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Measurement of respiration amount of white birch (*Betula platyphylla*) population in the mountainous region of Beijing

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Abstract—Measurement of forest community respiration is very important for clarifying the processes of matter cycle in forest ecosystem. Measurement of respiration of white birch (*Betula platyphylla*) population in the mountainous region of Beijing was reported herein and its results showed that the diameter frequency distribution of the woody organs was fitted by a power equation and the respiration rates of the organs decreased with their increasing diameter. These formulae to calculate the total respiration amount of every organ for an individual were introduced and those corresponding parameters were given. The quantitative relationship to estimate population respiration amount from three size was proposed. Using the above relationships, the annual respiration amount of white birch population was estimated to be 10.8t CO_2/ha/a, of which stem, root, branch and leaf were 1.4, 2.0, 2.8 and 4.7 tCO_2/ha/a, respectively.

Keywords: diameter distribution; mountainous region of Beijing; respiration; white birch population.

1 Introduction

Forest ecosystem is one of main elements in global carbon cycle (Woodwell, 1978; Lugo, 1986). Research on the process of carbon cycle is the most favorable method to understand the quantitative relationships between every elements of forest ecosystems (Odum, 1969; Kira, 1976; Kawaguchi, 1988). During the International Biological Programme (IBP) in the period of 1960s and 1970s, a large quantity of studies had been carried out in some developed countries, and they played an important role in recognizing structure and function of the global ecosystem. In studying carbon cycle of forest, it is the most difficult to measure tree respiration (Fang, 1995; Yoda, 1971). During the IBP, closed alkali absorption method was recommended as an effective one among a lot measuring methods proposed (Kawaguchi, 1988; Kirita, 1971; Kira, 1978; Yoda, 1971). Nowadays, as a result of which the increase of greenhouse gases in the atmosphere would lead to global warming, the carbon cycle of forest has been paid a great attention again. The reliability of the closed alkali absorption method was raised doubt because of possible over-measurement (Koizumi, 1991). Therefore, using an accurate analyzer to measure respiration of forest has been suggested.

Forest is a large heterogenic system in which every component exchanges CO_2 with the atmosphere at different rates, and the exchange rates vary in temporal and spatial scale as biological characteristics of forest (e. g., age, growth etc.) and its environmental conditions (e. g., weather, soil and season etc.). Therefore, these rates are really difficult to measure. For this reason, the authors suggested a method using a separate measurement which divides the whole tree into different parts and then integrates the respirations of all parts, namely, sample trees were felled down and the respiration rates of every organ were measured (Yoda, 1965; 1971; 1983; Kawaguchi, 1986). The method was used to estimate respiration amount of white birch (*Betula platyphylla*) stand in mountainous region of Beijing which is a typical temperate montane vegetation. The stand was defined as white birch population here because the stand studied was not a pure one.

2 Study site and method

2.1 Site description and tree growth

The permanent plot orienting to south at 1450 meters above sea level and with slope of 28° is located at the Beijing Forestry Ecosystem Research Station in the mountainous region of Beijing. The dominant tree is white birch. Some other canopy species, such as *Acer mono*, *Populus*, *Sorbus amurensis*, *Betula utilis* and *Salix caprea* and so on, can be found in the plot. Below tree canopy, shrub comprises *Cornus officinalis*, *Leptodermis oblonga* and *Abelia bitlora* and so on and forest floor consists of *Spirea dasyantha*, *Clematis*, *Lonicera*, *Carex*. According to the measurement in 1992—1993 at the meteorological station with an latitude of 1150 meters near the plot, the average temperature was −10.9°C for January and 18.1°C for July, and the annual mean temperature was 4.5°C. The annual mean temperature at the plot was estimated to be 2.9°C by using a temperature lapse rate of 0.55°C/100 meters.

The area of plot is 1050 m^2 in which 186 trees with DBH (diameter at breast height) more than 3 cm grow, this means a stand density of 2006 stems/ha. The mean height of stand was 8.2m and the mean DBH was 9.1 cm. The number of white birch in the plot was 83 that means its population density was 895 stems/ha. The average height of the white birch was 11.1m and the average DBH was 13.0 cm.

2.2 Measurement of diameter frequency distribution of woody parts

The respiration rates of woody parts, root, stem and branch, change greatly with their diameter (Kawaguchi, 1986; Fang, 1995). In order to measure respiration rates of parts with different diameters, separately measuring them for each diameter class is needed. For this reason, we determined the distribution of diameter frequency for each part at following intervals:

Branches were separated into eight classes: 0—0.5, 0.5—1.0, 1.0—1.5, 1.5—2.0, 2.0—2.5, 2.5—3.0, 3.0—3.5 and >3.5cm.

Roots were separated into nine classes: 0—0.3, 0.3—0.6, 0.6—1.0, 1.0—1.5, 1.5—2.0, 2.0—2.5, 2.5—3.0, 3.0—3.5 and >3.5cm.

Stem was cut into 1m intervals and their diameters at the middle were measured. The length of remainder less than 1 meter was measured and its diameter was determined at the middle point. Seven trees with a different DBH were sampled near the plot, and their distributions of diameter frequency for each part were determined based on the above separation. Before classing, the base diameter, DBH, height below branch crown and age of sampling trees were measured. The root, stem, branch and leaf of the sample trees were separated and weighted.

2.3 Measurement of respiration rate

Respiration rates were measured for each part and diameter class according to the result of woody part diameter classing. The measuring procedure has been reported in previous paper (Fang, 1995).

The CO_2 analyzer used in our study was made by Fuji Motor Co. Ltd., Japan. Its measurement range of CO_2 concentration is 0—5000ppm. Its accuracies are ±5% in the range of 0—2000 ppm and ±10% in the range of 2000—5000 ppm. The flow rate of gas is 1 L/min. More than 2 times of measurements can be done within 20 minutes.

Respiration rate can obtained by following formula (Fang 1994);

$$r = \frac{7.071}{tw}(C_2 - C_1)(V_c - V_s)\frac{273 + T}{273}. \quad (1)$$

where, r is respiration rate (mg CO_2/kg fresh weight/h), t is the interval time(s) between two measurements; w is the fresh weight (g) of the sample; C_1 and C_2 are CO_2 concentrations (ppmv) within measurement chamber at the first and second measurements, respectively. V_c and V_s are volumes(ml) of chamber and the sample, respectively; T is the average temperature within the chamber(°C).

In order to compare respiration rates among different temperatures and to estimate respiration rate at a given temperature, the relationship between respiration rate and temperature was assumed to follow $Q_{10}=2$.

3 Results and discussion

3.1 Relationship between respiration rates of woody parts and their diameter

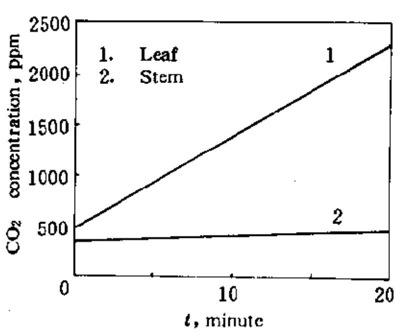

Fig. 1 The temporal change of CO_2 concentration in chamber at the temperature of 20°C

For each sample tree, the respiration rates for every part with different diameters were measured. Fig. 1 shows the temporal change in respiration amount (CO_2 concentration in the chamber) of leaf and stem with diameter of 9.3cm. The CO_2 concentration was increased linearly with measurement time, and this means these organ release CO_2 at constant rates. This also verify the measurement results reliable. As shown in Fig. 1, the respiration rate of stem was much less than that of leaf.

Fig. 2 shows relationships between respiration rates of woody parts(r) and their diameters(x) at the temperature of 20°C. With increasing diameter, respiration rates decrease in accordance with a power equation for stem and branch, and with reciprocal equation for root, respectively (Fig. 2). If the annual mean temperature was

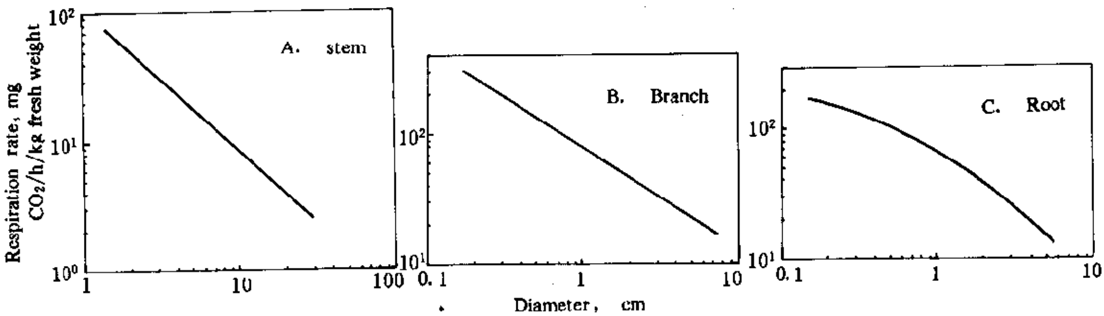

Fig. 2 The relationship between the respiration rates of woody parts and their diameter classes at the temperature of 20°C

2.9°C, these relationships can be showed as follows:

$$\text{Root:} \quad 1/r = Ax + B = 0.0313x + 0.0145, \quad (R = -0.91)$$
$$\text{Stem:} \quad r = Ax^B = 24.1769x^{-0.9504}, \quad (R = -0.83) \qquad (2)$$
$$\text{Branch:} \quad r = Ax^B = 22.9039x^{-0.7218}, \quad (R = -0.95)$$

The average respiration rate of leaf at the annual mean temperature of 2.9°C was 100.9mg CO_2/kg fresh weight /h.

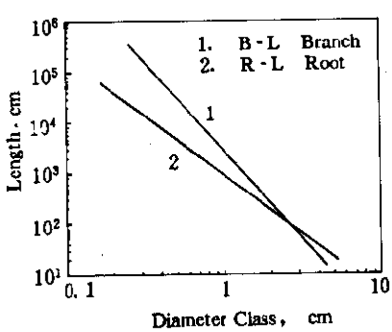

Fig. 3 The frequency distribution of diameter of branch and root of white birch

3.2 The distribution of diameter frequency of woody parts

Fig. 3 represents the relationship between the total length and its corresponding diameter classes of branch and root of tree No. 3. In logarithmic coordinates diagram, the total lengths $f(x)$ for each diameter class decreases linearly with the increase of corresponding diameter classes, it can be expressed as follows:

$$f(x) = kx^{-a}. \qquad (3)$$

The parameters in Equation (3) for each sample tree are listed in Table 1. The parameters for tree No. 2 are not shown because of too large stump. Since stem can be considered as a circular cone, the power of diameter, a, in Equation(3) was 0.

The fact of power distribution of diameter frequency can be explained by the pipe model theory (Shinozaki, 1964).

Table 1 The growth factors and respiration rate at the annual mean temperature of 2.9°C and related parameters of white birch in the mountainous region of Beijing

No.	DBH, cm	Height, m	Part	Fresh weight, kg	Diameter, cm		Parameters			Respiration rate, mg CO_2/h/tree
					Minimum	Maximum	KK'	a	KK'	
1	9.4	8.5	Branch	6.31	0.2	3.8	1583.5	2.675	2.157	162.5
			Root	8.91	0	9.4	980.5	2.0	0.948	92.3
			Stem	27.08	0.2	12.5		0	0.042	87.7
			Leaf	2.00						101.8
2	14.2	11.2	Branch	27.99	0.2	5.7	3680.9	1.731	3.958	360.7
			Root*	—	0	14.2	—	—	—	—
			Stem	80.81	0.2	20.4		0	0.029	165.3
			Leaf	5.71						576.1
3	13.9	9.8	Branch	22.45	0.2	5.6	3324.9	2.085	4.458	349.9
			Root	32.67	0	13.9	1874.0	1.5	0.946	276.4
			Stem	64.97	0.2	17.2		0	0.038	152.7
			Leaf	5.08						512.6
4	13.1	11.6	Branch	22.33	0.2	5.4	2733.8	1.858	3.805	315.8
			Root	22.88	0	13.1	486.5	1.5	0.946	206.5
			Stem	70.70	0.2	16.7		0	0.046	174.0
			Leaf	1.45						146.3
5	8.6	8.7	Branch	5.77	0.2	3.5	1119.1	1.883	1.658	106.8
			Root	9.60	0	8.6	345.0	1.0	0.260	66.3
			Stem	23.32	0.2	11.1		0	0.051	83.5
			Leaf	1.56						157.4
6	16.8	14.3	Branch	21.05	0.2	3.6	2459.5	1.9	5.904	385.9
			Root	47.90	0	16.8	2737.4	1.5	1.043	329.5
			Stem	130.30	0.2	22.0		0	0.037	246.2
			Leaf	9.56						964.2
7	5.8	6.1	Branch	1.80	0.2	2.8	440.7	2.15	0.713	41.7
			Root	3.50	0	5.8	254.8	1.5	0.376	77.8
			Stem	7.41	0.2	7.7		0	0.049	37.9
			Leaf	0.45						45.4

Note: - means not measured

3.3 Estimation of respiration amount of an individual

The procedure to estimate organ respiration of an individual has been discussed in detail in our previous paper (Fang, 1995), and calculation formulae were described only as follows: The weight of an organ within a range of $(x, x+dx)$ can obtained as follows, based on Equation (3):

$$dw(x) = K'x^2 f(x)dx = KK'x^{2-a}dx. \tag{4}$$

So the total respiration amount (R) is the integral of respirations for all diameter classes.

$$R = \int_{x_1}^{x_2} r(x)dw(x) = KK'\int_{x_1}^{x_2} x^{2-a} r(x)dx, \tag{5}$$

where, x_1 and x_2 are the minimum and maximum diameter of the part, $r(x)$ is the respiration rate with diameter class (x) in Equation (2). So the respirations amount of every part of an individual are calculated as follows:

(1) Root: with three cases:

$$\text{When } a=2, \quad Rr=\frac{KK'}{A}[ln(Ax+B)]|_{x_1}^{x_2},$$

$$\text{When } a=1.5, \quad Rr=2KK'[\frac{x^{0.5}}{A}-(\frac{B}{A^3})^{0.5}arctg(\frac{Ax}{B})^{0.5}]|_{x_1}^{x_2}, \tag{6}$$

$$\text{When } a=1, \quad Rr=\frac{KK'}{A^2}[(Ax+B)-Bln(Ax+B)]|_{x_1}^{x_2}.$$

Here, $A=0.0313$, $B=0.0145$.

(2) Stem: because the shape of stem is a circular cone, $a=0$ and $x_1=0$ can be adopted.

$$Rs=\frac{AKK'}{3+B}x^{3+B}. \tag{7}$$

Here, $A=24.1769$, $B=-0.9504$.

(3) Branch:

$$Rb=KK'\frac{A}{3-a+B}x^{3-a+B}|_{x_1}^{x_2}. \tag{8}$$

Here, $A=22.9039$, $B=-0.7218$.

(4) Leaf:

$$R_l=100.9W_1. \tag{9}$$

Here, W_1 is the total fresh weight of leave of the sample tree. Using Equations (6)—(9), the total respiration amount for every part of all sample trees at the annual mean temperature of 2.9°C can be obtained (Table 1).

3.4 Estimation of population respiration

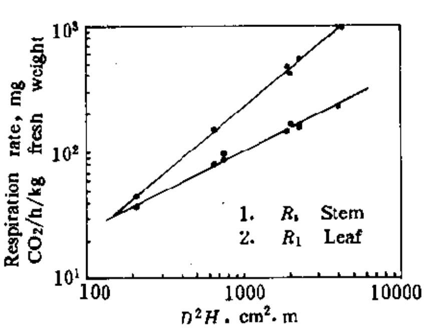

Fig. 4 The relationship between the respiration rates of stem and leaf and tree size (D^2H) at the annual mean temperature of 2.9°C

It has been known that the power relationship exists between the total organ respirations of a tree and the tree size (D^2H: D-diameter at breast height, and H-height, Fang, 1995). The authors have regressed the relationship and given an example in Fig. 4 in which good correlations between the total respiration amounts of stem and leaf and D^2H were showed. The regression equations are expressed as follows:

$$\begin{aligned} &\text{Branch:} && Rb=0.6303(D^2H)^{0.8104}, \\ &\text{Root:} && Rr=0.2549(D^2H)^{0.8842}, \\ &\text{Stem:} && Rs=1.4138(D^2H)^{0.6235}, \\ &\text{Leaf:} && Rl=0.1294(D^2H)^{1.0775}, \end{aligned} \tag{10}$$

Using the Equation (10) and data obtained from stand investigation, the total organ respirations of white birch population at the annual mean temperature of 2.9°C was calculated. Table 2 shows the average and the total of organ respirations in white birch population.

Table 2 The average and the annual total of respiration of every organ in white birch population at the annual mean temperature of 2.9°C

Organ	Average respiration rate,		Total respiration amount,
	mg CO_2/(h · tree)	g CO_2/(h · ha)	kg CO_2/(ha · a)
Root	262.4	226.6	1985.0
Stem	172.7	154.6	1354.3
Branch	353.1	316.0	2768.2
Leaf	666.0	596.1	4704.5
Total	1454.2	1301.5	10812.0

Note: respiration in leaf growing period

It is must be noted that the total annual respirations of leave is the one in the growing period of leaf which begins in May and end in October for white birch in our study site. If a temperature lapse rate of 0.55°C/100m was adopted, the mean temperature in the growing seasons of leaf at the white birch plot (1450m) was 11.4°C, at which the mean respiration rate of leaf was 1200.1 mg CO_2/(h · tree) and the annual respiration amount of leaf was $1200.1 \times 24(h) \times 895(trees/ha) \times 365/2 = 4704.6 \times 10^6 mg/ha = 4704.5 kg/ha$.

As shown in Table 2, the annual respiration amount of white birch was 10.8 ton CO_2/ha, which is almost the same as that of oak forest area (Fang, 1995). The contribution pattern of respiration among parts was 4.4:2.6:1.8:1.2 for leaf: branch:root: stem. The leaf respiration was nearly half of the total, while that of stem only one - eighth of the total that differs greatly from oak and pine (Fang, 1995). It can be concluded that the contribution pattern of respiration among parts varies considerably from tree species to tree species.

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1995 AIBS DISTINGUISHED SERVICE AWARD

JOHN CAIRNS, JR., University Distinguished Professor at Virginia Polytechnic Institute and State University, has spent most of his career studying protozoan community dynamics, toxicity and thermal shock in aquatic organisms, and recovery and restoration of damaged ecosystems. He has developed simple, practical methods for studying surface - dwelling, aquatic microorganisms, methods and instrumentation for analyzing sublethal effects of toxicants, and hazard evaluation protocols. He and his colleagues developed the concept of hierarchical hazard evaluation of chemicals, which is used to examine new chemicals, especially pesticides.

Cairns has worked to improve environmental protection by advocating the use of ecological information in management. Cairns, a member of the National Academy of Sciences, has served on 17 National Research Council Committees, including the one that produced in 1992 Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, a report of ground - breaking work in restoration ecology. His work on developing predictive models of ecosystem recovery began following studies of the biotic destruction caused by the collapse of a dike for a fly ash pond on the Clinch River. His studies on that river and elsewhere helped him to understand the ways in which colonists arrive at damaged sites. The principles he developed are now used to rehabilitate Superfund sites and to replace and repair damaged wetlands.

Cairns had served on the U. S. Environmental Protection Agency Science Advisory Board. His awards include the 1988 United Nations Environmental Programme Medal for unique and significant contributions to environmental restoration and sustainability and the 1984 Morrison Medal for Outstanding Accomplishments in the Environmental Sciences.