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Branch Respiration in Hinoki [*Chamaecyparis obtusa* (Sieb. et Zucc.) Endl.] Trees, with Reference to Branch Positions within Tree Crowns

Shigeta MORI* and Akio HAGIHARA**

Abstract

The respiration rates of branch segments of five 26-year-old *Chamaecyparis obtusa* trees were examined in relation to their positions within crowns. The dependence of respiration rate on the height above ground of the branch segments was described by a power function with an exponent of 0.69 to 3.07. The exponent took the highest value in a middle-sized tree and lower values in larger- and smaller-sized trees. The vertical distribution of the branch fresh weight of a tree was expressed using the beta-distribution. On the basis of the power function and the distribution, a new equation for estimating the total branch respiration rate of a tree was proposed. The relationship between the branch respiration rate and the branch weight of a tree was expressed by a power function with an exponent of 1.06. In November, the stand respiration rate of branches was estimated to be 0.23 $kgCO_2\ ha^{-1}\ h^{-1}$ for branch biomass of 7.6 $Mg_{dw}\ ha^{-1}$, and consequently a specific respiration rate of 0.030 $kgCO_2\ Mg_{dw}^{-1}\ h^{-1}$ was calculated.

Keywords : branch, *Chamaecyparis obtusa*, respiration, vertical distribution

I. Introduction

The knowledge of branch respiration rates and their vertical distributions are fundamental to the study of the primary production of forests. Branch respiration rate is thought to be closely related to the photosynthetic activity of leaves which are sustained by that branch. The photosynthetic activity of leaves decreases from the top to bottom of tree crowns (HOZUMI and KIRITA, 1970), so that branch respiration rates are likely to vary also within crowns.

Some studies have been carried out on the structure of tree branching, such as the spatial arrangement (FLOWER-ELLIS and PERSSON, 1980; HASHIMOTO, 1990) and vertical distribution (SHINOZAKI *et al.*, 1964; FUJIMORI, 1971) of branches. These characteristics affect the light environment within crowns and are determinants of primary production (KURACHI *et al.*, 1989). On the other hand, many studies of branch respiration rate have

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been made (MÖLLER *et al.*, 1954; YODA, 1965; NEGISI, 1974; HAGIHARA and HOZUMI, 1981; SPRUGEL, 1990; SPURGEL and BENECKE, 1991). However, integrating branch respiration rate has been rarely done in relation to its production.

In this study, we analyzed the dependence of the respiration rate of branches on their positions within crowns and described the vertical distribution of branches of a tree using the beta-distribution. A new equation for estimating the branch respiration rate of a tree was proposed taking account of the vertical distribution of branches within a crown. We examined the dependence of branch respiration rate on branch weight and attempted to estimate the stand respiration of branches.

II. Materials and Methods

The study was carried out at an elevation of 1000 m on a 26-year-old *Chamaecyparis obtusa* plantation (as of 1982) of Nagoya University Forest at Inabu, Aichi prefecture. Tree density, mean tree height, and mean stem diameter at breast height (1.3 m above ground) were 6039 trees ha^{-1}, 8.7 m, and 8.6 cm, respectively.

Fourteen sample trees were felled between November 1982 and August 1983. These trees were subjected to the stratified clip technique. Branch biomass was estimated to be 7.6 Mg_{dw} ha^{-1} from an allometric relationship between branch fresh weight, W (kg_{fw} $tree^{-1}$), and stem diameter at breast height, D (cm) (Fig. 1). A census of stem diameter at breast height and tree height was made for 118 trees in the plot.

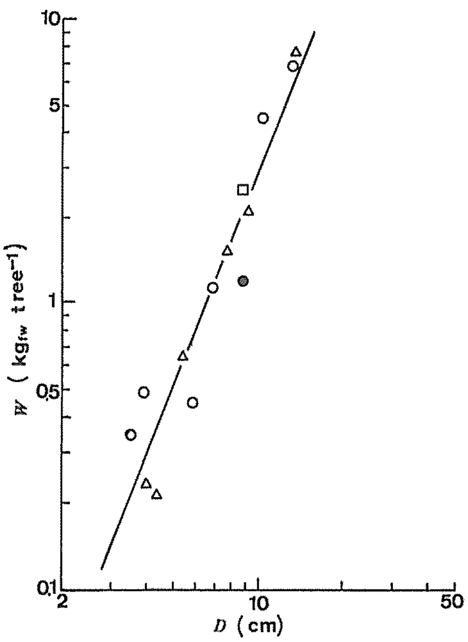

Fig. 1. Allometric relationship between branch fresh weight, W(kg_{fw} $tree^{-1}$), and diameter at breast height, D(cm). The solid line indicates the allometric regression ($W=0.00853D^{2.56}$; Coefficient of determination=0.93). ○, Nov. 1982; ●, Feb. 1983; □, May 1983; △, Aug. 1983.

Table 1. Some characteristics of sample trees.

Tree No.	Coefficients of Equation (1)		Tree hight	Clear bole length	Coefficients of Equation (2)		Branch respiration rate	Branch fresh weight	Specific respiration rate
	a ($mgCO_2\ kg_{fw}^{-1}\ h^{-1}\ m^{-b}$)	b	H (m)	H_B (m)	λ_1	λ_2	R ($mgCO_2$ $tree^{-1}\ h^{-1}$)	W ($kg_{fw}\ tree^{-1}$)	R/W ($mgCO_2$ $kg_{fw}^{-1}\ h^{-1}$)
1	0.162	2.29	12.1	4.7	2.56	4.13	117.8	6.82	17.3
2	0.058	2.85	10.4	3.8	5.07	7.87	56.9	4.44	12.8
3	0.052	3.07	9.2	5.3	1.54	2.70	20.9	1.12	18.7
4	0.300	2.29	7.0	4.1	2.08	2.42	6.5	0.44	14.6
5	4.48	0.69	5.2	1.8	1.63	1.62	5.1	0.48	10.6

Respiration rate was measured on five sample trees covering the range of stem diameter at breast height in the stand on 15 to 18 November 1982 (Table 1). Fresh weight of branches contained in each horizontal layer 1.0 m thick was measured. Branches of each layer were cut into segments of about 15 cm to measure respiration. The branch segments were collected into samples whose weight ranged from 20 to 120 g_{fw}. The samples were enclosed in a metal cylinder (either 2.8 or 4.4 L) which had a thermometer and a petri dish containing 25 mL of 0.2 N KOH to absorb CO_2. Controls without branches were also run. The lid of each cylinder was sealed with adhesive tape to ensure that it was airtight. The cylinders were placed on the forest floor under dense tree crowns to minimize variation in temperature. Mean values of the maximum and minimum temperatures in each cylinder were used for determing an average temperature during the period of enclosure, which was about 16 h. The average temperature ranged from 7.6 to 9.4℃.

At the end of the incubation period, the solution was transferred to plastic bottles and titrated according to the procedures proposed by KIRITA and HOZUMI (1966).

The effect of branch excision on respiration rate (EVANS, 1972) was not examined. However, OOHATA *et al.* (1967) and OGAWA *et al.* (1985) found that the effect was not very serious in *Chamaecyparis obtusa* trees.

III. Results and Discussion

1. Dependence of the respiration rate of branches on their position within crowns

The respiration rate on a fresh weight basis, r ($mgCO_2\ kg_{fw}^{-1}\ h^{-1}$), increased with increasing height above ground, h (m), at which branches were attached to the trees (Fig. 2). Branches at the upper part of the crowns are younger and more active metabolically, so that these branches are expected to have faster rates of respiration (OOHATA *et al.*, 1971; HAGIHARA and HOZUMI, 1981).

The relationship between r and h was approximated by the following power function:

$$r = a \cdot h^b, \qquad (1)$$

where *a* and *b* are coefficients specific to individual trees from which samples are taken. The value of *b* ranged from 0.69 to 3.07 (Table 1). The higher value of *b* means that the difference in respiration rates among heights above ground is larger. The value of *b* was highest in the middle-sized tree (Tree No. 3) and lower in larger- or smaller-sized trees (Fig. 3).

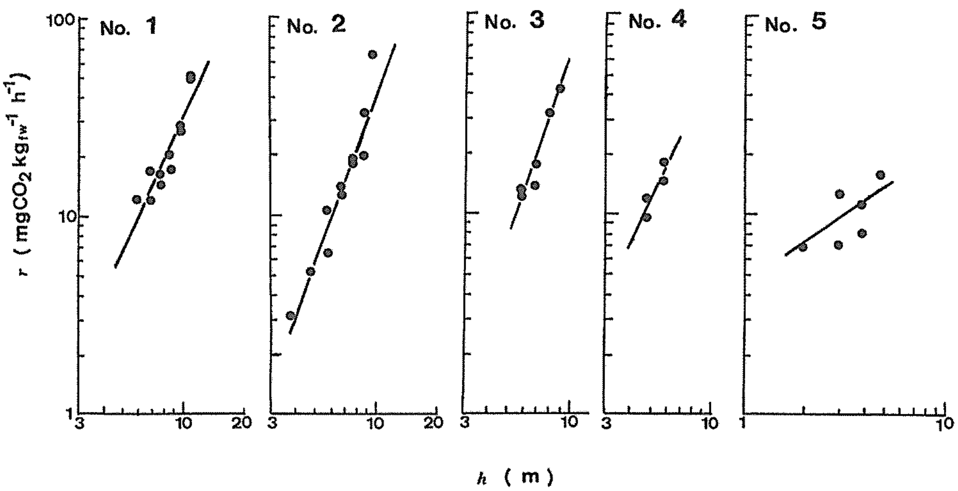

Fig. 2. Dependence of respiration rate of branch segments, r(mgCO_2 kg$_{fw}^{-1}$ h^{-1}), on the height above ground, h(m), at which the branches were originally growing. The data are fitted to Eq. (1). The numbers refer to the sample tree numbers. Coefficients of determination : No. 1, 0.80 ; No. 2, 0.92 ; No. 3, 0.90 ; No. 4, 0.81 ; No. 5, 0.46.

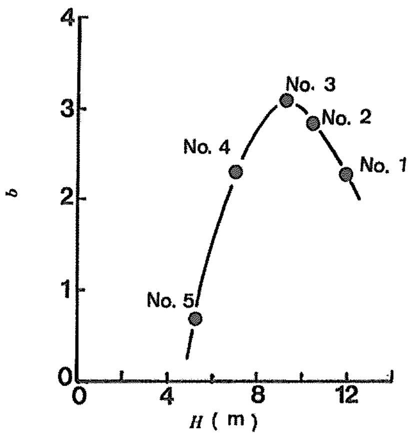

Fig. 3. Relationship between the parameter b in Eq. (1) and tree height, H(m). The numbers refer to the sample tree numbers.

2. Vertical distribution of the branch weight of a tree

To evaluate the total amount of branch respiration of a sample tree, the vertical distribution of the branch fresh weight of the sample tree must be known.

The vertical distribution of branch weight density, $\Gamma(h)$ (kg_{fw} m^{-1} $tree^{-1}$), at a height above ground, h (m), of a tree was well described by the beta-distribution (Fig. 4) :

$$\Gamma(h)=\beta(h-H_B)^{\lambda_1-1}(H-h)^{\lambda_2-1}, \qquad (2)$$
$$\beta=\frac{W}{(H-H_B)^{\lambda_1+\lambda_2-1}B(\lambda_1, \lambda_2)},$$

where H_B (m), H (m), and W (kg_{fw} $tree^{-1}$) are respectively clear bole length, total tree height, and total branch weight, and λ_1 and λ_2 are coefficients specific to sample trees. The symbol B stands for the beta function.

The values of the coefficients λ_1 and λ_2 were respectively calculated from the equations :

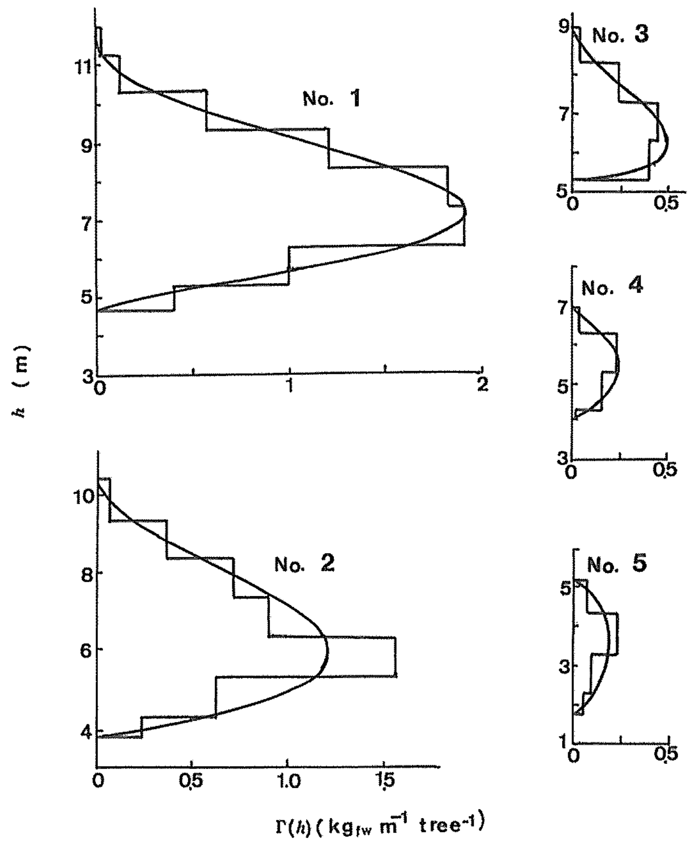

Fig. 4. Vertical changes in the branches fresh weight density, $\Gamma(h)$(kg_{fw} m^{-1} $tree^{-1}$), with the height above ground, h(m). The smooth curves show the beta-distribution of Eq. (2). The numbers refer to the sample tree numbers.

$$\lambda_1=\frac{M_1-H_B}{H-H_B}\left(\frac{(M_1-H_B)(H-M_1)}{M_2-M_1^2}-1\right), \tag{3}$$

$$\lambda_2=\frac{H-M_1}{H-H_B}\left(\frac{(M_1-H_B)(H-M_1)}{M_2-M_1^2}-1\right). \tag{4}$$

Here, M_1 and M_2 are respectively the first and second moments of the distribution :

$$M_1=\frac{\sum_{i=1}^{n}(h_i\cdot w_i)}{W}, \tag{5}$$

$$M_2=\frac{\sum_{i=1}^{n}(h_i^2\cdot w_i)}{W}, \tag{6}$$

where n is the total number of layers of each tree ; h_i (m) and w_i (kg_{fw} $tree^{-1}$) are the height above ground of the ith layer and the weight of the branches belonged to the layer, respectively.

3. Estimation of the branch respiration rate of a tree

The branch respiration rate per tree, R ($mgCO_2$ $tree^{-1}$ h^{-1}), is given by the definite integral of Eq. (1) times Eq. (2), with respect to the height above ground, h, from the clear bole length, H_B, to the total tree height, H :

$$R=\int_{H_B}^{H} r(h)\cdot\Gamma(h)\cdot dh. \tag{7}$$

We can obtain the solution of the above equation in the form :

$$R=a\cdot W\cdot H^b\cdot F\left(-b,\lambda_2\,;\,\lambda_1+\lambda_2\,;\,\frac{H-H_B}{H}\right), \tag{8}$$

where F shows the hypergeometric function (cf., OBERHETTINGER, 1972). The branch respiration rate per tree based on Eq. (8) is shown in Table 1.

4. Dependence of branch respiration per tree on tree size

The respiration rate per tree, R ($mgCO_2$ $tree^{-1}$ h^{-1}), was related to the branch fresh weight of the tree, W (kg_{fw} $tree^{-1}$), through a power function (Fig. 5) :

$$R=14.15\,W^{1.06}. \tag{9}$$

MORI and HAGIHARA (1988, 1991) showed in this hinoki stand that stem and root respiration rates per tree were respectively related to the weights of stems and roots through power functions with exponents of 1.3 and 1.11. The similar relationships have been

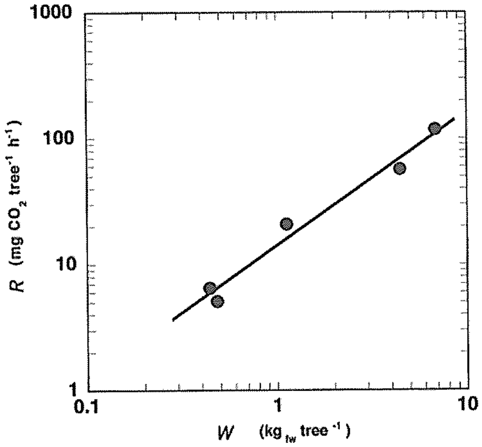

Fig. 5. Change in the branch respiration rate of a tree, R(mg CO_2 tree^{-1} h^{-1}), with the corresponding fresh weight, W(kg$_{fw}$ tree^{-1}). The line is given by Eq. (9) (Coefficient of determination=0.98).

Table 2. Specific respiration rates and biomasses of stems, roots, and branches in the stand.

	Specific respiration rate (kgCO_2 Mg$_{dw}^{-1}$ h^{-1})	Biomass (Mg$_{dw}$ ha^{-1})
Roots[1)]	0.013	28
Stems[2)]	0.012	81
Branches	0.030	7.6

1) The values were estimated by MORI and HAGIHARA (1988).
2) The values were estimated by MORI and HAGIHARA (1991).

noticed for young *Pinus densiflora* S. et Z. (NEGISI, 1974), *P. densi-thunberugii* Uyeki (NINOMIYA and HOZUMI, 1981), and *Chamaecyparis obtusa* (NINOMIYA and HOZUMI, 1981; YOKOTA *et al.*, 1994; YOKOTA and HAGIHARA, 1995). Thus, the functional relationships between the respiration rate of organs and their weight may be found generally in trees.

5. Stand respiration of branches

On the basis of Eq. (9), the stand respiration rate of branches can be assessed from the branch fresh weight of individual trees, which is estimated by means of the allometric relationship between branch fresh weight, W, and stem diameter at barest height, D (Fig. 1). The estimated amount of stand branch respiration rate was 0.23 kgCO_2 ha^{-1} h^{-1} and the specific respiration rate was 0.030 kgCO_2 Mg$_{dw}^{-1}$ h^{-1} for a branch biomass of 7.6 Mg$_{dw}$ ha^{-1} in November 1982. This value was larger than the specific respiration rate 0.020 kgCO_2 Mg$_{dw}^{-1}$ h^{-1} for branch biomass of 6.1 Mg$_{dw}$ ha^{-1} which was obtained for this stand in November in 1974 (HAGIHARA and HOZUMI, 1981).

The specific respiration rates of roots and stems agreed with each other (Table 2) ; 0.013 kgCO_2 Mg$_{dw}^{-1}$ h^{-1} for roots and 0.012 kgCO_2 Mg$_{dw}^{-1}$ h^{-1} for stems. On the other hand, the specific respiration rate of branches was about two and a half times as large as the specific respiration rates of roots and stems. This large specific respiration rate of branches is probably ascribed to the characteristic of branches, i.e., older branches in lower part within crowns tend to fall, whereas stems and roots accumulate less active cells of respiration inside their bark.

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ヒノキ林木の樹冠内の枝位置に関連した枝呼吸速度

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26年生ヒノキ林で5個体の枝短材の呼吸速度を樹冠内部の枝の位置と関連づけて調べた。短材の呼吸速度の地上高への依存性は巾指数が0.69から3.07の巾乗式で表現することができた。巾指数は中間サイズの個体で高く，より大きいサイズ，およびより小さいサイズの個体で低かった。個体の枝生重量の垂直分布はベータ分布を用いて表現することができた。これらの巾乗式と分布関数をもとに，個体の枝の呼吸速度を推定する新しい式を提案した。個体の枝の呼吸速度と重量の関係は，巾指数が1.06の巾乗式で表現することができた。11月の枝の林分呼吸速度は枝現存量7.6 $Mg_{dw}\ ha^{-1}$ に対して0.23 $kgCO_2\ ha^{-1}\ h^{-1}$ であり，すなわち現存量あたりの枝呼吸速度は0.030 $kgCO_2\ Mg_{dw}{}^{-1}\ h^{-1}$ であった。

キーワード：枝，呼吸，ヒノキ，垂直分布