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Yale-NUIST Center on Atmospheric Environment

Effects of elevated O_3 concentration on soil respiration and N_2O flux in soybean and winter wheat farmland

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Outline

1 Background

- The tropospheric ozone (O_3) concentration has increased considerably since preindustrial times (Runeckles and Krupa 1994).
- Regional levels of O_3 are likely to continue increasing where there is continued rapid population growth and use of fossil fuels in automobiles and industry (Hough and Derwent 1990; Yunuset al.1996).
- Particularly, the O_3 concentration has dramatically increased over the last decades in China, due to increased economic growth and higher emission levels of volatile organic compounds and nitrogen oxides (NO_x) (Wang and Mauzerall 2004; Wang et al. 2007).

1 Background

- Soil respiration, the flux of carbon dioxide (CO_2) from the soil surface to the atmosphere, comprises the second-largest (the largest is gross primary production) terrestrial carbon flux (Bond-Lamberty and Thomson 2010).
- Soil respiration represents the integrated response of plant roots and soil organisms to environmental conditions and the availability of C in the soil (Tingeyet al.2006).
- Nitrous oxide (N_2O) is an important greenhouse gas, its global warming potential in the 100-year window is 298 times greater than CO_2 (IPCC 2007).
- Furthermore, N_2O contributes to the depletion of the ozone layer in the stratosphere (Weatherhead et al. 2000).

1 Background

- These indirect effects of elevated O_3 may alter soil biological processes by modifying the soil physical conditions and mediating the availability of C substrates for microorganisms (Islam et al.2000;Kanervaet al. 2007), which may thus influence the production and emission of soil CO_2 and N_2O flux.
- There be some effect on above ground, underground and total dry matter yield, as well as total nitrogen content, nitrate nitrogen content and annonia nitrogen content in leaves and soil, which caused the influence of elevated O_3 radiation on respiration rate and N_2O emission from soil-crop system.

2 Objectives

- whether and how elevated O_3 affects soil respiration and N_2O emissions in the soybean- and winter wheat-growing seasons;
- whether elevated O_3 affects soil respiration and N_2O emissions through inhibiting soil C and nitrogen (N) transformation processes (rates of CO_2 production, nitrification, and denitrification);
- how soil temperature and moisture affect soil respiration and N_2O emissions under different O_3 treatments.

3 Methods

3.1 Experimental site

- The experimental farm of Nanjing University of Information Science & Technology (32° 12′N, 118° 15′E), East China.
- Annual average temperature of the experimental site is 15.6℃ and annual rainfall averages 1100mm.
- The soil (0–20 cm) was classified as hydromorphic, 26.1% clay, pH(H_2O) 6.22, TOC 19.4 g kg^{-1}, and TN 1.45 g kg^{-1}.

3.2 Experimental design

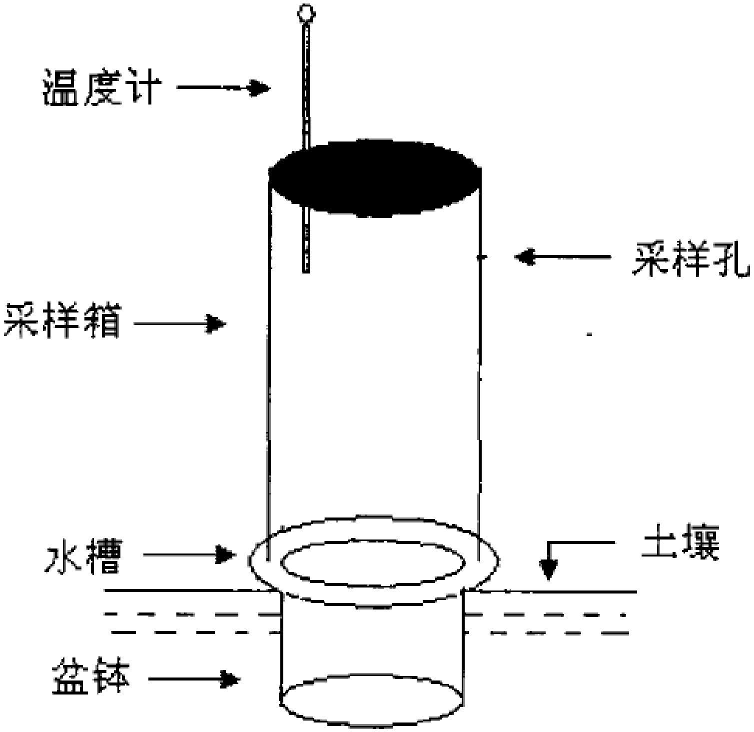
- Field experiments were carried out in the winter wheat and soybean growing seasons.
- For the exposure studies we used OTCs (2.5m high and 3.0m in diameter) consisting of steel frames covered by transparent plexiglass.
- In each OTC, pipes with many small holes (10mm in diameter and at an interval of 100mm) release gases.

3.3 O_3 treatments

- We set up three treatments: (i) ambient air (control, coded CK); (ii) elevated O_3(100 ppb O_3); (iii) elevated O_3(150 ppb O_3) .
- Crops and soils were exposed to ambient air or elevated O_3 except on rainy days. Daily exposure time was 8h (08:00–16:00).
- For the elevated O_3 treatment, pure O_3 produced as described above was mixed with air, in order to obtain the prescribed O_3 concentration (100 ppb).
- The O_3 was generated from pure oxygen by high-voltage electric discharge in an O_3 Production Machine (Wohuan Inc.,Nanjing, China). Solenoid valves and electromagnetic valves,linked with a programmable Log Controller (Wohuan Inc., Nanjing, China).

3.4 Soil respiration and N_2O Measurements

- Soil respiration: LI-8100.
- N_2O emission flux: a static chamber–gas chromatograph technique, Agilent-6890N.
- 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


温度计
采样孔
采样箱
水槽
土壤
盆钵

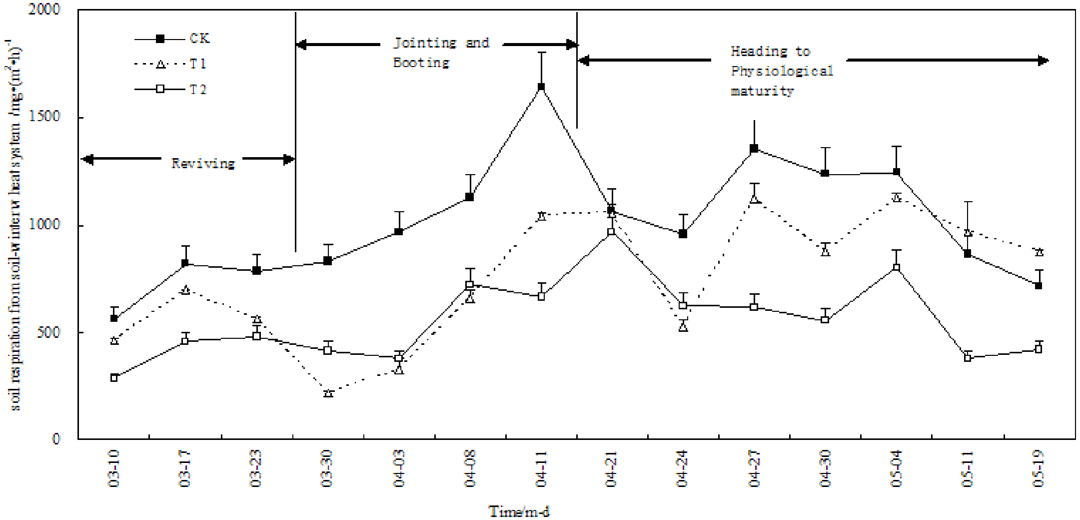

进气孔

3.5 Plant and Soil Samples Analysis

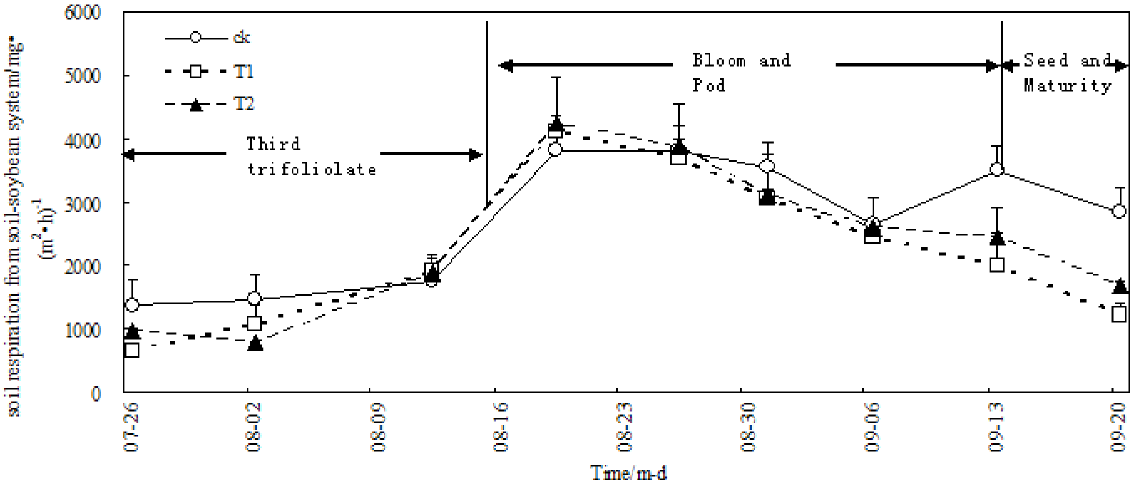
- BaPS (Barometric Process Separation)
- NO_3^--N, NH_4^+-N, and TN in soil and leaves.
- Microbial biomass C, N (Lu, 2000).
- Soluble protein content, and NR activity (Li, 2000).
- Soil temperature and moisture.

4 Results and Discussion

4.1 Effects of elevated O_3 on soil respiration



a



b

Fig. 1 Effects of elevated O_3 on CO_2 emission fluxes (Mean + SD) from soil-winter wheat (a) and soybean (b) system

4.1 Effects of elevated O_3 on soil respiration

Table 1 Effects of elevated O_3 on average CO_2 emission (Mean + SD) in different growth stages. a, b in the winter wheat-and soybean-growing seasons, respectively. *Designate the significant difference between CK and T.

(a) mg•(m^2•h)$^{-1}$

Treatments	Reviving	Jointing and Booting	Heading and Maturity	Whole growth period
CK	720.58	1140.15	1061.48	1010.91
T_1	570.48*	561.00*	933.99	749.53*
T_2	405.83*	543.30*	621.13*	552.76*

(b) g•(m^2•h)$^{-1}$

Treatments	Third trifoliolate	Bloom and Pod	Seed and Maturity	Whole growth period
CK	1.48±0.16	3.49±0.56	2.77±0.41	7.73±1.13
T_1	1.22±0.21	3.40±0.14	1.29±0.18*	5.91±0.53*
T_2	1.22±0.07	3.25±0.81	1.70±0.09*	6.17±0.97*

4.1 Effects of elevated O_3 on soil respiration

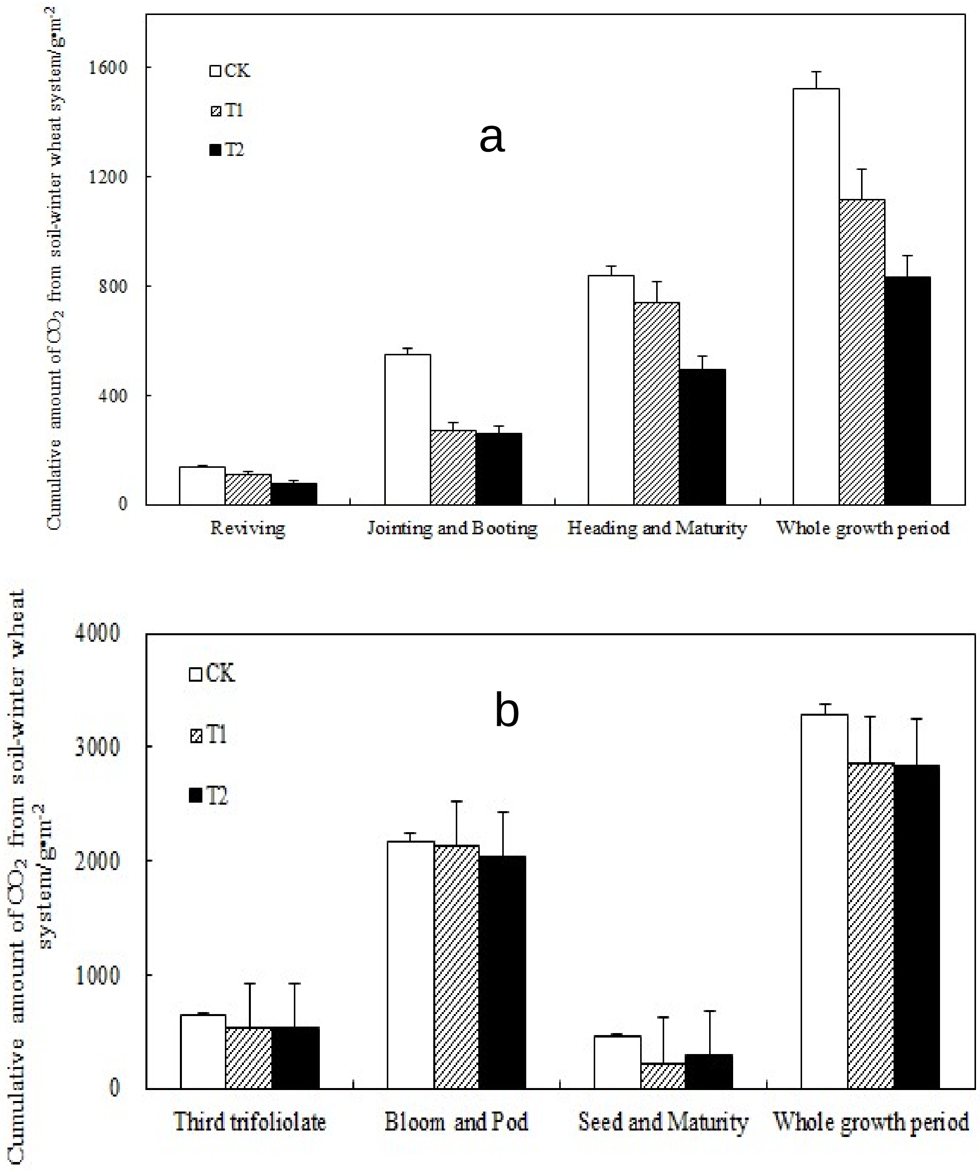
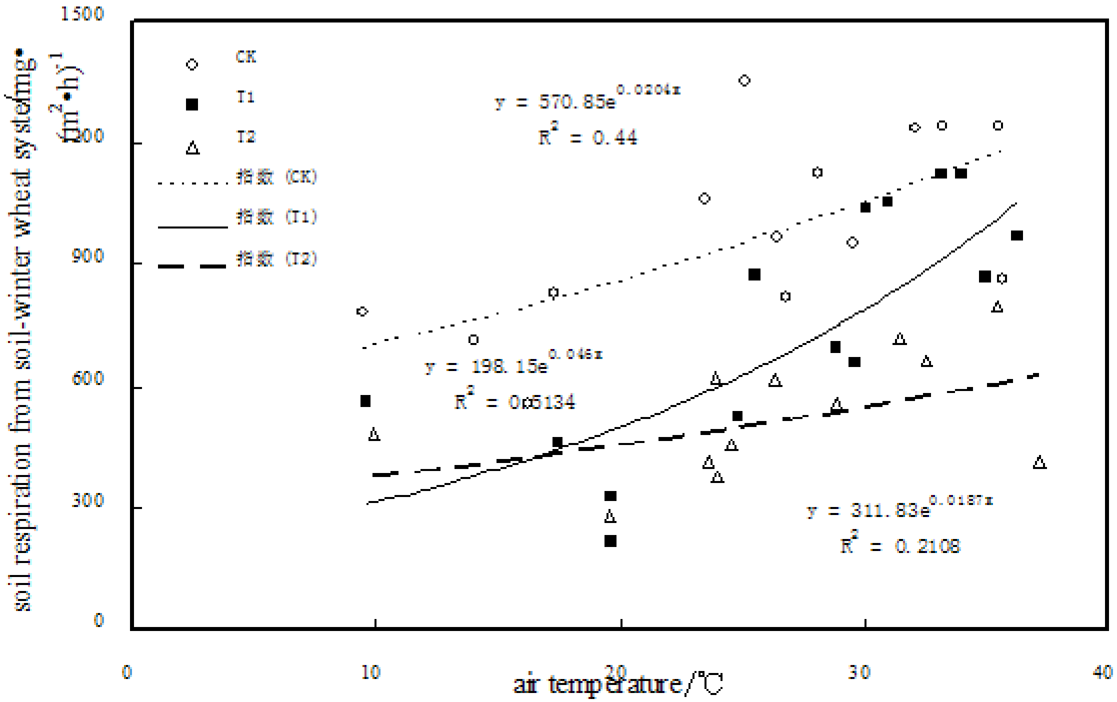


Fig. 2 Effects of elevated O_3 on cumulative amount of CO_2 emission in different growth stages. a, b in the soil-winter wheat-and soybean system, respectively.

4.1 Effects of elevated O_3 on soil respiration



Q_{10}

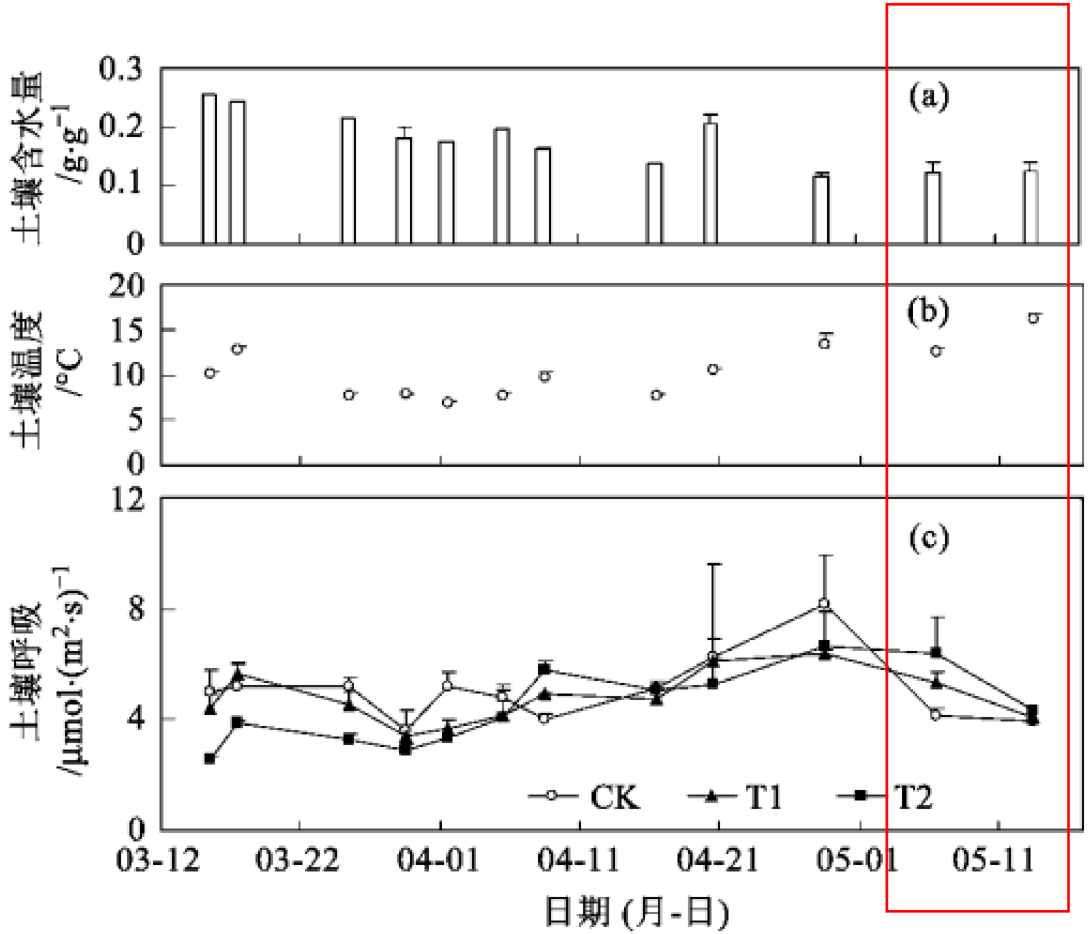
CK=1.13

T_1=1.58

T_2=1.21

Fig. 3 Relationship between soil-winter wheat system respiration rate and air temperature.

However, effects of elevated O_3 on soil CO_2 flux have been reported as
absent(Tingey *et al*. 2006;Kanerva *et al*. 2007),
negative (Edwards1991;Coleman *et al*. 1996; Pregitzer *et al*. 2006),
and positive (Andersen and Scagel 1997; Scagel and Andersen 1997;Kasurinen *et al*. 2005).



Q_{10}

CK=1.72

T_1=1.58

T_2=1.51

Fig. 4 Dynamic changes of soil water content, soil temperature and soil respiration rates in 2009

张勇 *et al*. 2010

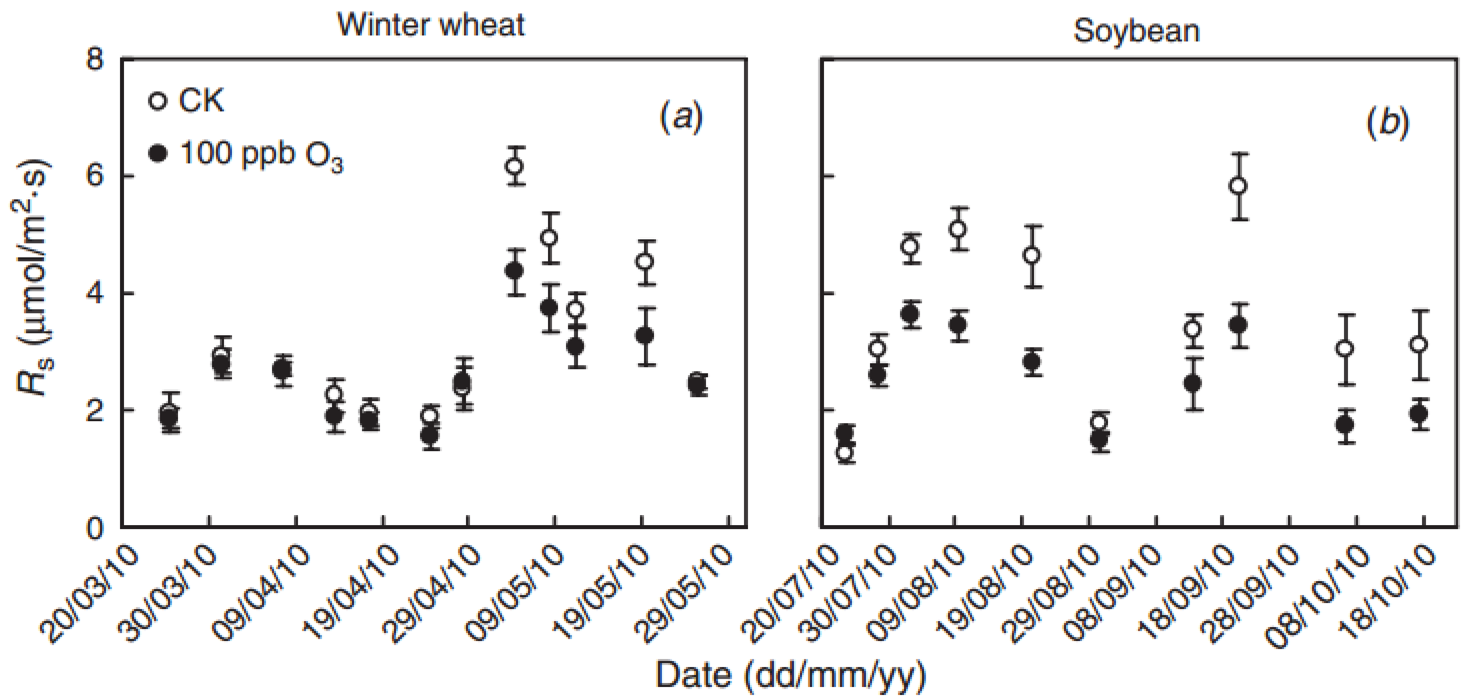


Fig. 5 Seasonal variations in soil respiration (R_s) in the CK and 100ppb O_3 treatments: (a) winter wheat, (b) soybean. Vertical lines are ± standard errors of the means; n=2 (two replicate chambers).

陈书涛 *et al*. 2012

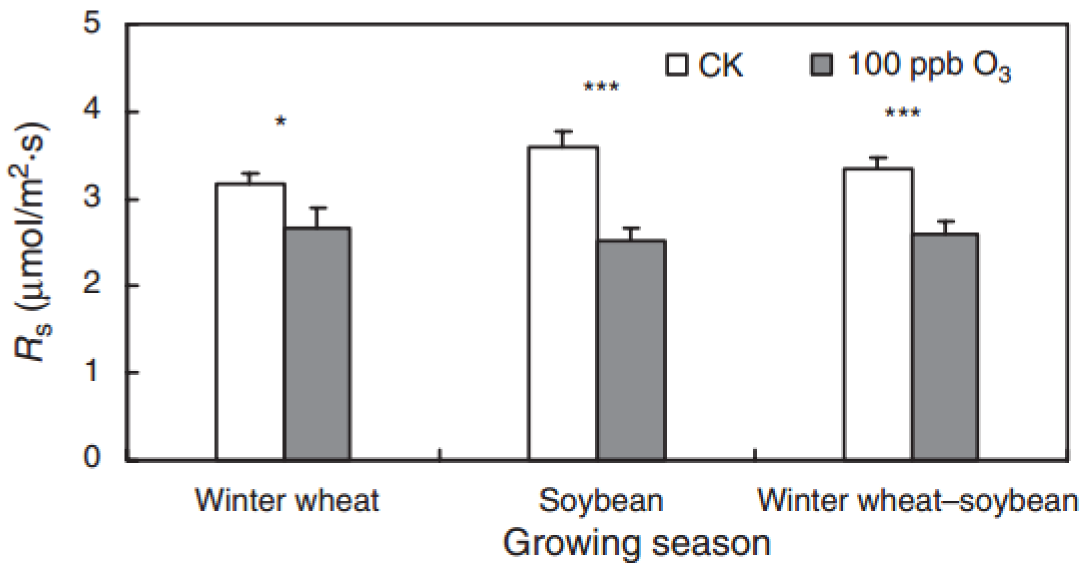
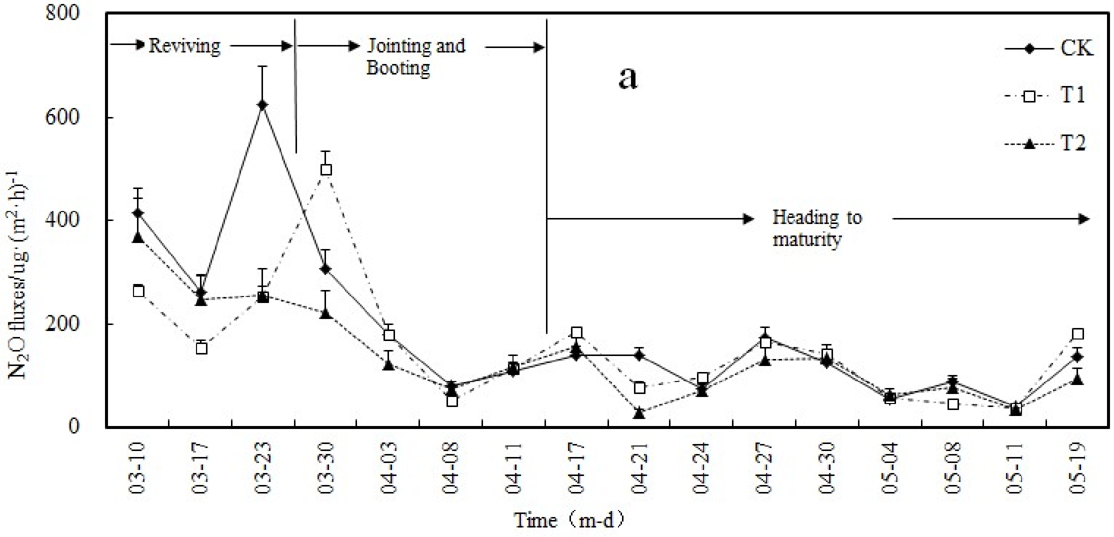


Fig. 6 Seasonal mean soil respiration rates (R_s) in the CK and 100ppb O_3 treatments for winter wheat and soybean. *$P<0.05$, ***$P<0.001$. Vertical lines are standard errors of the means; n (number of samples for each treatment) for paired-t test is 12, 10, and 22 for winter wheat, soybean, and winter wheat–soybean, respectively.

陈书涛 *et al*. 2012

4.2 Effects of elevated O_3 on N_2O emission from soil-crop systems



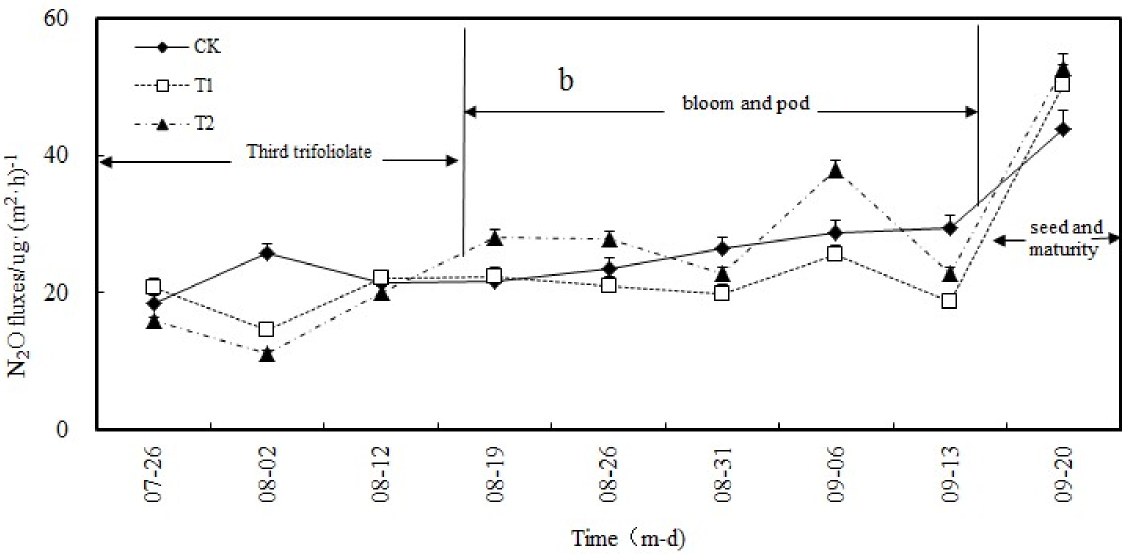


Fig. 7 Effect of elevated O_3 on the mean N_2O fluxes (Mean + SD) in different soil-crop. a, b in the soil-winter wheat and soybean system, respectively.

4.2 Effects of elevated O_3 on N_2O emission from soil-crop systems

Table 2 Effects of elevated O_3 on average N_2O emission fluxes from soil-winter wheat (a) and soybean (b) system during different growing stages/ $\mu g\ (m^2\ h)^{-1}$

a

Treatments	Reviving	Jointing and Booting	Heading and Maturity	Whole growth period
CK	432.71±11.88	167.82±4.72	107.93±3.23	183.8±153.17
T_1	224.43±12.69**	211.64±8.50**	109.69±1.13	156.7±115.43**
T_2	290.15±24.58**	133.31±5.36**	87.67±3.05**	137.05±92.91**

b

Treatments	Third trifoliolate	Bloom and Pod	Seed and Maturity	Whole growth period
CK	21.91±5.24	26.06±1.12	50.18±2.76	27.36±1.02
T_1	19.2±4.81	21.58±4.56	66.99±19.28	25.83±0.96
T_2	17.6±6.86	27.53±5.42	52.87±7.78	27.03±4.22

4.2 Effects of elevated O_3 on N_2O emission from soil-crop systems

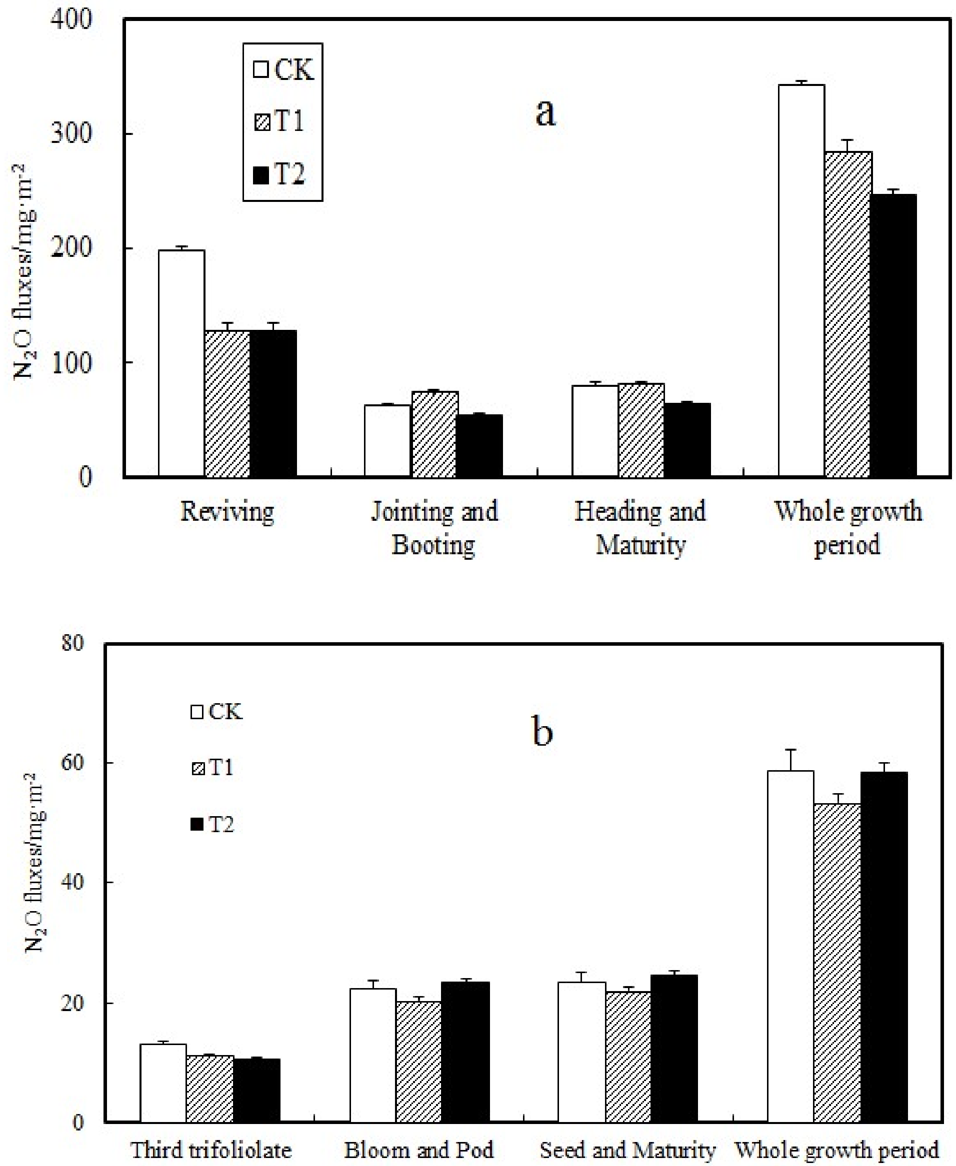


Fig. 8 Effects of elevated O_3 on cumulative N2O emission fluxes (Mean + SD) from soil-wheat system (a) and soil-soybean system(b) during different growing stages/mg m^{-2}

4.2 Effects of elevated O_3 on N_2O emission from soil-crop systems

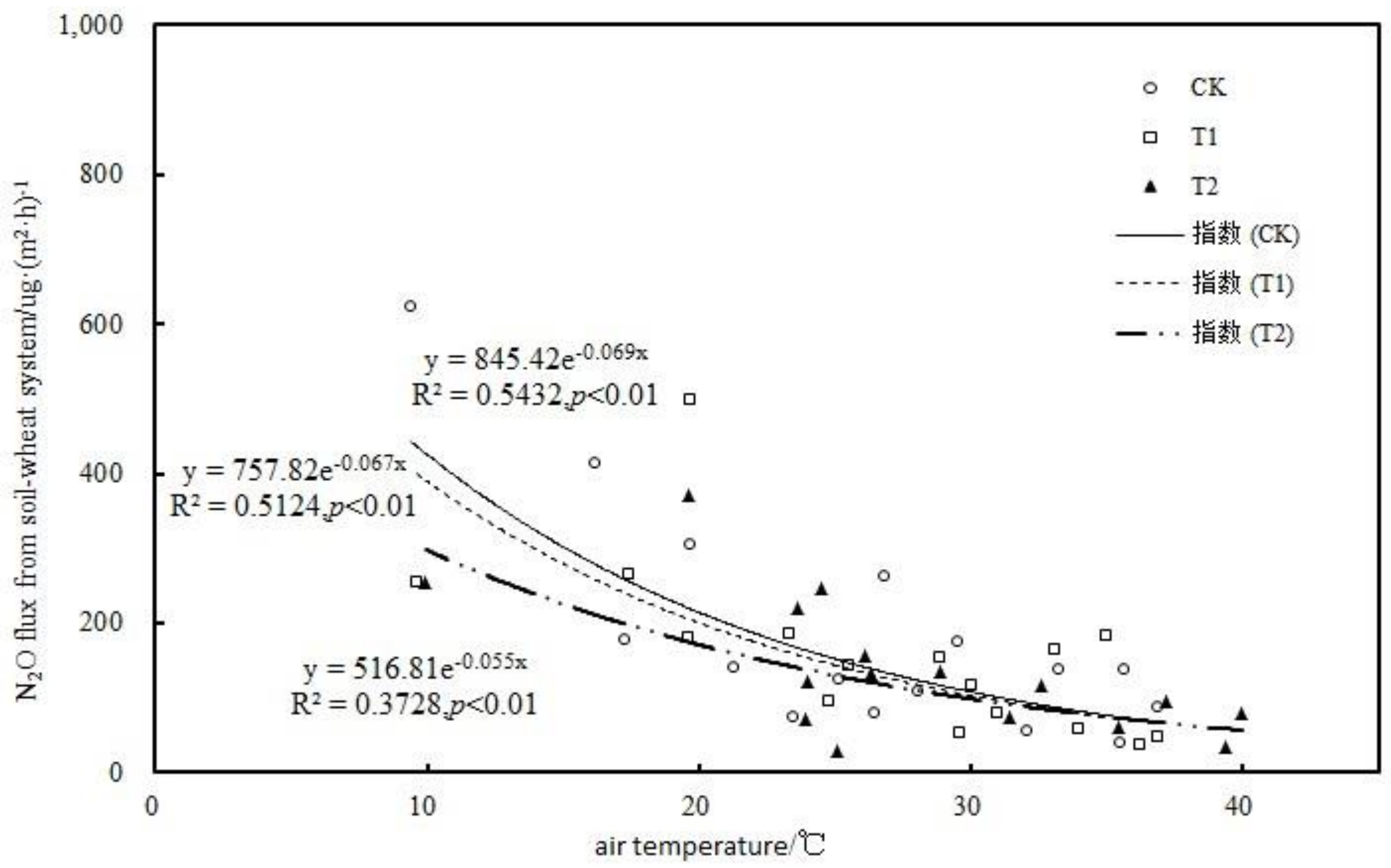


Fig.9 The relationship between soil-winter wheat N_2O emission rate and air temperature

4.3 Mechanism

➢ Biomass

Table 3 Effects of elevated O_3 on biomass (g/base frame). (Mean + SD) in different growth stages. *Designate the significant difference between CK and T.

winter wheat	**Jointing and Booting**			**Physiological maturity**		
	CK	**T_1**	**T_2**	**CK**	**T_1**	**T_2**
Shoot biomass	**0.54±0.21**	**0.36±0.12**	**0.37±0.12**	**1.52 ±0.44**	**1.04 ±0.48**	**0.76 ±0.42**
Root biomass	**0.10±0.04**	**0.07±0.14**	**0.07±0.14**	**0.07±0.02**	**0.06±0.05**	**0.04±0.02**
Total biomass	**0.64±0.24**	**0.43±0.19**	**0.44±0.19**	**1.58±0.44**	**1.10±0.53**	**0.8±0.43**

soybean	**Full maturity**	
	CK	**T**
Shoot biomass	**14.41 ±6.87**	**9.92±7.13***
Root biomass	**1.59±0.58**	**1.18±0.68***
Total biomass	**15.99±7.38**	**11.1±7.78***

Biomass

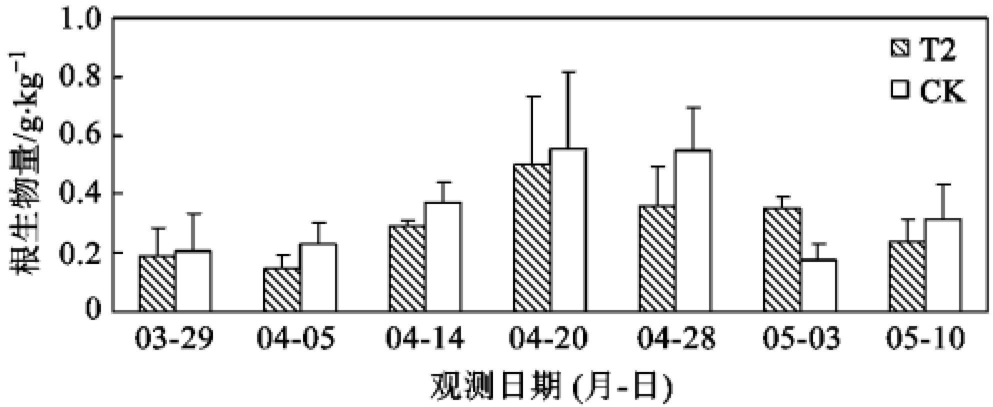


Fig.10 Dynamic changes of root biomass in 2009

张勇 *et al*. 2010

Nitrogen metabolism in plant leaves

Table 4 Effects of elevated O_3 on items related to N_2O emission of wheat leaves

winter wheat	Jointing		Heading		Maturity	
	CK	T_2	CK	T_2	CK	T_2
NO_3^--N/mg g^{-1}	0.25±0.03	0.27±0.02	0.25±0.02	0.26±0.01	0.22±0.02	0.20±0.02
NH_4^+-N/mg g^{-1}	2.11±0.02	2.10±0.02**	2.15±0.03	1.87±0.01**	2.8±0.01	2.6±0.02**
Total N/mg g^{-1}	38.71±3.75	38.23±3.8	39.19±2.94	37.68±0.72	10.22±2.36	5.84±7.59

soybean	Bloom		Pod		Seed	
	CK	T_2	CK	T_2	CK	T_2
chlorphyll /mg·g^{-1}	30.21±5.33	25.31±1.76**	36. 48±1.42	35.56±2.31**	45.63±2.11	30.25±1.23**
NR/μgN_2O·(g·h)$^{-1}$	341.1±24.9	391.7±20.9	72.4±11.4	253.8±15.4*	24.8±2.3	38.1±2.49
soluble proteins/mg·g^{-1}	5.43±0.36	5.13±0.51	6.94±0.71	9.63±1.44*	17.13±1.86	13.92±2.21

Soil properties

Table 4 Effects of elevated O_3 on items related to N_2O emission of soil

	Jointing		Heading		Maturity	
	CK	T_2	CK	T_2	CK	T_2
NO_3^--N/mg·g^{-1}	1.28±0.03	1.28±0.01	1.24±0.03	1.22±0.01*	1.28±0.02	1.27±0.02
NH_4^+-N/mg·g^{-1}	21.28±2.03	11.35±1.01**	27.37±1.43	16.24±1.62**	21.26±5.32	21.27±2.02**
Total N/mg·g^{-1}	0.58±0.15	0.76±0.09	0.64±0.07	0.66±0.12	0.98±0.12	0.91±0.09
organic carbon/ mg·g^{-1}	1.92±0.24	1.92±0.06	2.05±0.32	2.32±0.4	2.22±0.91	1.86±0.29

5 Conclusions

- Elevated O_3 did not change the seasonal pattern of respiration rate and N_2O emission from soil-winter wheat and-soybean system.
- Elevated O_3 leads to a decrease in soil respiration and in soil N_2O emissions.
- Elevated O_3 increased the temperature sensitivity of soil breath of winter wheat system.
- Elevated O_3 reduces the winter wheat and soybean plant biomass.
- Elevated O_3 reduces the total nitrogen content and NO_4^+-N content of wheat mature leaf soluble proteins content in leaves.
- Chlorophyll and NR activity of soybean, soybean soil NO_3^--N content decreased, soil organic carbon content increased.

Thank You