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Soil respiration in a triple intercropping system under conservation tillage

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ABSTRACT

Drivers of soil respiration (R_s) in farmland ecosystem have already been widely studied. However, the relationship between R_s and soil fauna (F_s), hydrothermic factor in the triple intercropping system remains poorly known. An LI-6400 XT portable photosynthesis measurement system equipped with a soil respiratory chamber was adopted in the experimental field. Straw mulching treatment increased soil respiration rate but ridge tillage treatment did not have a consistent effect. A regression analysis of the relationship revealed that exponential equation fitted well the relationship between R_s and soil temperature at 10 cm soil depth. However, the relationship between R_s and soil moisture was best confirmed by a parabolic function. The common dominant groups of F_s in wheat, corn, and soybean farmland were *Collembola* and *Acarina*, while *Diptera* emerged in the two rear crops farmlands. Compared to the control, ridge tillage reduced the number of F_s, but straw mulching increased it and improved the index of soil fauna diversity. In conclusion, the higher was the amount of animals being active above soil surface, the stronger was the soil respiration.

Keywords: triple cropping in dryland; wheat-maize-soybean; soil hydrothermic factor; soil animals

Soil respiration is closely associated with ecosystem carbon cycle and global climate change, and related research has become one of the main directions in the field of global climate change research. As the important component of the terrestrial ecosystem, farmland ecosystem had the most active carbon pool in the worldwide relation because it was subjected to intense anthropogenic disturbance (Han et al. 2008). Wang et al. (2009b) has once proposed the triple intercropping system of wheat-maize-soybean as a new conservation tillage pattern which is highly efficient, ecological, and water saving. Most studies investigate the soil respiration in single crop field, few research cases deal with multiple cropping, crop rotation and relay-intercropping. Especially the influencing factors of soil respiration in the triple intercropping system of wheat-maize-soybean in the purple soils in the hilly area of southwest China have not been reported, yet.

Recently, a lot of works show that soil animals stimulate the soil CO_2 emission for they directly take part in the original process of material cycle and soil respiration (Zhu and Wei 2007, Speratti and Whalen 2008). At present, the object is mainly concentrated in a few groups such as earthworms, termites, and nematodes (Liu and Zou 2002, Fu et al. 2005, Luo et al. 2008). It was difficult to precise that soil animal respiration contributes to soil respiration because of the complexity in composition, and sensitive response to environmental changes and greatly different regions and habitat of soil animals. These factors hinder the development of general rule of soil respiration. In view of the important status and role of soil animals underground in the ecological system,

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it is essential to study the soil animals for soil respiration principle. Therefore, in the present study, we examined soil respiration in response to soil animals coupling soil temperature and soil moisture in wheat-corn-soybean cropping system.

MATERIAL AND METHODS

Study areas and site description. The study was conducted from November 2012 to October 2013 on the teaching experimental farm, under the triple intercropping system of wheat-maize-soybean. Conservation tillage lasted for 7 years under a consistent tillage annually. There were six treatments: (1) traditional tillage (T) – using convention planting for the entire experimental period; (2) ridge tillage (R) – ridge was 20 cm high; (3) traditional tillage + straw mulching (TS) – using straw mulch for the entire experimental period with all the harvested straw maintained in situ; (4) ridge tillage + straw mulching (RS) – mulching straw on the ridge during the entire experimental period and keeping ridge 20 cm high; (5) traditional tillage + straw mulching + decomposing inoculants (TSD) – traditional tillage with crop straw left in the field as mulch amended with straw decomposing agent; and (6) ridge tillage + straw mulching + decomposing inoculants (RSD) – ridge tillage with crop straw left in the field as mulch amended with straw decomposing agent. The test used randomized block arrangement. Each plot had an area of 8.0 m × 3.6 m which was subdivided into four stripes each 1.0 m wide and 3.6 m long. Wheat was seeded three lines in each stripe, each line with 17 seeded holes. The superphosphate fertilizer was applied at 390 kg/ha and urea at 152 kg/ha as basal fertilization at planting. Corn was transplanted in two lines in each stripe and each line had 8 holes. Basal fertilizer applied at transplanting was compound fertilizer (148 kg/ha) and urea (74 kg/ha). Soybean was seeded in three lines in each stripe and each line had 12 holes. Basal fertilizer applied at planting was compound fertilizer (300 kg/ha). The straw used for mulching was the previous harvested wheat and corn, uniformly covered in the district, each plot with 42.7 kg, equivalent to 24 000 kg/ha. The decomposing inoculants were composite bacteria which had living bacteria ≥ 10^9 colony-forming units/g. The applying amount was 0.2% of straw amount, dissolved in water and then was evenly sprayed on the straw. Soybean was sowed in the strip planted with wheat originally and that was named W-S strip. Maize strip which was idle in maize transplanting before and after harvest was named C-K strip.

Soil respiration was measured every two weeks by using an infrared gas analyzer (Li-Cor 6400 potable photosynthesis system fitted with a 6400-09 soil CO_2 flux chamber, LI-COR Inc., Lincoln, USA) during the whole growth period. Self-made PVC collars (11 cm in diameter and 5 cm high) were placed at three fixed points in the measurement area, with 1 m in spacing and installed one day prior to measurement to minimize the disturbance of the soil. Each PVC collar was measured once in 3 cycles. Each treatment was repeated three times. All the measurements for each time were conducted between 9:00 a.m. and 11:00 a.m. to minimize the impact of the diurnal variation in soil respiration. Soil temperature was recorded simultaneously with soil respiration by the probe in the infrared gas analyzer; the depth in soil was 10 cm. Soil moisture in the 0–5 cm soil layer was determined by oven drying method when soil respiration and soil temperature were measured. Soil fauna was surveyed every two weeks by tullgren apparatus and pitfall traps method using random sampling method (quadrat was 10 cm × 10 cm × 5 cm). The soil animal separation was determined during the first four treatments.

Diversity index (Shannon-Wiener): $H = -\Sigma(P_i \ln P_i)$

Evenness index (Pielou): $E = H/\ln S$

Dominance index (Simpson): $C = \Sigma(P_i)^2$

Richness index (Menhinick): $D = \ln S/\ln N$

Where: $P_i = n_i/N$, n_i – number of individuals in the i^{st} group; N – number of individuals of all groups in the community; S – number of the groups.

The Q_{10} index indicated relationship between soil temperature and soil respiration. It meant multiplication of soil respiration rate when soil temperature increased by 10°C. Calculation formula:

$$Y = a \times e^{bx}, \quad Q_{10} = e^{10b}$$

Where: Y – soil respiration rate; a,b – simulation parameters; x – soil temperature.

Statistical analysis. Soil respiration rate in different growth period was analyzed by the ANOVA method. All the data were subjected to tests for normality and homoscedasticity before ANOVA analyses. Correlation analysis and regression analysis were used to test the relationship between soil

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respiration rate and soil temperature, soil moisture and the number of soil fauna. All differences were tested for statistical significance at the 95% level. Statistical analyses were performed with SPSS 13.0 (Chicago,USA) and Excel 2003 (Beijing,China).

RESULTS AND DISCUSSION

The dynamics of soil respiration rate. In the wheat growing seasons, the average soil respiration rate was 1.53 μmol/m^2/s with fluctuations between 0.89 and 2.67 μmol/m^2/s. Ridge tillage treatment reduced soil respiration from the jointing stage but it was opposite when after heading stage. Straw mulching treatment had little influence on soil respiration during the whole period because the straw cover coming from previous crops decayed. In the soybean growing period, soil respiration rate was ranged between 1.34 and 10.50 μmol/m^2/s. There was a severe decrease to 62–84% in the harvesting stage as a result of soil temperature which was low

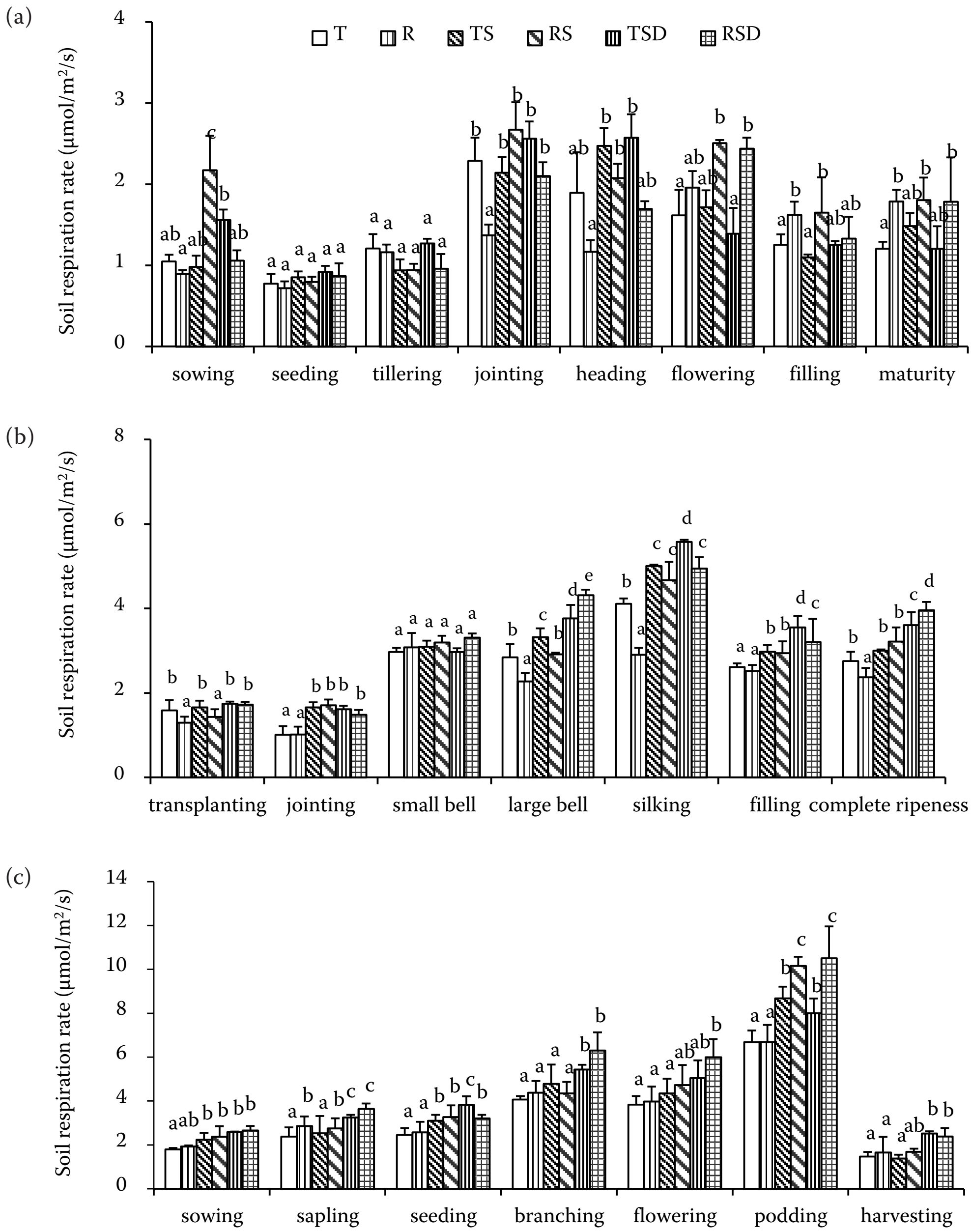

Figure 1. Soil respiration rate in growing seasons of (a) wheat; (b) corn and (c) soybean. T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching; TSD – traditional tillage + straw mulching + decomposing inoculants; RSD – ridge tillage + straw mulching + decomposing inoculants

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Table 1. Relationship between soil respiration rate and soil temperature

Code	Average soil temperature (°C)	*a*	*b*	Sample number	Fitting equation	R^2	*P*	Q_{10}
T	23.09	0.344	0.085	20	$R_s = 0.344e^{0.085T}$	0.512	0.000	2.34
R	23.13	0.357	0.083	20	$R_s = 0.357e^{0.083T}$	0.429	0.002	2.41
TS	23.20	0.279	0.099	20	$R_s = 0.279e^{0.099T}$	0.461	0.001	2.69
RS	23.10	0.407	0.083	20	$R_s = 0.407e^{0.083T}$	0.405	0.003	2.41
TSD	23.18	0.340	0.093	20	$R_s = 0.340e^{0.093T}$	0.537	0.000	2.53
RSD	23.17	0.451	0.081	20	$R_s = 0.451e^{0.081T}$	0.289	0.014	2.25
W-S	23.16	0.311	0.095	60	$R_s = 0.311e^{0.095T}$	0.465	0.000	2.59
C-K	22.98	0.350	0.088	60	$R_s = 0.350e^{0.088T}$	0.423	0.000	2.41

T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching; TSD – traditional tillage + straw mulching + decomposing inoculants; RSD – ridge tillage + straw mulching + decomposing inoculants; W-S – strip planted with wheat and soybean; C-K – strip planted with corn; *a,b* – simulation parameters; Q_{10} – multiplication of soil respiration rate when soil temperature increased by 10°C

when the soybean was mature, leading to reduced soil microbial activity. The soil respiration rate which was between 1.01 and 5.58 μmol/m^2/s during the whole growing season was the minimum in the jointing stage of corn, which was only 1.01 μmol/m^2/s. Along with the growth of corn, it began to increase and reached to the maximum in the silking stage. Straw mulching treatment enhanced soil respiration was certainly consistent, and the effect on soil respiration was gradually weakened as the straw decomposed (Zhang et al. 2005, Guan et al. 2011). The influence of ridge tillage on soil respiration was not constant. It was contrary in different crops with conventional and ridge tillage and also varied with growth stages in the same crop (Wang et al. 2009a).

Soil respiration and influencing factors. In the farmland ecosystem, the relationship between soil respiration and soil temperature was described as the exponential function, linear function, power function, parabolic function and so on. The fitting models used by different scientists were not the same (Zhu et al. 2008). However, the exponential function was used widespread, and Q_{10} index model could correctly reflect the relationship between them. Precvious studies showed that the value of Q_{10} was between 1.3 and 5.6 (Sun et al. 2009). In our study, the value was between 2.25 and 2.69 (Table 1). Ridge and straw mulching increased the Q_{10} value but this trend was decreased by adding decomposing inoculants. The high temperature sensitivity meant that lower soil temperature would bring greater decreases in soil respiration. Therefore, straw mulching treatment helps to cut carbon emissions because it reduced the soil temperature.

Table 2. Relationship between soil respiration rate and soil moisture

Code	Average soil moisture content (%)	*a*	*b*	*c*	Sample number	Fitting equation	R^2	*P*
T	15.01	–243.5	65.75	–1.2	20	$R_s = -243.5w^2 + 65.75w - 1.2$	0.288	0.056
R	13.99	–204.4	50.21	0.186	20	$R_s = -204.4w^2 + 50.21w - 0.186$	0.137	0.286
TS	15.85	–337.8	86.57	–1.589	20	$R_s = -337.8w^2 + 86.57w - 1.589$	0.279	0.062
RS	15.61	–237.9	61.47	–0.256	20	$R_s = -237.9w^2 + 61.47w - 0.256$	0.187	0.172
TSD	15.99	–263.8	75.18	–0.753	20	$R_s = -263.8w^2 + 75.18w - 0.753$	0.420	0.05
RSD	15.08	–153.8	31.44	3.558	20	$R_s = -153.8w^2 + 31.44w - 3.558$	0.159	0.386
W-S	16.18	–341.5	88.71	–1.352	60	$R_s = -341.5w^2 + 88.71w - 1.352$	0.170	0.009
C-K	15.31	–200.2	59.81	–1.105	60	$R_s = -200.12w^2 + 59.81w - 1.105$	0.306	0.000

T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching; TSD – traditional tillage + straw mulching + decomposing inoculants; RSD – ridge tillage + straw mulching + decomposing inoculants; W-S – strip planted with wheat and soybean; C-K – strip planted with corn; *a,b,c* – simulation parameters

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Table 3. Number and proportion of soil animals under different treatments during growing period of wheat

Animal species	T		R		TS		RS	
	number	proportion	number	proportion	number	proportion	number	proportion
Elastic tail	592**	72.11	570**	68.43	779**	74.76	890**	73.92
Acarina	189*	23.02	226*	27.13	205*	19.67	241*	20.02
Diptera	5	0.61	3	0.36	3	0.29	2	0.17
Coleoptera	3	0.37	8	0.96	6	0.58	7	0.58
Thysanoptera	1	0.12	0	0.00	0	0.00	0	0.00
Araneae	7	0.85	10	1.20	8	0.77	6	0.50
Hymenoptera	3	0.37	1	0.12	6	0.58	13	1.08
Scolopendromorpha	6	0.73	3	0.36	5	0.48	14	1.16
Tubificida	9	1.10	4	0.48	9	0.86	16	1.33
Unidirectional mesh earthworm	1	0.12	1	0.12	2	0.19	2	0.17
Diplura	0	0.00	0	0.00	13	1.25	0	0.00
Spirobolus bungii	1	0.12	0	0.00	0	0.00	2	0.17
Dermaptera	0	0.00	1	0.12	1	0.10	1	0.08
Orthoptera	0	0.00	4	0.48	1	0.10	5	0.42
Gnathobdellidda	0	0.00	0	0.00	0	0.00	1	0.08
Siphonaptera	1	0.12	0	0.00	0	0.00	0	0.00
Arachnida	1	0.12	2	0.24	0	0.00	3	0.25
Unknown 1	2	0.24	0	0.00	0	0.00	0	0.00
Unknown 2	0	0.00	0	0.00	1	0.10	0	0.00
Unknown 3	0	0.00	0	0.00	3	0.29	1	0.08
Total	821**	100.00	833**	100.00	1042**	100.00	1204**	100.00

Unknown 1,2,3 mean some soil animal species were not identified. **$P < 0.01$; *$P < 0.05$. T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching

The relationship between soil respiration and soil moisture was described as exponential function, linear function, power function and parabolic function (Meng et al. 2008). In this study, the relationship can be well described with a parabolic function (Table 2). According to the mathematical meaning of the function, it could be easily understood that soil moisture had a bidirectional regulation effect on soil respiration. Soil respiration was promoted by increasing soil moisture in relatively dry state, while it was inhibited when the soil moisture content exceeded a given limit (Che et al. 2010). The given limit in our study was 14.94%.

The numbers of soil fauna was seized by the Tullgren apparatus method during the growth period of wheat, corn and soybean reached 3893, 3111 and 3296 per 500 cm^3, respectively. The number of soil animal species was 20, 15 and 14, respectively (Tables 3, 4 and 5). It can be concluded that soil animal community structure changed more stably under long-term straw mulching in farmland (Table 6). Correlation analysis between soil respiration and the number of soil fauna showed that the two had a correlation. The average soil respiration at two time points was multiplied by the number of days, that is, the soil respiration of the two sampling interval was obtained. The number of soil fauna was obtained by the average of soil fauna in the two sampling time points. In corn farmland, correlation index was the highest under ridge tillage treatment (r = 1.000; P = 0.017). The second was the straw mulching treatment (r = 0.915; P = 0.029). However, it only emerged the soil fauna captured by pitfall traps method. The correlation index of RS treatment reached significant level (r = 0.930; P = 0.022) when correlation analysis of all soil fauna by the two methods and soil respiration. The phenomenon also appeared in soybean soil where the correlation index of T treatment reached significant level (r = 0.901; P = 0.037). As

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Table 4. Number and proportion of soil animals under different treatments during growing period of corn

Animal species	T		R		TS		RS	
	number	proportion	number	proportion	number	proportion	number	proportion
Elastic tail	394	64.80	368	65.95	490	55.30	752	71.01
Acarina	118	19.41	95	17.03	187	21.11	168	15.86
Diptera	70	11.51	57	10.22	90	10.16	66	6.23
Coleoptera	5	0.82	8	1.43	16	1.81	12	1.13
Thysanoptera	1	0.16	0	0.00	0	0.00	0	0.00
Araneae	4	0.66	4	0.72	8	0.90	3	0.28
Hymenoptera	1	0.16	8	1.43	3	0.34	2	0.19
Scolopendromorpha	2	0.33	3	0.54	4	0.45	9	0.85
Tubificida	11	1.81	4	0.72	20	2.26	30	2.83
Unidirectional mesh earthworm	0	0.00	0	0.00	0	0.00	2	0.19
Blind spider	1	0.16	1	0.18	1	0.11	1	0.09
Chilopoda	1	0.16	7	1.25	7	0.79	1	0.09
Isopoda	0	0.00	0	0.00	2	0.23	4	0.38
Orthoptera	0	0.00	3	0.54	4	0.45	8	0.76
Snail	0	0.00	0	0.00	4	0.45	0	0.00
Total	608**	100.00	558**	100.00	886**	100.00	1059**	100.00

**P < 0.01; *P < 0.05. T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching

a result, it was needed to expand the scope of soil animal captured for study in the relationship more clearly between soil respiration and soil fauna.

In conclusion, the daily average soil respiration rate under different crops farmland was sequenced by wheat < corn < soybean. Compared with con-

Table 5. Number and proportion of soil animals under different treatments during growing period of soybean

Animal species	T		R		TS		RS	
	number	proportion	number	proportion	number	proportion	number	proportion
Elastic tail	512	72.83	384	67.02	709	68.37	640	65.11
Acarina	70**	9.96	77**	13.44	135**	13.02	206**	20.96
Diptera	56*	7.97	58*	10.12	100*	9.64	88*	8.95
Coleoptera	9	1.28	10	1.75	16	1.54	13	1.32
Araneae	4	0.57	5	0.87	6	0.58	5	0.51
Hymenoptera	9	1.28	8	1.40	8	0.77	7	0.71
Chilopoda	7	1.00	13	2.27	28	2.70	11	1.12
Tubificida	24	3.41	8	1.40	17	1.64	4	0.41
Unidirectional mesh earthworm	2	0.28	1	0.17	4	0.39	2	0.20
Hirudinea	0	0.00	1	0.17	1	0.10	0	0.00
Diplopoda	0	0.00	0	0.00	0	0.00	1	0.10
Isopoda	5	0.71	5	0.87	4	0.39	3	0.31
Orthoptera	4	0.57	3	0.52	9	0.87	3	0.31
Snail	1	0.14	0	0.00	0	0.00	0	0.00
Total	703*	100.00	573*	100.00	1037*	100.00	983*	100.00

**P < 0.01; *P < 0.05. T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching

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Table 6. Comparison of soil animal diversity index in wheat farmland

Crop	Diversity index	T	R	TS	RS
Wheat	H	0.821	0.828	0.842	0.847
	E	0.303	0.306	0.311	0.313
	C	0.600	0.590	0.570	0.540
	D	0.380	0.393	0.370	0.382
Corn	H	1.054	1.012	1.216	1.124
	E	0.440	0.394	0.474	0.469
	C	0.471	0.534	0.362	0.476
	D	0.374	0.344	0.353	0.379
Soybean	H	1.055	1.178	1.138	1.070
	E	0.425	0.474	0.458	0.431
	C	0.548	0.479	0.495	0.476
	D	0.379	0.391	0.358	0.361

H – diversity index; E – evenness index; C – dominance index; D – richness index; T – traditional tillage; R – ridge tillage; TS – traditional tillage + straw mulching; RS – ridge tillage + straw mulching

ventional tillage, straw mulching treatment enhanced soil respiration rate but the ridge tillage had different effects. In wheat-soybean stripes, ridge tillage increased soil respiration rate but in corn stripe it was opposite. The experiment also shows that soil temperature and soil moisture content were the two major factors affecting soil respiration. It indicated that soil tillage patterns had great impact on soil animals. The more was the amount of animals being active above soil surface, the stronger was the soil respiration.

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