

Lanfang YANG, Jingjing YAN, Zucong CAI

Effects of N-applications and photosynthesis of maize (*Zea mays* L.) on soil respiration and its diurnal variation

© Higher Education Press and Springer-Verlag Berlin Heidelberg 2010

Abstract In order to understand the relationship of soil respiration to N-applications and photosynthesis, a soil pot experiment of planting maize with two N-applications was conducted. During the trumpeting stage, maize plants were shaded for three days and soil respiration was sampled by static chamber method and measured by gas chromatography. A clear diurnal cycle of soil respiration rate (SRR) showed a single peak curve in which the rate crested at about 14:00 during a day-night period and the daily average SRR was very close to that between 18:00 and 21:00. The SRR increased with soil N-application and the measured average SRR in three days was 29% higher in high N-application (HN, 300 mg·kg⁻¹ of N) than that in low N-application (LN, 150 mg·kg⁻¹ of N). The shaded plants significantly decreased the SRR and its diurnal variation. The soil respiration within the first, second and third day-night decreased to about 21%, 50% and 65%, respectively compared with the un-shaded plants. Under non-shading treatments, the exponential relativity of SRR was significantly dependent on temperature but not on time, while in shaded plants, it was significantly dependent on both temperature and shading time, with the relative coefficient to shading time significantly higher than that to temperature. In summary, soil N-application could increase the soil respiration, while the shaded plants not only decreased the SRR and its diurnal variation but also altered the relationship between the SRR with temperature, thus the soil respiration during maize growth was mainly derived from the recent photosynthates. Photosynthesis, together with temperature, are the key factors controlling the diurnal variation of soil respiration.

Keywords soil respiration, diurnal variation, N-application, shading plant, photosynthesis, temperature

1 Introduction

Soil respiration is a major CO₂ flux within terrestrial ecosystems as well as between the biosphere and the atmosphere (Buchmann, 2000). Global soil respiration is estimated at approximately 75×10¹⁵ g C·a⁻¹ and is the primary path by which CO₂, fixed by plants, returns to the atmosphere. The total worldwide emission of CO₂ from soils is recognized as one of the largest fluxes in the global carbon cycle. Therefore, small changes in the magnitude of soil respiration could have a large effect on the concentration of CO₂ in the atmosphere (Schlesinger and Andrews, 2000). Soil respiration is mainly made up of root respiration, microbial decomposition of carbon from roots (such as carbon exudates and old dead parts of the plant roots) and utilization of native soil organic matter (Domanski et al., 2001). In general, root respiration and microbial decomposition of carbon from roots are called rhizosphere respiration, and this accounts for 51%–89% of soil respiration (Cheng, 1996; Domanski et al., 2001). The carbon respired in the rhizosphere originates from green leaf photosynthates and a large fraction, and 10% to 40% (Warembourg and Estelrich, 2000), of the C fixed by photosynthesis is lost through rhizosphere respiration (Rochette and Flanagan, 1997). Rhizosphere respiration is tightly coupled with plant photosynthetic activity. Any factor affecting photosynthesis, and subsequent substrate supply to the roots and rhizosphere microorganisms, is an important determinant of root-derived CO₂ efflux (Kuzya-kov and Cheng, 2001). The total soil respiration is usually highly influenced by plant photosynthesis. The soil CO₂ flux which derives from the rhizosphere represents that portion of the photosynthate used and lost by the plant during root growth and maintenance (Domanski et al., 2001). Thus, knowledge of the relationship between soil respiration and photosynthesis is very important to evaluate the effects of plant growth on soil environment.

Received April 14, 2009; accepted June 30, 2009

Lanfang YANG (✉), Zucong CAI
State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China
E-mail: lfyang@hubu.edu.cn

Lanfang YANG, Jingjing YAN
School of Resources and Environmental Sciences, Hubei University, Wuhan 430062, China

Soil respiration has a diurnal variation (Ben-Asher et al., 1994; Bajracharya et al., 2000; Nakadai et al., 2002; Parkin and Kaspar, 2003), which introduces variation into the study of soil carbon gases sampled during a short time. The diurnal variation of soil respiration can be influenced by many factors, such as temperature, water, species of plants, plant growth stage, and so on (Zhang et al., 2007; Zhao et al., 2007). Understanding the diurnal variation of soil respiration and its controlling factors is beneficial in order to quantify soil respiration accurately, to choose the correct sampling time of measuring soil respiration and to predict the changing trend of soil respiration during plant growth.

Nitrogen is necessary for plant growth and development and is largely absorbed from the soil. Soil levels of N can affect photosynthesis and plant growth, thereby influencing rhizosphere and soil respiration. Liljeroth et al. (1990) and Johansson (1992) showed that the soil respiration in high soil N-application was higher than that in low soil N-application.

However, the effects of photosynthesis and nitrogen application on the diurnal variation of soil respiration are rarely reported. Therefore, in order to investigate the effects of nitrogen fertilizer and photosynthesis on SRR and the rate relationship to temperature we conducted experiments on corn (*Zea mays*) by applying various levels of N fertilizer and then stopping photosynthesis.

2 Materials and methods

2.1 Soil and plant

The soil used in this experiment was Udic Argosol in taxonomic classification. The soil content of organic

carbon was $5.0 \text{ mg} \cdot \text{kg}^{-1}$, total nitrogen $0.6 \text{ mg} \cdot \text{kg}^{-1}$, sand ($20\text{--}200 \mu\text{m}$) $325 \text{ g} \cdot \text{kg}^{-1}$, silt ($2\text{--}20 \mu\text{m}$) $462 \text{ g} \cdot \text{kg}^{-1}$, clay ($< 2 \mu\text{m}$) $213 \text{ g} \cdot \text{kg}^{-1}$ and the soil pH was 5.80 (H_2O , 2.5:1). The soil texture was heavy loam.

The experimental plant was maize (*Zea mays* L.), and the variety was Yedan-14. The seeds were purchased from Jiangzhong Seed Company in Nanjing, China.

2.2 Pot experiment

A cylinder PVC pot 20 cm high and 15 cm in diameter was specially designed for maize culture, Fig. 1. A trough was installed around the outside of the pot mouth and a PVC tube (6 cm long and 2.5 cm diameter) was fixed in the center of the pot (2.5 cm above the pot mouth and 3.5 cm deep into soil) for insulating the plant from soil during sampling. Each pot had an open-bottom PVC chamber with a size 20.5 cm in length, 20.5 cm in width and 6 cm in height, which was specially designed for gas sampling. There was a hole at the center of the chamber cover for precisely fitting the PVC tube and a silicon septum was fixed on the cover of the chamber for sampling gas by syringe. At the edge of the pot bottom a hole was burrowed, through which a rubber tube was precisely connected to a vitrified-clay pipe; this connected to a trough outside the container which was used to maintain stable water content.

Twelve pots were used in the experiment and 4 kg air-dried sieved soil, 5 mm, was loaded into each pot. Six pots were chosen for the low nitrogen treatment and were provided with $150 \text{ mg N} \cdot \text{kg}^{-1}$, $75 \text{ mg P} \cdot \text{kg}^{-1}$ and $150 \text{ mg K} \cdot \text{kg}^{-1}$ per pot. The remaining six pots were provided with $300 \text{ mg N} \cdot \text{kg}^{-1}$, $75 \text{ mg P} \cdot \text{kg}^{-1}$ and $150 \text{ mg K} \cdot \text{kg}^{-1}$ as the treatment of high soil N-application.

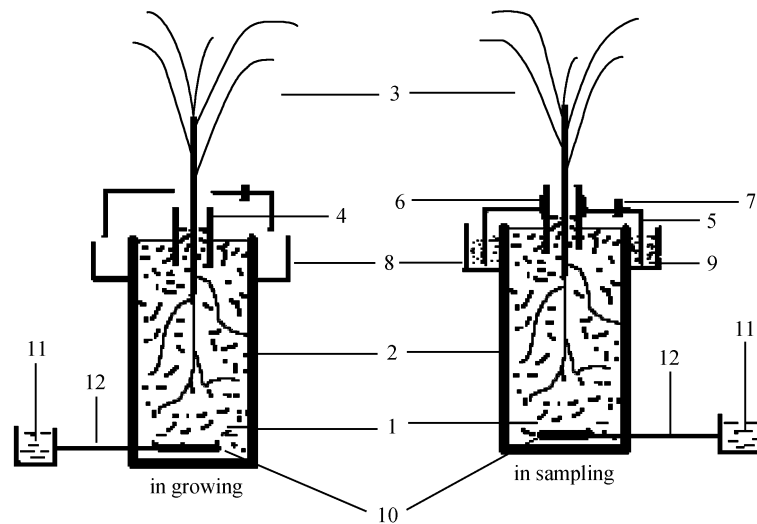


Fig. 1 Scheme of the experimental pot for maize growth and sampling for soil respiration measurement

Notes: 1–12 represent soil, PVC pot, maize plant, PVC tube for separating the plant from soil; gas sampling chamber (20.5 cm in length and width, 6 cm in height), silicone gel to seal the joint; septum used for gas sampling, water trough, water, vitrified-clay pipe, trough for providing water to soil and rubber tube, respectively.

N, P and K were provided in the form of $(\text{NH}_4)_2\text{SO}_4$, KH_2PO_4 and K_2SO_4 , respectively. Two maize seeds were planted in each tube at a 3-cm soil depth layer on April 30 2003. The pots were placed on a movable, experimental bench on the rail in order to facilitate movement between the netted house on fine days and into the glass house on rainy days. The air temperature and light for plant growth were controlled naturally. Seedlings emerged on May 5, 2003. All pots were thinned to one plant. During the maize trumpet stage (10–12 leaves, June 17, 2003, 48 days after sowing), the photosynthesis of maize plants in three pots with low soil N-application and three pots with high soil N-application was stopped for three days and nights by covering each plant with a bag made of opaque black fabric. The remaining maize plants were used as controls and received no black cloth treatment. A specially constructed iron wire cylinder was fitted over each corn stalk, to protect the stem and leaves, and then the entire aerial part of the corn plant was covered with a double-layered, black cloth bag. The open bottom of the bag was tightly fastened at the base of the plant stem with plastic rope for lightproofing. This shading device eliminated almost 100% of the available light but had no measured effect on the soil.

2.3 Sampling

Soil gas emission sampling began when the corn plants had about 10–12 leaves, known as the ‘trumpet stage’ of corn development. CO_2 emission measurements started at 8:00 on June 17th and ran for three days until 8:00 on June 20th, 2003. Gas was sampled at 2-hour intervals during the daytime (6:00–18:00) and at 3-hour intervals at night (18:00–6:00). On collecting gas samples, the chamber was moved down to the water filled trough which prevented air exchange between inside and outside the chamber. Silicon gel was used to seal gas leakage between the chamber and the PVC tube. Three gas samples were collected by a 20 mL syringe through the silicon septum at 10-min intervals and immediately transferred to a pre-evacuated vial (18 mL) for analyses of CO_2 concentrations. On each sampling day we collected on ten occasions, with three reps for each occasion, for a total of thirty samples in 24 hours. After each sampling, the plant chamber was moved away from the trough, thus permitting free air exchange. Air temperature, soil surface temperature and soil temperature, at 5 cm depth, were recorded at each sampling.

2.4 Measurements and calculations

CO_2 was determined by a gas chromatograph (Shimadzu GC-14B) with a thermal conductivity detector (TCD) and an 80/100 mesh Chromosorb 102 column. The oven, injector, and detector temperatures were 60°C, 100°C and

60°C, respectively. The carrier gas (H_2) flowed at a rate of 80 mL·min⁻¹.

The fluxes of CO_2 were calculated using the rate of increase of its concentration in the chamber headspace with the following equation:

$$F = \rho \times \frac{dc}{dt} \times \frac{V}{A} \times \frac{273}{273 + T},$$

where F is the soil respiration rate (SRR) in $\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$, ρ is the density of CO_2 under standard conditions, dc/dt is the rate of increasing of CO_2 concentration in the headspace of chamber, V is the headspace volume of the chamber, A is the area of soil surface covered by chamber and T is air temperature.

When the sampling was over, the shaded maize plants were harvested. The roots and aerial parts were rinsed with distilled water and cut into about 1 cm size pieces and then placed into paper bags to dry at 70°C in an oven. The dry weights of roots and aerial parts of maize comprised their biomass. After being ground through a 0.25 mm sieve, the roots and aerial parts of maize were measured for their nitrogen content by a PIE 2400-II CHNOS Analyzer.

3 Results and analyses

3.1 Diurnal variation of soil respiration

Figure 2 indicates that in treatments of both high N (HN) and low N (LN) applications, soil respiration rate (SRR) shows a distinct diurnal cycle, which presents a single peak curve during the day, about 16:00 and a broad valley curve at night, with the lowest rate at about 4:00. SRR ranged from 312 to 716 $\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ in HN, and from 231 to 559 $\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$ in LN during the period of sampling. Table 1 shows that the average SRR during day and night is near each other at 8:00–10:00 and later at 18:00–21:00, but only during the 18:00–21:00 are there no significant differences.

Table 2 reveals that the SRR during daytime (8:00–20:00) is significantly higher than that during nighttime (20:00–8:00) both in HN and LN. It could be calculated from Table 2 that the average SRR at daytime for three day-nights was about 45% higher than that at nighttime both in LN and HN.

3.2 Effects of shading plant on soil respiration

Figure 3 shows that the diurnal cycles of soil respiration are different between shaded and un-shaded treatments. During three 24 hour periods the degrees of fluctuation of SRR and the shape of the curves were similar in un-shaded treatments, but they decreased quickly and the curve of that cycle flattened out over time in the shaded treatments. After only two hours of shade in HN and four hours in LN,

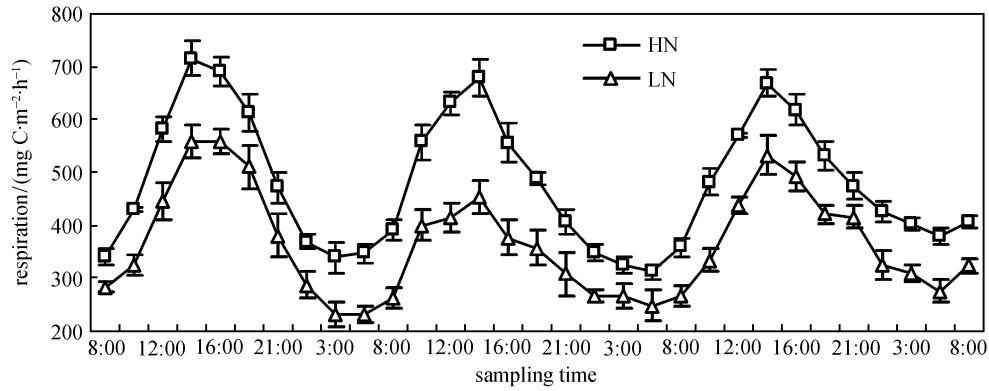


Fig. 2 The effect of soil N-application on the diurnal variation of SRR

Notes: SRR, HN and LN stand for soil respiration rate, high soil N-application and low soil N-application, respectively. The same as below.

Table 1 The comparison of SRR at 8:00–10:00 and 18:00–21:00 with average rate of day-night ($\text{mg C}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$) (SRR = soil respiration rate)

treatment	period	the day-night			average SRR of three day-nights
		first	second	third	
HN	8:00–10:00	385.2±5.3a	473.2±26.2a	420.0±21.1a	426.1±14.2a
	18:00–21:00	541.9±32.8b	448.0±8.1a	502.1±27.1b	497.3±22.7b
	average of day-night	462.3±29.4c	451.6±22.6a	485.4±14.5b	466.4±21.9b
LN	8:00–10:00	304.0±14.3a	331.2±23.9a	300.7±20.6a	312.0±18.6a
	18:00–21:00	445.5±37.7b	332.1±32.7a	417.7±64.9b	398.5±45.1b
	average of day-night	382.7±17.5c	327.2±26.4a	378.0±24.3ab	362.6±22.2ab

Notes: The value was expressed as mean±standard error, and the values followed by a different letter within the same column are significantly different at 0.05 probability level. The same as below.

Table 2 Difference of soil respiration between daytime and nighttime ($\text{mg C}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$)

treatment	item	SRR during day and night			average SRR
		first	second	third	
HN	daytime	553.7±41.6a	451.6±22.6a	485.4±14.4a	553.3±29.8a
	nighttime	370.9±17.2c	350.0±16.3b	417.9±9.5b	379.6±14.0c
LN	daytime	467.8±10.8b	327.2±26.4b	378.0±24.3b	429.6±21.8b
	nighttime	297.5±26.2d	270.3±22.5c	319.2±20.6c	295.7±22.9cd

the SSR in shaded plants was significantly lower than that in un-shaded plants ($P < 0.05$). Thereafter, the difference of SSR between shaded and un-shaded treatment increased with the shading time.

Table 3 shows the average SRR in a 24 hour period in shaded plants with high N-application (SHN) and shaded plants with low N-application (SLN). The SRR was significantly lower in the shaded plants, compared to the un-shaded ones. The difference of a 24 hour period average SRR between shaded and un-shaded plants increased with an increase in the shading period. In the HN treatment, the absence of photosynthesis caused a 21.1%, 54.4% or 65.0% decrease in SRR compared to the un-shaded plants. In the LN treatment, the absence of photosynthesis in the shaded plants caused a 20.8%, 48.7% or 65.6% decrease in SRR during the three time periods. Both in SHN and SLN,

the average SRR was in order of the first > the second > the third day-night.

3.3 Effects of shading plant on the relationship between soil respiration and temperatures

Table 4 indicates that in both un-shaded and shaded plants, the diurnal variation of SRR was significantly correlated to temperatures exponentially, but the correlative coefficients were significantly higher in un-shaded plants than in shaded plants. There was a significant negative exponential relationship between SRR and shading time. Moreover, the absolute value of the exponential correlative coefficient of SRR to shading time was higher in the shaded plants, compared to the un-shaded plants. However, in un-shaded plants, the relationship between SRR and shading time was

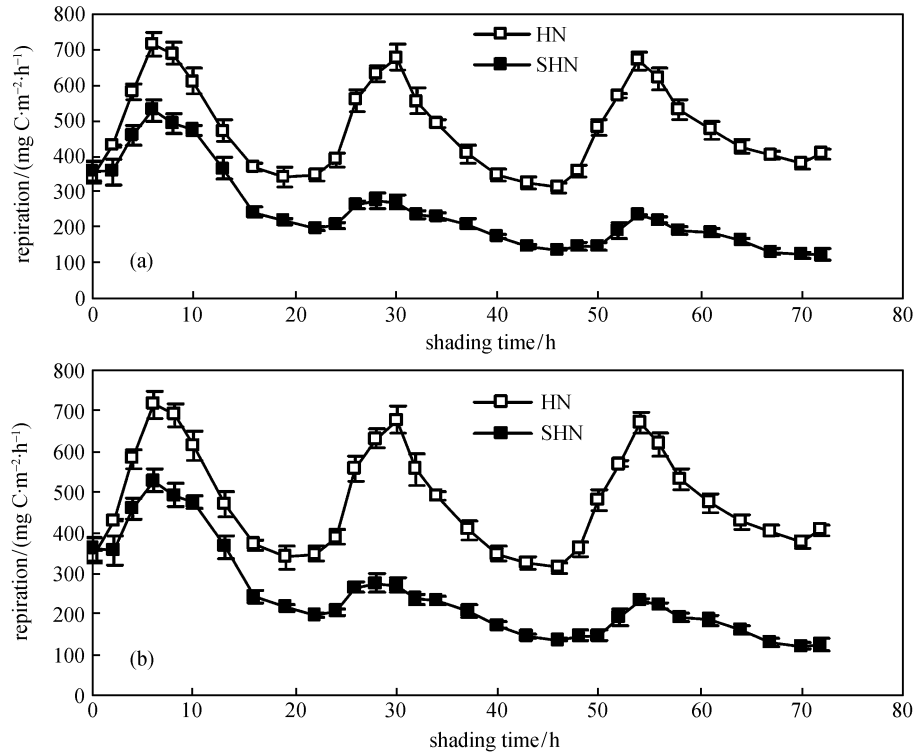


Fig. 3 The effect of stopping photosynthesis by shading plants on the diurnal variation of SRR

Notes: (a) is under high soil N-application and (b) is under low soil N-application. HN, SHN, LN and SLN denote high N-application, shading plants in high N-application, low N-application and shading plants in low N-application, respectively. The same as below.

Table 3 Averaged SRR during each day-night after shading plant

treatment	averaged SRR during day-night after shading plant/(mg C·m ⁻² ·h ⁻¹)			mean of three day-nights (mg C·m ⁻² ·h ⁻¹)
	first	second	third	
HN	462.3±29.4a	451.6±22.6a	485.4±14.5a	466.4±21.9a
SHN	364.1±19.8c	206.0±6.6c	169.7±3.7c	246.6±9.8c
LN	382.7±17.5b	327.2±26.4b	378.0±24.3b	362.6±22.2b
SLN	303.1±5.5d	167.8±1.4d	130.1±10.6d	200.4±5.4d

Table 4 The exponential relation coefficients of SRR to temperatures and the shading time

treatment	<i>T</i>	type of exponential relation coefficient		
		simply to <i>T</i>	simply to <i>t</i>	binary to <i>T</i> and <i>t</i>
HN	Air	0.878**		0.877**
	Surface	0.868**	0.121	0.855**
	5 cm	0.915**		0.908**
SHN	Air	0.516**		0.923**
	Surface	0.680**	-0.855**	0.953**
	5 cm	0.651**		0.969**
LN	Air	0.845**		0.828**
	Surface	0.894**	0.100	0.884**
	5 cm	0.938**		0.930**
SLN	Air	0.488**		0.930**
	Surface	0.467**	-0.885**	0.964**
	5 cm	0.595**		0.974**

Notes: *T* stands for temperature; *t* for shading time; ** for 0.01 significant level.

not significant. The binary exponential coefficients of SRR to temperature and shading time in both high and low N treatments were significantly greater than the simple correlative coefficients of SRR to temperature alone or to shading time. However, there was no difference between the simple exponential correlative coefficient of SRR to temperature and the binary exponential coefficient to temperature and shading time in HN and LN.

3.4 Effect of N-applications on soil respiration

Figure 2 shows that the pattern of SRR in diurnal variation in HN was the same as in LN, but the SRR in HN was significantly higher than that in LN. In the HN treatment the mean of SRR during the three day time period was 28.6% and 23.1% higher than that in LN in both un-shaded and shaded plants, respectively. Table 5 indicates that HN brought on a higher biomass and nitrogen content in maize plants than LN.

Table 5 The maize biomass and its N content in trumpeting stage

treatment	root		aerial part	
	biomass/g	N-content ($\text{mg} \cdot \text{g}^{-1}$)	biomass/g	N-content ($\text{mg} \cdot \text{g}^{-1}$)
LN	4.57±0.13a	5.7±0.2a	26.88±1.34a	17.1±0.7a
HN	5.03±0.18b	9.9±0.3b	30.60±1.13b	21.9±0.8b

4 Discussion

4.1 Diurnal variation of SRR in maize soil system

In our experiment, the SRR had a clear diurnal cycle and the shapes of curves in three day-nights were similar, which was in accord with some results reported by Ben-Asher et al. (1994) and Bajracharya et al. (2000). Results from the grassland are different from our experiment. Zhang et al. (2007) found that the maximum SRR occurred at 18:00 for the *Populus* woodland, 12:00 for the *Tamarix ramosissima* + *Phragmites communis* community, and 14:00 for the *Haloxylon ammodendron* community, while in our experiment the maximum rate occurred at about 14:00. Zhao et al. (2007) showed that in the shrubland on Ordoa Plateau of Inner Mongolia, the diurnal variation of soil respiration was slight or not correlated with daily temperature change during the vegetative growth stage, but was significantly correlated during the reproductive growth stage. However, in our experiment, the SRR was significantly correlated with temperature, which implied that the region, the type of vegetation and growth stage may be the factors influencing the diurnal variation of the soil respiration.

Because of the diurnal variation of soil respiration, there was uncertainty in the determination of soil respiration by sampling at one time. In order to understand the effects of soil respiration on the carbon cycle and greenhouse effect,

the diurnal fluctuation of SRR should be taken into account in the measurement and estimation of the soil respiration. The result of having an average SRR in one day-night close to the rate at 8:00–10:00 and 18:00–21:00 in our experiment could be used as reference for studying the soil respiration and carbon cycle. When continuous sampling cannot be done, the choice of a proper sampling time by light of the diurnal variation of soil respiration should improve the representation and accuracy of measuring and estimating the soil respiration.

4.2 Effects of soil N-application on soil respiration

The main reason for HN having higher SRR than LN was that there was more biomass and higher nitrogen content in maize plants in HN than in LN (Table 5). The increment of plant growth caused by N brought about more root absorbency and transportation of nutrients and water, while the root absorbency and transportation were at the cost of energy provided by root respiration. The increase of N content in maize biomass by high N-application must lead to an increase in root respiration, namely the actual respiration by roots to obtain energy for maintenance of metabolism and concentration gradient in cells, growth and active uptake of nutrients (George et al., 2003), which continues throughout the plant growing season. The proportion of root respiration to total soil respiration during a plant growing season ranges from 38% to 76% under the grasslands of northeast China (Wang et al., 2006), accounting for 49%–58% under ryegrass (*Lolium perenne* L.) and 43%–66% under radiata pine (Chen et al., 2006). Soil respiration, which was increased by N-application in our experiment, was consistent with the results reported by Lijeroth (1990) who labeled wheat with ^{14}C , Johansson (1992) who labeled barley, and Lu et al. (1998) who used douglas-fir (labeled) seedlings.

4.3 Effects of photosynthesis on soil respiration

SRR was significantly higher during daytime than at nighttime in both HN and LN. SRR was significantly decreased by covering plants with black fabric, and different diurnal variation curves between shaded and un-shaded plants showed that SRR had an immediate connection to photosynthesis. When plants were shaded, photosynthesis was weakened or ceased and the assimilate input to roots was also decreased or ceased, thereby, substrates supplied for rhizosphere processes as well as the SRR was reduced. Plant allocation of photosynthate to roots is a very important source of available C for soil microorganisms and root respiration (Liang et al., 2002). Wang et al. (2003) suggested that soil respiration under favorable temperature and moisture conditions was principally determined by substrate supply. In our experiment two hours after shading plants, the SRR was obviously lower in shaded plants than in un-shaded plants.

Thus we may say that the current assimilate could be viewed as the main source supplying nutrients for rhizosphere respiration. The assimilation of CO₂ and its downward transport in plants are very rapid processes. Kuzyakov et al. (2001) found that the beginning of ¹⁴CO₂ efflux from the soil was recorded within the first hour after labeling the shoots of *Lolium Perenne*. Cheng et al. (1993) reported that the ¹⁴CO₂ evolution from the soil with winter wheat and rye began within 30 min after pulse labeling. The rate of flow of assimilates towards roots was estimated to be about 100 cm·h⁻¹ (Kuzyakov et al., 2001). Johansson (1993) showed that rhizosphere respiration rapidly declined after photosynthesis was blocked. Using isotope labeling, Warembourg and Estelrich (2001) confirmed that recent assimilates are rapidly utilized by roots and rhizosphere microorganisms. The decline in SRR after shading the plant is actually the decrease in substrates for soil respiration. Illeris et al. (2003) indicated that the major part of the below-ground respiration originates from turnover of recently fixed C. Ekblad and Högberg (2001) reported that the new photo-assimilates could account for at least 65% of the total soil respiration. In our experiment, shading plants caused 21.2%, 54.4% and 65% of soil respiration reduction in SHN and 20.8%, 48.7% and 65.6% of that in SLN during the first, second and third day-night after shading plants, respectively, and these results were also similar to those reported by Kuzyakov et al. (2001), Craine et al. (1999) and Kuzyakov and Cheng (2004). In short, soil respiration in maize-planting soil was tightly coupled with photosynthetic activity and mainly controlled by recently photosynthesized carbon.

4.4 Effects of shading plants on the relationship of soil respiration to temperature

SRR was significantly correlated exponentially with temperatures of air, soil surface and soil at 5 cm depth, as seen in Table 5, which is similar to results reported by Buyanovsky et al. (1986), Buchmann (2000) and Alvarez and Alvarez (2001). However, the relativity of SRR to temperature was significantly lower in shaded plants than in un-shaded plants. More than 71%–88% of variability of soil respiration during the diurnal cycle in un-shaded plants and only 23%–46% in shaded plants were involved in changes in temperature, but there was a significantly negative exponential relationship between SRR and the time after shading plants, which accounted for 73%–78% of variability in diurnal variation of soil respiration. The binary exponential relative coefficient of soil respiration to shading time and temperature was notably higher than the simple relation coefficient of soil respiration to temperature in shading treatment. The shading time and the temperature could explain 85%–95% of variability in diurnal variation of soil respiration, which suggests that the diurnal variation of soil respiration is dominated by temperature under normal growth, however it is mainly controlled by

photosynthesis under shaded plants. The photosynthesis influenced not only the SRR and the intensity of diurnal variation, but also the relationship of SRR to temperature. Thus, the diurnal variation of soil respiration was the result of interactions between temperature and photosynthesis during plant growing season.

5 Conclusion

The SRR had a clear diurnal cycle with a single peak curve, in which the SRR was significantly higher in daytime than in nighttime, while the average SRR within a day-night period was close at two intervals: 8:00–10:00 and 18:00–21:00. Soil N-application enhanced SRR significantly, while shaded plants have less photosynthates, which not only decreased the magnitude of SRR, but also influenced the relationship of SRR to temperature. The significant effects of shaded plants on SRR and its diurnal variation suggests that the recently photosynthesized carbon is the main factor controlling SRR, and the diurnal variation of SRR during plant growing season is the interaction of photosynthesis and temperature.

Acknowledgements This study was financially supported by the Open Foundation of the State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences.

References

- Alvarez R, Alvarez C R (2001). Temperature regulation of soil carbon dioxide production in the Humid Pampa of Argentina: estimation of carbon fluxes under climate change. *Biol Fert Soils*, 34: 282–285
- Bajracharya R M, Lal R, Kinble J M (2000). Diurnal and seasonal CO₂-C flux from soil as related to erosion phases in central Ohio. *Soil Sci Soc Am J*, 64: 286–293
- Ben-Asher J, Cardon G E, Peters D, Rolston D E, Biggar J E, Phene C J, Ephrath J E (1994). Determining root activity distribution by measuring surface carbon dioxide fluxes. *Soil Sci Soc Am J*, 58: 926–930
- Buchmann N (2000). Biotic and abiotic factors controlling soil respiration rates in *Picea abies* stands. *Soil Biol Biochem*, 32: 1625–1635
- Buyanovsky G A, Wagner G H, Gantzer C J (1986). Soil respiration in a winter wheat ecosystem. *Soil Sci Soc Am J*, 50: 338–344
- Chen C R, Condon L M, Xu Z H, Davis M R, Sherloch R R (2006). Root, rhizosphere and root-free respiration in soils under grassland and forest plants. *Eur J Soil Sci*, 57: 58–66
- Cheng W X (1996). Measurement of rhizosphere respiration and organic matter decomposition using natural ¹³C. *Plant Soil*, 183: 263–268
- Cheng W X, Coleman D C, Carroll C R, Hoffman C A (1993). In situ measurement of root respiration and soluble C concentrations in the rhizosphere. *Soil Biol Biochem*, 25: 1189–1196
- Craine J M, Wedin D A, Chapin F S (1999). Predominance of

- ecophysiological controls on soil CO₂ flux in Minnesota grassland. *Plant Soil*, 207: 77–86
- Domanski G, Kuzyakov Y, Siniakina S V, Stahr K (2001). Carbon flows in the rhizosphere of ryegrass (*Lolium perenne*), *J Plant Nutr Soil Sci*, 164: 381–387
- Ekblad A, Högberg P (2001). Nature abundance of ¹³C in CO₂ respired from forest soils reveals speed of link between tree photosynthesis and root respiration. *Pedologia*, 127: 305–308
- George K, Norby R J, Hamilton J G, DeLucia E H (2003). Fine-root respiration in loblolly pine and sweetgum forest growing in elevated CO₂. *New Phytol*, 160: 511–522
- Illeris L, Michelsen A, Jonasson S (2003). Soil plus root respiration and microbial biomass following water, nitrogen, and phosphorus application at a high arctic semi desert. *Biogeochem*, 85: 15–29
- Johansson G (1992). Below-ground carbon distribution in barley (*Hordeum vulgare* L.) with and without nitrogen fertilization. *Plant Soil*, 144: 93–99
- Johansson G (1993). Carbon distribution in grass (*Festuca pratensis* L.) during regrowth after cutting-utilization of stored and newly assimilated carbon. *Plant Soil*, 151: 11–20
- Kuzyakov Y, Cheng W (2001). Photosynthesis controls of rhizosphere respiration and organic matter decomposition. *Soil Biol Biochem*, 33: 1915–1925
- Kuzyakov Y, Cheng W (2004). Photosynthesis controls of CO₂ from maize rhizosphere. *Plant Soil*, 263: 85–99
- Kuzyakov Y, Ehrensberger H, Stahr K (2001). Carbon partitioning and below-ground translocation by *Lolium perenne*. *Soil Biol Biochem*, 33: 61–74
- Liang B C, Wang X L, Ma B L (2002). Maize root-induced change in soil organic carbon pools. *Soil Sci Soc Am J*, 66: 845–847
- Liljeroth E, Van Veen J A, Miliier H J (1990). Assimilate translocation to the rhizosphere of two wheat lines and subsequent utilization by rhizosphere microorganisms at two soil nitrogen concentrations. *Soil Biol Biochem*, 22: 1015–1021
- Lu S, Mattson K G, Zaerr J B, Marshall J D (1998). Root respiration of douglas-fir seedlings: effects of N concentration. *Soil Biol Biochem*, 30(3): 331–336
- Nakadai T, Yokozawa M, Ikeda H, Koizumi H (2002). Diurnal changes of carbon dioxide flux from bare soil in agricultural field in Japan. *Appl Soil Ecol*, 19: 161–171
- Parkin T B, Kaspar T C (2003). Temperature control on diurnal carbon dioxide flux: implications for estimating soil loss. *Soil Sci Soc Am J*, 67: 1763–1772
- Rochette P, Flanagan L B (1997). Quantifying rhizosphere respiration in a corn crop under field conditions. *Soil Sci Soc Am J*, 61: 466–474
- Schlesinger W H, Andrews J A (2000). Soil respiration and the global carbon cycle. *Biogeochem*, 48: 7–20
- Wang W J, Dalal R C, Moody P W, Smith C J (2003). Relationships of soil respiration to microbial biomass, substrate availability and clay content. *Soil Biol Biochem*, 35: 273–284
- Wang W, Guo J X, Feng J, Oikawa T (2006). Contribution of root respiration to total soil respiration in a *Leymus chinensis* (Trin) Tzvel grassland of Northeast China. *J Integr Plant Biol*, 48: 409–414
- Warembourg F R, Estelrich H D (2000). Towards a better understanding of carbon flow in the rhizosphere: a time-dependent approach using carbon-14. *Biol Fert Soils*, 30: 528–534
- Warembourg F R, Estelrich H D (2001). Plant phenology and soil fertility effects on below-ground carbon allocation for an annual (*Bromus madritensis*) and a perennial (*Bromus erectus*) grass species. *Soil Biol Biochem*, 33: 1291–1303
- Zhang L H, Chen Y N, Li W H, Zhao R F (2007). Seasonal variation of soil respiration under different land use/land cover in arid region. *Sci China Ser D-Earth Sci*, 50(Suppl 1): 76–85
- Zhao J, Qi Y C, Dong Y S (2007). Diurnal and seasonal dynamics of soil respiration in desert shrubland of *Artemisa Ordosica* on Ordos Plateau of Inner Mongolia, China. *J Forestry Res*, 18(3): 231–235