adapted for stem measurements, with their bulkiness and operational constraints, limits comprehensive investigation of spatial patterns and underlying mechanisms.

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