Contribution of root respiration to soil respiration in a maize field in Southwest China

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Abstract

Soil respiration, which originates from autotrophic root respiration and heterotrophic microbial respiration in the rhizosphere and the bulk soil, provides the main carbon efflux from terrestrial ecosystems to the atmosphere and is therefore an important component of the global carbon balance. Soil respiration, root biomass and nitrogen content in root in a subtropical maize field of Southwest China over a growing season (June to September) in 2007 were investigated to separate the respective contributions of root and heterotrophic respiration to the total soil respiration, and to reveal the seasonal variations of root respiration coefficient. The rates of soil respiration showed a remarkably high spatial variability and were 779, 611 and 425 mg $CO_2/m^2/h$ near the plant, inter-plants and inter-rows, respectively. The contribution of root respiration to soil respiration varied from 47.26~63.59%, with mean value of 56.38%. The root respiration coefficient was much higher on 23 June (0.09) and 18 July (0.12) and gradually decreased to 4 September (0.05). Root respiration coefficient was positively correlated with root nitrogen content. The root nitrogen content could explain 91% changes of root respiration coefficient during the maize growing season.

Key Words

Root respiration, soil respiration, root respiration coefficient, root nitrogen content, maize field.

Introduction

Soil respiration is a major component of the global carbon cycle, accounting for about 25% of the global carbon dioxide exchange (Bouwmann and Germon 1998). Therefore, soil respiration becomes one of the important research issues in the global carbon cycle (Schimel 1995).Soil respiration originates mainly from root and the associated rhizosphere and soil microorganisms, the partitioning of soil respiration helps to improve our understanding of the environmental changes that drive carbon cycling (Bond-Lamberty *et al.* 2004) and to accurately estimate carbon budgets of ecosystems and turnover rates of soil organic matter (Wang *et al.* 2006). Separating root and heterotrophic respiration from total soil respiration is exceptionally difficult and presents one of the greatest challenges to quantify carbon cycling (Killham and Yeomans 2001). In this study, soil respiration, root mass, nitrogen content in root in a subtropical maize field of Southwest China during the growth season (June to September) in 2007 were investigated to separate the respective contributions of root and heterotrophic respiration to the total soil respiration, and to reveal the seasonal variations of root respiration coefficient.

Methods

Site description

The experimental site (30°26′ N, 106°26′ E) is located at the farm of Southwest University, Chongqing, China. The average total annual precipitation was 1105.4 mm, and the annual mean air temperature was 18.3℃. The soil for this study was classified as Purplish in the Second Soil Survey of China. It was developed from purple parent material of Mesozoric sandstone formation. The soil properties are described as follows: clay content, 144.2 g/kg; sand content, 447.4 g/kg; pH (H_2O), 7.1; total N content, 1.74 g/kg; total P content (as P_2O_5), 0.75 g/kg; total K content (as K_2O), 22.7 g/kg. The selected crop type was Yayu $2^{\#}$. It was sown on 22 May and harvested on 12 September in 2007, Plants were planted 40 cm apart in rows. The distance between rows was 50 cm. The field was fertilized with 150 kg N /ha, 120 kg P_2O_5 /ha and 41 kg K_2O /ha surface-applied as basal fertilizer before sowing.

Soil respiration measurement

Soil respiration rates were measured five times on 23 June, 18 July, 10 August, 21 August and 4 September in 2007. Three measurement positions in the maize field were chosen: near a plant (1-7cm from a plant), inter-plants (8-20 cm from the plant) and inter-rows (20-25cm from the plant) and every position had three replicates. Soil respiration rates were measured every two hours from dawn to cockshut at clear days. Soil respiration rates were measured using a closed chamber technique. The gas was collected using an stainless steel cylinder (7 cm dia., 7 cm high) which had a white-colored acrylic lids equipped with two ports, one for gas sampling and the other for the attachment of a sampling bag to equilibrate the chamber pressure with the atmospheric pressure. Two days before the sampling, the chamber bases made of stainless steel were inserted into soils at each site, to a depth of 3 cm. During sampling, the stainless steel cylinder was placed over the base and filled with water in the groove to ensure air-tightness. Air sample inside the chamber was taken for every 10 min over a 30 min period by using 20 ml plastic syringes (total of four samples). Air temperature inside the chamber was measured during taking samples. Concentrations of CO_2 were analyzed in the laboratory (within a period of at most 12 hours) using a gas chromatograph equipped with a flame ionization detector and an electron capture detector (Wang and Wang 2003). Soil respiration rate was 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. Air temperature, wind speed and atmospheric pressure at 2 m height were measured at a climate station in close proximity to the measurement sites. Soil temperatures and moisture contents were measured in parallel with soil respiration.

Partitioning of root and heterotrophic respiration
Root respiration in this study refers to the combination of rhizosphere respiration and root respiration, and heterotrophic respiration refers to the respiration of soil microbes that are free from roots, *i.e.*, derived from soil organic matter. The CO_2 attributable to roots and microorganisms was apportioned using a regression method (Kucera and Kirkham 1971), in which soil respiration was plotted against total root mass at 0-30 cm depth. The regression line between the two has a *y*-intercept, which estimates the respiration in the absence of roots, *i.e.*, heterotrophic respiration. Root respiration was estimated by the differences between total soil respiration and heterotrophic respiration.

Results

Root respiration
Soil respiration rates showed a remarkably high spatial variability among the three measurement positions (Table 1). The order of soil respiration was as follows: near the plants>inter-plants>inter-rows. During the growing season in 2007, soil respiration rates from the maize agricultural ecosystem were 778.52, 610.78 and 425.48 mg $CO_2/m^2/h$ near plant, inter-plants and inter-rows, respectively.

Table 1. Soil respiration rates at the three measurement positions during the maize growing season in 2007 (mg $CO_2/m^2/h$).

Date	Near plant	Inter-plants	Inter-rows
23 June	430.57±48.95	371.82±20.53	310.77±3.81
18 July	844.11±74.46	632.83±53.64	464.01±50.00
10 August	1034.34±141.21	846.47±128.35	644.72±51.75
21 August	972.24±94.15	737.97±95.37	389.13±64.75
4 September	611.33±115.59	464.81±101.50	318.78±40.55

Soil respiration increased with the increase of root biomass, the relationships between soil respiration and root mass were established based on the data derived from the measurements conducted on 23 June, 18 July, 10 August, 21 August and 4 September of 2007, respectively (Table 2). The determinant coefficients (R^2) between soil respiration and root mass at different observation dates ranged from 0.76 to 0.88 (Table 2).

Table 2. Regression analysis between soil respiration and root biomass on the sampling date during the maize growing season in 2007.

Date	Intercept	Slope	R^2	p
23 June	215.11	13.81	0.76	0.002
18 July	290.13	16.70	0.83	0.001
10 August	335.37	7.96	0.88	<0.001
21 August	281.21	7.83	0.87	<0.001
4 September	221.67	5.29	0.84	<0.001

Heterotrophic respiration averaged 268.70 mg $CO_2/m^2/h$, ranging from 215.11~335.37 mg $CO_2/m^2/h$ (Table 3). Root respiration varied from 192.73 to 585.60 mg $CO_2/m^2/h$, with mean value of 373.96 mg $CO_2/m^2/h$.

The seasonal variation of the contribution of root respiration to soil respiration presented as a single peak. The contribution was the lowest on 23 June and rose with the increase of root biomass and reached the maximum value on 10 August. This was ascribed to not only the higher soil temperature but also the enhancement of root respiration. Strong photosynthesis provided more nutrients for root in this period, which stimulated the root growth and therefore promoting the root respiration (Kuzyakov and Cheng, 2001). The contribution declined slowly from later August and during the entire maize growing season the average value was 56.38%. Kuzyakov and Larionova (2005) found that the contribution of root respiration to soil respiration is 48%±5% generally in agroecosystems. Hanson *et al.* (2000) summarized that the contribution of root respiration to soil respiration averaged 60.4% for non-forest ecosystems. These values were close to our result. However, Yang and Cai (2006) found that the ratios of root respiration to soil respiration during the soybean growing season fluctuated in the range of 62%~98%, which were much bigger than the values in this paper. Probably the discrepancy was owing to the different experimental methodologies or crop species.

Table 3. Root respiration and heterotrophic respiration on the sampling date during the maize growing season in 2007.

Date	Soil Respiration ($mg\ CO_2/m^2/h$)	Heterotrophic respiration ($mg\ CO_2/m^2/h$)	Root respiration ($mg\ CO_2/m^2/h$)	Ratio of root respiration to soil respiration (%)
23 June	407.84	215.11	192.73	47.26
18 July	784.50	290.13	494.37	63.02
10 August	920.97	335.37	585.60	63.59
21 August	634.99	281.21	353.78	55.71
4 September	464.97	221.67	243.30	52.33

Root respiration coefficient

In order to correct the influence of soil temperature on soil respiration, we set the value of Q_{10} as 2. The soil respiration rates measured in different temperatures in our experiment were all corrected into the values in 25℃ according to equation 1. Then we calculated the ratio of root respiration to root biomass, namely root respiration coefficient (Sun *et al.* 2004), which unit is g/g/d and its meaning is how many gram carbon were respired by per gram plant per day.

$$RR_{25} = \frac{RR}{2^{[(T-25)/10]}} \qquad (1)$$

Where RR_{25} is soil respiration rates in 25℃, RR is soil respiration rate measured in our experiment, T is the soil temperature when sampling. The value 2 is the temperature coefficient of soil respiration. Accordingly, we could obtain root respiration coefficients on every sampling date (Figure 1), which was much higher on 23 June and 18 July and gradually decreased to 4 September. Gifford (2003) reported that the root respiration coefficients were higher in early growing stage than in later maturing stage, which was consistent with our results.

Root respiration coefficient was positively correlated with root nitrogen content (Figure 2). The root nitrogen content could explain 91% changes of root respiration coefficient in the maize growing season. Ryan (1991), Tjoelker *et al.* (1999) and Sun *et al.* (2004) all reported that there existed the significantly linear correlation between respiration coefficient of different plant organ and its nitrogen content from tree, shrub and crops.

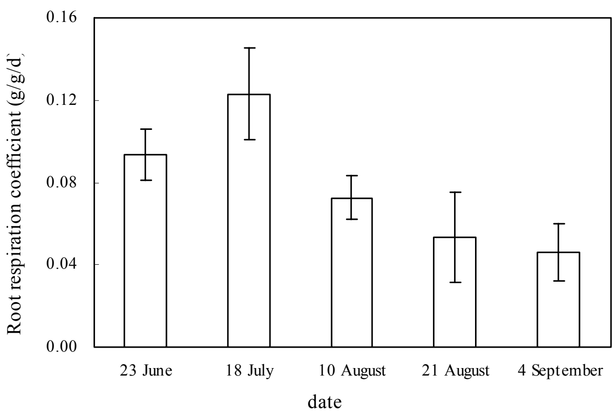

Figure 1. Root respiration coefficients during the maize growing season in 2007.

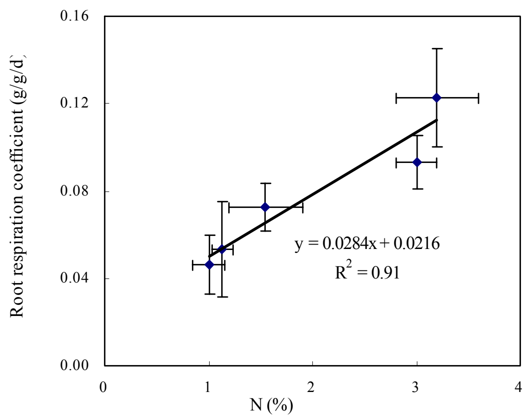

Figure 2. The relationship between root respiration coefficient and root nitrogen content.

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Conclusion

The rates of soil respiration showed a remarkably high spatial variability and were 778.52, 610.78 and 425.48 mg $CO_2/m^2/h$ near the plant, inter-plants and inter-rows, respectively. Hetetotrophic respiration averaged 268.70 mg $CO_2/m^2/h$, ranging from 215.11~335.37 mg $CO_2/m^2/h$. Root respiration varied from 192.73 to 585.60 mg $CO_2/m^2/h$, with mean value of 373.96 mg $CO_2/m^2/h$. The contribution of root respiration to soil respiration varied from 47.26~63.59%, with mean value of 56.38%. Root respiration coefficient was much higher on 23 June (0.09) and 18 July (0.12) and gradually decreased to 4 September (0.05). Root respiration coefficient was positively correlated with root nitrogen content. The root nitrogen content could explain 91% changes of root respiration coefficient during the maize growing season.

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