Contribution of root respiration to soil respiration in a rape (*Brassica campestris* L.) field in Southwest China

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ABSTRACT

This study aimed to separate the respective contributions of root and microbial respiration to soil respiration in a rape field in Southwest China. The soil respiration was measured with a closed chamber technique and a regression method was used to apportion root and microbial respiration. Microbial and root respiration ranged from 70.67 to 183.77 mg $CO_2/m^2/h$ and 21.99 to 193.09 mg $CO_2/m^2/h$, averaged 127.16 and 116.66 mg $CO_2/m^2/h$ during the rape growing season, respectively. Root respiration coefficient ranged from 0.41 to 5.39 mg C-CO_2/g C/h and was negatively correlated with root/shoot ratio, aboveground and belowground biomass, but positively correlated with root N content. The contribution of root respiration to soil respiration averaged 44.2%, ranging from 14.5% to 62.62%.

Keywords: root respiration coefficient; microbial respiration; root biomass; root N content; root/shoot ratio

After photosynthesis, soil respiration is the second largest carbon flux in most ecosystems, and can account for 60–90% of total ecosystem respiration (Longdoz et al. 2000). Therefore, soil respiration is one of the most important research issues in the global carbon cycle (Schimel 1995). Soil respiration is the sum of root respiration and microbial respiration. The contribution of these groups needs to be understood to evaluate implications of environmental changes on soil carbon cycling and sequestration (Hanson et al. 2000).

Separating root and microbial respiration from the measured total soil respiration is exceptionally difficult and presents one of the greatest challenges to quantify the carbon cycling (Killham and Yeomans 2001). In China, the researches on the contributions of root respiration to soil respiration were focused on forest and grassland ecosystems (Jia et al. 2006, Liu et al. 2007, Wang et al. 2009), but very rarely in agricultural ecosystem (Han et al. 2007, Li et al. 2011). This study aims to reveal the partition of soil respiration to root and microbial contributions by developing a regression relationship between soil respiration rates and root biomass over the rape growing season.

MATERIAL AND METHODS

Study area. The study area is located in a farm in the Southwest University (30°26'N, 106°26'E), Chongqing, managed by the Key Field Station for Monitoring of Eco-Environment of Purple Soil of the Ministry of Agriculture of China. The average altitude of this study site is 230 m a.s.l. The annual precipitation is 1105.4 mm, of which nearly 70% falls in the five months of year from May to September. Daily mean air temperature is 18.3°C. The annual sunshine hours are 1276.7 h and the non-frost period is 334 days. The soil is classified as Hydragric Anthrosol developed from the parent material of Jurassic purple shale and sandstone

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weathering product. Soil properties were as follows: bulk density 1.2 g/cm^3, clay (< 0.005 mm) content 42%, pH 6.5, total organic carbon 16.2 g/kg, total nitrogen 1.82 g/kg, total phosphorus 0.86 g/kg, total potassium 24.1 g/kg, alkali-soluble nitrogen 128.5 mg/kg, available phosphorus 9.2 mg/kg, available potassium 82.3 mg/kg.

The study was conducted during the rape growing season in a rape-rice rotation agricultural field. The rape was transplanted on November 14, 2009 and harvested on April 24, 2010. The application of fertilizers in the rape growth season was as follows: 77.7 kg N/ha (urea), 2/3 as basal and 1/3 as topdressing; 29.5 kg P/ha (superphosphate) applied as basal; 23.6 kg K/ha (potassium chloride), 1/2 as basal and 1/2 as topdressing. The basal and topdressing fertilizers were applied on November 14, 2009 and February 17, 2010, respectively.

Soil respiration measurements. During the rape growing season soil respiration rates were measured monthly using a closed chamber technique as described by Mu et al. (2008). Three measurement positions were selected-on a plant, between plants and between rows and each position had three replicates (Figure 1). Soil respiration rates were measured on clear days every 2 h from 7:00 to 19:00 (November 22 and December 20, 2009; January 28, February 28, March 27 and April 17, 2010). A stainless steel collar (20 cm inside diameter and 6 cm height) with a water groove on top was inserted to a depth of 3 cm below soil surface one day before the measurements. At each sampling, an open-ended stainless steel cylinder with an internal diameter of 20 cm and a height of 25 cm was mounted on soil collar and the groove was filled with water to ensure air-tightness. The

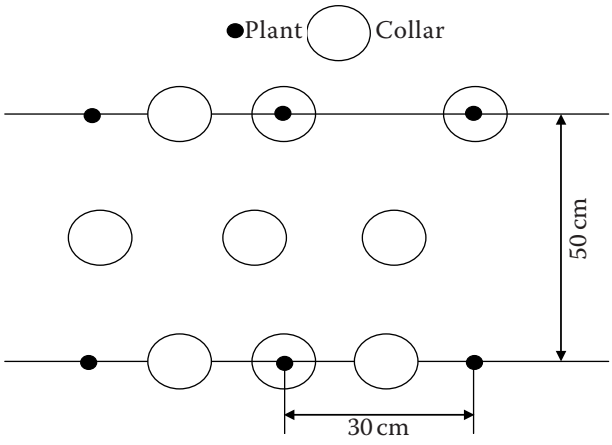

Figure 1. The positions of measurement plots

cylinders were left open for 30 min to obtain an equilibrium state before gas sampling (Norman et al. 1997). When equilibrium was reached, the cylinders were sealed using white acrylic lids with two ports, one for gas sampling and the other for the attachment of compensation air to equilibrate the chamber pressure with the atmospheric pressure. To determine soil respiration rate, air sample inside the chamber was taken for every 10 min over a 30 min period with 60 mL plastic syringes (total of four samples). CO_2 concentrations of the air samples were analyzed in the laboratory (within 12 h) using a gas chromatograph equipped with a flame ionization detector (Zhang et al. 2012). The soil respiration rates were calculated from a linear regression of the changes in the concentration. Corrections were made for air temperature and pressure. The data deviating significantly from linearity (R^2 < 0.95) were discarded.

Root biomass measurements. In order to evaluate the effect of root biomass on soil respiration, soil sample down to 30 cm was excavated below each soil collar after the soil respiration measurement. Each sample was washed by 0.2 mm mesh steel screen and live roots were picked by hand. Sorted roots were weighed after drying at 80°C to a constant mass. Total C and N contents of the roots were measured by the dry combustion method and Kjeldahl method (Bremner 1960), respectively. There was no root in the soil below the collars located between rows.

Partitioning of root and microbial respiration. Soil respiration consists of functionally different components, root respiration and microbial respiration. Root respiration in this study refers to root-derived CO_2 which is the combination of actual root respiration and rhizosphere respiration, and microbial respiration refers to the respiration of soil microbes that are free from roots, i.e., derived from soil organic matter. In this study the regression method was used to apportion root and microbial respiration (Kucera and Kirkham 1971). A linear relationship exists between soil respiration rate and root biomass:

$$Rs = aB + b$$

Where: Rs – soil respiration rate (mg CO_2/m^2/h); B – root biomass in the soil collars (g/m^2); a, b – parameters. Microbial respiration (Rm) can be estimated when B = 0, i.e., the respiration in the absence of roots. Root respiration (Rr) is estimated by the difference between Rs and Rm.

Statistical analysis. All statistical analyses were performed by the SPSS 13.0 (SPSS for Windows,

Version 13.0, Chicago, USA). Linear regression was used to evaluate the relationship between soil respiration and root biomass.

RESULTS AND DISCUSSION

Microbial respiration. The regression approach was first suggested by Kucera and Kirkham (1971) and was applied in some later studies (Behera et al. 1990, Jia et al. 2006, Wang et al. 2009). Kuzyakov (2006) listed several methods for separating the components of soil respiration in his review. By comparing the methods, he concluded that the regression technique is the most suitable because of the lowest disturbance and highest universality. This approach is also rather simple and cheap, and can be used in several ecosystems, such as forests (Behera et al. 1990), agricultural fields (Han et al. 2007) and grasslands (Wang et al. 2009). During soil respiration measurements, multiple samples can be taken by placing several sampling collars simultaneously, thereby reducing the bias caused by soil heterogeneity. This method is based on the assumed linear relationship between root biomass and the amount of CO_2 respired by roots and rhizosphere microorganisms.

The microbial respiration rates were estimated indirectly by the relationships between soil respiration and root biomass. In terms of the soil respiration rates from the two measurement positions (on a plant and between plants) and their corresponding root biomass values, a set of linear regressive relationships between soil respiration rates (Rs) and root biomass (B) were developed on each measurement occasion from November 22, 2009 to April 17, 2010 (Figure 2). The soil respiration values with zero biomass could be interpreted as the minimum rate for microbiological activity alone (Kucera and Kirkham 1971). Microbial res-

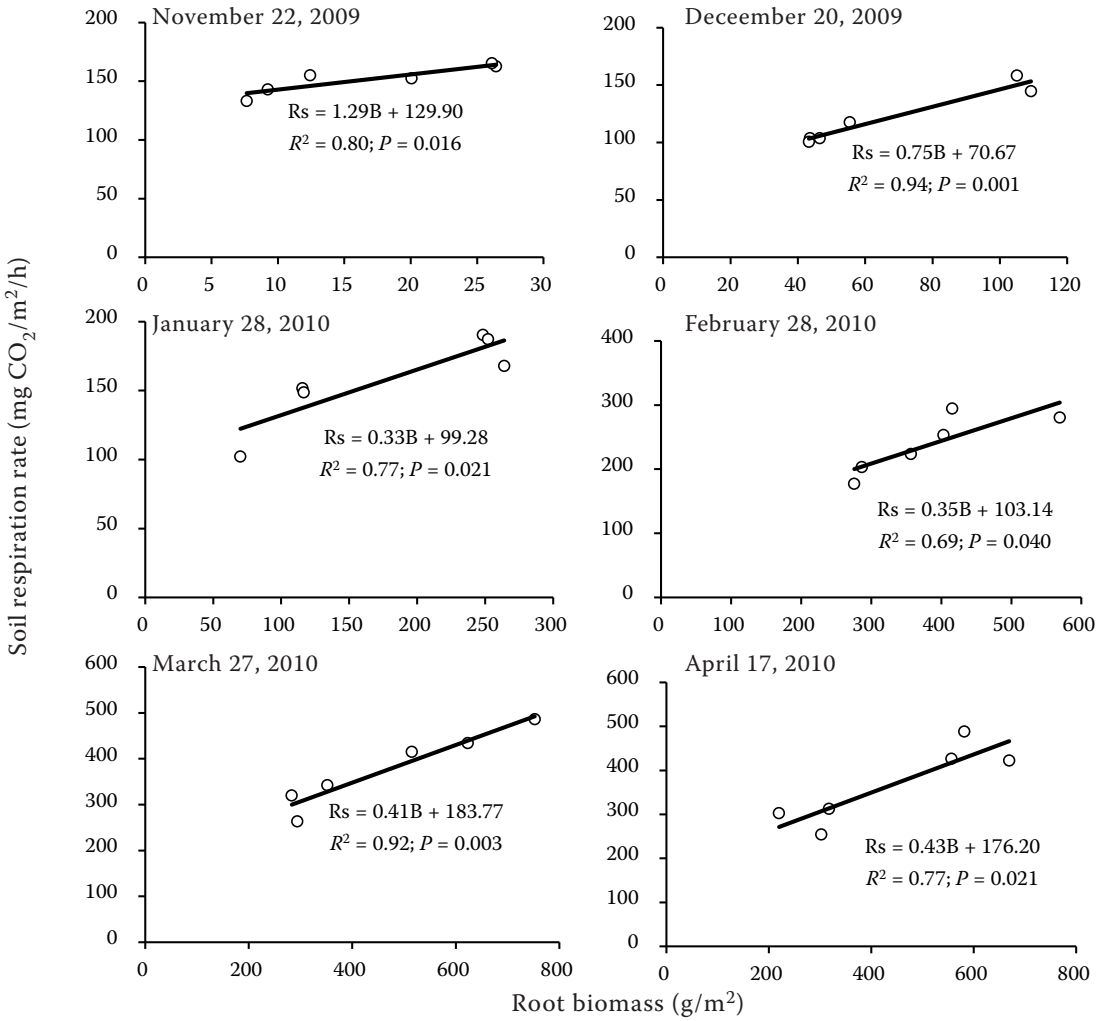

Figure 2. Linear relationships between soil respiration rate and root biomass at different observed times

piration inferred from the equations at zero root biomass averaged 127.16 mg $CO_2/m^2/h$, ranging from 70.67 mg $CO_2/m^2/h$ (December 20, 2009) to 183.77 mg $CO_2/m^2/h$ (March 27, 2010).

In this study, microbial respiration rates were also observed directly from the between rows measurement positions owing to without root in the soil. The observed microbial respiration rates in each month were 112.73, 87.54, 79.81, 83.28, 103.22 and 127.41 mg $CO_2/m^2/h$ from November 2009 to April 2010. The mean observed microbial respiration rates during the whole experiment was 99.00 mg $CO_2/m^2/h$. The observed microbial respirations were lower than those from the regression method except December 20, 2009. Our result was consistent with the results reported by Chen et al. (2008) but in contrast with the results reported by Jia et al. (2006).

One important uncertainty of the approach was that high variation of root biomass and CO_2 flux led to a relatively low R^2 (Kucera and Kirkham 1971). This caveat is especially important if the regression line has to be extrapolated far outside the root biomass range to calculate the soil organic matter derived CO_2 efflux. From Figure 2 it can be seen that the determination coefficients (R^2) between soil respiration rate and root biomass ranged from 0.69 to 0.94. The correlation between soil respiration and root biomass was positive and significant. Additionally, the regression line on each sampling date was not needed to extrapolate far outside the measured root biomass range to calculate soil organic matter derived CO_2 efflux. Therefore, the basic assumption of this study is valid. The other shortcoming is that increasing root biomass is strongly correlated with the quantity of large, older roots, which respire and exude much less C than fine, young roots (Behera et al. 1990). However, Kuzyakov (2006) remarked that this shortcoming was actually minor compared to those of other methods (e.g. tree girdling, shading and clipping, root exclusion technique where soil was disturbed).

Root respiration. Based on the estimated soil microbial respiration rates and the corresponding soil respiration rates, root respiration rates were estimated (Table 1). The mean root respiration rate during the whole experiment was 116.66 mg $CO_2/m^2/h$, ranging from 21.99 mg $CO_2/m^2/h$ (November 22, 2009) to 193.09 mg $CO_2/m^2/h$ (March 27, 2010). Root respiration rates increased sharply from January 28 to February 28 (Table 1), a period that was characterized by rapid root productivity (Figure 3). The higher root respiration rates may have resulted from high physiological activity associated with root growth (Högberg et al. 2001).

Models based on physiological and biochemical mechanisms of CO_2 exchange assume that plant respiration is proportional to the mass of plat dry matter (Gifford 2003). So root respiration coefficient (mg C-CO_2/g C/h) was calculated from root respiration rates and dry root weights. Root respiration coefficient ranged from 0.41 to 5.39 mg C-CO_2/g C/h during the growing season (Figure 4). Root respiration coefficients were higher in the early stage and decreased sharply with time and became almost constant in the late stage. Jia et al. (2006) and Chen et al. (2008) both reported the similar results. Root respiration coefficient was negatively correlated with the aboveground and belowground biomass during the rape growing season (Figures 3 and 4). Root respiration coefficient was mainly dependent on the development stages,

Table 1. Root contribution to soil respiration during the rape growing season

Sampling date	Rs	Rm	Rr	Rr/Rs (%)
	(mg $CO_2/m^2/h$)			
November 22, 2009	151.89	129.90	21.99	14.48
December 20, 2009	121.40	70.67	50.73	39.97
January 28, 2010	169.14	99.28	69.86	41.30
February 28, 2010	275.95	103.14	172.81	62.62
March 27, 2010	376.86	183.77	193.09	54.55
April 17, 2010	367.66	176.20	191.46	52.07

Rs – soil respiration; Rm – microbial respiration; Rr – root respiration

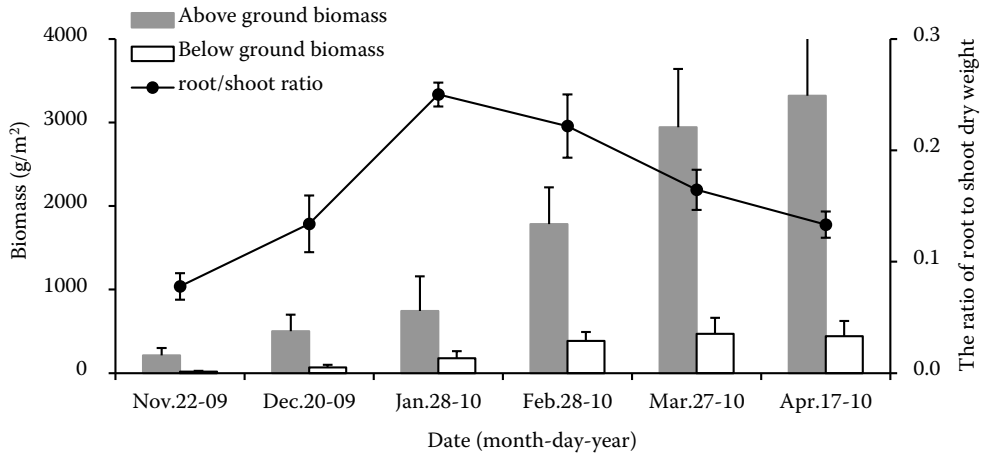

Figure 3. Changes of root/shoot ratio, above- and below-ground biomass of rape during the experiment. Vertical bars indicate standard deviations

being remarkably high in young seedlings (i.e. low biomass), then decreasing rapidly and tending to be constant with growth (i.e. high biomass). Root respiration coefficient was also negatively correlated with root/shoot ratio (Figures 3 and 4). The smallest root/shoot ratio corresponded with the highest root respiration coefficient at initial stage, showing that rapid respiration of young root might mainly support for aboveground growth. The increasing root/shoot ratio along with plant growth showed that more photosynthates were allocated to belowground structures, a process of accumulation for the next year's growth, while root respiration coefficient declined.

Root respiration coefficients had a significant positive relationship with root N contents (Figure 4). Plant respiration is partitioned into construction respiration that used for construction of new tissues and maintenance respiration that used for maintenance of existing tissues. Respiration, especially maintenance respiration, has been linked with tissue N content (Ryan 1991) because typically 90% of the N in plant cells is protein. Maintenance respiration and protein are linked because maintenance respiration may support protein repair and replacement (about 20% of the maintenance respiration, Bouma et al. 1994), and because other maintenance process such as ion transport may be correlated with protein content (Vose and Ryan 2002). Ryan et al. (1996) demonstrated that efflux of CO_2 from fine roots was linearly related to root N content in *Pinus radiata* in Australia. Vose and

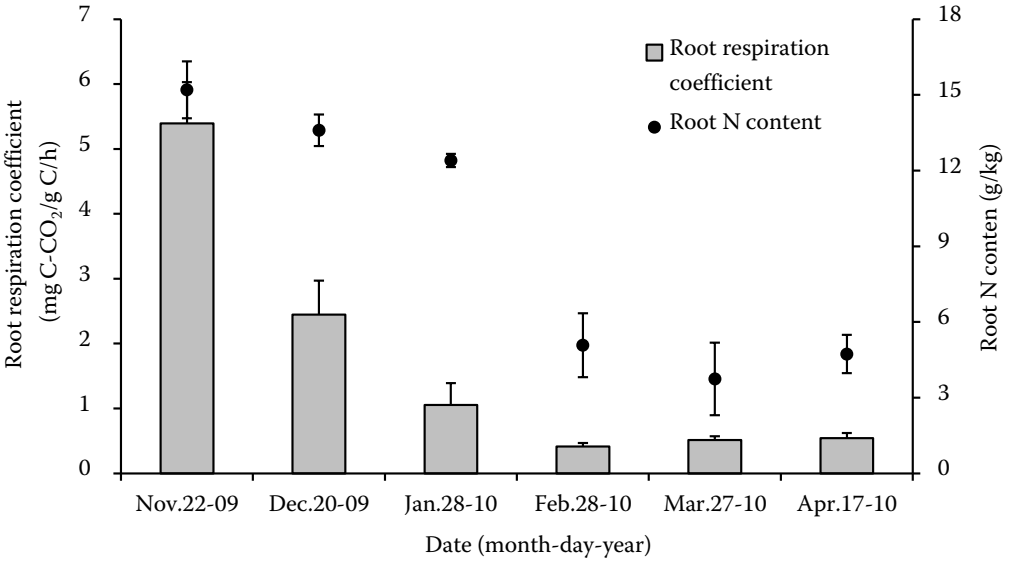

Figure 4. Root respiration coefficients and root N contents during the experiment. Vertical bars indicate standard deviations

Ryan (2002) found that a significant correlation existed between coarse root respiration and root N content in a white pine forest in USA. Sun et al. (2004) and Chen et al. (2008) both observed a positive correlation between wheat root respiration coefficient and root N content.

Proportion of root respiration to soil respiration. The contribution of root respiration to soil respiration gradually increased in the early stage and reached its maximum in February, then declined slowly to the harvest (Table 1). Average proportion of root respiration to soil respiration was 44.17%, ranging from 14.48% (November) to 62.62% (February). The proportions of root respiration to soil respiration increased gradually with the increase of root biomass (Table 1 and Figure 3). These results suggested soil respiration was dominated by microbial respiration in the early growing season and by root respiration in the late growing season.

In a maize agricultural field in Northeast China the proportions of root respiration to soil respiration was 54.5% ranging from 43.1% to 63.6% (Han et al. 2007), and 32% (ranging from 18% to 54.3%) in a winter wheat field in North China Plain (Zhang et al. 2009). Hanson et al. (2000) presented that the annual average contribution of root respiration of the soil respiration was 60.4% in a non-forest ecosystems. These results are similar with our results.

In conclusion, the contribution of root respiration to soil respiration in the rape growing season in Southwest China was estimated by the regression method in this study. Root respiration rates increased with time during the rape growing season, especially from January 28 to February 28, there was a sharp increase. Average proportion of root respiration to soil respiration was 44.17% during the growing season, ranging from 14.48% to 62.62%. Root respiration coefficient was negatively correlated with root/shoot ratio, aboveground and belowground biomass, but positively correlated with root N content during the growing season.

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