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Full Length Research Paper

Characteristics of soil CO_2 fluxes and N_2O emission in a winter wheat ecosystem under enhanced UV-B radiation

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Field experiments were conducted during the 2007 to 2008 winter wheat-growing season to investigate the influence of enhanced UV-B radiation on diurnal variations in soil CO_2 fluxes and nitrous oxide (N_2O) emissions from a winter wheat ecosystem. CO_2 and N_2O fluxes were measured by static opaque chamber-gas chromatograph technique. Results showed that on sunny days, soil CO_2 fluxes and N_2O emissions from the soil-wheat system exhibited obvious diurnal variation patterns, which enhanced UV-B radiation. During the jointing, booting, and heading stages, enhanced UV-B radiation significantly decreased the mean diurnal CO_2 fluxes of the soil by 49.62% ($p = 0.000$), 50.39% ($p = 0.004$) and 51.44% ($p = 0.022$), respectively. Enhanced UV-B radiation also reduced the mean diurnal N_2O fluxes (MNF) of the soil-wheat system by 48.35% ($p = 0.017$) and soil MNF by 36.87% ($p = 0.027$) during the grain-filling stage. Our findings suggested that enhanced UV-B radiation did not change the diurnal variation patterns of soil CO_2 fluxes and N_2O emissions from the soil-wheat system, but influenced mean diurnal CO_2 and N_2O fluxes.

Key words: Enhanced UV-B radiation, winter wheat, soil, CO_2, nitrous oxide.

INTRODUCTION

Global warming and enhanced ultraviolet-B radiation (UV-B, 280 to 320 nm) that reaches the biosphere are major global environmental problems. An agro-ecosystem is an important source of greenhouse gas emissions that are crucial to the carbon and nitrogen cycle of terrestrial ecosystems. Agricultural activities are estimated to account for approximately 60% of global anthropogenic nitrous oxide (N_2O) emissions (IPCC, 2007). The rapid decline in stratospheric ozone concentrations has significantly increased UV-B radiation (Kaurola et al., 2000). However, enhanced UV-B radiation inhibits crop photosynthesis and transpiration rate (Yang et al., 2007; Pandey and Chaplot, 2007), reducing biomass and agricultural production (Yao et al., 2006; Agrawal et al., 2006; Peng and Zhou, 2010). It can indirectly influence soil microbial communities and activities (Johnson et al., 2002, 2003; Robson et al., 2004). Crop growth and soil microbial activities are the primary factors that influence plant respiration rate and N_2O emissions from croplands.

To the best of our knowledge, only Hu et al. (2010a, 2010b) and Chen et al. (2011) have documented the effects of UV-B on the respiration and N_2O emissions from winter wheat and soybean ecosystems.

However, diurnal variations in soil respiration and N_2O emissions under elevated UV-B radiation have rarely been examined in agro-ecosystems.

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Table 1. Main growth stages and fertilization schedules of winter wheat.

Date	Growth stages	Date	Fertilization
12 November, 2007	Sow	12 November, 2007	100 kg N ha^{-1} (urea), 78 kg P ha^{-1}, 100 kg K ha^{-1}
24 November, 2007	Seedling	13 January, 2008	50 kg N ha^{-1}, 21 kg P ha^{-1}, 27 kg K ha^{-1}
16 December, 2007	Tillering	19 February, 2008	50 kg N ha^{-1}
12 March, 2008	Booting	20 March, 2008	50 kg N ha^{-1}
7 April, 2008	Heading		
18 April, 2008	Flowering		
28 April, 2008	Grain-filling		
15 May, 2008	Physiological maturity		
28 May, 2008	Harvest		

In the present study, we hypothesize that elevated UV-B radiation may change the diurnal variations in soil respiration and N_2O fluxes in a winter wheat ecosystem. To validate this hypothesis, a soil-winter wheat system was exposed to elevated UV-B radiation supplied by a modulated irradiation system under field conditions. This study primarily aimed to investigate the response of diurnal variations in soil respiration and N_2O emissions from a winter wheat ecosystem to elevated UV-B radiation.

MATERIALS AND METHODS

Experimental site

Winter wheat field plots were set up at the experimental farm of Nanjing University of Information Science and Technology (32° 03′ N, 118° 51′ E) in southeast China. Annual rotations such as paddy rice (*Oryza sativa*)-winter wheat (*Triticum aestivum*) and soybean (*Glycine max*)-winter wheat are the main crop production regimes in the area. The annual average temperature is 15.6°C and the annual rainfall averages at about 1,100 mm.

Field experiments

The field experiments were conducted during the 2007 to 2008 winter wheat-growing season. The experiment was arranged in a completely randomized plot design, with three replicate plots (1m × 1 m area of each plot) of UV-B treatment (*T*) and three replicate plots of ambient control (*C*). The soil (0 to 20 cm) was classified as hydromorphic, and contained 26.1% clay, an initial pH (H_2O) of 6.22, total organic carbon of 19.4 g/kg and total nitrogen of 1.45 g/kg before the experiment. At the same time, bare soil experiments were carried out in wheat land. There were 6 bare soil experimental points in winter wheat fields, each point lay in-between the crop rows. 3 bare soil points lay in UV-B treatments plots and other bare soil points lay in the control plots. Wheat and weed were got off artificially in bare soil points. A local prevailing winter wheat cultivar, Yangmai 12 was sown on 12 November 2007 and harvested on 28 May 2008. Phosphorus and potassium were applied as the basal fertilizer at the local rate and no additional organic manure was incorporated into the field.The information of wheat growth stages and fertilization can be found in Table 1.

UV-B treatments

Supplemental UV-B radiation was supplied by fluorescent UV lamps (40 W, Huade Instrument Factory, Shanghai, China). The lamps were hung over and perpendicular to the planted rows, arranged east–westward to minimize shading. The experiment consisted of treatment group (*T*) with 20% UV-B enhancement, and control group (*C*) with the lamps wrapped with a polyester plastic film (Mylar-D, 125 μm thick, Dupond Co., Wilmington, DE, USA) which filters off all radiation below 320 nm (Figure 1). The polyester plastic film was replaced weekly to ensure uniformity of UV-B absorption. Plants under the polyester-filtered lamps received only ambient levels of UV-B radiation, whereas, those beneath the UV-B lamps received ambient plus supplemental levels of UV-B. UV-B radiant intensity was automatically recorded using a UV-B radiance measurement instrument composed of UV-B radiation sensors (spectral range 280 to 315 nm; SKU430, Skye Co., UK) and a DataHog (Skye-DataHog, Skye Co., UK).Sensors were installed at the level of vegetation at the center of the plots. Plants were irradiated for 8 h (08:00 to 16:00) daily from the seedling to the harvest stage.

Gas samples and measurements

CO_2 and N_2O emission fluxes were measured using a static chamber-gas chromatograph technique (Zou et al., 2005). During the wheat-growing season, boardwalks were installed to reduce soil and crop disturbance during gas sampling. The circular base frames for gas gather chamber were installed in wheat plots and bare soil points. Each base frame is 8 cm high and has a 2.5 cm width groove on the top edge. The sampling chamber was a 100 cm high PVC cylinder with a diameter of 25 cm, wrapped in one layer of sponge and aluminum foil to minimize the effect of solar radiation on the internal temperature. As the gas samples were collected, the opaque chamber was placed over the vegetation or soil with its rim matching the groove of the base frame. The chamber was closed when a groove on the top edge of the base frame was filled with water. Three gas samples were taken by syringes at 0, 10 and 20 min after closing the chamber. In each treatment, gas samples were collected from three chambers to serve as replicates.

The mixing ratios of N_2O and CO_2 were simultaneously analyzed with a modified gas chromatograph (Agilent 6890N, Agilent Co., USA) equipped with two detectors, an electron capture detector (ECD) and a flame ionization detector (FID) (Wang and Wang, 2003). The oven was operated at 55°C, the ECD at 330°C and the FID at 200°C. Fluxes were determined from the slope of the changes in the mixing ratio with durations at 0, 10 and 20 min following chamber closure. Almost all the sample sets yielded linear regression values of $R^2 > 0.99$ for the CO_2 flux and $R^2 > 0.90$ for the N_2O flux. The average flux and standard errors were calculated from the three replicates. Air temperature inside the chamber was recorded for each set of emission measurements. Soil temperature

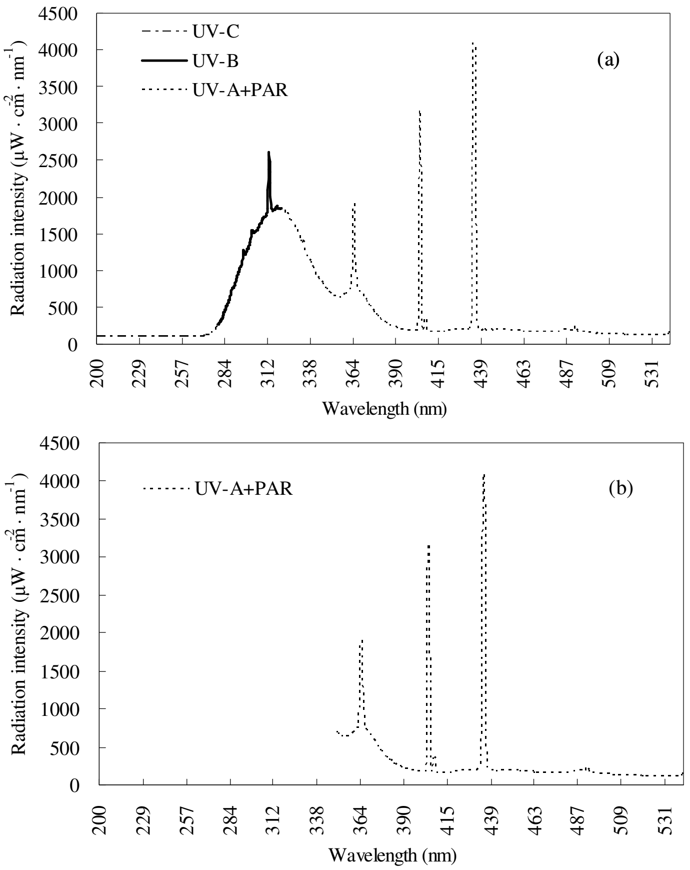

Figure 1. Spectrum of UV-B tubes (a) and Mylar film-filtrated UV-B tubes (b).

Table 2. Soil moisture and temperature, the *p* values are from paired t-test between the *C* and *T* treatments.

Date	**Soil moisture (%)**			**Soil temperature (℃)**		
	C	**T**	***p***	**C**	**T**	***p***
17 March	18.8 ± 0.7	20.1 ± 0.7	0.597	20.6 ± 1.6	20.7 ± 1.6	0.544
28 March	16.2 ± 0.6	15.1 ± 1.1	0.497	17.0 ± 0.8	17.6 ± 0.8	0.006
7 April	13.6 ± 0.4	12.8 ± 0.6	0.336	25.4 ± 1.7	25.5 ± 1.6	0.784
14 April	27.1 ± 1.2	26.6 ± 1.2	0.726	22.6 ± 1.5	22.7 ± 1.5	0.669
28 April	21.3 ± 0.5	20.5 ± 0.5	0.135	25.7 ± 1.6	26.0 ± 1.7	0.424

and moisture were measured at the time as gas sampling with a W.E.T. monitor (Delta-T Devices Ltd., Burwell, Cambridge, UK) at a depth of 10 cm and adjacent to each base frame, but not in the base frame to prevent disturbance. To study the diurnal variation in CO_2 and N_2O fluxes, gas samples were collected six times a day (once every 2 h, 08:00 to 18:00) on a sunny day at different growing periods.17 March, 28 March, 7 April, 14 April and 28 April, 2008 were the jointing, booting, heading, flowering and grain-filling stages, respectively.

Statistical analysis

The average CO_2, N_2O fluxes and standard errors were calculated based on three replicated measurements. The primary and interaction effects of enhanced UV-B treatment and time on soil respiration (N_2O fluxes) were studied by ANOVA. All statistical analyses were conducted using SPSS 13.0 (SPSS Inc., Chicago, USA).

RESULTS

Environmental conditions

Table 2 shows the variability in soil moisture and temperature. The mean value of soil moisture measured at each sampling point was highest in 14 April and lowest

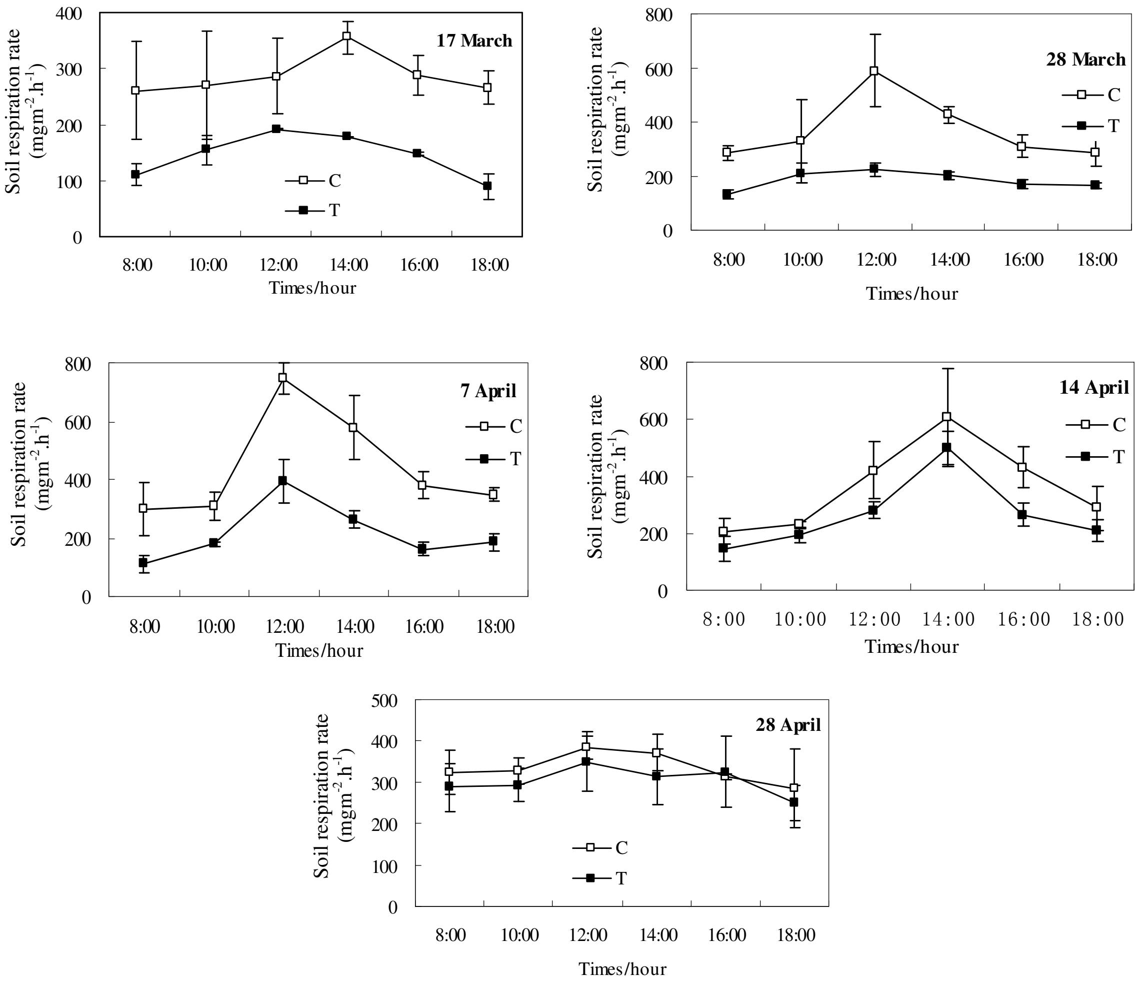

Figure 2. Effects of UV-B treatment on diurnal variations in soil CO_2 fluxes. Values are means (± SE) of three replicates with the errors bars showing SE.

in 28 March. Relative to the control, UV-B treatments had no significant effect on soil moisture. The mean value of soil temperature was highest in 28 April and lowest in 28 March. Soil temperature of UV-B treatments had no significant difference compared to that of the control (except in 28 March). In our study, no differences in soil moisture between the *C* and UV-B treatments were observed. In this case, soil moisture of *C* and *T* had the same effects on the respiration rate and N_2O emission (Cook and Orchard, 2008).

Effects of UV-B treatment on diurnal variations in soil respiration rate

The diurnal variations in bare soil respiration rates are shown in Figure 2. A similar tendency for the respiration rates and peak fluxes occurred mainly at 12:00 to 14:00 when soil and air temperatures were relatively higher. Soil respiration rates were positively significantly correlated with soil temperature (C: $R^2 = 0.536$, $p = 0.002$; T: $R^2 = 0.531$, $p = 0.003$) and air temperature (C: $R^2 = 0.465$, $p = 0.010$; T: $R^2 = 0.641$, $p = 0.000$), but had no significant correlation with soil water content (C: $R^2 = -0.190$, $p = 0.315$; T: $R^2 = 0.125$ and $p = 0.509$). The principal trends of soil respiration rates are reflected in Figure 2. Enhanced UV-B radiation did not change the diurnal variation patterns of soil respiration rate. During the five sampling days, soil CO_2 fluxes decreased under enhanced UV-B radiation by 49.62% ($p = 0.000$), 50.39% ($p = 0.004$), 51.44% ($p = 0.022$), 27.34% ($p = 0.242$) and 9.23% ($p = 0.166$).

Effects of UV-B treatment on diurnal variations in N_2O fluxes

N_2O fluxes from the soil-wheat system

Figure 3 shows diurnal changes in the N_2O fluxes from

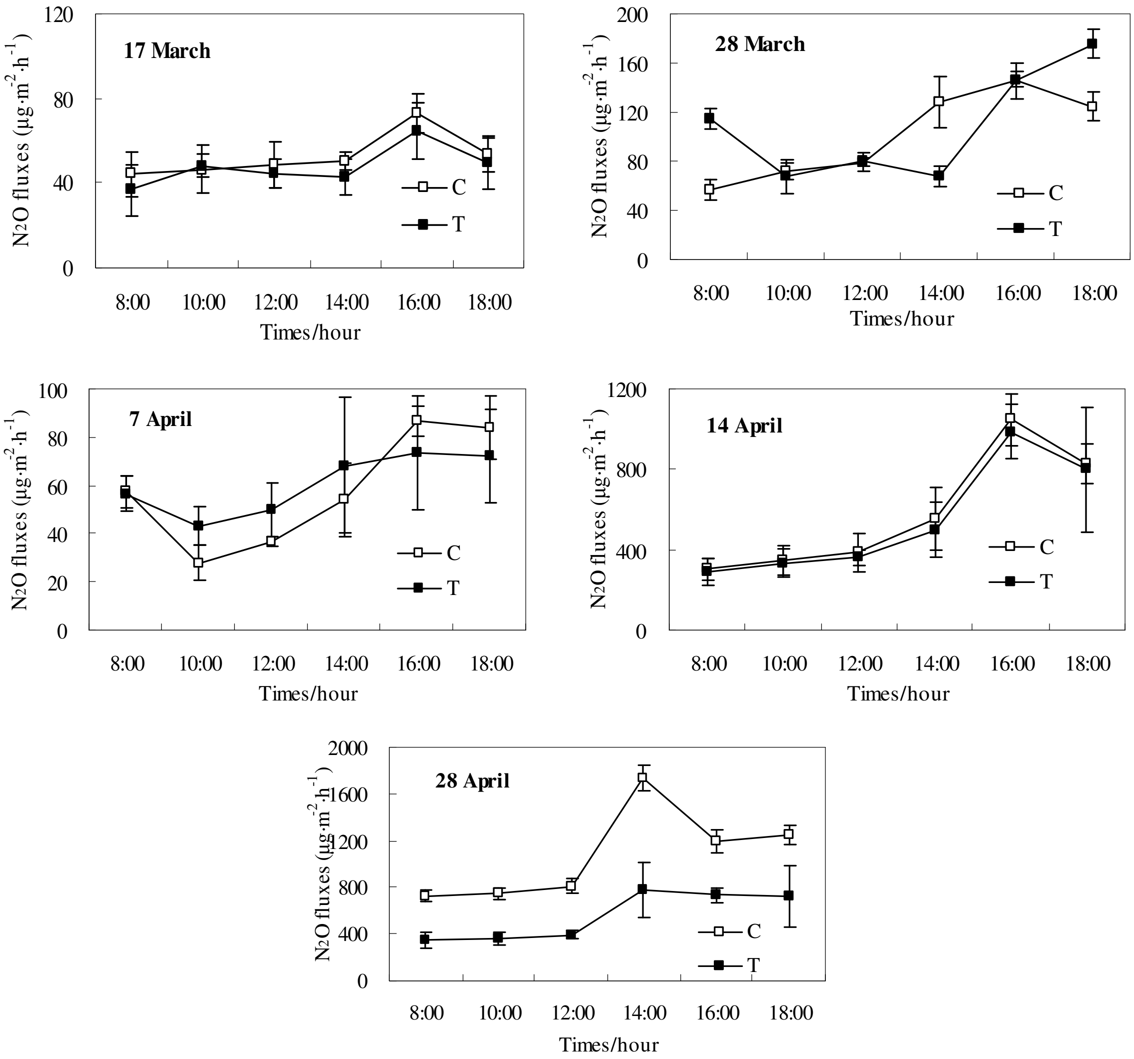

Figure 3. Effects of UV-B treatment on diurnal variations in the N_2O fluxes from the soil-wheat system. Values are means (± SE) of three replicates with the errors bars showing SE.

the soil-wheat system. Single N_2O emission peaks were observed except on 28 March and 7 April. This result is attributed to the low soil temperature (14.7℃) and minimal soil temperature change (3.1℃) on 28 March as well as the low soil water content (13%) on 7 April. Enhanced UV-B radiation did not change the diurnal variation patterns of N_2O fluxes. A significant difference in mean diurnal N_2O fluxes (MNF) between *C* and *T* during the grain-filling stage (28 April) was observed. Soil MNF decreased by 48.35% ($p = 0.017$) under enhanced UV-B radiation.

Soil N_2O fluxes

Enhanced UV-B radiation did not change the diurnal variation patterns of soil N_2O fluxes (Figure 4). Single soil N_2O flux peaks were observed except on 7 April because of the low soil water content (13.2%) on that day. Enhanced UV-B radiation decreased soil N_2O fluxes particularly during the grain-filling stage (28 April). Soil MNF decreased by 36.87% ($p = 0.027$).

DISCUSSION

Enhanced UV-B radiation did not change the diurnal variations patterns of soil respiration but reduced soil respiration rates particularly during the early stages of winter wheat growth. The reasons of this decline may be due to: 1) the inhibition of crop growth caused by the enhanced UV-B treatment. Enhanced UV-B inhibits crop growth and decreases crop biomass (Reddy et al., 2003; Kakani et al., 2003; Kadur et al., 2007; Yao et al., 2008). Li et al. (2000) examined the growth and yield of 20 wheat cultivars under field conditions by simulating a

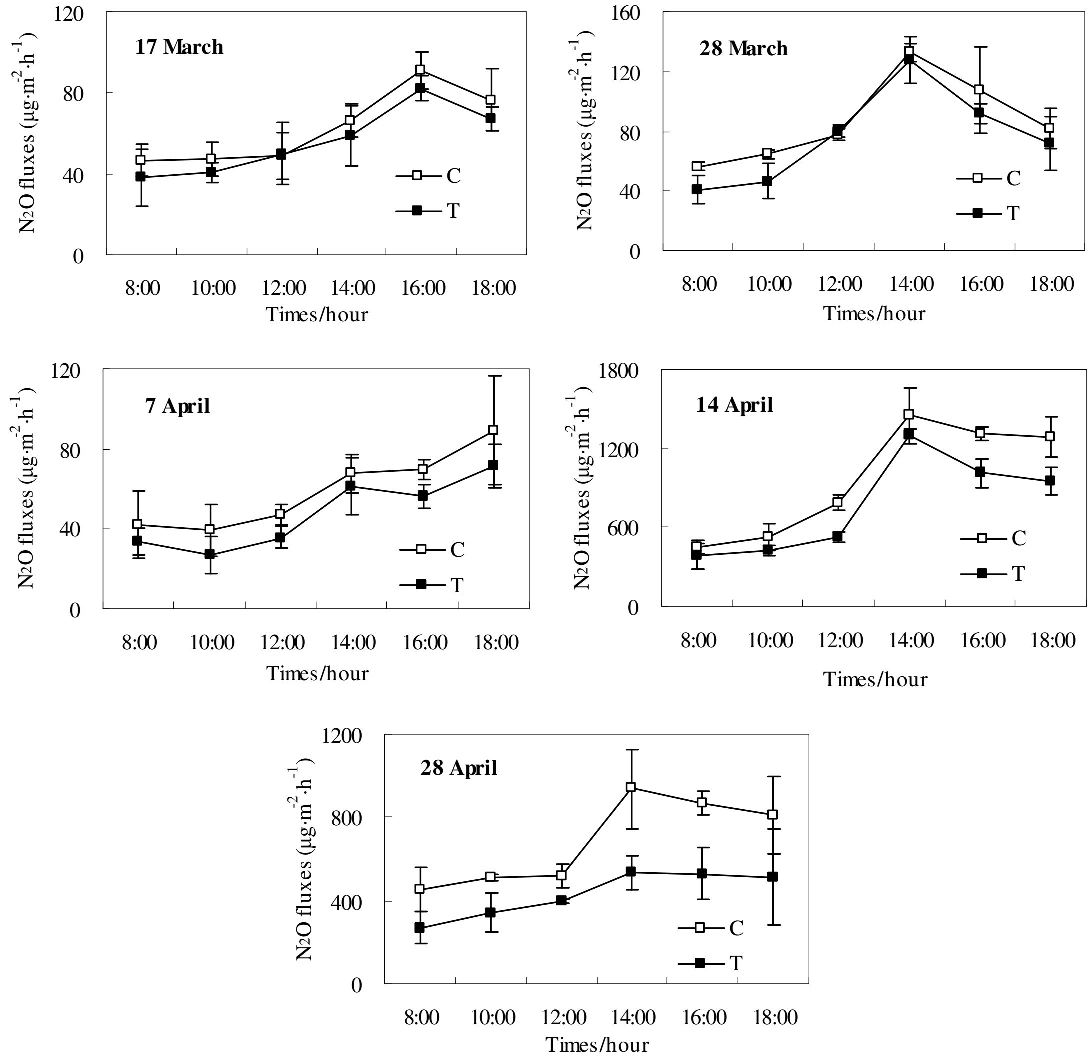

Figure 4. Effects of UV-B treatment on diurnal variations in soil N_2O fluxes. Values are means (± SE) of three replicates with the errors bars showing SE.

supplemental UV-B level similar to 20% stratospheric ozone reduction, and found that the growth and yield of 19 out of the 20 wheat cultivars were inhibited by UV-B radiation. 2) Enhanced UV-B radiation can indirectly influence soil microbial populations and activities (Searles et al., 2001; Johnson et al., 2002, 2003; Robson et al., 2004). This effect may add to our understanding of the differences in soil respiration between C and *T*. 3).

The significant reduction in soil respiration during early growth stages may be due to the sterilization effect of UV-B radiation while the smaller reduction at later growth stages may be due to less sterilization effect as a result of a closed wheat canopy that blocked UV-B radiation. Enhanced UV-B radiation did not change the diurnal variation patterns of the N_2O fluxes from the soil-wheat system and soil. A significant difference in mean diurnal N_2O fluxes between *C* and *T* was observed in the grain-filling stage. The inhibition of crop growth by enhanced UV-B has been extensively reported (Reddy et al., 2003; Kadur et al., 2007; Yao et al., 2008), and crop growth can affect N_2O production because it affects available nitrogen, soluble organic carbon and O_2 in soil (Del Grosso et al., 2000). Crops also serve as a conduit that transports N_2O in soil to the atmosphere (Chang et al., 1998; Yan et al., 2000). Thus, enhanced UV-B may influence N_2O emissions from croplands by inhibiting crop growth. Zheng et al. (2003) found that enhanced UV-B radiation significantly reduced grain yield and aboveground biomass of winter wheat. We made an investigation in the 2009 winter wheat growing season and found elevated UV-B radiation decreased spike, leave and stem biomass by 23.8, 27.9 and 18.7%, respectively.

In addition, N_2O is produced naturally through the nitrification and denitrification activities of soil micro-organisms (Firestone and Davidson, 1989). Lower N_2O

Table 3. Effects of enhanced UV-B radiation on rhizosphere soil NT, NO_3^-N and NH_4^+-N content during the grain-filling stage. Values shown in the table are means ± SE; the *p* values are from paired t-test between the *C* and *T* treatments.

Treatments	TN (mg/g)	NO_3^--N (μg/g)	NH_4^+-N (μg/g)
C	1.60 ± 0.02 ($p = 0.001$)	20.57 ± 0.48 ($p = 0.000$)	45.87 ± 4.43 ($p = 0.012$)
T	1.44 ± 0.01	4.25 ± 0.02	25.58 ± 1.24

emissions may be due to the effects of enhanced UV-B radiation on soil microbial. Since UV-B can penetrate below 5 mm into soil (Moorhead and Callaghan, 1994), enhanced UV-B radiation may impose an effect on microbial populations mainly through direct influence on crop growth and physiological metabolism. This direct effect, in turn, reduces the absorption of available N and affects root secretion, thereby indirectly inducing increased dynamics in microbial communities. UV-B radiation changes soil microenvironment and microbial communities (Searles et al., 2001; Robson et al., 2004). Li et al. (1999) found that enhanced UV-B significantly decreased the total amount of bacteria in the rhizosphere soil of spring wheat. Accordingly, the influence of N_2O emissions on enhanced UV-B radiation may be due to the indirect effects on soil microbial communities.

The significant differences in N_2O emissions on 28 April also could be explained with the difference in plant nitrogen uptake under UV-B radiation.

Ghisi et al. (2002) found that the enzyme activity of nitrate reductase and glutamine synthetase in barley seedlings decreased, although only after a few days of UV-B radiation treatment. Our later study in the 2009 winter wheat growing season in the same farmland showed that enhanced UV-B radiation reduced rhizosphere soil TN (total nitrogen), NO_3^--N and NH_4^+-N content by 10.00, 79.34 and 44.23%, respectively, during grain-filling stage (Table 3). A further investigation, we find that enhanced UV-B significantly reduced soil CO_2 emissions, but not N_2O emissions from soil before the flowering stage (Figures 2 and 4). This phenomenon may have enhanced UV-B radiation effect more on the soil microbial groups that are responsible for decomposition of soil organic matter than the nitrification and denitrification. Nevertheless, more field measurements are deserved to be carried out.

Conclusion

Enhanced UV-B radiation did not change the diurnal variation patterns of soil respiration rate, but reduced soil respiration rate particularly during the early stages of winter wheat growth because mean diurnal respiration rate was markedly reduced. Moreover, enhanced UV-B radiation did not change the diurnal variation patterns of the N_2O emissions from the soil-winter wheat system. During the grain-filling stage, the mean diurnal N_2O fluxes of the soil-wheat system as well as soil mean diurnal N_2O fluxes markedly decreased under enhanced UV-B radiation.

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