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The Rate of Soil Respiration in *Populus maximowiczii* Stand on Volcano Mt. Usu, Northern Japan

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ABSTRACT: The response of respiration rates of root, A_0 layer and mineral soil to varying environmental factors was studied in *Populus maximowiczii* stand (25-year-old) during the growing season of 1997. Soil temperature showed a pronounced seasonal course, in contrast to soil moisture. The mineral soil respiration was high in August, and root and A_0 layer respiration, were high in July. An exponential equation best described the relationships between soil temperature and mineral soil respiration, and total soil respiration (r=0.95 and 0.92, p<0.001), respectively. In *P. maximowiczii* stand, soil respiration rates were reduced by about 19% after removal of the A_0 layer, and by about 30% after removal of living root. Therefore, mineral soil respiration seemed to contribute gretly to the total soil respiration (50%).

Key Words: A_0 layer respiration, Mineral soil respiration, *Populus maximowiczii*, Root respiration, Soil temperature, Volcanic eruption

INTRODUCTION

There has long been concern about the effects of management and climate on C oxidation from soil to the atmosphere for several reasons. Soils contain about twice the amount of C as the atmosphere, that is, 1500Pg of C in soils versus 750Pg of C in the atmosphere (Eswaran *et al.* 1993), and are an important global C reservoir. The flux of carbon from soils to the atmosphere occurs primarily in the form of CO_2, and is the result of 'soil respiration'. Soil respiration represents the combined respiration of soil macro- and micro-organisms and roots. As measurement of the soil respiration in decomposing substrate has been recognized as an useful index of decomposition and mineralization rate of organic matter, and carbon cycling in forest ecosystem (Mathes and Schriefer 1985, Ewel et al. 1987, Gordon *et al.* 1987), measurements of soil respiration have been made in a variety of forest ecosystems. Despite a great quantity of informations, estimations of soil respiration rate by species and dominant forest are open to question. Moreover, the relative contributions of autotrophic respiration (CO_2 released by respiring roots) and heterotrophic respiration (CO_2 released by decomposition of litter) to total soil respiration are still poorly known. For example, root respiration estimates range from 4 (Phillipson *et al.* 1975) to 60% (Ewel *et al.* 1987) of soil respiration. And, studies have shown the influence of environmental factors on soil respiration (Carlyle and U Ba Than 1988).

On the other hand, study on soil respiration within forest ecosystem has lately attracted considerable attention. An international countermeasure on global warming has work out at Kyoto in 1997. More recently, anthropogenic activities such as exceeding deforestation, agricultural practices, and the burning of fossil fuels have resulted in large shifts of carbon pools, particularly since the beginning of the industrial revolution (IPCC 1995). However, despite its global significance as well as the dedication of considerable scientific resources to its study over the last several decades, we have only a limited understanding of the magnitude of soil respiration within and across ecosystems and the factors controlling soil respiration (Raich and Potter 1995).

The purpose of this study is to grasp the seasonal patterns of soil respiration and to assess heterotrophic (soil microbes) and autotrophic (root) contributions to total soil respiration and to understand the effects of environmental factors such as soil temperature and moisture on each group in *Populus maximowiczii* stand, which is in early stages of vegetation recovery after volcanic eruptions.

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MATERIALS AND METHODS

Study sites

Measurements were from April through November, 1997 in a *Populus maximowiczii* stand on the Mt. Usu (727m, 42°32′ N, 140°50′ E), which was created by volcanic eruptions in the period 1977-1978, Hokkaido, northern Japan. Annual precipitation and mean annual temperature in this area are about 1,024 mm and 6.2°C, respectively. This study area is covered with snow for about 4 months, from December to late March. The soils of this area are lapilli, andesite and pumice stone developed after volcanic eruptions.

During 23 years after the 1977-1978 eruptions, Mt. Usu has recovered deciduous broad-leaved species such as poplar (*Populus maximowiczii*), alder (*Alnus maximowiczii*), and herbaceous species such as *Lotus corniculatus* var. *japonicus* through the natural invasions. Stand selected in this study is nearly consisted of a pure stand of poplar, which constitute, 92% of the total biomass in the study stand. The maximum tree height of poplar was 10.4 m, and their basal area was 19.9 m^2/ha. The tree density was 8,200 trees/ha.

Soil respiration measurement

To separate the contributions (mineral soil, A_0 layer, living root) to total soil respiration by the different sources, we used trench method. The six subplots of 2x2 m size were established at intervals of 5 m within *Populus maximowiczii* stand. Roots were removed in April 1997 from 0.5x0.5 m areas to a depth of 30 cm and soil was returned to each pit. No barrier were used to limit root invasion since the respiration measurements were performed only 4 weeks after root removal. Significant root invasion was unlikely in this short time. Treatments were as follows: control, no-A_0 layer and no-root (Bowden *et al.* 1993). Measurement of each treatment was conducted in 2 subplots.

Soil respiration was measured from April through November, 1997 using the alkali absorption technique (Kirita 1971). CO_2 evolved from soil was absorbed for 24 hr in sponge contained 20 ml of KOH solution in plastic chambers that were 23 cm in height and 13 cm in diameter. Seven chambers were pushed into the soil to a depth of 5 cm while taking precautions to minimize soil disturbance. Aluminum foil was placed over the chambers to minimize heating within the chamber. After 24 hr, all sponges were collected and refrigerated at 3°C for transport to the laboratory. In the laboratory, 5 ml of solution extracted from the sponge was titrated with 0.1 N HCl using phenolphthalein and methylorange as indicators. Soil temperature at 5 cm depth was observed at 1hour intervals through the year using a thermo recorder (TR-71, T AND D) and moisture content was measured by drying at 105°C

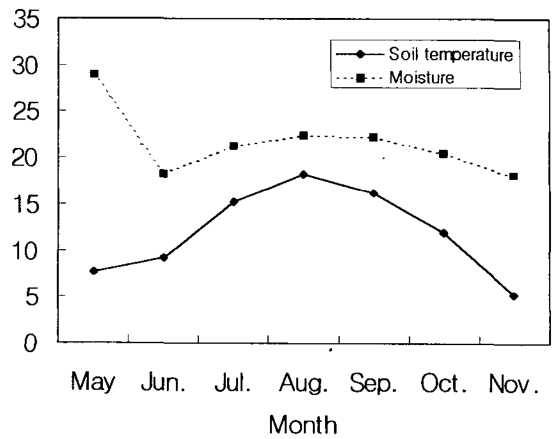

Fig. 1. Soil temperature (℃) and moisture content (%) during the study period for *Populus maxmowiczii* stand.

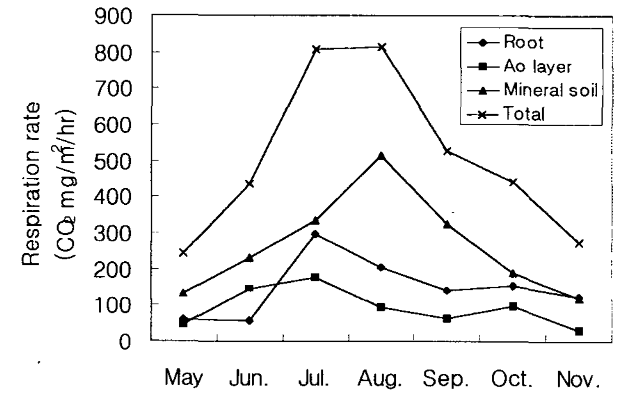

Fig. 2. Seasonal patterns of respiration rates of contribution and total soil respiration for *Populus maximowiczii* stand.

RESULTS AND DISCUSSION

Fig. 1 showed the soil temperature and moisture content of *Populus maximowiczii* stand. Soil temperature was the highest in August and the mean soil temperature during the study period was estimated to be 11.9°C Moisture content was the highest in May, because of snow thawing. Soil moisture content hardly show the seasonal variation except the period.

The respiration rates of each contribute and total soil respiration were shown in Fig. 2. Although the mineral soil respiration exhibited a marked seasonal variation, the respiration of A_0 layer and living root didn't show a conspicuous seasonal variation (Fig. 2). The highest rate of mineral soil respiration was observed in August. The lowest mineral soil respiration was observed in November. High respiration rates in summer and low rates in winter have been reported by authors in forest ecosystems (Ewel et al. 1987, Gordon *et al.* 1987, Buchmann 2000). The mineral soil respiration rate increased with rising soil temperature with a high correlation (r=0.95, p<0.001) between the two variables. Total soil respiration also have a high correlation with soil temperature (r=0.92, p<0.001). Numerous studies have described the relationships between soil respiration and environmental factors such as temperature and moisture. And, it is commonly agreed that soil biological activity may relate to soil temperature and water availability, depending on conditions considered (Killham 1994). In this study, soil temperature has a greater effect on soil respiration than soil moisture. The relationship between mineral soil respiration and soil temperature can be expressed exponentially by the following equation (Fig. 3), but the relationships between soil temperature and root respiration, and A_0 layer respiration were not observed.

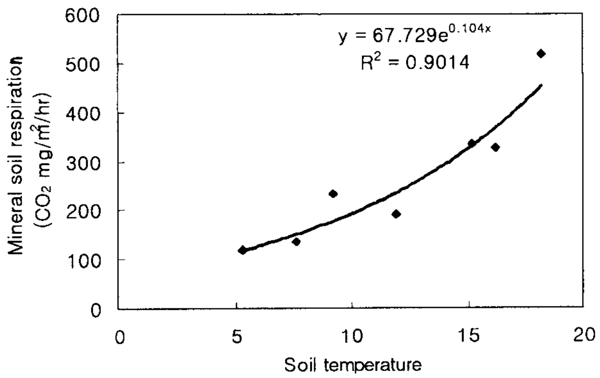

Fig. 3. The relationships between the rates of mineral soil respiration and soil temperature for *Populus maximowiczii* stand.

Table 1. Comparison of major sources as percent of total respiration in *Populus maximowiczii* stand, northern Japan

Sampling month	Root	A_0 layer (%)	Mineral soil
97 May	24.9	19.9	55.2
Jun.	13.3	33.6	53.1
Jul.	36.8	22.0	41.2
Aug.	25.2	11.5	63.3
Sept.	27.1	11.6	61.3
Oct.	35.2	22.1	42.7
Nov.	45.2	11.4	43.4
Ave.	30.3	19.2	50.5

The peak respiration of A_0 layer and high percentage of A_0 layer respiration to total soil respiration during the study period were observed in July and June (Fig. 2 and Table 1), respectively. The higher respiration and high percentage of A_0 layer in July and June suggests that litters that had sojourned over the winter period, because of low microbial activity, provided a suitable substrate for microbial decomposition with the approach of warmer weather and consequent increase in soil temperature (Van Cleve *et al.* 1993). The contribution of A_0 layer to total soil respiration was averaged 19% during study period.

Although the respiration of living root was the highest in July (Fig. 2), the highest percentage of root respiration to total soil respiration were observed in October (Table 1). A high percentage of root respiration in July suggest that it showed a flourishing respiration of the plant root, because a large portion of leaves of deciduous broad-leaved tree is expanded in June. The highest percentage of root respiration to total soil respiration in October may be due to relatively diminished mineral soil respiration. And, the contribution of root respiration to total soil respiration was estimated at 30% for *Populus maximowiczii* stand (Table 1).

The ratio of root respiration to total soil respiration coincides closely with 35% reported by Edwards and Sollins (1973) and Edwards and Harris (1977). However, it is considerably lower than ratios reported for other stands. Higher values of this ratio in broad-leaved forests were estimated by many researchers. Nakane *et al.* (1983) and Ewel *et al.* (1987) estimated that root respiration contributed 47-51% and 62% to total soil respiration in *Pinus densiflora* and *Pinus elliottii* stand, respectively. Also Behera *et al.* (1990) estimated that root respiration was 50% of soil respiration in tropical stand. In this study, the results indicate that total soil respiration is composed of aboveground litter (19%), belowground litter (51%), and root respiration (30%). 81% of total soil respiration in *Populus maximowiczii* stand is due to belowground processes, in agreement with the results of Raich and Nadelhoffer (1989) and Nadelhoffer and Raich (1992) who

Table 2. Soil respiration rates from several forest ecosystems

Forest	Place	Soil respiration ($gCO_2/m^2/hr$)	Method	Authors
Pinus elliottii	Florida, USA	0.18~0.72	IRGA	Ewel *et al.* (1987)
Picea glauca	Alaska, USA	0.45(Ave.)	Soda lime	Gordon *et al.* (1987)
Alnus maximowiczii	Hokkaido, Japan	0.16~0.60	KOH	Moon *et al.* (1998)
Siberial taiga	Siberia, Russia	0.07~1.43	IRGA	Sawamoto *et al.* (2000)
Populus maximowiczii	Hokkaido, Japan	0.29~0.91	KOH	Moon *et al.* (1998)
Pinus radiata	Victoria, Australia	0.23~0.89	Soda lime	Carlyle *et al.* (1988)
Populus maximowiczii	Hokkaido, Japan	0.23~0.81	KOH	Moon and Haruki (present study)

indicated that 70-80% of total soil respiration in a wide range of forests are due to belowground litter decomposition plus root respiration. Although all of these different experimental approaches have uncertainties, microbial respiration appears to represent the dominant fraction of total soil respiration in a wide range of terrestrial ecosystems. Kirschbaum (1995) and Boone *et al.* (1998) reported that it is crucial to get more insight into both components of soil respiration, because autotrophic and heterotrophic respiration will react differently to changes in environmental conditions such as soil temperature and moisture content. Therefore, further progress in defining temperature and moisture functions will probably require isolation of root and microbial processes and measurements of temperature, moisture content and CO_2 evolution for each respiration source.

Table 2 summarizes the soil respiration from various ecosystems reported by other researchers. Our result is within this range, although it is relatively lower value. Although several recent papers have compared two or more of these techniques (Rochette *et al.* 1992, Jensen *et al.* 1996), a comprehensive study comparing all techniques has not yet been reported. It is due to that it is difficult to compare data collected from different sites with different methods. It is also difficult to compare the soil respiration rates measured in various ecosystems because there are some differences in environmental and soil factors such as chemical and physical characteristics.

A number of factors controlling relative contributions to total soil respiration rates in different forests are not well understood. The total soil respiration is influenced by soil temperature and moisture (Davidson *et al.* 1998, Rustad and Fernandez 1998), vegetation and substrate quality (Raich and Schlesinger 1992), net ecosystem productivity (Raich and Potter 1955), and management practices, including fire (Gordon *et al.* 1987). More accumulated understanding of these factors is needed to predict relative contributions to total soil respiration in various forest ecosystems.

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