Influence of carbon inputs on soil respiration in a *Platycladus orientalis* plantation in mountainous Beijing

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ABSTRACT

To understand carbon source characteristics of soil respiration, a trench method was used to control carbon inputs (control treatment: CK, no litter treatment: NL, no root treatment: NR, and no litter and no root treatment: NLNR) in a *Platycladus orientalis* (L.) Franco plantation, so that soil respiration, temperatures and moisture content could be analyzed. Results indicate that different carbon inputs created no significant variance in soil temperatures and moisture content ($P > 0.05$), whereas soil respiration was significantly influenced ($P < 0.01$). During the measurement period, mean soil respiration of CK, NL, NR and NLNR were 3.69, 1.41, 3.11, and 1.99 $\mu\text{mol}/\text{m}^2/\text{s}$, respectively. Soil respiration was reduced by $36.28 \pm 5.79\%$, $15.25 \pm 2.62\%$ and $25.53 \pm 4.95\%$ in the NL, NR and NLNR treatments, respectively. The proportions of mineral soil, litter and root respirations were 40.95%, 46.91% and 12.14%, respectively. Different carbon inputs caused no significant R^2 variance in the temperature index model or in the temperature-water combined model. These results provide guidelines for investigating *Platycladus orientalis* ecosystem carbon emissions, as well as carbon input and output balance, and the role of soil respiration in the carbon cycle.

Keywords: soil respiration, carbon input, *Platycladus orientalis*, soil temperature, soil moisture

RÉSUMÉ

On a utilisé la méthode par tranchée afin de caractériser les entrées (inputs) de carbone dans la respiration du sol; les mesures portaient sur les entrées de carbone (témoin : CK; sans traitement de la litière : NL; sans traitement des racines : NR et sans traitement de la litière ni des racines : NLNR) dans une plantation de *Platycladus orientalis* (L.) Franco, afin de permettre l'analyse de la respiration, de la température et du taux d'humidité du sol. Les résultats indiquent que les différentes entrées de carbone n'ont pas eu d'effet significatif sur la température et le taux d'humidité du sol ($P > 0,05$), alors que la respiration du sol a connu un impact significatif ($P > 0,01$). Au cours de la période de mesure, la respiration moyenne du sol des CK, NL, NR et NLNR se chiffrait respectivement à 3,69, 1,41, 3,11 et 1,99 $\mu\text{mol}/\text{m}^2/\text{s}$. La respiration du sol a été réduite respectivement de $36,28 \pm 5,79\%$, $15,25 \pm 2,62\%$ et de $25,53 \pm 4,95\%$ pour les traitements NL, NR et NLNR. Les proportions de la respiration en provenance du sol minéral, de la litière et des racines étaient respectivement de 40,95 %, 46,91 % et 12,14 %. Les variations des entrées de carbone n'ont pas entraîné d'écart significatif de la variance selon le modèle d'indice de température ni le modèle combinant la température et l'humidité. Ces résultats donnent des indications pour l'étude des émissions de carbone des écosystèmes de *Platycladus orientalis*, ainsi que du bilan entrée-sortie de carbone au cours de respiration du sol.

Mots clés : respiration du sol, entrée de carbone, *Platycladus orientalis*, température du sol, taux d'humidité du sol

Introduction

Soil respiration can return the carbon fixed in an ecosystem back into the air, which is an important part of the global carbon cycle (Trumbore *et al.* 1996, Smith and Fang 2010). Both human disturbances and environmental factors can cause changes in soil respiration, leading to changes in the stocks of different carbon pools (Luo and Zhou 2006, Magnani *et al.* 2007). Some studies have shown that total circulation from soil respiration is greater than all other carbon exchanges between atmosphere and land, except for that of net photosynthesis (Raich and Schlesinger 1992, Liu and Fang 1997, Schlesinger and Andrews 2000, Li *et al.* 2002). One minor change in soil respiration can bring about significant changes in the concentration of CO_2 in the atmosphere (Hou *et al.* 2006).

Forest soil carbon pools are important components of global carbon pools (Canadell and Raupach 2008, Hunt 2009, Ashton *et al.* 2012). The substrate for forest soil respiration comprises: (1) root systems and underground litter (i.e., deciduous root tissue) that provide substrate for live root cells and rhizosphere microorganisms; and, (2) ground litter (including debris, fallen leaves, fallen flowers and fruits, and deadwood) that supplies substrate for non-rhizosphere microorganisms and most soil animals (Singh and Gupta 1977, Rustadi *et al.* 2000, Ryan and Law 2005, Meier and Bowman 2008). Several authors have suggested that the control of carbon inputs can significantly change a soil's respiratory rate (Li *et al.* 2004, Prévost-Bouré *et al.* 2010, Zhou *et al.* 2012). However, these changes can vary depending on differ-

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ences in vegetation type, study area and land use (André *et al.* 2010, Ruehr *et al.* 2010, Gao *et al.* 2011, Zhang *et al.* 2012).

As a common species for environmental planting, *Platycladus orientalis* (Chinese arborvitae) is readily found across China (Zhang 2007, Fang *et al.* 2011). These ecosystems may serve as important carbon pools. Current research on soil respiration in these plantations has focused on respiration characteristics and environmental factors that affect respiration (Li *et al.* 2004, Wang *et al.* 2011). However, there is little research on the effects of respiration on litter and root systems in the forest.

This paper focuses on soil respiration of a *Platycladus orientalis* plantation by studying the influences of different carbon inputs on soil respiration and by modeling the impacts of soil temperature and moisture on soil respiration under different carbon inputs. This will provide a theoretical basis for evaluating the role of *Platycladus orientalis* ecosystem carbon pools in the carbon cycle of temperate needleleaf forests.

Materials and Methods

Research area

The research area is located in Jiufeng National Forest Park which belongs to the Xishan Forestry Farm in the northwest Haidian District of Beijing (Fig. 1). The GPS of the area is 40° 03' 51" N, 116° 06' 08" E. The mountainous area of Beijing has a complex topography with forested slopes ranging from 16°–35°, some 70.4% of the total area; slopes greater than 36° account for 25.2%. Elevation ranges from 100 m to 1153 m; the elevation of the research area is 140 m. The main soil type in our study area is Cinnamon soil, mainly loamy clay with an average depth of 1.2 m, a pH of 7.4 and an average humus layer less than 20 cm. There is an obvious argillic horizon within 50 cm–80 cm depth. The main mineral is vermiculite, the organic matter content is 10 g/kg–20 g/kg and soil bulk density is 1.3 g/cm³ in 0–20 cm layer. Annual precipitation is 630 mm; 70% occurs during July and August. The

predominant species in the plantation is *Platycladus orientalis*. However, several other species have encroached into the plantation from the surrounding natural forest. These include *Quercus variabilis* Blume (Chinese cork oak), *Robinia pseudoacacia* L. (black locust), *Broussonetia papyrifera* (L.) Vert. (paper mulberry), and *Pinus tabulaeformis* Carr. (Chinese red pine). There is a scattered understory of *Grewia biloba* L. (smallflower grevia), *Vitex negundo* L. (Chinese chastetree), and *Ramnus parvifolia* Bunge (little-leaf buckthorn).

Experimental design

The research was carried out from October 2013 to October 2014. Four 1 m × 1 m sample plots were randomly selected from the individual tree canopies where similar micro-site conditions, slope, soil depth, soil properties and root densities were observed. The experiment was designed to use the four plots as follows: a control (CK) that maintained the plot in an intact condition; a no-litter (NL) plot that had litter removed from the surface; a no-root (NR) plot that had roots removed; and a no-litter, no-root (NLNR) plot that had litter from the surface and roots removed. Litter was collected with a two-layer nylon mesh and removed twice monthly. In our study, the trenching method, which has been widely used for separating soil CO₂ efflux into heterotrophic and autotrophic respiration in forest ecosystems (Ewel *et al.* 1987, Jassal and Black 2006, Ngao *et al.* 2007, Díaz-Pinés *et al.* 2010, Boström 2011), was employed for root exclusion. In August 2013, a trench was dug around the outer edge of each sample plot (0.2 m wide and 0.5 m deep approximately, the bottom of the root zone) using a shovel and steel knife, and lined with landscape fabric to prevent root growth into the trench. Within each plot, three sub-plots were selected as replicates. Soil collars were fixed on each sub-plot to simultaneously measure soil respiration, temperature and moisture (Fig. 2). Measurements were taken every ten days during the July to August growing season and every month during other seasons. Five sets of data were collected from each collar for every measurement.

Data processing

Duncan's new multiple range test was used to compare the differences in soil temperature (T_s), soil water content (θ) and soil respiration (R_s) among the four treatments. The formulas for the soil respiration components in the four treatments are as follows (Rey *et al.* 2002):

- (1) $R_m = R_{nrnl}$
- (2) $R_l = R_c - R_{nl}$
- (3) $R_r = R_c - R_{nr}$

Where R_m and R_{nrnl} are mineral soil respiration, primarily from microbial respiration and soil organic matter decomposition without root and litter respiration; R_l is litter respiration, R_c

Fig.1. Map of research site

Fig. 2. Soil temperature, moisture and respiration measurement layout

soil respiration under control treatment, R_{nl} soil respiration with the no-litter treatment, R_r the root respiration, and R_{nr} soil respiration with the no-root treatment. To validate the data coincidence between the soil respiration components and total soil respiration, a linear relationship was fitted between the sum of each soil respiration component and the total soil respiration under the control treatment. The relationship between soil respiration rate, temperature and moisture was simulated by two models. An exponent L model from Lloyd and Taylor (1994) was used to analyze the relationship between soil respiration and temperature:

$$(4) \quad R_s = R_{s10} \times Q_{10Rs}^{((T_s-10)/10)}$$

Where R_s is the soil respiration rate ($\mu\text{mol}/\text{m}^2/\text{s}$), R_{s10} the soil respiration rate at 10°C ($\mu\text{mol}/\text{m}^2/\text{s}$), T_s the soil temperature ($^\circ\text{C}$), and $Q_{10Rs}^{((T_s-10)/10)}$ the temperature sensitivity parameter.

Another model (G model) built by Gaumont-Guay *et al.* (2006) was employed to simulate the response of soil respiration to soil temperature and soil moisture:

$$(5) \quad R_s = (a + b\theta + c/\theta \times R_{s10} \times Q_{10Rs}^{((T_s-10)/10)})$$

Where θ is the soil moisture, and, a , b and c are the fitted parameters. All calculations were completed using SPSS and SigmaPlot software.

Results

Influence of carbon inputs on soil temperature and moisture

There was no significant difference in soil temperatures among the four treatments (Table 1). Highest temperatures in the CK, NL, NR and NLNR treatments appeared in late July as 26.8°C , 26.3°C , 26.9°C , and 27.3°C , respectively. Lowest temperatures in the CK, NL, NR and NLNR treatments appeared in mid-January and were -4.0°C , -3.3°C , -3.9°C , and -3.4°C , respectively. Average temperatures in the CK, NL, NR, and NLNR treatments were 16.6°C , 16.4°C , 16.9°C , and 16.9°C (Table 1). Although soil moisture fluctuated over time, there was no significant difference among the four treatments (Table 1). The highest levels for CK, NL, and NLNR treatments appeared in late July and were $0.29 \text{ m}^3/\text{m}^3$, $0.22 \text{ m}^3/\text{m}^3$ and $0.28 \text{ m}^3/\text{m}^3$, respectively. The highest level for the NR treatment was $0.28 \text{ m}^3/\text{m}^3$ in mid-August. The no-litter treatment significantly reduced maximum soil moisture. The lowest soil moisture levels for CK, NL, NR, and NLNR appeared in mid-January and were $0.03 \text{ m}^3/\text{m}^3$, $0.03 \text{ m}^3/\text{m}^3$, $0.03 \text{ m}^3/\text{m}^3$, and $0.05 \text{ m}^3/\text{m}^3$, respectively. Average soil moistures were $0.13 \text{ m}^3/\text{m}^3$, $0.12 \text{ m}^3/\text{m}^3$, $0.14 \text{ m}^3/\text{m}^3$ and $0.15 \text{ m}^3/\text{m}^3$, respectively. There is a paired significant difference in average values of soil respiration during the observation period between CK and NR with NL and NLNR ($P=0.001$; Table 1). The changing trend is more obvious from mid-May to October than in other months. During the observation period, average values were ranked: CK $4.31 \pm 5.28 \mu\text{mol}/\text{m}^2/\text{s}$ > NR $3.56 \pm 4.27 \mu\text{mol}/\text{m}^2/\text{s}$ > NLNR $2.09 \pm 2.03 \mu\text{mol}/\text{m}^2/\text{s}$ > NL $1.47 \pm 1.19 \mu\text{mol}/\text{m}^2/\text{s}$). Maximum value was $14.39 \mu\text{mol}/\text{m}^2/\text{s}$ in August. Minimum value appeared in winter. From November 2013 to June 2014, soil respiration rates changed little and the respiration curve resembles a parallel line (Fig. 3). Using the CK soil respiration as a reference, there were significant

Table 1. Multiple comparison of soil temperature, moisture and respiration among four treatments

Index	CK	NL	NR	NLNR	Mean	Sig.
T_s ($^\circ\text{C}$)	16.59 ± 9.50^a	16.40 ± 9.20^a	16.86 ± 9.59^a	16.88 ± 9.41^a	16.68 ± 9.36	0.992
θ (m^3/m^3)	0.13 ± 0.07^a	0.12 ± 0.05^a	0.15 ± 0.08^a	0.14 ± 0.08^a	0.14 ± 0.07	0.247
R_s ($\mu\text{mol}/\text{m}^2/\text{s}$)	4.31 ± 5.28^a	1.47 ± 1.19^b	3.56 ± 4.27^a	2.09 ± 2.03^b	2.86 ± 3.74	0.001

Note: Different superscript letters denote a significant difference at a 5% confidence level.

effects of different carbon inputs on experimental respiration rates (Fig. 4). Soil respiration of the NL treatment decreased the most, with an average of $37.8\% \pm 26.5\%$; the highest values occurred in July and August whereas the lowest were in March and October. The decreasing trend in soil respiration for the NLR treatment was similar to that for NL treatment, with an average decrease of $27.9\% \pm 23.3\%$. The greatest values for the NLR treatment occurred in July and August and the lowest in March and October. The decreasing value in the NR treatment was the least, with an average of $15.3\% \pm 11.1\%$; the decrease changed randomly and without obvious clustering. Soil respiration can be divided into mineral soil respiration (R_m), litter respiration (R_l) and root respiration (R_r) (Meng *et al.* 2008); their respiration rates are $2.0 \pm 0.4 \mu\text{mol}/\text{m}^2/\text{s}$, $2.3 \pm 0.8 \mu\text{mol}/\text{m}^2/\text{s}$ and $0.6 \pm 0.3 \mu\text{mol}/\text{m}^2/\text{s}$, respectively, and the relative contribution rates of each respiration component are 41.0%, 46.9% and 12.1%, respectively. The value of R^2 for the fitted equation between the sum of

R_m , R_l and R_r with soil respiration under control treatment reached 0.99 (Fig. 5), which indicates a high match between them.

Modeling impacts of soil temperature and moisture on respiration rates

Numerous studies have shown that soil temperatures and moisture are the major environmental factors that affect soil respiration rates (Boone *et al.* 1998). An L model and a G model were used to simulate the influence of temperature and moisture on respiration (Table 2). Decision coefficients on soil respiration showed that the G model was higher than the L model. The decision coefficient of the L model was approximately 0.7. The highest value was 0.75 for the NL treatment and the lowest 0.68 for the NR treatment. The decision coefficient of the G model was approximately 0.8. The highest value was 0.85 for the NL treatment and the lowest 0.68 for the CK, NLNR and NR treatments. Due to the addition of soil moisture, the decision coefficient of the G model increased but the extent was not obvious, as its largest value was 0.14. Therefore, temperature was the primary factor affecting soil respiration.

Conclusions

Influence of litter on soil respiration

Recent studies have shown that the input or removal of outside carbon sources can affect soil respiration through the impact on soil organisms (Boström 2011, Wang *et al.* 2012). This study shows that litter removal can reduce average soil respiration by 36.3% and was the most effective means of respiration reduction among the four treatments. Limited research has shown that soil respiration can be reduced by 36.0% in pine (*Pinus tabulaeformis*) and 22.0% in black locust (*Robinia pseudoacacia*) stands through litter removal (Wang *et al.* 2012, Zhou *et al.* 2012). The influence of litter on soil respi-

Fig. 3. Seasonal changes of different carbon input effects on soil respiration

Fig. 4. Changing magnitudes of soil respiration for different carbon inputs

ration changes in different stands because of chemical component differences leads to differences in soil chemical properties (Binkley and Giardina 1998, Likens 2013).

Changes in external carbon inputs can also affect temperature and moisture and further affect soil respiration. Changes in temperature and moisture among the four treatments showed that different carbon inputs had no significant impact on soil temperatures, with average values showing a ranking of NR>NLNR>CK>NL. Litter covering the forest floor insulated the thermal exchange between the soil and atmosphere, thus reducing the sensitivity of the soil to the environment and affecting soil respiration. The decision coefficients of the temperature–soil respiration exponent model (L model) showed a ranking of NL>CK>NLNR>NR — the opposite trend from the impacts of different carbon inputs on soil temperature; in other words, soil respiration with litter cover demonstrated higher thermal sensitivity (Lloyd and Taylor 1994, Sulzman *et al.* 2005).

Influence of roots on soil respiration

Root respiration is an important component in soil respiration, and the results of this study showed that root cutting reduced soil respiration by 15.3%. Nutrients from canopy photosynthesis cannot be transported to a cut root, which leads to a reduction of available carbon sources; the quantity and activity of microorganisms will be repressed and soil respiration will gradually decrease (Uchida *et al.* 1998; de Kroon and Visser 2003, Gregory 2006).

The contribution of roots to soil respiration varies due to differences in vegetation type. Root-cutting treatments in a Norway spruce forest by Boström (2011) showed that roots contributed to 16% of total soil respiration, which is similar to the results of this paper. However, some research has shown that conifer roots may contribute up to 58% of soil respiration (Sulzman *et al.* 2005) and more than 30% in a *Cunninghamia lanceolata* plantation (Zhu *et al.* 2010). Possible reasons for these differences include differences in land use types, site conditions, climate and age of the stand (Bowden *et al.* 1993, Eshel and Beeckman 2013).

Fig. 5. Correlation between the sum of each respiration component and soil respiration under control treatment

Influence of litter and roots on soil respiration

Theoretically, soil respiration should significantly decrease when combining root cutting and litter removal (NLNR). However, the results of this study showed that soil respiration reduction through NLNR was lower than NL (litter removal) and greater than NR (root cutting). Although roots were cut off at approximately 1 m × 1 m, they did not die immediately; most lived for quite a long time (Uchida *et al.* 1998, Ngao *et al.* 2000, Jassal and Black 2006). However, root cutting halted the transport of nutrients from canopy photosynthesis, thus accelerating organic carbon decomposition from soil microorganisms and further increasing soil heterotrophic respiration within this small soil chamber (Nordgren *et al.* 2003, Li *et al.* 2006, Högborg 2010). Therefore, soil respiration was not as low as expected. Furthermore, a trench dug for root cutting prevents thermal and moisture exchange to the soil chamber from the surrounding environment (Comstedt *et al.* 2011).

In conclusion, soil respiration in a *Platycladus orientalis* plantation is such that: (1) soil temperature and humidity

Table 2. Soil respiration model for four treatments

Model				
	L	R ²	G	R ²
CK	$R_s = 0.06 \times 25.34^{((Ts-10)/10)}$	0.72	$R_s = (3.83 + 184.76 \times VWC - 0.51/VWC) \times 0.03 \times 3.97^{((Ts-10)/10)}$	0.82
NL	$R_s = 0.38 \times 3.68^{((Ts-10)/10)}$	0.75	$R_s = (2.04 + 32.31 \times VWC - 0.05/VWC) \times 0.11 \times 2.31^{((Ts-10)/10)}$	0.85
NR	$R_s = 0.13 \times 13.20^{((Ts-10)/10)}$	0.68	$R_s = (0.09 + 27.18 \times VWC - 0.06/VWC) \times 0.15 \times 3.95^{((Ts-10)/10)}$	0.82
NLNR	$R_s = 0.28 \times 5.57^{((Ts-10)/10)}$	0.71	$R_s = (0.99 + 9.89 \times VWC - 0.34/VWC) \times 0.31 \times 2.64^{((Ts-10)/10)}$	0.82

with different carbon inputs (litter or roots) may be significantly different; (2) different carbon inputs may cause significant differences in soil respiration. Soil respiration in the control plot was greatest, followed by NR, NLNR, and NL treatments. This phenomenon primarily occurred from June to October. There was little variation from November to May in the second year; and, (3) litter respiration provided the greatest contribution to soil respiration among the different components of soil respiration, reaching 46.9%. Compared to the soil temperature model, the soil temperature-moisture coupling model can better account for a soil respiration ratio.

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