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Seasonal Change in the Temperature Coefficient Q_{10} for Respiration of Field-Grown Hinoki Cypress (*Chamaecyparis obtusa*) Trees

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The effect of temperature upon nighttime respiration was examined on four different sized sample trees in a 17-year-old hinoki cypress (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.) stand over two years. Seasonal changes in Q_{10} values and their responses to mean temperature were investigated. On the basis of the monthly relationships between nighttime respiration (r) and temperature inside a chamber (θ), $r = r_0 \exp(k\theta)$, the Q_{10} value ($= \exp(10k)$) was calculated. The Q_{10} values were high ($Q_{10} \geq 3.0$) in winter when mean air temperature was low, and gradually decreased toward summer ($Q_{10} \leq 1.5$) through spring with increasing temperature. The Q_{10} values were negatively correlated with mean air temperature. The response of Q_{10} values to mean air temperature was described by a single equation, regardless of tree size. This result, which might be characteristic of this species, shows that respiration of *C. obtusa* trees is promoted by slight increases of air temperature in winter season. On the other hand, temperature sensitivity of total respiration reduced during growing season when ambient temperature was high. These changing temperature sensitivity according to seasons may depend on the seasonal change of the ratio of growth respiration to total respiration. It is concluded that changes in temperature due to changing seasons not only change respiration rate, but also change the response of respiration rate to temperature by shifting Q_{10} values.

Key words: *Chamaecyparis obtusa*, dark respiration, mean nighttime temperature, Q_{10}, seasonal change

Physiological processes, such as photosynthesis, dark respiration, cell division, ion uptake, enzyme activity, of plants are affected by various environmental and internal conditions. According to Kramer and Kozlowski (1979), the factors affecting respiration were shown as age and physiological condition of tissues, available substrate, hydration, soil moisture, soil and air temperatures, composition of the atmosphere, injuries and mechanical stimuli, and chemicals. One of the major factors affecting respiratory processes is air temperature (Kramer and Kozlowski, 1979).

The effects of temperature on the respiratory processes are usually indicated by Q_{10} values which refer to the ratio of the rate at temperature $t + 10$ °C to the rate at temperature t°C. The Q_{10} value is about 2 in physiologically relevant temperature ranges (*e.g.*, Negisi, 1970, 1977; Landsberg, 1986; Fitter and Hay, 1987). According to Fitter and Hay (1987) and Amthor (1989), some reports show that the growing temperature itself influences Q_{10} values for respiration of crop plants. In the case of woody species, changes in Q_{10} values with growing temperature are reported for detached stems (Negisi, 1975, 1981), detached leaves (Hagihara, 1973), and aboveground parts of a tree (Sakagami and Fujimura, 1981; Hagihara and Hozumi, 1991; Paembonan *et al.*, 1991). Whereas there are reports where Q_{10} values are constant through a year (Butler and Landsberg, 1981; Linder and Troeng, 1981). Although Landsberg (1986) concluded that the respiration-temperature relationship shifts from seasons to seasons with a constant Q_{10} value, there is no consensus on woody plants whether Q_{10} values change with temperature. Comparing with herbaceous species, our knowledge of respiratory behavior of woody plants is restricted.

The temperature response of respiration is needed for predicting the effect of climate change on carbon balance in the biosphere. But in spite of the variation of respiratory response to temperature, a constant Q_{10} value has been used for the models (*e.g.*, Ryan, 1991; Ryan *et al.*, 1995). Since each plant species adapts to several environmental conditions and has different respiratory behavior, much concern should be paid for temperature response of respiration when we deal with a model of plant respiration (Breeze and Elston, 1978).

The relationship between growing temperature and Q_{10} values for respiration has been already reported on aboveground parts of a single hinoki cypress (*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.) tree (Paembonan *et al.*, 1991). In this paper, on the basis of the measurement of nighttime respiration of *C. obtusa* trees using an open-gas exchange system, seasonal changes in Q_{10} values for nighttime respiration with mean ambient temperature are examined on four different sized trees. We compare our results and the result of Paembonan *et al.* (1991), and evaluate the temperature dependence of Q_{10} values for respiration of hinoki cypress. In addition, mechanisms of changing Q_{10} values with growing temperature are discussed.

Materials and Methods

Measurements were made from November 1991 to October 1993 on 17-year-old (as of 1991) hinoki cypress (*Chamaecyparis obtusa*) trees planted in the experimental field on the School of Agricultural Sciences, Nagoya University. The field was established on a flat area. Tree density was 9091 trees ha^{-1}. Four different sized sample trees were selected for respiration measurement. Tree size measurement was monthly made on height and stem girths at 50-cm intervals along the stem. The general features of the four sample trees in July 1992 were shown in Table 1.

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The CO_2 gas exchange under field conditions was measured with an open gas-exchange system (Hagihara *et al.*, 1987; Paembonan *et al.*, 1991, 1992). The aboveground parts of a tree were enclosed in a chamber made of transparent polyvinyl chloride films (Takafuji Chem. & Syn. Co., Ltd.) 0.2 mm thick. The skirt of the chamber was tied around the base of the tree stem. The air temperature inside the chamber was adjusted to that of outside by means of a temperature controller (MC-D3KW; Koito Ind., Ltd.). Air inside the chamber was stirred with an air mixing fan at a flow rate of 480 m^3 h^{-1}. The flow rate of air introduced into the chamber, as measured with a thermal flow meter (TH-1200; Tokyo Keiso Co., Ltd.), was adjusted to 15 to 35 m^3 h^{-1}, according to tree size. Sample air at the inlet and outlet of the chamber was sucked through vinyl tubes into an infra-red gas analyzer (IR21; Yokogawa Elect. Works, Ltd.). Air temperatures and CO_2 concentrations were recorded at 3-min intervals on a microcomputer (PC-9801, NEC Co., Ltd.) throughout the experimental period. Calculation of the nighttime respiration was based on the difference in CO_2 concentration between inlet and outlet air, and the flow rate.

Two sets of the system were rotated at 10−15 days intervals to perform the respiration measurement of all sample trees within a month. Therefore, the nighttime respiration was not measured on the same night. Measured data over 10 nights within each month were used for this analyzing. All the experimental results were dealt with as hourly averaged values of 20 measurements.

Table 1 General features of the sample trees in July 1992.

Features	Tree number			
	1	2	3	4
Tree height (m)	6.72	6.10	5.51	5.32
Stem girth at 1 m above ground (cm)	26.5	19.8	16.1	13.7
Stem volume (dm^3)	20.1	11.3	6.89	5.17

Results

Figure 1 shows examples of the relationship between nighttime respiration rate, r (g CO_2 tree^{-1} h^{-1}), and air temperature inside the chamber, θ (°C), on semi-log coordinates. The nighttime respiration rate increased exponentially with an increase of the air temperature. These relationships were approximated by the following equation (Butler and Landsberg, 1981; Jarvis and Leverenz, 1983; Paembonan *et al.*, 1991),

$$r = r_0 \exp(k \cdot \theta), \qquad (1)$$

where r_0 and k are coefficients specific to each month and each tree.

The temperature coefficient Q_{10} is commonly used as a quantitative expression of chemical reactions of biological processes in relation to temperature. The Q_{10} value indicates how much the physiological function increases with a temperature increase of 10°C. Considering Eq. (1), we can estimate Q_{10} for nighttime respiration as follows:

$$Q_{10} = \exp(10k). \qquad (2)$$

Seasonal changes in Q_{10} values for nighttime respiration are shown in Fig. 2. It is apparent that Q_{10} values are not constant, but vary with season. These seasonal changes were slightly different among sample trees, but the trends were similar. General trends of Q_{10} values were as follows, *i.e.*, Q_{10} values were high in winter (December to March), decreased gradually toward summer of July to August, and after that increased steeply toward winter. The smallest value of Q_{10} was 1.1 in August 1992 (Tree no.4) with nighttime air temperatures ranging from 22.4 to 28.0°C. Whereas Q_{10} values in winter season were higher than 3.0, for instance 3.5 (for Tree no. 2) in January 1992 with nighttime air temperatures ranging from 2.2 to 9.8°C. These results show that the sensitivity of respiration to temperature is higher in winter than in summer.

Figure 2 suggests that there exists a strong relationship between Q_{10} values and temperature, so that Q_{10} values are plotted against the mean nighttime air temperature, T (°C) (Fig.

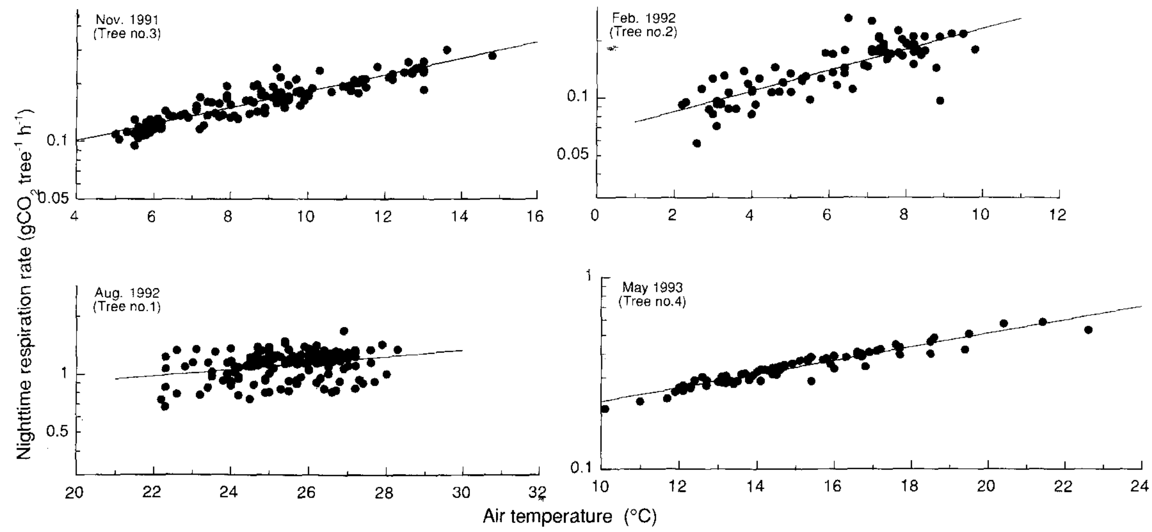

Fig. 1 Examples of the exponential relationship between nighttime respiration rate and air temperature inside the chamber. The curves correspond to Eq. (1).

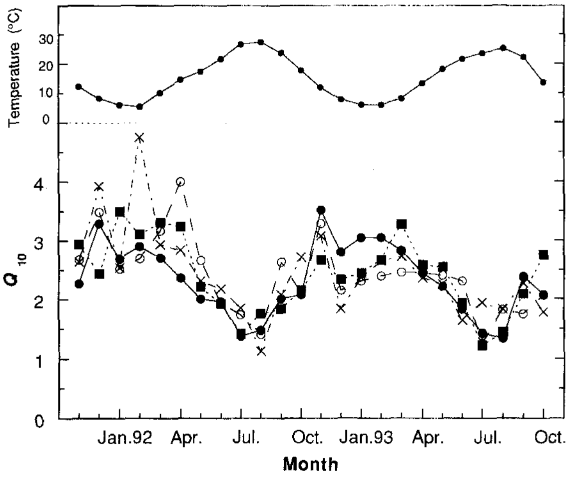

Fig. 2 Seasonal changes in Q_{10} values for nighttime respiration for four different sized *C. obtusa* trees and monthly mean air temperature during a two-year period. The Q_{10} values were calculated from Eq. (2). ●, Tree no. 1; ■, Tree no. 2; ○, Tree no. 3; ×, Tree no. 4.

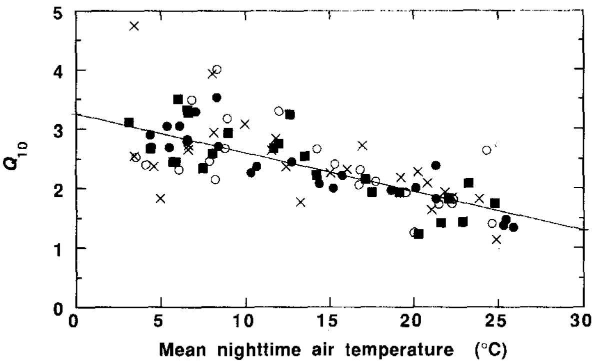

Fig. 3 Relationship between Q_{10} values and mean nighttime air temperature. The straight line corresponds to Eq. (3). ●, Tree no. 1; ■, Tree no. 2; ○, Tree no. 3; ×, Tree no. 4.

3). The Q_{10} values decreased with increasing mean nighttime air temperature. This negative correlation was found for all sample trees, but the correlation was weaker in smaller sized trees. This relationship was described by the following formula:

$$Q_{10} = -0.0667 \cdot T + 3.32. \tag{3}$$

This equation indicates that respiratory sensitivity to temperature depends on mean air temperature but not on tree size.

Paembonan *et al.* (1991) reported that monthly Q_{10} values for nighttime respiration decreased with increasing monthly mean temperature for the aboveground parts of a 12-year-old *C. obtusa* tree. Our result was consistent with the result of Paembonan *et al.* (1991). When we apply Eq. (3) to the result of Paembonan *et al.* (1991), our result satisfied their result. It is concluded that the relationship of Q_{10} values to temperature is independent not only of tree size but also of age.

Discussion

The Q_{10} values express the pattern of the response of certain biological functions (*e.g.*, photosynthesis, dark respiration, cell division, ion uptake, enzyme activity) to temperature (Fitter and Hay, 1987). Higher Q_{10} values indicate that the biological functions are more sensitive to temperature changes. Our results that Q_{10} values for dark respiration are high when monthly mean air temperature is low, indicates that a higher sensitivity of respiration to temperature occurs in low temperature ranges. It is concluded that changes in temperature due to changing seasons not only change respiration rate, but also change the response of respiration rate to temperature by shifting Q_{10} values.

There are several reports concerning temperature relationships of Q_{10} values for respiration. It is reported on aerial parts of apple trees (Butler and Landsberg, 1981), standing stems of *Pinus sylvestris* (Linder and Troeng, 1981) and *Magnolia obovata* (Negisi, 1972), and detached cones of *Picea abies* (Koppel *et al.*, 1987), that Q_{10} values were constant through a year or over wide temperature ranges. Whereas, some reports presented decreases of Q_{10} values with increasing ambient temperature; detached stems of *Pinus densiflora* (Negisi, 1975, 1978) and *Quercus myrsinaefolia* (Negisi, 1981), detached leaves of *Pinus Thunbergii* (Hagihara, 1973) and *C. obtusa* (Hagihara and Hozumi, 1977), aboveground parts of *Pinus densi-thunbergii* (Ninomiya and Hozumi, 1981) and *C. obtusa* (Ninomiya and Hozumi, 1983; Hagihara and Hozumi, 1991; Paembonan *et al.*, 1991), and seedlings of *C. obtusa* (Ogawa *et al.*, 1985). Hagihara and Hozumi (1991) and Paembonan *et al.* (1991) showed a clear trend of decreases of Q_{10} values for aboveground parts of a *C. obtusa* tree with increasing temperature.

It is very difficult to give an explicit explanation to these contradictory results, because several kinds of factors affect the respiratory behavior. Adaptability to coldness, i.e., Q_{10} values increase drastically below 10℃ in cold-intolerant species (Raison, 1980), and difference of respiratory activity in temperature dependence between electron transport systems (Collier and Cummins, 1990) are known as factors affecting change in Q_{10} values with temperature. Temperature dependence of maintenance and growth respiration may be another factor affecting Q_{10} values. Maintenance respiration is dependent of temperature, whereas growth respiration is not affected by ambient temperature (*e.g.*, Johnson and Thornley, 1985; Amthor, 1989; Mariko and Koizumi, 1993). Because total respiration was dominated by growth respiration in summer (Paembonan *et al.*, 1992, Yokota and Hagihara, 1995), the high ratio of growth respiration may play an important role to reduce temperature sensitivity of total respiration during growing season when ambient temperature is high. These factors complexly affect respiratory behavior of each species. Therefore the respiratory behavior to ambient temperature should be studied on each species throughout seasons.

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