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Woody Tissue Respiration in Stems of Red Pine (*Pinus densiflora*) Trees

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소나무(*Pinus densiflora*) 줄기의 목부조직호흡

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ABSTRACT

The woody tissue respiration rates in stems (R_{stem}) of red pine (*Pinus densiflora* Sieb. et Zucc.) forest in Higashi-Hiroshima, west Japan, were measured using an open flow measurement system with several chambers in two seasons (the winter and summer in 2002). R_{stem} ranged from 0.25 to 0.55 μmol $m^{-2}s^{-1}$ in winter, and from 1.25 to 1.63 μmol $m^{-2}s^{-1}$ in summer. The variability of R_{stem} among the sampled trees (n=15) was similar between the two seasons, with the coefficient variation of about 23%. The numbers of sampling points required to estimate the stem respiration rate within 10 to 20% of its actual value were 24 and 6, respectively in both seasons (probability level is 95%). Based on the relationship between stem temperature and average R_{stem}, the Q_{10} values of the winter and summer seasons were 1.49 and 1.45, respectively. The R_{20} (R_{stem} at 20°C of stem temperature) was higher in summer (1.23 μmol $m^{-2}s^{-1}$) than winter (0.61 μmol $m^{-2}s^{-1}$). The woody tissue respiration in stems of red pine trees during the summer season amounted about 50% of the total respiration rates.

***Key words*: Q_{10}, Red pine forest, Woody tissue respiration rate, Stem temperature**

I. INTRODUCTION

Woody tissue respiration in stem (i.e., CO_2 efflux from stem surface) is an important part of the carbon cycle in forest ecosystems, because the amount of stem increases continuously with stand development and accounts for the largest of the forest biomass. Therefore, recently interest in stem respiration is increasing (Ryan *et al.*, 1995; Damesin *et al.*, 2002; Kim and Nakane, 2005). Hagihara and Hozumi (1981) reported that biomass and its increment for each organ for *Chamaecyparis obtuse* plantation were 37 and 8.4 t d.wt ha^{-1} yr^{-1} for stems, 6.1 and 1.4 t d.wt ha^{-1} yr^{-1} for branches, 16 and 3.8 t d.wt ha^{-1} yr^{-1} for roots, respectively. They found that the annual respiration rates were 6.1 t d.m. ha^{-1} yr^{-1} in stems, 1.6 t d.m. ha^{-1} yr^{-1} in branches, and 2.8 t d.m. ha^{-1} yr^{-1} in roots. The results of Sprugel and Benecke (1991) indicated that woody

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tissue respiration rates in the growing season are typically greater than foliar respiration rates. Damesin *et al.* (2002) reported that stem and branch respiration accounted for about one third of total carbon loss by respiration in beech forest. Their results indicate that stem respiration is an important component for estimating the total amount of respiration of a tree or a forest ecosystem.

Woody tissue respiration can be subdivided into growth and maintenance components (McCree, 1970; Penning de Vries *et al.*, 1974; Penning de Vries, 1975; Ryan *et al.*, 1994). The common method for measuring maintenance respiration in trees, and the one that was used in this study, is to assume that measurements taken after the growing season represent maintenance respiration rates (Butler and Landsberg, 1981; Sprugel, 1990; Sprugel and Benecke, 1991; Lavigne, 1996). The growth respiration is calculated as the difference between total respiration and maintenance respiration. Partitioning respiration into maintenance and growth respiration to estimate woody tissue respiration may greatly affect estimates of total respiration for stands (Ryan, 1990).

In this study, we measured CO_2 efflux from stems of red pine (*Pinus densiflora*) trees. Our objectives were (1) to determine the response of respiration to stem temperature during winter and summer; (2) to estimate the number of sampling points required to adequately describe stem respiration rates; (3) to separate the maintenance and growth respiration.

II. MATERIALS AND METHODS

2.1. Study site

The study was conducted in a red pine (*Pinus densiflora* Sieb. et Zucc.) forest in Yosikawa, Higashi-Hiroshima City, west Japan (132° 39' E, 34° 23' N). The

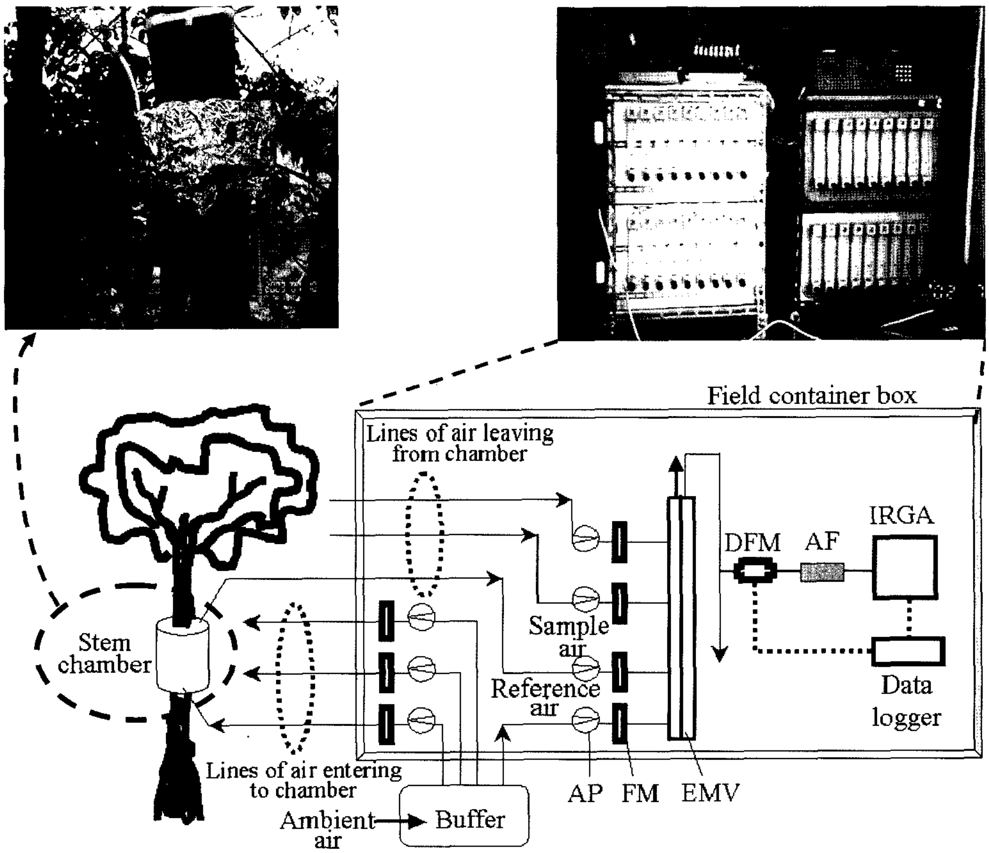

Fig. 1. The schematic of the open flow system used for measurement of the woody tissue respiration rate. (AP: air pump; FM: flow meter; EMV: electromagnetic valve; DFM: digital flow meter; AF: air filter; IRGA: infra red gas analyzer. Arrows indicate airflow.)

study site is located on the lower part of a hill, with an elevation of ca. 208 m a.s.l., southern aspect and an inclination of ca. 5 degrees.

According to a tree census at the study site, the basal area, tree density, mean DBH (diameter at breast height), mean $D_{0.1}$ (diameter of tree at height equal to 1/10 of tree height), and mean height of red pine trees, which is the dominant species of tree layer, was 49.80 m^2 ha^{-1} (81.8%), 1000 trees ha^{-1}, 187 (±23) mm, 180 (±65) mm, and 14.3 (±1.02) m, respectively.

This region belongs to the warm-temperature monsoon zone. At a station ca 5 km northeast from the study site, the average of annual mean temperature is 13.5°C and the average annual precipitation is 1494 mm (Hiroshima Prefectual Agriculture Research Center, based on records from 1992 to 2001). The monthly mean air temperature reached at a maximum of 25.6°C in August and decreased to a minimum of 2.4°C in January.

2.2. Measurement of respiration

Our measuring system comprises one reference line and fifteen sample lines consisting of air pump, flow meter controller and electromagnetic valve (Fig. 1). Behind the electromagnetic valve, the air stream was passed through an air filter and digital flower meter (SEF-21A; STEC Inc., Kyoto) to an infrared gas analyzer (IRGA) (LI-6252; LiCor Inc., Lincoln) with absolute mode (Kim and Nakane, 2005). Chambers were made of a flexible acrylic film (thickness is 1 mm). The air pressure within the chambers was kept in near ambient pressure by a pump at both sides of inlet and outlet tubes. Continuous air flow through the chambers was controlled with the pump and flow meter, and maintained 0.6 L min^{-1} (winter) or 1.2 L min^{-1} (summer). The chambers were attached to the stems with a silicone gasket or putty after removing loose bark. During measurements, chambers were covered with aluminum foil to prevent bark photosynthesis and stem heating caused by direct sun exposure.

Air temperature was measured at 1.3 m above ground, and stem temperature was measured at a bark depth of 15 to 20 mm with a thermocouple.

Woody tissue respiration rate in stem (R_{stem}) was estimated by the difference between CO_2 concentrations in air leaving and entering the chamber as follows:

$$R_{stem} = f \cdot a^{-1} \cdot (C_l - C_e) \quad (1)$$

where R_{stem} is the woody tissue respiration rate (in μmol m^{-2} s^{-1}), f is the molar flow of air (in mol s^{-1}), a is the surface area of the enclosed stem (in m^2), and C_l and C_e are the CO_2 concentrations (in μmol mol^{-1}) of air leaving and entering the stem chamber, respectively.

The response of woody tissue respiration to stem temperature can be expressed in the following exponential function:

$$R_{stem} = R_0 \exp(\beta T) = R_0 Q_{10} \quad (2)$$

where R_0 is R_{stem} at 0°C, β is a coefficient for stem temperature response and T is stem temperature (in °C).

Table 1. Characteristics of red pine (RP) trees sampled

Sample trees	D_0 (mm)	DBH (mm)	$D_{0.1}$ (mm)	Height (m)	Diameter of sampling point (mm)
RP1	340	268	265	15.5	235
RP2	290	236	230	17.7	214
RP3	320	240	225	18.0	207
RP4	360	277	228	19.8	210
RP5	357	263	250	19.2	243
RP6	148	274	258	19.1	242
RP7	335	230	219	17.1	211
RP8	488	405	263	19.5	348
RP9	320	247	238	16.1	217
RP10	297	215	214	13.5	190
RP11	407	298	282	19.4	258
RP12	306	250	236	18.5	207
RP13	428	329	312	19.5	297
RP14	285	228	215	17.6	192
RP15	290	245	222	17.1	195

The Q_{10} value used to describe this relationship is a factor by which respiration increase with a 10°C increase in stem temperature and is given by exp (βT). R_{stem} was better correlated with air or stem temperatures of the past than to concurrent air or stem temperatures (Linder and Troeng, 1981; Ryan *et al.*, 1995; Lavigne *et al.*, 1996; Stockfors and Linder, 1998; Kim and Nakane, 2005). The lagged time between R_{stem} and the temperature data was determined from the best fit between the data and the exponential equation (Eq. 2).

Fifteen red pine trees reaching at tree layer were selected for estimating the R_{stem}. The characters of each sample tree are shown in Table 1. The chambers were set at the same height (2.5 m above ground). Stem temperature was measured at north side and at 0.1 m above the chambers (RP 1, 2, 3, 5, 6, 7, 8, 9, 11, and 12) with a thermocouple. Measurements were conducted during the summer growing season (from 1 to 4 July 2002) and during the winter dormant season (from 15 November to 2 December 2002).

III. RESULTS AND DISCUSSIONS

Fig. 2 shows the diurnal changes in hourly temperatures and stem respiration rates. During the measurement period from 1 to 4 July 2002, the average, minimum, and maximum air temperatures were 24.0°C, 20.9°C, and 29.6°C, respectively (Fig. 2C). The average, minimum, and maximum stem temperatures were 23.9°C, 21.4°C, and 27.3°C, respectively (Fig. 2C). During the winter measurement from 15 November to 2 December 2002, the average, minimum, and maximum air temperatures were 7.0°C, -1.7°C, and 18.8°C, respectively (Fig. 2A). The average, minimum, and maximum stem temperatures were 8.4°C, 1.9°C, and 15.6°C, respectively (Fig. 2A). The variations in stem temperature were smaller than those of air temperature during both the summer and winter seasons. The daily averaged stem temperature was similar to air temperature in the summer, but not in the winter. During the latter season, the daily averaged stem temperature was higher than air temperature, because the stem temperatures were always above 0°C.

The diurnal changes in R_{stem} were parallel with those of air and stem temperatures (Fig. 2). In the summer season, average, minimum, and maximum R_{stem} were 1.42, 1.25, and 1.63 μmol $m^{-2}s^{-1}$, respectively (Fig. 2D). In the winter season, average, minimum, and maximum R_{stem} were 0.39, 0.25, and 0.55 μmol $m^{-2}s^{-1}$, respectively (Fig. 2B). The result for red pine trees was close to those of Takeshi *et al.* (1994) for trees of same species (approx. 1 to 2 μmol $m^{-2}s^{-1}$) in summer season.

The variability of R_{stem} among 15 sampling points was described by the coefficient of variation (CV) of the average R_{stem} of individual sampling trees during the measurement period. The CV in winter and summer was 22.8% and 23.0%, respectively. The variations were lower than those of soil respiration (Yim *et al.*,

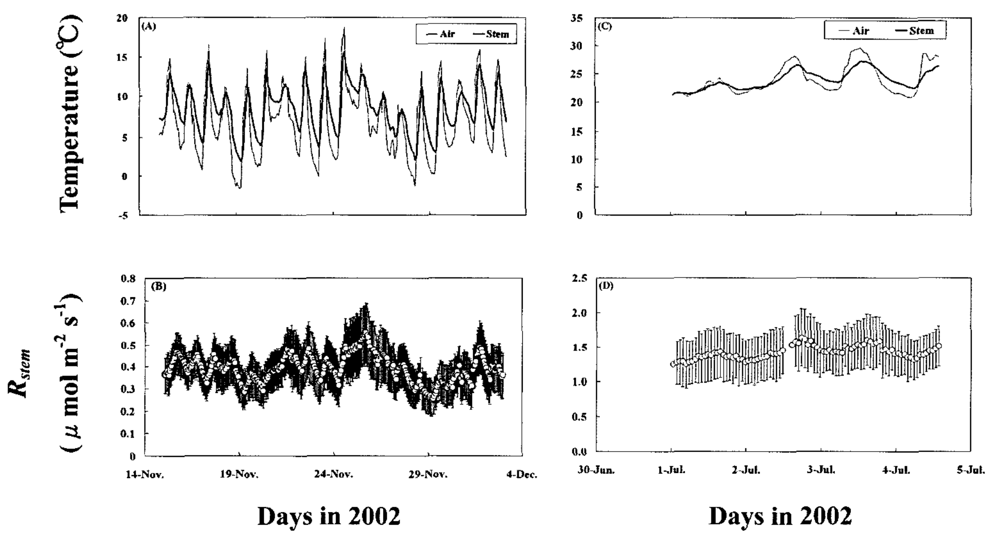

Fig. 2. Diurnal changes in temperatures (A, C) and the woody tissue respiration rates (B, D) in the winter (A, B) and the summer (C, D) season in 2002.

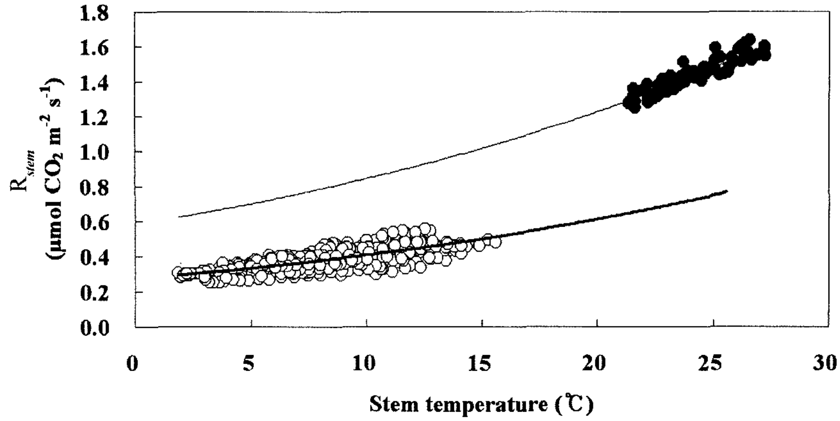

Fig. 3. Comparison of the relationships between hourly mean stem temperature and woody tissue respiration rate in summer (●) and winter (○). The regression curves are $y = 0.2741 \exp(0.0401x)$ (R^2=0.52) for winter (thick line), and $y = 0.5815 \exp(0.0373x)$ (R^2=0.85) for summer (thin line).

2003; Adachi *et al.*, 2005). Yim *et al* (2003) reported that the average CV was 28% in August. According to their suggestion, the numbers of sampling points required to estimate representative stem respiration rate within 10 and 20% of its actual value at the 95% probability level were 24 and 6, respectively for both winter and summer seasons.

Fig. 3 shows the relationships between stem temperature and R_{stem} in winter and summer. R_{stem} was more closely correlated with the stem temperatures observed earlier than those observed concurrently. Many studies have reported the lagged response of respiration to temperature (Linder and Troeng, 1981; Ryan *et al.*, 1995; Lavigne *et al.*, 1996; Stockfors and Linder, 1998; Kim and Nakane, 2005; Kim *et al.*, 2006). In this study, we considered the lagged responses for deducing the relationships between stem temperatures and R_{stem}. The lagged time was about 1 hr. The Q_{10} value in winter and summer was 1.49 and 1.45, respectively. Some studies also have found no seasonal variation in Q_{10} (Linder and Troeng, 1981; Lavigne and Ryan 1997; Butler and Landsberg, 1981). Other studies have reported that Q_{10} decreased in summer (Carey *et al.*, 1997; Lavigne, 1996; Maier, 2001; Kim *et al.*, 2006). According to the results of the regression equations (in Fig. 3), the mean R_{20} was twice larger in summer (with 1.23 μmol $m^{-2}s^{-1}$) than in winter (with 0.61 μmol $m^{-2}s^{-1}$). On the other hand, Kim *et al.* (2006) reported that the stem respiration rate for black locust trees (i.e., deciduous broad-leaved trees) ranged from 0.13 μmol $m^{-2}s^{-1}$ in January to 4.44 μmol $m^{-2}s^{-1}$ in August at the same stand. The variations in R_{stem} of black locust were larger than those of evergreen coniferous red pine trees.

If the respiration rates during the winter were maintenance R_{stem}, and those during the summer were the sum of the maintenance and growth respiration rates, then the maintenance respiration rates during the summer season would amount approximately 50% of the total respiration rates. Yokota and Hagihara (1995) reported for hinoki cypress that the aboveground respiration was >40% of the total respiration used for growth purpose, i.e., approximately 60% in May.

적 요

본 연구에서는 동시에 여러 지점을 측정할 수 있는 open flow 시스템을 이용하여 소나무 줄기에서 발생하는 호흡을 겨울과 여름 두 시기에 측정하였다. 연구 결과, 줄기의 목부조직에서 호흡속도(R_{stem})는 겨울에 0.25-0.55 μmol $m^{-2}s^{-1}$, 여름에 1.25-1.63 μmol $m^{-2}s^{-1}$의 범위를 나타냈다. 시기별 측정된 수목(15개체)간 R_{stem}의 변화성은 변동계수로 나타낼 수 있으며, 그 결과 여름과 겨울이 모두 23%로 시기에 따른 차이를 보이지 않았다. 이러한 변동계수 값에 근거하면 R_{stem}이 95% 신뢰수준에서 실제 값과의 차이가 10%와 20% 보다 적기 위해서는 샘플링 수가 각각 최소 24개와 6개가 필요한 것으로 확인되었다. 또한 겨울과 여름의 온도와 개체간 평균 R_{stem}의 상관관계에서, Q_{10} 값은 겨울이 1.49, 여름이1.45로 계절간에 큰 차이를 나타내지 않았다. 그러나 R_{20}(줄기 온도 20°C일 때의 R_{stem})은 겨울(0.61 μmol $m^{-2}s^{-1}$)보다 여름(1.23 μmol $m^{-2}s^{-1}$)이 두 배 정도 컸다.

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