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Soil Respiration and N_2O Flux Response to UV-B Radiation and Straw Incorporation in a Soybean–Winter Wheat Rotation System

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Abstract Field experiments were conducted in the 2008–2009 soybean and winter wheat-growing seasons to assess soil respiration (SR) and nitrous oxide (N_2O) emission as affected by enhanced UV-B radiation and straw incorporation. The SR rate was measured using a soil CO_2 flux system; the N_2O flux was measured using a static chamber–gas chromatograph technique. The results showed that in the soybean and winter wheat-growing seasons, enhanced UV-B radiation significantly decreased the SR rates and that straw incorporation increased the SR rates compared to the control treatment. The combined treatment of UV-B and straw incorporation had no obvious influence on the SR rates. Enhanced UV-B radiation, straw incorporation, and the combination treatment increased the temperature sensitivity of SR in the soybean-growing season. The study also showed that N_2O emissions were reduced by enhanced UV-B radiation and that straw incorporation had no significant effects on the mean N_2O emission fluxes in the soybean and winter wheat-growing seasons. Our findings suggest that enhanced UV-B radiation may lead to a decrease in SR and in N_2O emissions, straw incorporation may increase SR, and the combined treatment may have no significant influence on SR and N_2O emissions from soybean–winter wheat rotation systems.

Keywords UV-B radiation · Straw incorporation · Soil respiration · N_2O fluxes · Soybean · Winter wheat

1 Introduction

Nitrous oxide (N_2O) is an important greenhouse gas that contributes to global warming and stratospheric ozone depletion. Its global warming potential in the 100-year window is 298 times greater than CO_2 and has a longer atmospheric lifetime than CH_4 (IPCC 2007a). Furthermore, N_2O contributes to the depletion of the ozone layer in the stratosphere (Weatherhead et al. 2000). The atmospheric N_2O concentration continued to increase with a rate of 0.26 % per year and reached 319 ppb in 2005 (IPCC 2007a). Agroecosystems are considered to be the principal source of atmospheric N_2O, which accounts for 1.7–4.8 Tg N_2O–N per year and 60 % of the global anthropogenic N_2O emission (IPCC 2007b).

Soil respiration (SR), including the autotrophic respiration of plant root and heterotrophic respiration of soil microbes, plays an important role in the global carbon cycle (Buchmann 2000; Schlesinger and Andrews 2000). The global SR flux is 75×10^{15} gC/year (Schlesinger and Andrews 2000), accounting for

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about 80 % of the gross ecosystem respiration (Longdoz et al. 2000). Therefore, small changes in the SR rate may dramatically alter atmospheric CO_2 concentrations and soil C sequestration (Iqbal et al. 2009).

The significant increase in CFC concentrations has lead to stratospheric ozone depletion, which has resulted in the enhancement of ultraviolet-B (UV-B, 280–320 nm) radiation reaching the earth's surface (Rozema et al. 2005; Erickson et al. 2000). The ozone recovery rate depends on many factors, including N_2O emissions (Weatherhead et al. 2000). It is well documented that enhanced UV-B radiation decreases crop photosynthesis rates (e.g., Yang et al. 2007; Pandey and Chaplot 2007), inhibits crop growth (e.g., Kakani et al. 2003; Kadur et al. 2007), and reduces crop biomass (e.g., Yao et al. 2006; Agrawal et al. 2006). It has also been reported that UV-B can influence indirectly the quantity and activity of soil microbial populations (Johnson et al. 2002, 2003). Johnson et al. (2003) suggested that enhanced UV-B radiation causes a decline in the C/N ratio of soil microbial biomass. Crop growth and soil microorganisms are the main factors affecting SR and N_2O emissions in cropland. Chen et al. (2011) and Hu et al. (2010a, b) reported that enhanced UV-B radiation can alter the SR rates and N_2O emissions in farmland.

Agricultural activities produce large quantities of crop residues. Agricultural residue is either removed from the field, burned in situ, or mulched in the field and incorporated into the topsoil (Vibol and Towprayoon 2010). Returning crop residue back to the field is an important way to increase soil fertility and soil organic carbon (e.g., Nie et al. 2007; Lennart and Jan 2006). Therefore, straw incorporation can have an effect on SR and N_2O emission in cropland. Ma et al. (2010) incorporated rice straw into the topsoil of a winter wheat farm and found that the rice straw incorporation can reduce N_2O emission during the wheat-growing season. Cai et al. (2001) and Hao et al. (2001) also stated that straw incorporation can inhibit N_2O emission from croplands. On the contrary, Pathak et al. (2006) found that straw incorporation stimulates N_2O emission from a wheat farm because of higher microbial activity.

Previous research suggests that UV-B radiation or straw incorporation can alter the respiration rates and N_2O emissions in agroecosystems. However, the combination effect of enhanced UV-B and straw incorporation on SR and N_2O emissions has received little attention. To our knowledge, only single-factor effects of UV-B radiation or straw incorporation on SR and N_2O emissions have been reported in the literature (e.g., Hu et al. 2010a, b; Zou et al. 2005; Pathak et al. 2006).

In this study, we hypothesize that the combination impact of UV-B radiation and straw incorporation on crop growth may result in potential changes in SR and N_2O emission fluxes. To test this hypothesis, we returned straw into the topsoil and exposed the soil–soybean and soil–winter wheat system to enhanced UV-B radiation under field conditions using a soil CO_2 flux system and a static chamber–gas chromatograph technique to measure the SR rate and the N_2O flux. The objective of this study was to investigate the effects of enhanced UV-B radiation and straw incorporation on the SR rates and the N_2O emission fluxes in the soybean- and winter-wheat growing seasons. Such information will be beneficial to develop management practices that minimize greenhouse gases emissions from cropland.

2 Materials and Methods

2.1 Experimental Site

The field experiment was carried out during the soybean (July–October 2008) and winter wheat (December 2008–May 2009) growing seasons. The experimental field was located at the experimental farm of Nanjing University of Information Science and Technology (32° 03′ N, 118°51′ E) in East China. Annual rotations such as soybean (*Glycine max*)–winter wheat (*Triticum aestivum*) and paddy rice (*Oryza sativa*)–winter wheat are the main crop production regimes in the area. The annual average temperature was 15.6 °C and the annual rainfall averaged at about 1,100 mm.

The soil (0–20 cm) was classified as hydromorphic and contained 26.1 % clay, an initial pH(H_2O) of 6.22, a total organic carbon of 19.4 $g\,kg^{-1}$, and a total nitrogen of 1.45 $g\,kg^{-1}$.

2.2 Experimental Design

The field experiment was designed with four treatments: control (C, ambient UV-B radiation and no straw incorporation); cropping with the 20 % enhancement of UV-B (U); cropping with straw incorporation (S, wheat straw in the soybean-growing season and

rice straw in the winter wheat-growing season); and cropping with the 20 % UV-B enhancement plus straw incorporation (US). Each treatment had three replicate plots (2×2-m^2 area of each plot). Plots were randomly arranged in three blocks, each block containing a replicate plot of the four treatments. The blocks were separated by 0.5-m strips. The interval distance of crop rows was 30 cm. The main growth stages and fertilization schedules of soybean (cv. Bayuedou) and winter wheat (cv. Yangmai 14) are shown in Table 1.

2.3 UV-B Treatments

Supplemental UV-B radiation was supplied with fluorescent UV lamps (40 W, Huade Instrument Factory, Shanghai, China). Lamps were hung over and perpendicularly to the planted rows and were arranged east–westward to minimize shading. The UV-B lamps of the control group (C) were wrapped with a polyester plastic film (Mylar-D, 125-μm thickness; DuPont Co., Wilmington, DE, USA) which filters off all UV-B radiation and UV-C radiation of the lamps (Fig. 1). The plastic film was replaced weekly to ensure uniformity in UV-B absorption. Plants under polyester-filtered lamps received only ambient levels of UV-B radiation, whereas plants beneath the exposed UV-B lamps received ambient and supplemental levels of UV-B radiation.

The UV-B radiant intensity was recorded automatically with a UV-B radiance measurement instrument composed of UV-B radiation sensors (spectral range, 280–315 nm; SKU430, Skye Co., UK) and data loggers (Skye-Datahog, Skye Co.). The sensors were installed at the vegetation level at the center of each plot. Plants were irradiated daily for 8 h (08:00–16:00 hours) from the seedling to the harvest stages.

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

Growing season	Date	Growth stages or fertilization schedules
Soybean	6 July 2008	Sow
	9 July 2008	Seedling
	14 July 2008	Trefoil
	14 August 2008	Branching
	23 August 2008	Flowering
	7 September 2008	Pod
	19 September 2008	Grain-filling
	13 October 2008	Harvest
Winter wheat	2 December 2008	Sow, 100 $kgNha^{-1}$ (urea), 78 $kgPha^{-1}$, 100 $kgKha^{-1}$
	18 December 2008	Seeding
	15 January 2009	50 $kgNha^{-1}$, 21 $kgPha^{-1}$, 27 $kgKha^{-1}$
	14 February 2009	Turning green, 50 $kgNha^{-1}$
	23 March 2009	Elongation
	11 April 2009	Booting
	17 April 2009	Heading
	21 April 2009	Flowering
	27 April 2009	Grain filling
	31 May 2009	Harvest

2.4 Straw Incorporation

The straw of winter wheat and rice were collected from wheat and rice fields. Dried straw was chopped into 2-cm length. The total C and total N of wheat straw were 51.2 and 0.9 %, respectively, and the total C and total N of rice straw were 46.7 and 1.2 %, respectively. Straw was spread evenly over the plots and incorporated into the plough layer (0–20 cm). The applied rate of straw was 225 gm^{-2} in treatments S and US.

2.5 SR and N_2O Flux Measurements

SR was measured using an automated soil CO_2 flux measurement system (Li-8100, Li-Cor Inc., Lincoln, NE, USA) with an attached chamber. PVC soil collars, with a height of 10 cm and a diameter of 20 cm, were permanently inserted 3 cm into the soil for SR measurements. There were three collars in each plot and nine collars for each treatment. Aboveground vegetation within the soil collar was eradicated by hand several days prior to chamber placement. Therefore, the SR we measured did not include aboveground respiration from living plants. The Li-8100 chamber was put on the PVC collar to measure SR at each plot and then moved to the next plot. The analyzer optical bench measured CO_2 concentration in the chamber; the CO_2 flux rates (in micromoles CO_2·per square meter per second) were calculated from the increase in CO_2 concentration over time. SR measurements were made once or twice weekly. On each measurement day, SR was measured from 8:00 to 11:00 hours.

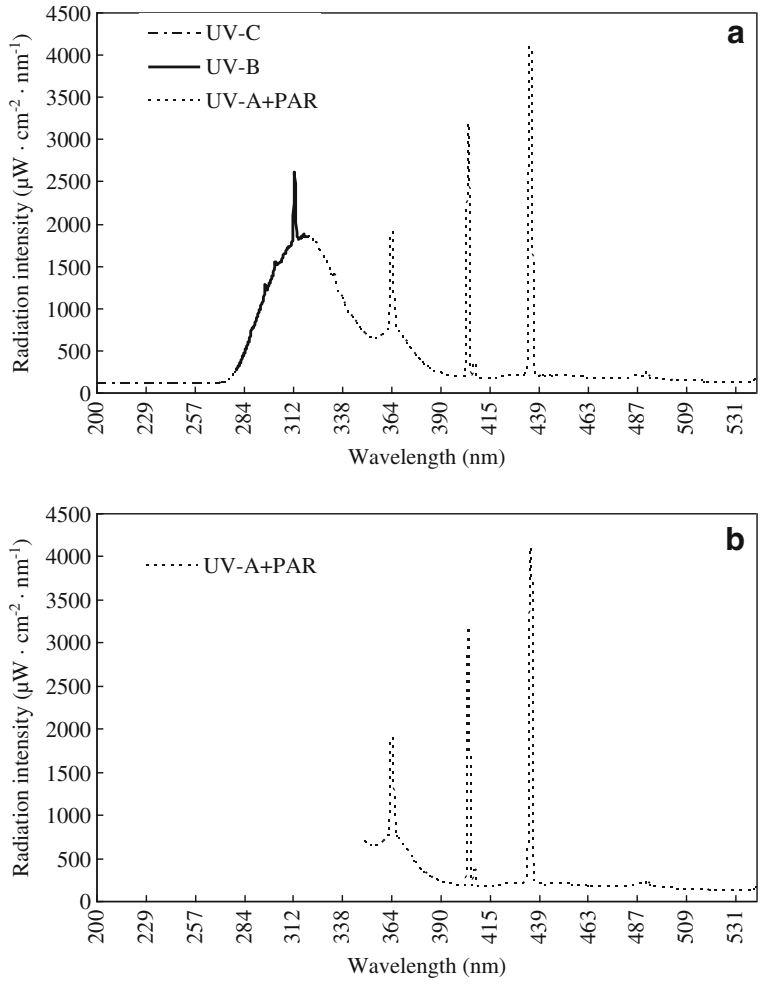

Fig. 1 Spectrum of UV-B tubes (**a**) and Mylar film-filtrated UV-B tubes (**b**)

The Li-8100 system included soil temperature and moisture sensors. The soil temperature and moisture sensors were inserted into the soil at the time of SR measurement. Soil temperature and moisture at the 5-cm depth were monitored adjacent to each PVC collar.

The N_2O emission flux was measured using a static chamber–gas chromatograph technique (Zou et al. 2005). During the crop growing season, boardwalks were installed to reduce soil and crop disturbance during gas sampling. Circular base frames for the gas chamber were installed in the plots. Each base frame was 8 cm high and had 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 a layer of sponge and aluminum foil to minimize the effect of solar radiation on the internal temperature. During the measurement, the chamber was placed over the vegetation with its rim matching the groove of the base frame. The chamber was sealed by filling water in the groove on the top edge of the base frame. 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. N_2O flux measurements were made once or twice weekly. Air temperature inside the chamber was recorded for each flux measurement. Soil temperature and moisture at a 10-cm depth were measured adjacent to the base frames at the time of gas sampling, with a W.E.T. monitor (Delta-T Devices Ltd., Burwell, Cambridge, UK).

The gas samples were analyzed for N_2O with a gas chromatograph (Agilent 6890N, Agilent Co., USA) equipped with an electron capture detector (ECD) (Wang and Wang 2003). The oven was operated at 55 °C and the ECD at 330 °C. The N_2O flux was determined from the slope of the changes in the

mixing ratio with durations at 0, 10, and 20 min following chamber closure (Chen and Huang 2009). Almost all the sample sets yielded linear regression values of $R^2>0.90$ for the mixing ratio–time relationship.

2.6 Crop Biomass Measurements

At the end of each cropping season, root biomass and aboveground biomass (shoot biomass) were harvested and determined by oven drying to constant weight at 70 °C.

2.7 Statistical Analysis

The average SR rates and N_2O flux and their standard errors were calculated based on replicated measurements. The primary and interaction effects of enhanced UV-B radiation and straw incorporation on SR and the N_2O flux were evaluated by ANOVA. Significance referred to in the text is at the $p=0.05$ level, unless otherwise stated. All statistical analysis was conducted using SPSS 13.0 (SPSS Inc., Chicago, IL, USA).

3 Results

3.1 Changes of Soil Temperature and Moisture

The seasonal changes of soil temperature and moisture are shown in Fig. 2. Soil temperature (Fig. 2a, b) shows the seasonal patterns following seasonal variation in air temperature. No significant difference in soil temperature was observed among the C, U, S, and US treatments ($p>0.05$). Soil moisture (Fig. 2c, d) has no clear seasonal variation, and no differences in soil moisture among different treatments were observed. In this case, soil moisture of different treatments had the same effects on the respiration rate and the N_2O emission (see also Cook and Orchard 2008).

3.2 Effects of Enhanced UV-B Radiation and Straw Incorporation on SR

3.2.1 Temporal Dynamics of SR

The SR rate shows similar seasonal patterns for different treatments (Fig. 3a, b). It is clear that enhanced UV-B radiation and straw incorporation did not alter

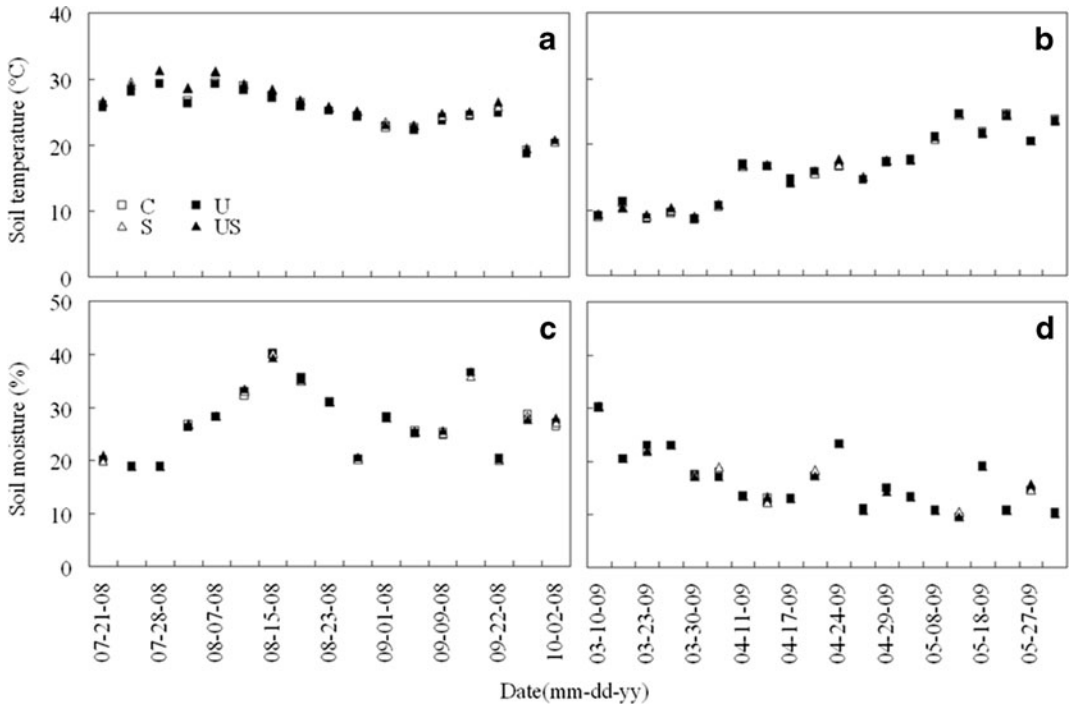

Fig. 2 Seasonal variation in soil temperature (T_s) and moisture (M_s). **a**, **b** T_s in the soybean- and winter wheat-growing seasons, respectively. **c**, **d** M_s in the soybean- and winter wheat-growing seasons, respectively

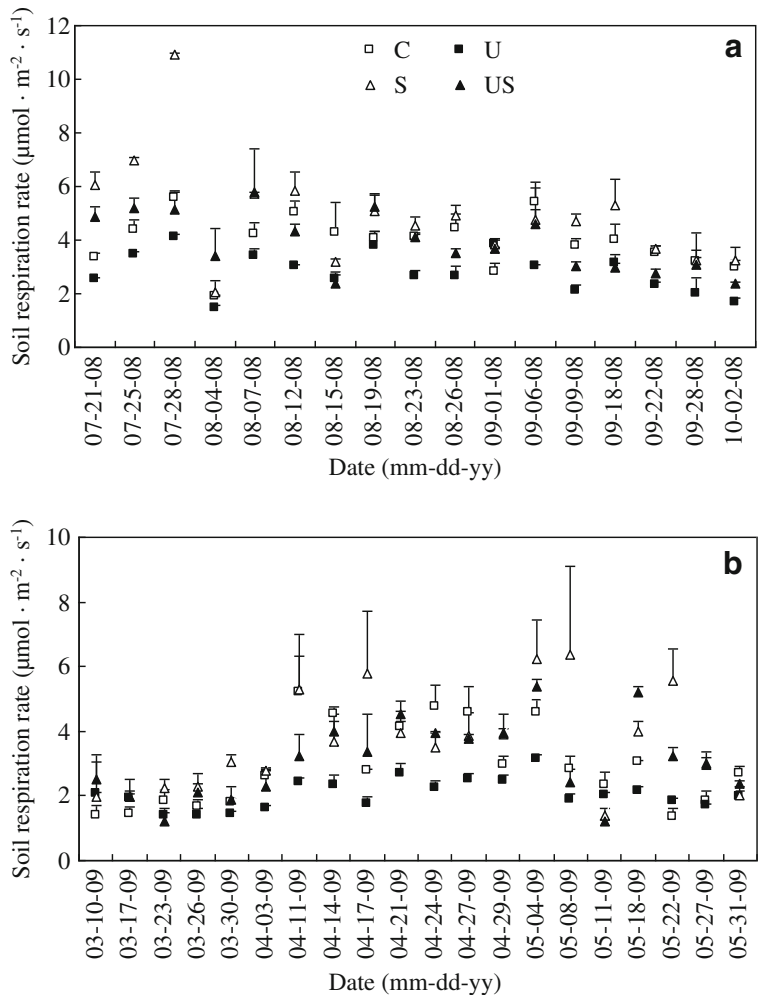

Fig. 3 Effects of enhanced UV-B and straw incorporation on SR rates. **a**, **b** SR rates in the soybean- and winter wheat-growing seasons, respectively. Data are the mean values. *Error bars* are SEs

the seasonal patterns of SR in the soybean- and winter wheat-growing seasons, which generally corresponded to the seasonal variation of soil temperature.

3.2.2 Seasonal Mean SR Rates

The seasonal mean SR rates of the four treatments are shown in Fig. 4. In the soybean-growing season, the SR rates were significantly reduced by 30.3 % (p=0.002) under the U treatment and increased by 14.5 % (p=0.050) under the S treatment compared with that under the C treatment. No difference existed between the SR rates of C and US (p=0.193), suggesting that there may be an antagonism between enhanced UV-B radiation and straw incorporation. In the winter wheat-growing season, the SR rates were significantly reduced by 29.6 % (p=0.007) under the U treatment and increased by 25.1 % (p=0.108) under the S treatment compared with that under the C treatment. No

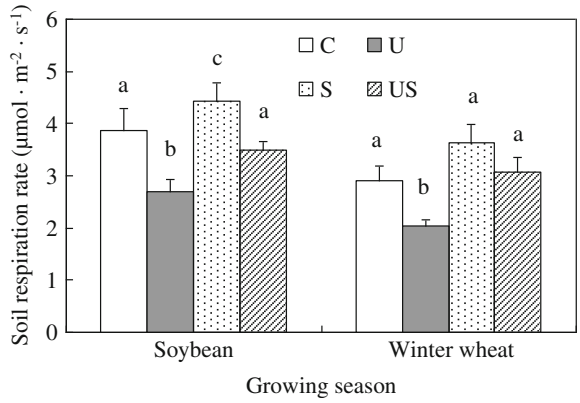

Fig. 4 Seasonal mean SR rates. Data are the mean values±SE. *Different lowercase letters* denote significant difference among different treatments at $p \leq 0.05$

significant difference in SR rates was observed between the C and the US treatments (p=0.669).

The seasonal mean SR rates for the C, U, S, and US treatments were 3.86, 2.69, 4.42, and 3.50 μmol$m^{-2}s^{-1}$ in the soybean-growing season, respectively, and 2.91, 2.05, 3.64, and 3.08 μmol $m^{-2}s^{-1}$ in the winter wheat-growing season, respectively (Fig. 4). During the two growth seasons, the greater inhibition effect of UV-B and the greater promotion effect of straw incorporation on the SR rates were found in the soybean-growing season and the winter wheat-growing season, respectively.

3.2.3 Temperature Sensitivity of SR

Regression analysis shows an extremely significant exponential relationship between the SR rates and soil temperature (p<0.01; Fig. 5). Soil temperature itself can explain about 50 % of the seasonal variations in the SR rates (Fig. 5). The regression b values were used to calculate the SR temperature sensitivity coefficient Q_{10} ($=e^{10b}$). In the soybean-growing season, the Q_{10} values of the C, U, S, and US treatments were 1.55, 1.91, 1.80, and 1.71, respectively. The U, S, and US treatments increased the Q_{10}, indicating that UV-B radiation and straw incorporation increased temperature sensitivity of SR in the soybean-growing season.

3.3 Effects of Enhanced UV-B Radiation and Straw Incorporation on N_2O Emission

The mean N_2O emission fluxes of the different growth stages in the soybean- and winter wheat-growing seasons are shown in Fig. 6. In the soybean-growing season, the mean N_2O fluxes were lower in the U treatment than in the C, S, and US treatments. The U treatment reduced N_2O fluxes by 37.9 % (p=0.001), 24.6 % (p=0.038), 48.4 % (p=0.007), and 34.2 % (p=0.001) in the trefoil–branching stage, the flowering–podding stage, the seed filling–mature stage, and the whole growth stage, respectively, compared with that under the C treatment. Enhanced UV-B radiation had a significant inhibition on the N_2O emission from the cropland. Compared to the C treatment, both S and US increased the mean N_2O fluxes by 19.4 and 20.6 % in the flowering–podding stage and reduced the mean N_2O fluxes by 26.4 % (p= 0.006) and 22.3 % (p=0.015) in the trefoil–branching stage. According to the mean N_2O fluxes in the whole growth stage, S and US had no significant effect on the N_2O emission compared to the C treatment.

In the winter wheat-growing season, compared to the C treatment, the U treatment reduced N_2O fluxes by 23.4 % (p=0.022), 35.7 % (p=0.000), 39.7 % (p= 0.001), and 24.7 % (p=0.000) in the elongation–

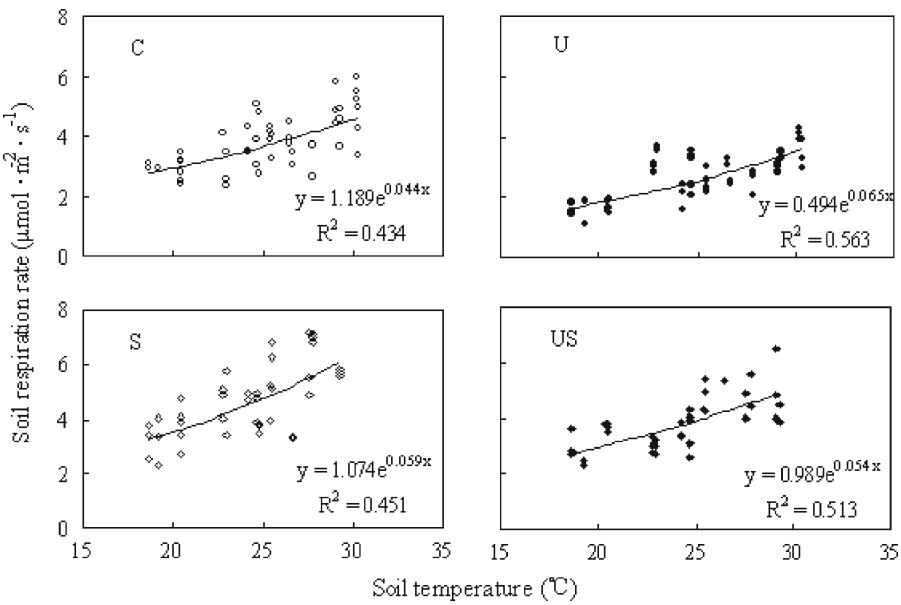

Fig. 5 Relationship between SR rates and soil temperature in the soybean-growing season

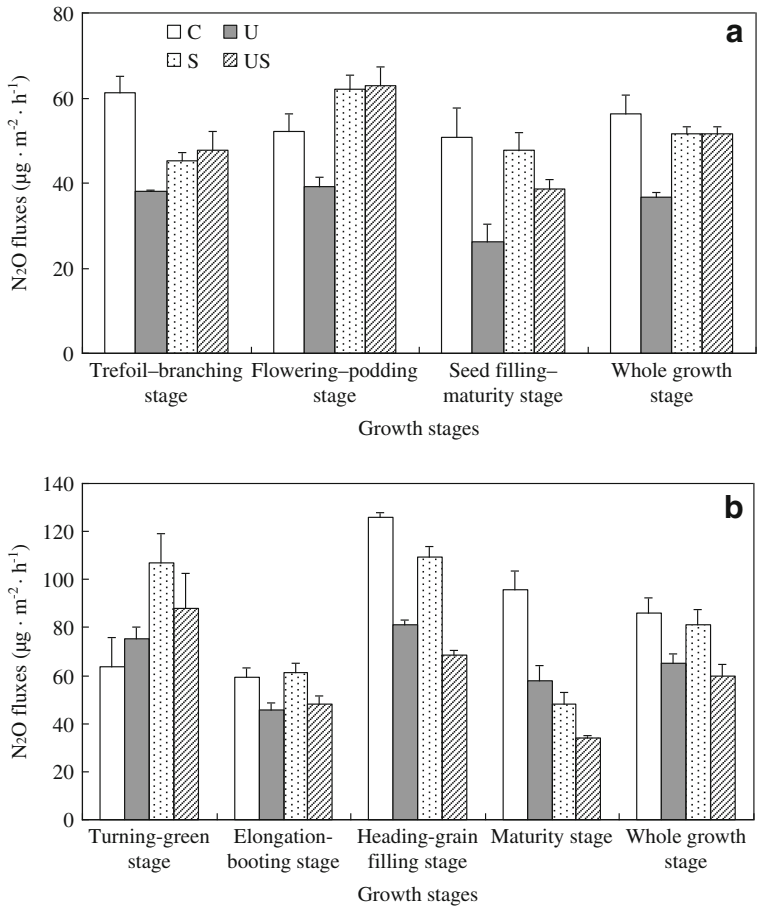

Fig. 6 Effect of enhanced UV-B radiation and straw incorporation on the mean N_2O fluxes in different growth stages. **a**, **b** N_2O fluxes in the soybean- and winter wheat-growing seasons, respectively. Data are the mean values. *Error bars* are SEs

booting stage, the heading–grain filling stage, the maturity stage, and the whole growth stage, respectively. According to the mean N_2O fluxes of the whole growth stage, compared to C, S had no significant effects on the N_2O emission, while US reduced the mean N_2O fluxes by 44.5 % (p=0.016).

4 Discussion

4.1 Soil Respiration

Our study suggests that enhanced UV-B radiation reduced SR rates in the soybean-growing season and the winter wheat-growing season. It has been shown that enhanced UV-B radiation can inhibit photosynthesis and growth of crop, leading to inhibited root development and the accumulation of dry matter (Pal et al. 2006). In the present study, we found that enhanced UV-B radiation significantly decreased root biomass, shoot biomass, and total biomass of soybean by 68.3, 73.9, and 73.6 %, respectively (Table 2). The relationship between soybean biomass and the SR rates was y=0.3191x−6.263 (R^2=0.938), indicating that the mean SR rate had a significantly positive relationship with biomass. In the winter wheat-growing season, enhanced UV-B radiation decreased shoot biomass and total biomass by 14.1 and 12.1 %, respectively (Table 2). Enhanced UV-B had a more negative effect on soybean than on winter wheat (Table 2), explaining the greater UV-B's inhibition effect on the SR rates in the soybean-growing season.

Since UV-B radiation can penetrate, below 5 mm, into the soil (Moorhead and Callaghan 1994), UV-B radiation may impose an effect on microbial communities via direct influence on plant growth and physiological metabolism and therefore decrease the respiration of root and soil microorganisms. It has also been well recognized that enhanced UV-B radiation can indirectly influence soil microbial populations and

Table 2 Effect of enhanced UV-B radiation and straw incorporation on biomass of soybean and winter wheat (grams per base frame)

Treatments	Root biomass		Shoot biomass		Total biomass	
	Soybean	Winter wheat	Soybean	Winter wheat	Soybean	Winter wheat
C	2.87±0.16a	2.10±0.10a	50.64±2.46a	29.49±0.51a	53.50±2.31a	31.58±0.41a
U	0.91±0.10b	2.44±0.04ab	13.21±1.17b	25.33±0.64b	14.12±1.26b	27.77±0.63b
S	5.39±0.86c	2.76±0.18b	81.27±12.80c	30.15±1.01a	86.66±13.63c	32.92±0.89a
US	4.87±0.70c	2.11±0.45a	92.35±6.63c	29.24±0.40a	97.22±7.18c	31.34±0.47a

Data are the mean values±SE. Different lowercase letters denote significant difference among different treatments at $p \leq 0.05$

activities (Searles et al. 2001; Johnson et al. 2002, 2003; Robson et al. 2004), which may add to our understanding of the differences in SR between C and U treatments.

In this study, straw incorporation can promote SR rates (as shown by comparing the S with the C treatment), consistent with the observations of Montoya-González et al. (2009). Curtin et al. (1998) conducted an experiment under controlled conditions (constant 20 °C) and also found that wheat straw incorporation significantly increases soil CO_2 flux. The reasons may be twofold: (1) straw incorporation can increase the amount of organic matter in soils (Nie et al. 2007), facilitate the mineralization of soil carbon (Duong et al. 2009; Jacinthe et al. 2002), and increase the light constituent of organic carbon that can be easily decomposed and utilized by soil microbe (Malhi and Lemke 2007). Xu et al. (2011) found that total C mineralization, microbial biomass C, particulate organic C, and labile organic C are significantly increased under straw incorporation after a 2-year duration. Roldán et al. (2003) also found similar results in short-term (1 year) residue management experiments. (2) Straw incorporation can promote the root/shoot biomass ratio of crop plant (Li et al. 2008), which is a benefit to root respiration. Previous studies suggest that about 70 % of the total carbon allocated to the root is used for respiration and only 30 % total carbon is used for growth (Högberg et al. 2002). Table 2 shows that straw incorporation significantly improved the root/shoot biomass ratio by 21.5 and 35.3 % in the soybean- and the winter wheat-growing seasons, respectively. Thus, straw incorporation had the greater promotion effect on the SR rates in the winter wheat-growing season.

Compared to C treatment, the US treatment had no significant effect on the SR rates in the soybean- and winter wheat-growing seasons. In the winter wheat-growing season, the US treatment had no significant effect on the root, shoot, and total biomass and the ratio of root/shoot biomass (Table 2). In the soybean-growing season, the US treatment increased the root, shoot, and total biomass (Table 2), but did not change the ratio of root/shoot biomass (0.056 and 0.053 of the C and US treatments, respectively). It is well known that crop growth is the main factor influencing the SR rates, thereby explaining the no significant difference in the SR rates between the C and US treatments. Table 2 also shows that enhanced UV-B radiation has a significant negative influence on plant biomass and that straw incorporation had a positive influence on biomass, which means that the application of straw can effectively alleviate, even eliminate, the negative influence brought by enhanced UV-B radiation.

4.2 Soil Temperature, Moisture, and SR

Soil temperature and moisture are two crucial factors in controlling the SR rates. Our results show the expected exponential correlation of the SR rates with soil temperature. Soil temperature controls the rate of biological reaction through its influence on enzyme kinetics (Davidson and Janssens 2006; Davidson et al. 2006). Soil moisture is another factor driving the seasonal variations in the SR rates. If a wet site dries substantially or a dry site is wet substantially, a large variability of soil respiration may occur (Davidson et al. 1998; Jassal et al. 2008; Lee et al. 2004). Our site experienced great variations of soil moisture during the experimental period (Fig. 2), which contributed substantially to the significant effects of soil moisture on the SR rates.

Q_{10} has been commonly used to estimate the SR rates from temperature (Curiel et al. 2004). Q_{10} is

related to many factors including temperature, organic matter, microbial biomass, soil available matter, and plant LAI (Davidson et al. 1998). In this study, we did not discuss the Q_{10} of SR in the winter wheat-growing season, for there were large influences on Q_{10} not only from soil temperature but also plant senescence and lower soil moisture in the later growth stages of winter wheat (Fig. 2), and the effect of soil moisture on Q_{10} is complex (Qi et al. 2002).

In our study, UV-B radiation can promote the Q_{10} of SR in the soybean-growing season. There are several potential reasons for this: (1) UV-B radiation can inhibit plant photosynthesis, root growth, and dry matter accumulation (Pal et al. 2006), which are related to the Q_{10} value. Davidson et al. (1998) suggested that Q_{10} responses not only to temperature but also plant root biomass, litter inputs, and microbial populations. (2) UV-B radiation has an indirect positive effect on the amount of soil bacteria, which may be sensitive to temperature change. Previous research suggested that UV-B radiation can increase the biomass C and N in soil microbes (Hu et al. 2010b), which may accelerate the decomposition of carbon and nitrogen compounds as temperature rises, resulting in the rise of the Q_{10} values. Therefore, enhanced UV-B may modify the value of Q_{10} by changing the growth of crop and the structure and the quantity of microbial communities. On the other hand, straw incorporation also increased Q_{10} in the soybean-growing season, which may be attributed to increased soil microbial biomass (Jacinthe et al. 2002) and the abundance and the activity of soil microbes. The Q_{10} value will change as the proportion of temperature-sensitive microbe increases.

Further studies on plant chemistry and the decomposition processes in soil are needed to understand the mechanisms of the effects of UV-B and straw incorporation on the temperature sensitivity of SR. Further studies attempting to investigate the temperature sensitivity of SR should characterize the different responses of the autotrophic and the heterotrophic respiration to UV-B radiation and straw incorporation.

4.3 N_2O Fluxes

Sharp variations in the N_2O emission between the C and U treatments were observed in the soybean- and winter wheat-growing seasons (Fig. 6a, b). The potential reason for the reduced N_2O emission under U treatment is that UV-B radiation can inhibit the growth of plant and the accumulation of organic matter and therefore reduce the biomass (Table 2).

Some studies suggest that incorporation of straw into the soil is an effective way to reduce N_2O emission. Ma et al. (2010) reported that rice straw incorporation in which straw was evenly incorporated into the topsoil decreases N_2O emission by 3–18 %. Our study shows that straw incorporation had no significant effect on the mean N_2O emission fluxes in the soybean- and the winter wheat-growing seasons. Cai et al. (2001) reported that straw addition does not play a significant role in N transformation compared to the effect of the inherent soil organic carbon content. Our results are also consistent with the result of Hao et al. (2001) who observed no enhanced N_2O emission from straw incorporation into the soil, even in the same place for over 10 years, indicating that the proportion of straw N converted to N_2O may be less than the proportion of fertilizer N converted to N_2O. According to the integrated effects of UV-B and straw incorporation (US) on the mean N_2O fluxes in the winter wheat-growing season, enhanced UV-B radiation played a larger role in N_2O emission than straw incorporation.

Straw incorporation can stimulate the denitrification rates by providing available C for denitrifying bacteria (with adequate NO_3^- and moisture). Additionally, the decomposition of straw will consume oxygen, which stimulates denitrification rates and N_2O production (Groffman 1985; Hao et al. 2001). On the other hand, the addition of a high C/N ratio straw will induce N immobilization and decrease the available N for nitrification and denitrification, which reduces N_2O production (Hao et al. 2001). In other words, the amount of N_2O production is determined by two compensating processes.

5 Conclusions

Enhanced UV-B radiation, straw incorporation, and the combination treatment did not change the seasonal pattern of the SR rates in the soybean- and winter wheat-growing seasons. Over the growing seasons, enhanced UV-B radiation significantly reduced the SR rates, straw incorporation increased the SR rates, and the combined treatment of UV-B and straw incorporation had no obvious influence on the SR rates. Enhanced UV-B radiation, straw incorporation, and

the combination treatment increased the temperature sensitivity of SR in the soybean-growing season.

In the whole growth stage, enhanced UV-B radiation significantly decreased the mean N_2O emission fluxes, and straw incorporation had no significant effect on the mean N_2O emission fluxes in the soybean- and winter wheat-growing seasons. The combination treatment of UV-B and straw incorporation had no significant effect on the mean N_2O emission fluxes in the soybean-growing season, but decreased the mean N_2O emission fluxes in the winter wheat-growing season.

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