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Research Article

Influence of Environmental Factors on Variation of Soil Respiration Rate in a Wheat-Maize Rotation Field in China

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Abstract: Soil respiration in agroecosystem, especially in wheat-maize rotation system is a important component in carbon cycle, which is a key index of soil CO_2 efflux from soil to atmosphere. To discern the dynamic variation of soil respiration and the relationship between soil respiration and environmental factors, a experiment was conducted in the experimental field of Qingdao agricultural university. In this study CO_2 soil efflux was measured by automated soil CO_2 flux system (LI-8100A) during the periods from March to June (maize season) and from June to October (wheat season) in 2014, meanwhile the driving environmental factors were measured by eddy covariance system. The CO_2 emission rate from wheat soil varied from 1.093 μmol CO_2 $m^{-2}s^{-1}$ in March to 6.028 μmol CO_2 $m^{-2}s^{-1}$ in June and that for maize soil from 1.80 μmol CO_2 $m^{-2}s^{-1}$ in October to 10.36 μmol CO_2 $m^{-2}s^{-1}$ in July. The dynamics of GPP was similar to a shape "W" during wheat and maize seasons. Two peaks of GPP lied in April and August. To find the influence of the driving factors to soil respiration, the correlation analysis was processed between soil respiration and seven environment factors. The analysis showed that there was a significant correlation relationship between soil respiration rate and soil temperature at 10 cm depth and soil water content at 10 cm depth. To clearly understand the relationship between soil respiration and soil temperature and soil water content at 10 cm depth, three models (y = ae^{bx}, y = $ae^{bx_1} e^{cx_2}$, and y = $ae^{bx_1}x^{c}{}_2$) were used. The results showed that the bivariate compound model was the best model to depict the relationship between soil respiration rate and soil temperature and soil water content at 10 cm depth. About 88% and 78% of temporal variability in soil respiration could be explained by the variations in soil temperature and soil water content during wheat and maize season, respectively, highest in these three regression models.

Keywords: Correlation analysis, eddy covariance system, model performance, soil respiration

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INTRODUCTION

Due to human activities, the CO_2 concentration in the atmosphere is increasing and scientists have predicted that this increase will lead to critical changes in global climate in the future (Hashimoto *et al*., 2004). As a major carbon pool of the biosphere, the soil is containing globally twice as much as the atmosphere and three times as much as vegetation (Raich and Schlesinger, 1992; Lohila *et al*., 2003). Soil respiration (Soil CO_2 efflux) is a major CO_2 flux from ecosystems to the atmosphere which may constitute about three-quarters of total ecosystem respiration (Law *et al*., 2001) and small changes in CO_2 efflux from soil over long periods may accumulate to strong changes in atmospheric CO_2 concentration (Kuzyakov and Gavrichkova, 2010). Therefore, soil respiration is an important component of the global carbon cycle (Raich and Tufekcioglu, 2000; Schulze, 2000; Savage and Davidson, 2003; Chen *et al*., 2012). Because of importance of the role of soils, more efforts are being put into making better estimates of soil CO_2 efflux and the understanding of the variation of soil CO_2 efflux and the influence of environmental factors soil respiration (Vargas *et al*., 2011).

Agricultural land accounts for 12% of the land surface (Wood *et al*., 2000). Agroecosystem is a special system which is more vulnerable to human's activities (Lal, 2002). Thus, full understanding of carbon exchange in agroecosystems is vital to estimate carbon exchange between land and atmosphere more reliably (Suyker *et al*., 2005). However, in the past 20 years

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(1995-2015), compared with numerous research on forest (Pilegaard *et al*., 2001; Subke *et al*., 2003) and grassland (Novick *et al*., 2004; Reth *et al*., 2005; Dhital *et al*., 2010), less efforts has been done on carbon exchange in agroecosystem, especially on wheat-maize rotation cropping system.

It has been reported that soil respiration is mainly affected by temperature (Tang *et al*., 2003; Yan *et al*., 2006; Han *et al*., 2007; Ren *et al*., 2007; Inoue and Koizumi, 2012; Jing *et al*., 2014) and soil moisture (Jin *et al*., 2007; Liu *et al*., 2009; Li *et al*., 2010; Karelin *et al*., 2014), which are more important than other factors, such as soil texture (Kucharik *et al*., 2001; Xu and Qi, 2001; Lohila *et al*., 2003; Bae *et al*., 2013).

Shandong province is the most important winter wheat and maize production region in China. In this area, wheat-maize rotation is the main cropping system, so studies on soil respiration in this area is very important to carbon cycle in agroecosystem in China. In the present study, automated soil CO_2 flux system (LI-8100A-103, LI-COR, USA) and Eddy Covariance (EC) system was used to measure in situ soil respiration rates and CO_2 flux between vegetation and atmosphere, respectively. The objectives of this study are:

- To quantify the magnitude of soil respiration in wheat-maize rotation system in a semi-humid and prone to drought region in China
- To determine the seasonal dynamics of soil respiration during the growing season of wheat and maize
- To describe the effects of environmental factors on soil respiration during wheat and maize seasons.

The results might provide information towards a full carbon cycle analysis of these agroecosystems and the response of global change.

MATERIALS AND METHODS

Site description and soil properties: Field experiments were performed in 2014 at Research Farm of Qingdao Agricultural University-Jiaozhou Experiment Station (36°26'15"N, 120°5'21"E) Qingdao, one of the most important maize and wheat production area of Shandong province. The soil at the experimental site was a Shajiang black soil (Anonymous, 1998). The site is characterized by a warm temperate continental monsoon climate. The average temperature is 12.4°C, the mean annual sunshine is 2229 h and the 10-year mean annual rainfall for 2003-2013 is 662 m. The majority of precipitation falls in late July and early August.

The main crops are wheat (from October to June) and maize (from June to October). The experiment was performed from Mar. 1 to Oct 10 in 2014. Area of the experimental field was 30000 m^2. Maize and wheat material we used were 'Zhengdan 958' cultivar and 'Jimai 22' cultivar which were planted on a large scale in the local areas. Wheat was planted with a harrow planter after one plough and one rotary tillage with automatic control of the fertilizer N-P_2O_5-K_2O at a rate of 525 kg/ha. Wheat seeds were planted at 187.5 kg/ha with 0.18 m row space. Maize was planted using a no-tillage planter with automatic control of the fertilizer N-P_2O_5-K_2O at a rate of 525 kg/ha. Maize seeds were planted at 69900 plants/ha with 0.22 m plant distance and 0.65 m row space. The total precipitation was 91.7 mm during wheat growing season and 355.8 mm during maize growing season, respectively. The basic characteristics of soil are presented in Table 1.

Experimental details: In the field experiments, we used LI-8100A to measure in situ soil respiration rates. Two collars made of PVC (diameter 20 cm, height 12 cm) were inserted into the soil (to a depth of 10 cm) at least one day before the first sampling. The collars remained steady throughout the measurements in both wheat and maize growing seasons. Plants and their roots in the collars were pulled out and new seedings were periodically clipped when necessary. CO_2 efflux from soil was measured over a periods of about 180 s at each sampling time. The measurement was done usually at the relatively uniform time mostly at 09:00-17:00 once a week from March to November in 2014. Simultaneous with the soil respiration measurements, soil temperature at 10 cm depth was measured by the soil temperature probe (8100-201, LI-COR, USA). Following each measurement mode, the flux from soil to the chamber was calculated automatically by using the best fit of a linear or exponential regression. Each measurement took about 3 min with three repetition.

The meteorology, soil and other environmental parameters were measured by the EC system which was installed in the center of the experimental field to measure the energy, water and CO_2 exchanges between crops and atmosphere. The three wind components were measured using three-dimensional sonic anemometers (CSAT3, Campbell) and CO_2 and H_2O densities measured using an open-path infrared gas analyzer (LI-7500A, LI-COR), The sensors were mounted 2.5 m above the ground for measurements in the initial and middle stage of maize growth periods and whole wheat season and moved to 3.5 m above ground for measurement during the end of the maize growth period. Each radiation component was measured separately using a net radiometer (CNR1, Kipp and Zonen). The soil temperature and water content at 5, 20, 50, 100 cm depth were measured by

Table 1: Soil characteristics of the experimental fields during wheat and maize seasons

	pH	Organic matter (g/kg)	Available N(mg/kg)	Available P(mg/kg)	Available K(mg/kg)
Wheat season	5.93	9.80	69.60	37.62	110.8
Maize season	5.85	12.42	72.05	38.82	114.2

soil temperature probe (109, Campbell) and water content reflectometer (CS616, Campbell) respectively. The precipitation was measured by Rain gauge (52202, RM Young). All sensors were installed by specialists and regularly maintained every month. The raw data were recorded on a flash card at a frequency of 10 Hz and then processed using Eddypro software (a readily available and free software program designed by Li-COR science). Half-hourly averages of the latent heat flux were then calculated. To maintain the quality of eddy covariance data, data obtained during rainfall and regular maintenance of the sensors were deleted.

Except for parameters mentioned above, leaf area was obtained once a week by measuring the length and width of leaves by destroyed method. The leaf area (m^2) was calculated as:

$$\text{Leaf area} = L \times W \times K \qquad (1)$$

where,

L = Maximum length of leaf

W = Maximum width of leaf

K = Adjustment factor which is 0.75 for maize and 0.83 for wheat

The Leaf Area Index (LAI) was calculated as suggested by Sestak *et al.* (1971):

$$\text{Leaf Area Index (LAI)} = (\text{Leaf area}/m^2) \,/\, (\text{Land area}/m^2) \qquad (2)$$

Statistical analysis: To understand the influence of the meteorology, soil and other parameters on soil respiration, correlation was used to evaluate the relationship between soil respiration and other parameters (meteorology, soil etc.) Significant differences for all statistical tests were evaluated at the level 0.05 and 0.01. Based on the correlation analysis, three regression models were used to fit the variation of the soil respiration. The models are univariate exponential model ($y = ae^{bx}$), bivariate exponential model ($y = ae^{bx_1}\, e^{cx_2}$) and bivariate compound model ($y = ae^{bx_1}x^{c}{}_2$). In the process of evaluation, parameters (such as R^2, $RMSE$, Chi-square and F-statistic) were chosen to evaluate the performance of the three models on soil respiration. All statistical analyses were performed using SAS and Excel 2007 and all figures were plotted by Origin 8.5.

RESULTS AND DISCUSSION

The dynamics of the main environmental factors: The soil temperature, soil water content and precipitation were measured during wheat and maize seasons from January to October 2014 (Fig. 1). The daily mean value of soil temperature at 5 cm depth was 14.4°C, ranging from a minimum of -3.8°C in January to a maximum of 30.5°C in July. The daily mean soil temperature at 20 cm depth was 14.1°C, ranging from -2.0°C to 28.9°C. In wheat season, the soil temperature was increasing gradually with the time lasting. In maize season, the soil temperature firstly kept increasing until nearly August, then decreased slowly. The average daily soil water content was ranging from 11 to 35% at 5 cm depth and from 11 to 28% at 20 cm depth, respectively. The precipitation during wheat season was mainly in May-June and in July-August during maize season. Due to heavy rainfall and power outages resulted in missing data from July 24 to Aug14 in 2014, soil temperature, water content and precipitation (about 245 mm) were not included in Fig. 1.

Daytime dynamics of soil respiration rate: To understand the daytime dynamics of soil respiration, the samplings were done from the returning green stage of wheat (March) to the harvest of maize (October) in 2014. When performing the experiment, sampling was done every 1 h during wheat and maize seasons once a week. Among all the sampling, three key days we chose to describe the variations of soil respiration were March 26 (returning green stage), April 24 (booting stage) and June 5 (kernel stage) in wheat season; July 18 (seeding stage), August 21 (booting stage) and October 4 (kernel stage) in maize season. The variation of the daytime soil respiration during wheat and maize seasons was plotted in Fig. 2.

The soil respiration rate was obvious diurnal variation from 1.71 μmol/m^2·s to 2.18 μmol/m^2.s in the returning green stage, from 1.94 μmol/m^2·s to 2.49 μmol/m^2·s for the booting stage, from 4.45 μmol/m^2·s to 6.03 μmol/m^2·s for the kernel stage. That variation range was from 9.14 to 10.36 μmol/m^2·s, 4.2 to 4.61 μmol/m^2·s and 2.42 to 2.73 μmol/m^2·s for the seeding stage, booting stage and the kernel stage of maize. During the returning green stage of wheat, the soil respiration rate was slight and its mean value was about 1.87 μmol/m^2·s, in the booting stage of wheat, the mean soil respiration was 2.24 μmol/m^2·s and 5.36 μmol/m^2·s in the kernel stage. The soil respiration rate was gradually increasing following with the growth of wheat. The soil respiration in maize season was slight variation in the seeding and booting stage, there was obvious variation in the kernel stage. The daytime mean soil respiration rate was 9.74, 4.38 and 2.57 μmol/m^2·s in the seeding stage, booting stage and kernel stage, respectively. The soil respiration rate was gradually decreasing with the maize growing.

Seasonal dynamics of daytime soil respiration rate, GPP and LAI: Soil respiration showed obviously seasonal dynamics in the both two growing seasons (Fig. 3). In late spring (wheat season), soil CO_2 efflux stayed at a low level, then the soil respiration became gradually enhanced with time, reaching highest emission value in July with the maximum value 10.36 μmol CO_2 $m^{-2}s^{-1}$ and then began to decrease. Its variation was very similar to the soil temperature. The dynamics of GPP which was calculated by using soil respiration and CO_2 flux measured by EC system was similar to a shape of "W" during both wheat and maize seasons. There were two peak values in GPP, one lied in middle of April, the other one lied in middle of August, these two periods were in the vigorous growth period of wheat and maize, respectively, with the maximum LAI in these two periods. The minimum value of GPP was occurring at the harvest of wheat and the seeding stage of maize with the minimum LAI, almost zero. The dynamics of LAI and GPP was opposite variation.

The correlation analysis of daytime soil respiration to environment factors during wheat and maize seasons: Seven environment factors including inter-chamber humidity (RH_c), inter-chamber temperature

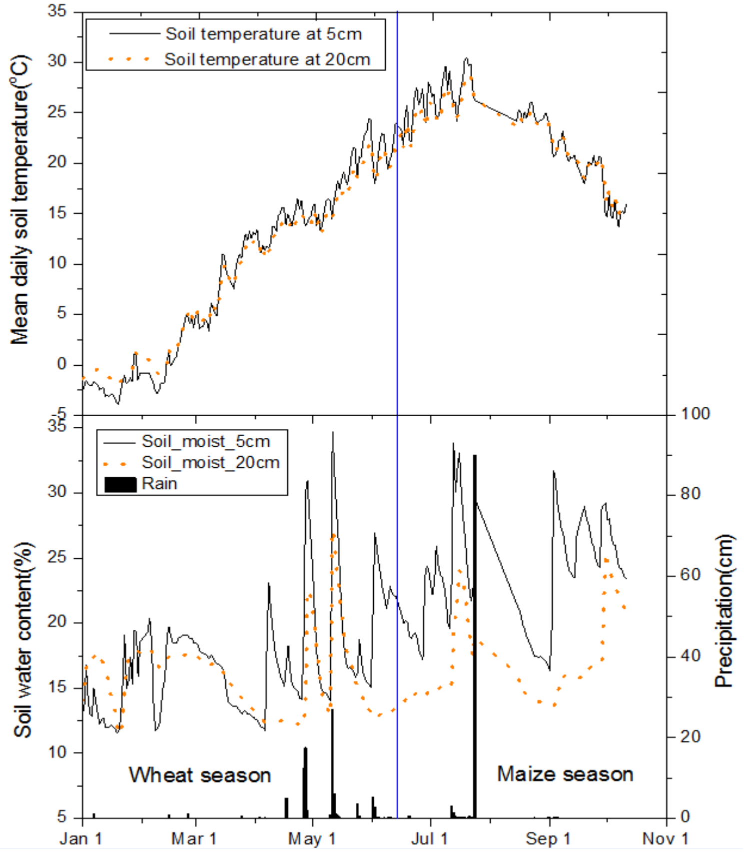

Fig. 1: The dynamics of main environment factors in wheat and maize seasons

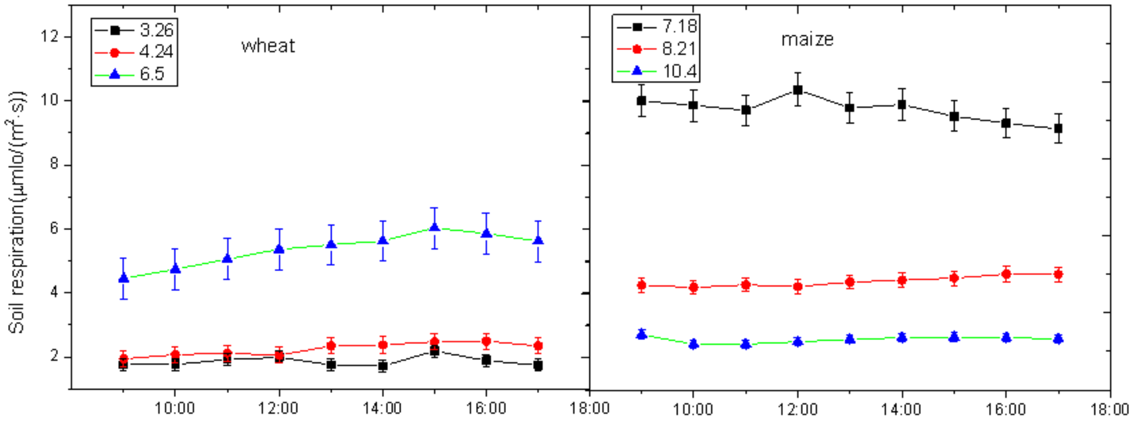

Fig. 2: Diurnal dynamics of soil respiration during wheat and maize seasons

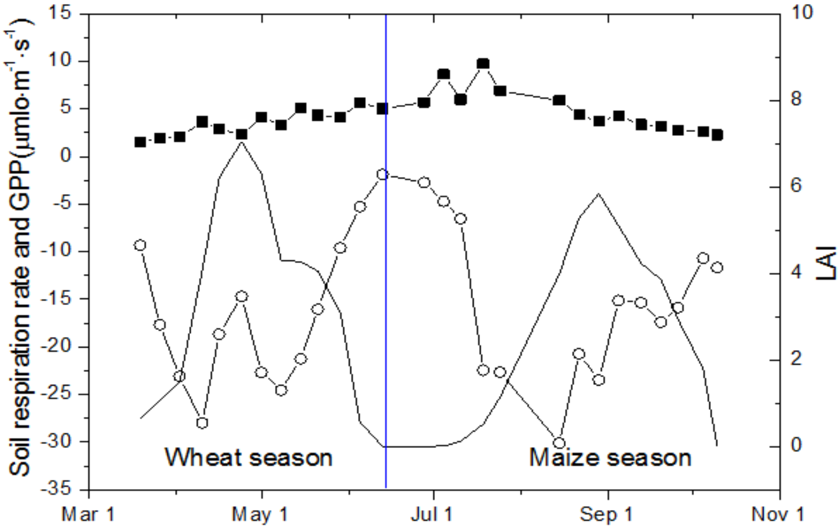

Fig. 3: Seasonal dynamics of soil respiration rate, GPP and LAI during wheat and maize seasons with soil respiration rate (■), GPP (○) and LAI curve (——)

Table 2: The correlation analysis of soil respiration to environment factors during wheat and maize seasons

	*RH*c	*T*c	*ST*5	*ST*10	*ST*20	*SWC*5	*SWC*20
Wheat	0.106	0.622**	0.776**	0.843**	0.831**	0.821**	0.293**
Maize	-0.100	0.786**	0.850**	0.880**	0.876**	0.068	-0.180*

*: correlation is significant at the 0.05 level; **: correlation is significant at the 0.01 level (2-tailed)

Table 3: The fitting results using univariate exponential model ($y = ae^{bx}$) in wheat and maize seasons

Season	*x*	*a*	*b*	*R*²	*RMSE*	*Chi-square*	*F statistics*
Wheat season	*T*c	1.460	0.033	0.362	0.992	31.109	162.941
	*ST*5	1.330	0.046	0.565	0.819	21.302	238.918
	*ST*10	0.961	0.072	0.664	0.720	16.229	309.212
	*ST*20	1.183	0.067	0.654	0.731	17.238	299.999
	*SWC*5	1.102	0.066	0.623	0.763	19.031	275.416
Maize season	*T*c	0.528	0.075	0.655	1.255	32.554	292.525
	*ST*5	0.833	0.071	0.587	1.464	44.758	285.614
	*ST*10	0.324	0.114	0.701	1.248	34.317	393.445
	*ST*20	0.464	0.103	0.621	1.402	40.120	311.370
	*SWC*5	3.306	0.016	0.021	2.254	120.913	120.479

(T_c), soil temperature at 5 cm depth (ST_5), soil temperature at 10 cm depth (ST_{10}), soil temperature at 20 cm depth (ST_{20}), soil water content at 5 cm depth (SWC_5) and soil water content at 20 cm depth (SWC_{20}) were chosen to process correlation analysis. The correlation analysis was done by SAS.

From the analysis in Table 2, the soil respiration rate was most significantly correlated with variation of soil temperature at 10 cm depth, but it was not the only factor affecting flux variations. The soil respiration was else significantly correlated with variation of inter-chamber temperature, soil temperature at 5 cm and 20 cm depth, soil water content at 5 cm and 20 cm depth (Table 2). These factors significantly correlated with soil respiration were also very important.

The regression of soil respiration with environment factors: To clearly know the relationship of the soil respiration with the environment factors, three models were analyzed.

Univariate exponential model: To validate the influence degree on environment factors to soil respiration, the seven factors mentioned above in correlation analysis were analyzed using univariate exponential model. From the results in Table 3, one can find which factor was most closely related.

If describing the variation of soil respiration using one factors in both wheat and maize seasons, it was certainly that the soil temperature at 10 cm depth was the most suitable because there was the minimum *RMSE* and *Chi-square* and the maximum *F*-statistics. It can explain about 66.4 and 70.1% of the variance in soil respiration during wheat and maize season respectively. So only taking into account the influence of soil temperature, the relationship between soil respiration

Table 4: The fitting results using bivariate exponential model ($y = ae^{bx_1}e^{cx_2}$) in wheat and maize seasons

Season	x_1	x_2	*a*	*b*	*c*	R^2	*RMSE*	*Chi-square*	*F-statistics*
Wheat season	ST_5	ST_{10}	0.903	-0.016	0.094	0.670	0.714	15.950	155.976
	ST_{10}	ST_{20}	1.022	0.044	0.027	0.672	0.712	16.108	156.665
	ST_5	ST_{20}	1.183	0.001	0.065	0.654	0.731	17.225	148.586
	ST_{10}	SWC_5	0.623	0.052	0.043	0.869	0.451	6.788	390.529
	ST_5	SWC_5	0.742	0.031	0.049	0.833	0.509	8.353	306.971
	ST_{20}	SWC_5	0.757	0.045	0.043	0.842	0.496	7.953	322.799
Maize season	ST_5	ST_{10}	0.282	-0.022	0.144	0.706	1.234	33.749	198.866
	ST_{10}	ST_{20}	0.325	0.120	-0.006	0.701	1.247	34.889	195.193
	ST_{10}	SWC_5	0.204	0.107	0.026	0.774	1.084	25.855	258.540
	ST_5	SWC_5	0.318	0.075	0.034	0.728	1.188	31.278	215.092
	ST_{20}	SWC_5	0.180	0.107	0.036	0.758	1.120	25.938	242.078

Table 5: The fitting results using bivariate compound model ($y = ae^{bx_1}x_2^c$) in wheat and maize seasons

Season	x_1	x_2	*a*	*b*	*c*	R^2	*RMSE*	*Chi-square*	*F-statistics*
Wheat season	ST_5	ST_{10}	1.662	0.049	-0.098	0.578	0.807	20.682	121.982
	ST_{10}	ST_{20}	0.244	0.018	0.847	0.692	0.689	15.077	167.004
	ST_5	ST_{20}	0.126	-0.007	1.258	0.691	0.691	15.180	166.356
	ST_{10}	SWC_5	0.126	0.050	0.833	0.878	0.435	6.279	419.563
	ST_5	SWC_5	0.122	0.029	0.941	0.843	0.492	7.789	327.044
	ST_{20}	SWC_5	0.152	0.043	0.836	0.851	0.481	7.396	343.968
Maize season	ST_5	ST_{10}	0.0004	-0.121	3.078	0.691	1.275	37.813	188.176
	ST_{10}	ST_{20}	0.544	0.125	-0.251	0.705	1.243	33.794	198.168
	ST_5	ST_{20}	0.017	0.024	1.616	0.628	1.396	40.169	156.991
	ST_{10}	SWC_5	0.052	0.108	0.621	0.779	1.076	25.249	264.385
	ST_5	SWC_5	0.050	0.077	0.837	0.738	1.169	30.292	223.590
	ST_{20}	SWC_5	0.029	0.107	0.847	0.762	1.115	25.629	245.916

and soil temperature at 10 cm depth during wheat and maize seasons could be fitted as:

Wheat: $R_s = 0.961e^{0.072ST_{10}}$, $R^2 = 0.664$, $p<0.0001$, $n = 106$

Maize: $R_s = 0.324e^{0.114ST_{10}}$, $R^2 = 0.701$, $p<0.0001$, $n = 120$ (3)

From the results, it was clearly seen that this model used here and other papers (Han *et al*., 2007; Zhang *et al*., 2014) was not suitable to depict the soil respiration well.

Bivariate exponential model: By the results of correlation analysis, the soil respiration was significantly with more than one parameter, so we analyzed the relationship between soil respiration and two factors chosen from all the factors using a bivariate exponential model ($y = ae^{bx_1}e^{cx_2}$).

It was clearly to see from Table 4 that soil respiration was most suitable to describe with soil temperature at 10 cm depth and soil water content at 5 cm depth if using bivariate exponential model with the minimum *RMSE* and Chi-square and the maximum *F*-statistics. It can explain about 86.9 and 77.4% of the variance in soil respiration during wheat and maize season, respectively. Thus, if considering the influence of soil temperature and soil water content, the relationship between soil respiration and soil temperature at 10 cm depth and soil water content at 5 cm depth during wheat and maize seasons could be fitted as:

Wheat: $R_s = 0.623e^{0.052ST_{10}}e^{0.043SWC_5}$ $R^2 = 0.869$, $p<0.0001$, $n = 106$

Maize: $R_s = 0.204e^{0.107ST_{10}}e^{0.026SWC_5}$ $R^2 = 0.774$, $p<0.0001$, $n = 120$ (4)

Except univariate exponential model and bivariate exponential model, an extra model was analyzed which was bivariate compound model ($y = ae^{bx_1}x_2^c$) for wheat and maize (Table 5).

From the analysis of Table 5, we can see that the best factors for this model were soil temperature at 10 cm depth and soil water content at 5 cm depth. The regression equations were:

Wheat: $R_s = 0.126e^{0.050ST_{10}}(SWC_5)^{0.833}$ $R^2 = 0.878$, $p<0.0001$, $n = 106$

Maize: $R_s = 0.050e^{0.108ST_{10}}(SWC_5)^{0.623}$ $R^2 = 0.779$, $p<0.0001$, $n = 120$ (5)

By the analysis of these three models mentioned above, it was clearly to see that the soil respiration was most significant with soil temperature at 10 cm depth and soil water content at depth 5 cm in the experimental field. The bivariate compound model Eq. (5) was the most appropriate model to depict the relationship

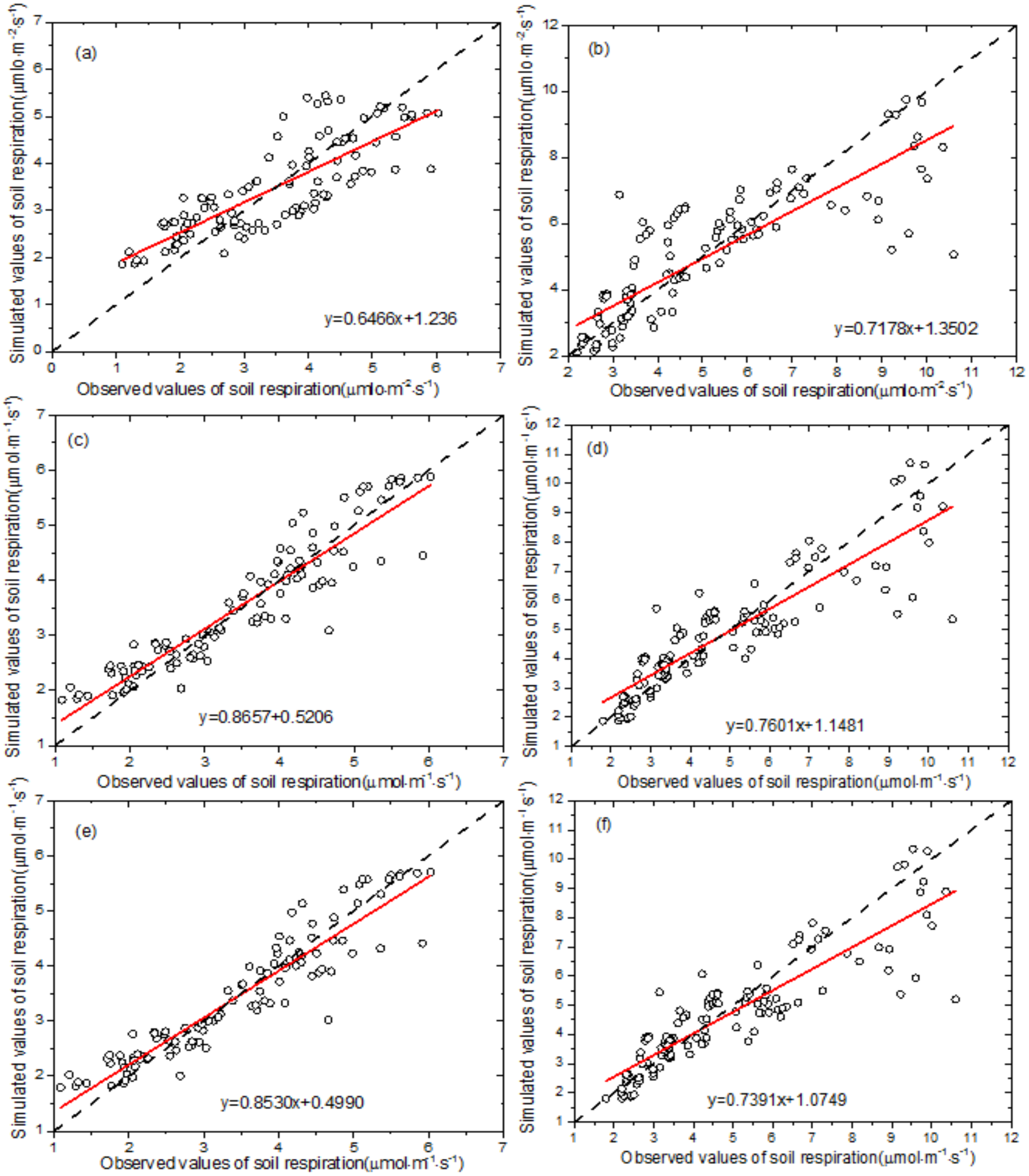

Fig. 4: Simulated values and observed values of soil respiration rate using univiarate exponential model in; (a): wheat season and; (b): maize season; biviarate exponential model in; (c): wheat season and; (d): maize season; biviarate compound model in; (e): wheat season and; (f): maize season with soil respiration data (ο), regression line curve (——) and 1:1 line (- - -)

between soil respiration and environment factors and it can explain about 88 and 78% of the variance in soil respiration during wheat and maize season, respectively, highest in these three regression models.

Validation of models: To validate the performance of these three models, the comparison of the observed value of soil respiration obtained by field measurement with the predicted value of soil respiration calculated by using three models mentioned above were conducted (Fig. 4).

The comparison between the predicted value with the univariate exponential model Eq. (3) and the observed value was done by linear fit with its slope 0.6466 and intercept 1.236 (Fig. 4a), moreover this model can explain 66.4% of variation in the observation during wheat season. The slope was 0.7178 and intercept was 1.3502 in maize season (Fig. 4b) and this model can explain 70.1% of variation in the observation. Thus we can see that the univariate exponential model was more appropriate for maize than wheat. When the comparison was processed by linear fit using bivariate exponential model Eq. (4), its slope was 0.8657 and intercept was 0.5206 (Fig. 4c), moreover this model can explain 86.9% of variation in the observation during wheat season. Meanwhile the slope was 0.7601 and intercept was 1.1481 in maize season (Fig. 4d) and this model can explain 77.4% of variation in the observation. It was clearly to see that the bivariate exponential model was more appropriate for predicting the soil respiration for wheat than for maize. And at last, the comparison between predicted value with bivariate compound model Eq. (5) and observed value was done by linear fit with its slope 0.8530 and intercept 0.4990 (Fig. 4e), moreover this model can explain 87.8% of variation in the observation during wheat season. The slope was 0.7391 and intercept was 1.0749 in maize season (Fig. 4f) and this model can explain 77.9% of variation in the observation. It was clearly to see that the bivariate model was more appropriate for predicting the soil respiration for wheat than for maize. Among these three models, the bivariate compound model was the most suitable for predicting soil respiration rate in wheat and maize field.

CONCLUSION

CO_2 efflux from soil was measured in wheat and maize fields in the experimental farm of Qingdao agricultural university, China. For wheat, the mean soil respiration rate was 1.87, 2.24 and 5.36 in the returning green stage, the booting stage and the kernel stage, respectively and that for maize was 9.74, 4.38 and 2.57 in the seeding stage, the booting stage and the kernel stage, respectively. The soil respiration rate showed obviously seasonal dynamics with a low level in spring and enhanced to the maximum in July, after then began to decrease.

To discern the relationship between soil respiration rate and environmental factors, the correlation analysis was done and regression using three models (univariate exponential model, bivariate exponential model and bivariate compound model) were established and validated. If analyzed using the univariate exponential model, the soil temperature at 10 cm depth was the best parameter. If combined with soil temperature and soil water content, soil temperature at 10 cm depth and soil water content at 5 cm depth were most significant factors to influence the soil respiration rate. So two bivariate models were established and validated to simulate the soil respiration rate. Through comparison, it was found that the bivariate compound model can well simulate the dynamics of soil respiration rate during wheat and maize seasons. This may be help other researchers in this field to predict the soil efflux and understand the carbon cycle in wheat and maize seasons.

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