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Long-term organic fertilisers application increase plant autotrophic, soil heterotrophic respiration and net ecosystem carbon budget in a hillslope agroecosystem

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Abstract: The effects of long-term various organic fertilisers application on ecosystem respiration components and net carbon budget have rarely been investigated in a hillslope agricultural ecosystem. Hence, we measured the rates of plant autotrophic (R_a) and soil heterotrophic respiration (R_h) from 2011 to 2012 with five treatments: no fertiliser (CK); mineral fertiliser (MF); MF combined with swine manure (MFS); MF combined with crop straw (MFC), and swine manure (SM). Our results confirm that R_a was found to be more temperature-moisture sensitive than R_h, whereas R_h was more temperature sensitive than R_a. Soil microbial biomass carbon (MBC) is a major factor influencing the temperature sensitivity coefficient of R_h (Q_{10}), thereby application of organic fertilisers combined with mineral fertilisers (MFS and MFC) significantly increased annual by 19.3% and 17.2% compared with MF treatment. Annual carbon emissions *via* R_h and R_a under MFS, MFC and SM treatments were increased by 24.6, 28.5, 48.8% and 6.6, 10.6, 1.8%, respectively compared with MF treatment (4.6 and 23.2 t C/ha/year). Net primary production (NPP) under MFS, MFC and SM treatments were increased by 5.4, 6.01, and 15.6% relative to MF treatment (13.6 t C/ha/year), respectively, and the corresponding net ecosystem carbon budget (NECB) increased by 121.2, 172.8, and 342.4%. Our findings establish that long-term organic fertilisers application increase plant autotrophic, heterotrophic respiration and net ecosystem carbon budget, which can increase the carbon sink function. Overall, crop straw combined with mineral fertiliser is a feasible agronomy practice to increase carbon sink function, reduce soil erosion and maintain crop yield.

Keywords: carbon cycle; wheat; maize; farmyard manure; carbon balance; sloping croplands

Ecosystem respiration, including plant autotrophic and soil heterotrophic respiration components, results in the exchange of carbon between soil, plant and the atmosphere, and therefore is a key link in the carbon cycle process in terrestrial ecosystems (Janzen 2004). In agroecosystems, ecosystem respiration can be strongly affected by fertilisation, tillage, irrigation, and cropping system, which significantly affects the net ecosystem carbon budget (Smith and Dukes 2013). Therefore, it is essential that the ecosystem respiration components and changes in carbon budgets in agroecosystems be quantified.

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As we have known, organic fertilisers can greatly improve crop yields and increase soil organic carbon sequestration, thereby influencing soil carbon cycling process (Maillard and Angers 2014). The application of organic fertilisers can substantially alter the micro-ecological environment and the physicochemical properties of the soil, thereby strongly influencing plant autotrophic and soil heterotrophic respiration and affecting the net ecosystem carbon budget (Jian et al. 2016). Lai et al. (2017) showed that organic manure combined with mineral fertilisation increased the rates and cumulative carbon emissions from crop root respiration and soil heterotrophic respiration. According to Chen et al. (2018), chicken manure combined with mineral fertilisation stimulated carbon emission *via* soil heterotrophic but not plant root respiration. Although those studies focused on plant root and soil heterotrophic respiration under organic fertilisers, the effects of long-term various organic fertilisers (e.g. farmyard manure and crop straw) application on plant autotrophic, soil heterotrophic respiration, and the ecosystem carbon budget in croplands remain unclear.

The sloping cropland located in Regosol is characterised by its inherently high water erosion. Organic fertilisers are commonly used to increase soil organic carbon sequestration and to decrease water erosion in the area. However, the effects of long-term farmyard manure and crop straw application on ecosystem respiration components rate and the net carbon budget have not been investigated, and the optimal fertilisation practices that can increase the carbon sink function remain unclear. The specific objectives of this study were to: (1) quantify the rates of plant autotrophic and soil heterotrophic respiration; (2) evaluate the effects of the organic amendment application on the ecosystem carbon budget, and (3) identify the optimal fertilisation practice that fulfills the dual goals of sustaining grain yield and increasing the carbon sink function.

MATERIAL AND METHODS

Site and soil description. The experiment (31°16'N, 105°28'E) was conducted at the Yanting Agro-Ecological Station of Purple Soil (400–600 m a.s.l.) in the central Sichuan Basin of Southwest China. The soil at the site is classified as a Regosol (IUSS Working Group WRB 2006). The soil is developed from purplish shale and has the typical binary structure of soil and bedrock (Xiong and Li 1986). The specific soil used in this study was a silt loam soil (measured in 2002) with a pH_{H_2O} of 8.3, bulk density of 1.3 g/cm^3, organic carbon content of 5.1 g/kg, total N content of 0.62 g/kg, C/N ratio of 8.2, total P content of 0.6 g/kg, available P of 4.2 mg/kg, available N content of 42.3 mg/kg, and saturated hydraulic conductivity of 16.8 mm/h (Zhu et al. 2009).

Experimental setup. The experimental plots (size: 8 × 4 m, slope 7%) were laid out in a randomised block design with three replicates in 2002. The datasets used in this paper were observed from 2011 to 2012. One control and four fertiliser treatments were used: control (no fertiliser, CK); mineral nitrogen fertiliser (conventional treatment, MF); mineral nitrogen fertiliser (60% of applied total nitrogen) combined with swine manure (40% of applied total nitrogen) (MFS); mineral nitrogen fertiliser (60% of applied total nitrogen) combined with crop straw (40% of applied total nitrogen) (MFC); and swine manure application (100% of applied total nitrogen) (SM). The mineral nitrogen, phosphorus and potassium fertilisers used were urea, superphosphate and potassium chloride, respectively. The types and application rates of mineral or organic fertilisers are shown in Table 1.

Ecosystem respiration components and environmental factors measurements. Field measurements of plant autotrophic and soil heterotrophic respiration were completed *via* static chamber-gas chromatography methodology (Zhou et al. 2007). Gas samples were performed between 9:00 and 11:00 AM local time (Ding et al. 2007). The CO_2 concentration in gas samples was analysed with a gas chromatograph (HP-5890 SeriesII, Hewlett-Packard, Palo Alto, USA). Soil temperature and moisture (water filled pore space, WFPS) were measured at a depth of 5 cm using a manual thermocouple thermometer and a portable frequency domain reflector sensor. Field-moist soil samples were collected to analyse physicochemical (soil organic carbon, SOC; dissolved organic carbon, DOC; dissolved organic nitrogen, DON; ammonium nitrogen, NH_4^+-N; nitrate nitrogen, NO_3^--N) and microbial biomass (microbial biomass carbon, MBC; microbial biomass nitrogen, MBN) properties.

Analytical methods. The DOC concentration in the filtrate was automatically analysed by flow injection technology using an AA3 Auto-analyser (Bran + Lubbe, Norderstedt, Germany). Soil ammonium (NH_4^+-N) and nitrate (NO_3^--N) were analysed using a continuous-flow analyser (AA3). Soil MBC and MBN were measured using fumigation-incubation according to the methods provided by Jenkinson and Powlson (1976).

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Table 1. Application rates of mineral fertilisers and organic amendments in the treatments

		Mineral fertiliser			Organic amendment (dry weight basis)							Total input		
Growing season	Treatment	N	P	K	amount	N content	N input	P content	P input	K content	K input	N	P	K
		(kg/ha/year)			(kg/ha/year)	(%)	(kg/ha/year)	(%)	(kg/ha/year)	(%)	(kg/ha/year)	(kg/ha/year)		
Wheat	CK	0	0	0	0	0	0	0	0	0	0	0	0	0
	MF	130	39.3	30	0	0	0	0	0	0	0	130	39.3	30
	MFS	78	39.3	30	3 240	1.6	52	0.55	17.8	0.31	1.00	130	57.1	31.0
	MFC	78	39.3	30	5 049	1.03	52	0.035	1.8	1.75	8.84	130	41.1	38.8
	SM	0	0	0	8 125	1.6	130	0.55	4.5	0.31	2.52	130	4.5	2.5
Maize	CK	0	0	0	0	0	0	0	0	0	0	0	0	0
	MF	150	39.3	30	0	0	0	0	0	0	0	150	39.3	30
	MFS	90	39.3	30	3 740	1.6	60	0.55	20.6	0.31	1.16	150	59.9	31.2
	MFC	90	39.3	30	6 315	0.95	60	0.033	2.1	1.42	8.97	150	41.4	39.0
	SM	0	0	0	9 375	1.6	150	0.55	5.2	0.31	2.91	150	5.2	2.9

CK – no fertiliser; MF – conventional treatment; MFS – mineral nitrogen fertiliser (60% of applied nitrogen) combined with swine manure (40% of applied nitrogen); MFC – mineral nitrogen fertiliser (60% of applied nitrogen) combined with crop straw (40% of applied nitrogen); SM – swine manure application (100% of applied total nitrogen); mineral fertiliser: N – urea; P – superphosphate; K – potassium chloride. Total N content of swine manure was 1.60%. Total N contents of maize and wheat straw from local farms were 1.03% and 0.95%, respectively. Total P and K contents of swine manure were 0.55% and 0.31%. Total P and K contents of maize straw applied in the wheat growing season were 0.035% and 1.75%. Total P and K contents of wheat straw applied in the maize growing season were 0.033% and 1.42%

Calculations. We used a straw to yield ratio of 1.2:1 for wheat and 1.1:1 for maize to calculate the straw biomass (Hua et al. 2016). The organic carbon inputs from the roots were estimated at 30% of the aboveground biomass for wheat (Kuzyahov and Domenski 2000) and 19% for maize (IPCC 2006). The ratios of root biomass in topsoil to total root biomass in the soil profile were set at 0.753 for wheat and at 0.984 for maize (Hua et al. 2016). The organic carbon input from crop litter was estimated to account for 5% of the aboveground and root biomass (Kimura et al. 2004). The organic carbon input from rhizodeposition was estimated to account for 18% of the total biomass carbon for wheat and maize (Gregory 2006). Swine manure and crop straw were the primary organic carbon input sources in addition to crop residues for MFS, MFC, and SM treatments. The water content of air-dried grain was 14%, according to the National Center for Agricultural Technology Service standard (1994). Hence, the annual organic carbon input *via* crop residues was estimated from the summation of annual root, stubble, and litter organic carbon inputs using Eqs. 1–5:

$$\text{Stubble}_C = Y_{straw} \times C_{straw} \times 10\% \times 10^{-6} \tag{1}$$

$$\text{Root}_C = (Y_{grain} \times C_{grain} + Y_{straw} \times C_{straw}) \times \times R \times 10^{-6} \tag{2}$$

$$\text{Litter}_C = (Y_{grain} \times C_{grain} + Y_{straw} \times C_{straw} + + \text{root}_C) \times 5\% \times 10^{-6} \tag{3}$$

$$\text{Rhizodeposition}_C = (Y_{grain} \times C_{grain} + + Y_{straw} \times C_{straw} + \text{root}_C) \times 18\% \times 10^{-6} \tag{4}$$

$$\text{Crop residues}_C = \text{stubble}_C + \text{root}_C + + \text{litter}_C + \text{rhizodeposition}_C \tag{5}$$

where: Y_{grain} and Y_{straw} – grain and straw biomass, respectively (kg/ha); C_{grain} and C_{straw} – organic carbon content of grain and crop straw, respectively (g/kg), measured in 2012; R – ratio root biomass to aboveground biomass. Crop residues_C – sum of annual root, stubble, and litter organic carbon inputs (t/ha/year). The organic carbon inputs from organic fertilisers under MFS, MFC, and SM treatments were calculated for each period as follows:

$$C_o = Q \times W \times C_m \tag{6}$$

where: C_o – annual organic carbon input (t/ha/year); Q – amount of the organic amendment application in each year (t/ha/year); W (%) – average water content; C_m (%) – average organic carbon content of organic fertilisers, measured in 2011 and 2012.

Calculation of net primary productivity, net ecosystem carbon exchange and net ecosystem carbon budget. The sum of organic carbon in grain, straw, root, litter, and rhizodeposits was used to estimate net primary productivity (NPP, t/ha/year). Gross primary productivity (GPP, t/ha/year) was calculated as the sum of NPP and plant respiration (R_a). Net ecosystem production (NEP, t/ha/year) was obtained as the difference between NPP and soil heterotrophic respiration (R_h). The net ecosystem carbon budget (NECB, t/ha/year) was calculated using Eqs. 7–10 (Zhang et al. 2014):

$$\text{NPP} = \text{C}_{\text{grain}} + \text{C}_{\text{straw}} + \text{C}_{\text{root}} + \text{C}_{\text{litter}} + \text{C}_{\text{rhizodeposition}} \tag{7}$$

$$\text{GPP} = \text{NPP} + \text{R}_{\text{a}} \tag{8}$$

$$\text{NEP} = \text{NPP} - \text{R}_{\text{h}} \tag{9}$$

$$\text{NECB} = \text{NEP} + \text{C}_{\text{o}} - \text{C}_{\text{H}} \tag{10}$$

where: R_a – annual cumulative carbon emission *via* plant respiration (t/ha/year); R_h – annual cumulative carbon emission *via* soil heterotrophic respiration (t/ha/year); C_H – annual organic carbon loss *via* aboveground biomass removed by harvest (t/ha/year).

Statistical analyses and graph preparation. All statistical analyses were performed using the SPSS19.0 software package (SPSS Inc., Chicago, USA). One factor ANOVA followed by the Tukey's range test was employed, with $P < 0.05$ considered statistically significant. We used multiple stepwise regression analysis to identify the main factors that regulate plant autotrophic respiration.

RESULTS AND DISCUSSION

Environmental factors. In the wheat growing season, the average soil temperature was 14.1 °C in CK, 12.3 °C in MF, 17.7 °C in MFS, 18.2 °C in MFC, and 11.5 °C in SM, and in the maize growing season, temperatures were 25.1 °C in the CK, 24.3 °C in MF, 23.5 °C in MFS, 23.7 °C in MFC, and 23.4 °C in SM (Figure 1A). In the wheat growing season, average WFPS was 56.6% in the CK, 49.4% in MF, 47.9% in MFS, 47.8% in MFC, and 47.5% in SM, and in the maize growing season, it was 66.0% in the CK, 59.5% in MF, 63.3% in MFS, 58.8% in MFC, and 60.3% in SM

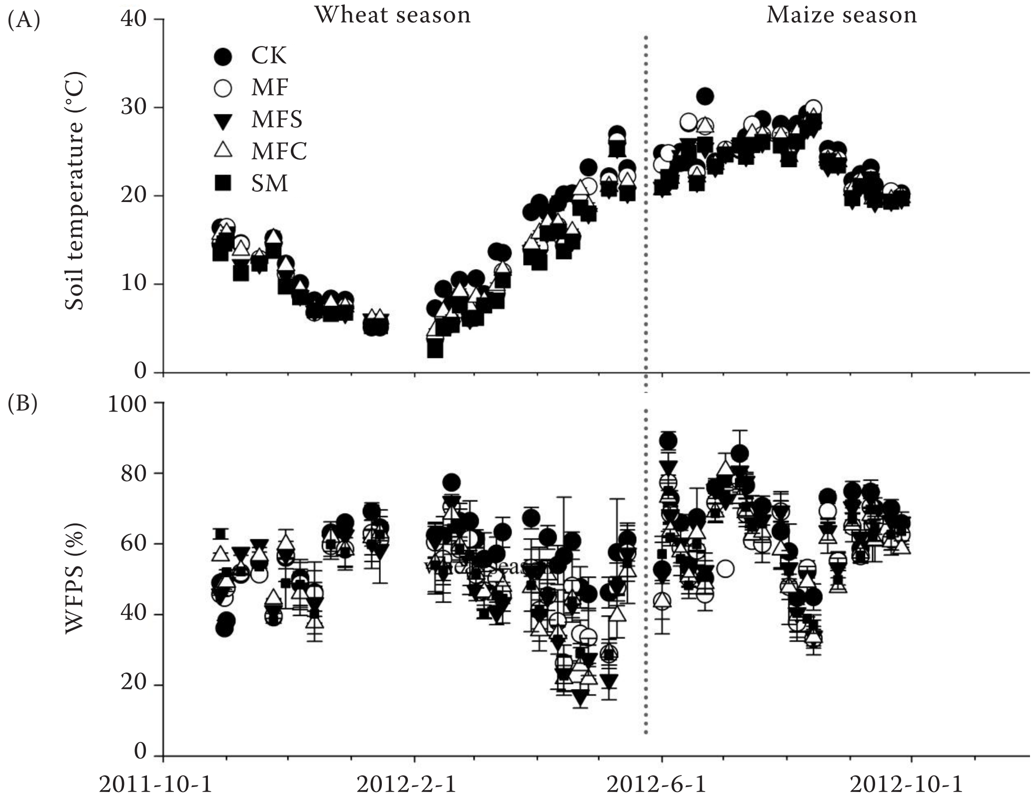

Figure 1. Seasonal variations in (A) soil temperature at a depth of 5 cm and (B) soil moisture from 2011 to 2012. CK – no fertiliser; MF – conventional treatment; MFS – mineral nitrogen fertiliser (60% of applied nitrogen) combined with swine manure (40% of applied nitrogen); MFC – mineral nitrogen fertiliser (60% of applied nitrogen) combined with crop straw (40% of applied nitrogen); SM – swine manure application (100% of applied total nitrogen); WFPS – water filled pore space

Table 2. Soil chemical and microbial properties at a depth of 0–20 cm for all treatments

Growing season	Treatment	MBC	MBN	DOC	DON	NH_4^+-N	NO_3^--N
		(mg/kg)					
Wheat	CK	93.5^d	26.1^d	15.3^c	6.4^d	5.80^c	3.66^c
	MF	195.6^c	48.7^c	18.3^b	12.4^a	5.65^c	7.75^a
	MFS	312.0^a	86.3^a	21.3^a	8.9^c	7.42^b	5.86^b
	MFC	278.8^a	60.5^b	25.6^a	7.9^c	10.35^a	7.51^a
	SM	224.5^b	54.2^c	23.9^a	10.2^b	9.17^a	7.73^a
Maize	CK	101.8^c	28.5^d	16.3^c	2.2^b	3.52^a	1.54^d
	MF	240.7^b	66.7^c	19.8^b	3.1^a	3.72^a	3.49^c
	MFS	397.3^a	103.2^a	23.6^a	4.2^a	2.61^b	4.00^b
	MFC	341.6^a	79.3^b	27.8^a	3.6^a	2.88^b	4.87^b
	SM	264.7^b	60.9^c	25.8^a	1.7^b	4.02^a	6.50^a

MBC and MBN – microbial biomass carbon and nitrogen; DOC and DON – dissolved organic carbon and nitrogen; NH_4^+-N – soil ammonium; NO_3^--N – nitrate. Data are presented as means (n = 3). Values followed by the same letter are not significantly different from each other ($P < 0.05$)

(Figure 1B). In the MF treatment, microbial biomass (MBC and MBN) and substrate (DOC, DON, NO_3^--N) contents increased significantly compared with the CK in the wheat and maize growing seasons (Table 2). In treatments with organic fertilisers (MFS and MFC), microbial biomass and substrate contents increased significantly ($P < 0.05$) compared with those in the MF treatment. The finding was consistent with the results reported by Yu et al. (2020).

Plant autotrophic and heterotrophic respiration. The annual R_a rates (mg CO_2/h/m^2) were 150.2 in the CK, 346.4 in MF, 416.3 in MFS, 339.9 in MFC,

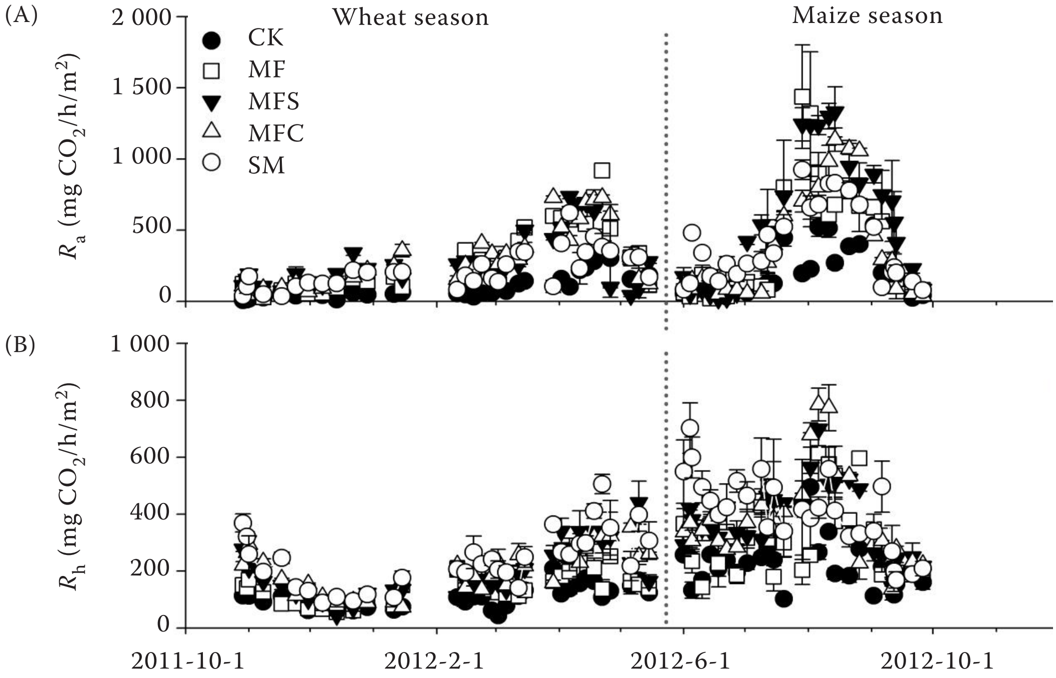

Figure 2. Seasonal variations in (A) plant autotrophic respiration (R_a), and (B) soil heterotrophic respiration (R_h) rate from 2011 to 2012. Vertical bars indicate standard errors of three spatial replicates (n = 3). CK – no fertiliser; MF – conventional treatment; MFS – mineral nitrogen fertiliser (60% of applied nitrogen) combined with swine manure (40% of applied nitrogen); MFC – mineral nitrogen fertiliser (60% of applied nitrogen) combined with crop straw (40% of applied nitrogen); SM – swine manure application (100% of applied total nitrogen)

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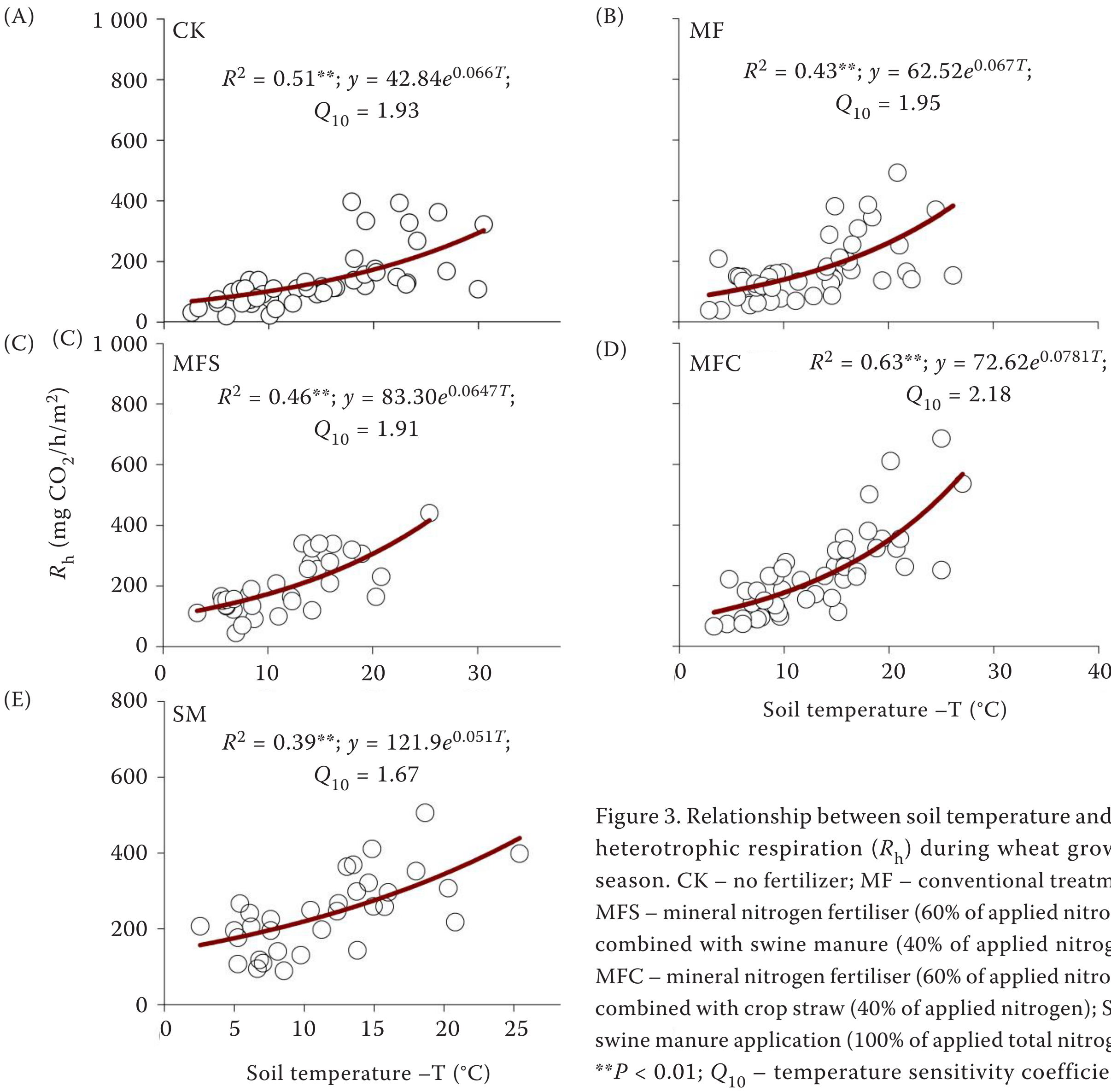

Figure 3. Relationship between soil temperature and soil heterotrophic respiration (R_h) during wheat growing season. CK – no fertilizer; MF – conventional treatment; MFS – mineral nitrogen fertiliser (60% of applied nitrogen) combined with swine manure (40% of applied nitrogen); MFC – mineral nitrogen fertiliser (60% of applied nitrogen) combined with crop straw (40% of applied nitrogen); SM – swine manure application (100% of applied total nitrogen); $^{**}P < 0.01$; Q_{10} – temperature sensitivity coefficient

and 298.9 in SM (Figure 2A). Compared with the MF treatment, the annual cumulative carbon emissions increased significantly ($P < 0.05$) increased by 6.6% and 10.6% in the MFS and MFC treatments, respectively, whereas no significant difference was found in the SM treatment. The annual cumulative carbon loss fluxes (g C/m^2) *via* R_h were 339.6 in the CK, 458.8 in MF, 573.1 in MFS, 589.6 in MFC, and 683.2 in SM. Compared with the MF treatment, the annual cumulative carbon emission *via* R_h increased significantly ($P < 0.05$) by 24.9, 28.5, and 48.9% in the MFS, MFC, and SM treatments, respectively (Figure 2B). These findings indicated that the cumulative carbon emissions of R_a and R_h could be increased under long-term organic manure or crop straw application, which was similar with the results reported by Lai et al. (2017).

Environmental factors influencing R_a and R_h. The R_a rate was significantly correlated with soil temperature and moisture, which could be described by a stepwise linear regression equation (R_a = 13.1T – 6.4WFPS + 429.3, $P < 0.05$). Because R_a is the result of carbohydrate metabolism in plants, the respiration rate is strongly dependent on the intensity of plant growth and metabolism (Zhong et al. 2016). Soil temperature and moisture had a significant relation with R_a because they indirectly influence crop growth and thereby affect R_a. Similar to our findings, Liu et al. (2018) reported that a quadratic equation describes the relationship between soil moisture and total ecosystem respiration

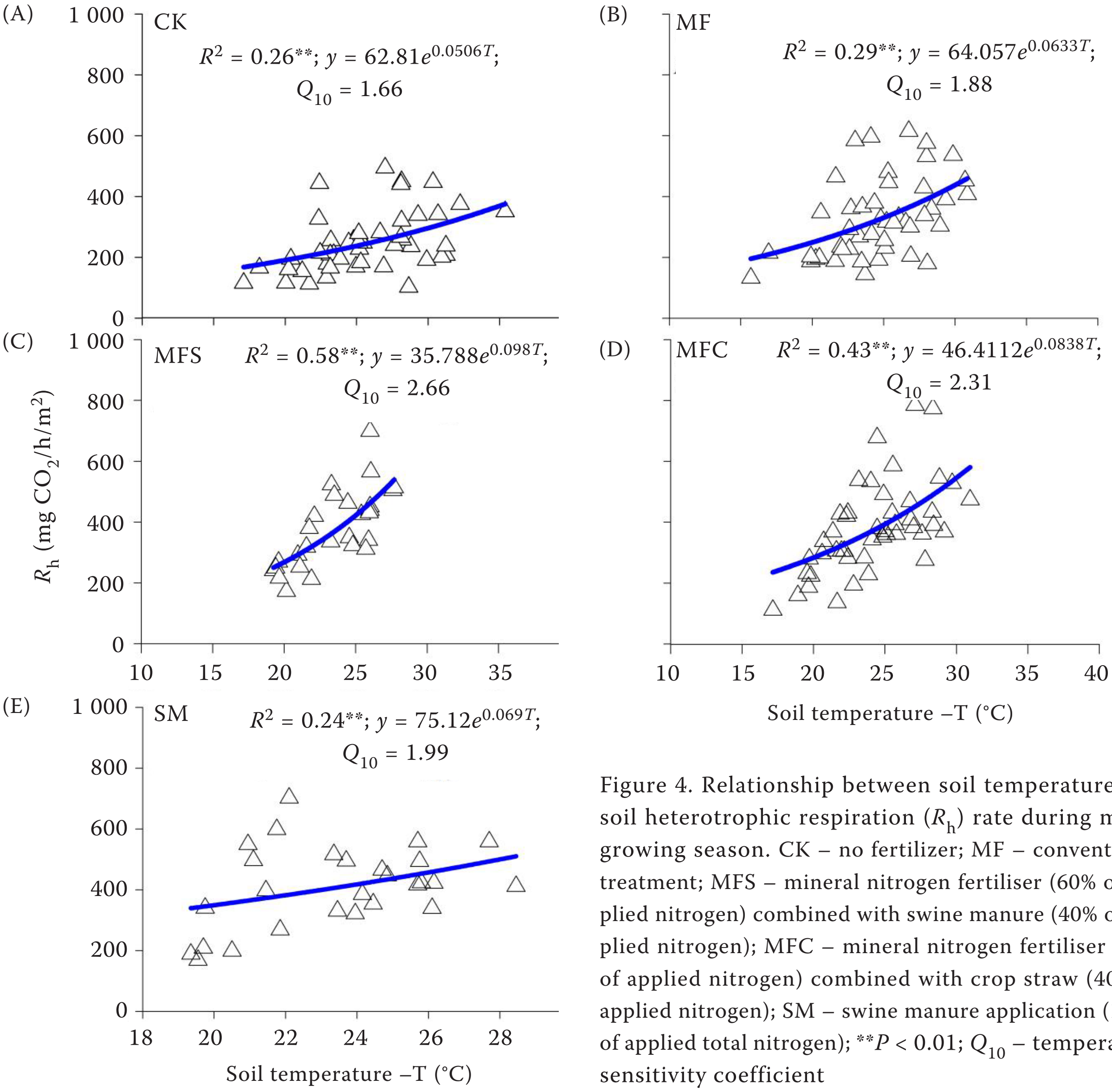

Figure 4. Relationship between soil temperature and soil heterotrophic respiration (R_h) rate during maize growing season. CK – no fertilizer; MF – conventional treatment; MFS – mineral nitrogen fertiliser (60% of applied nitrogen) combined with swine manure (40% of applied nitrogen); MFC – mineral nitrogen fertiliser (60% of applied nitrogen) combined with crop straw (40% of applied nitrogen); SM – swine manure application (100% of applied total nitrogen); $^{**}P < 0.01$; Q_{10} – temperature sensitivity coefficient

(including plant autotrophic and soil heterotrophic respiration) in grassland ecosystems. These findings indicated that soil hydrothermal conditions controlled the seasonal variation in R_a. Compared with the Q_{10} value of R_a in the CK, Q_{10} values increased by 6.7% in MF, 27.2% in MFS, and 25.0% in MFC, whereas no significant difference was detected between values in the CK and SM treatments (Figures 3 and 4). The Q_{10} values of R_h were significantly positively correlated with microbial biomass (r = 0.757 for MBC and 0.713 for MBN) (Table 4), and the stepwise linear regression indicated that soil MBC was the major factor influencing the Q_{10} of R_h (Q_{10} = 0.002MBC + 1.44, $P < 0.05$). Because the temperature sensitivity of R_h was closely related to the microbial community composition, soil labile substrate quality, and enzyme activity (Gershenson et al. 2009, Pang et al. 2015, Hursh et al. 2017). Swine manure or crop straw application combined with mineral fertiliser could have increased the temperature sensitivity of R_h primarily because of increases in soil microbial biomass carbon *via* organic amendments application (Wei et al. 2016).

C_o, C_H, NEP, and NECB. The MFS treatment had the lowest annual carbon input *via* organic fertilisers (C_o) (3.4 t C/ha/year) in the organic fertilisers treatments, whereas the average annual C_o in the MFC and SM treatments were greatly higher by 33.9% and 149.7% compared with the MFS treatment (Table 3). The values of annual carbon input *via* crop residues (C_H) under CK, MF, MFS, MFC and SM treatments were

Table 3. Carbon input and output carbon emissions *via* plant autotrophic (R_a) and soil heterotrophic respiration (R_h), net primary productivity (NPP), net ecosystem production (NEP), gross primary productivity (GPP) and net ecosystem carbon budget (NECB) for all the treatments

Growing season	Treatment	C_O	C_H	R_a	R_h	NPP	GPP	NEP	NECB
		(t C/ha/year)							
Wheat	CK	0	0.70^{b}	5.28^{c}	1.53^{d}	0.96^{b}	6.24^{b}	−0.58^{d}	−1.06^{d}
	MF	0	3.23^{a}	11.46^{b}	1.97^{c}	4.44^{a}	15.90^{a}	2.46^{a}	0.25^{c}
	MFS	1.59^{b}	3.25^{a}	11.85^{b}	2.62^{b}	4.41^{a}	16.26^{a}	1.78^{b}	1.14^{b}
	MFC	2.18^{b}	3.20^{a}	12.93^{a}	2.73^{b}	4.33^{a}	17.26^{a}	1.60^{b}	1.57^{b}
	SM	3.96^{a}	3.27^{a}	11.11^{b}	3.17^{a}	4.55^{a}	15.66^{a}	1.38^{c}	3.12^{a}
Maize	CK	0	2.39^{c}	6.48^{c}	1.86^{c}	3.16^{d}	9.65^{c}	1.30^{c}	−0.36^{d}
	MF	0	6.79^{b}	11.72^{b}	2.62^{b}	9.20^{c}	20.92^{b}	6.59^{b}	1.92^{c}
	MFS	1.83^{c}	7.32^{b}	12.87^{a}	3.10^{a}	9.96^{b}	22.83^{a}	6.86^{b}	3.66^{b}
	MFC	2.45^{b}	7.58^{b}	12.71^{a}	3.17^{a}	10.13^{b}	22.84^{a}	6.96^{b}	4.16^{b}
	SM	4.57^{a}	8.24^{a}	12.49^{a}	3.66^{a}	11.22^{a}	23.71^{a}	7.56^{a}	6.48^{a}
Annual	CK	0	3.09^{b}	11.76^{b}	3.39^{d}	4.12^{d}	15.89^{c}	0.72^{b}	−1.42^{e}
	MF	0	10.02^{a}	23.18^{a}	4.59^{c}	13.64^{c}	36.82^{b}	9.05^{a}	2.17^{d}
	MFS	3.42^{c}	10.57^{a}	24.72^{a}	5.72^{b}	14.37^{b}	39.09^{a}	8.64^{a}	4.80^{c}
	MFC	4.62^{b}	10.78^{a}	25.64^{a}	5.90^{b}	14.46^{b}	40.10^{a}	8.56^{a}	5.73^{b}
	SM	8.53^{a}	11.51^{a}	23.60^{a}	6.83^{a}	15.77^{a}	39.37^{a}	8.94^{a}	9.60^{a}

C_o – annual organic carbon input *via* exogenous organic fertilisers; C_H – annual organic carbon loss *via* above-ground biomass removed by harvest. Data are presented as means (n = 3). Values followed by the same letter are not significantly different from each other (P < 0.05)

3.1, 10.0, 10.6, 10.8 and 11.5 t C/ha/year, respectively. The NEP in the CK in the wheat and maize seasons was −0.6 and 1.3 t C/ha/year, respectively, with an annual value of 0.7 t C/ha/year, which was significantly (P < 0.05) lower than that in other treatments. Compared with NEP in the MF treatment, the annual NEP in MFS, MFC, and SM treatments decreased slightly by 4.7, 5.7, and 1.2%, respectively. The annual NECB (t C/ha/year) was −1.4 in the CK, 2.2 in MF, 4.8 in MFS, 5.7 in MFC, and 9.6 in SM. Thus, a net organic carbon loss of 1.4 t C/ha/year occurred without fertilisation application, and carbon sequestration was achieved with the fertilisation practices. Compared with the MF treatment, the sequestration increased significantly by 121.2% in MFS, 164.1% in MFC, and 342.4% in SM. The annual NECB in the CK treatment was −1.4 t C/ha/year, which is consistent with the result from Zhang et al. (2014), who found that the carbon input from unfertilised crops cannot sustain the native SOC content of upland soils. By contrast, the annual NECB values

Table 4. Correlation between soil properties and temperature sensitivity of soil heterotrophic respiration (Q_{10})

	MBC	MBN	DOC	DON	NH_4^+-N	NO_3^--N	Q_{10}
MBC	1						
MBN	0.972**	1					
DOC	0.753*	0.606	1				
DON	−0.072	−0.075	−0.129	1			
NH_4^+-N	−0.113	−0.182	0.115	0.695*	1		
NO_3^--N	0.280	0.158	0.498	0.697*	0.668*	1	
Q_{10}	0.757*	0.713*	0.426	−0.191	−0.323	0.005	1

MBC and MBN – microbial biomass carbon and nitrogen; DOC and DON – dissolved organic carbon and nitrogen; NH_4^+-N – soil ammonium; NO_3^--N – nitrate; *P < 0.05; **P < 0.01

increased significantly by 121–173% after application of organic fertilisers, particularly in the organic manure only treatment. The increase was primarily due to the exogenous organic carbon inputs in swine manure or crop straw (Chen et al. 2018). Therefore, our findings suggest that organic amendment application should be a recommended practice to increase the carbon sink function and maintain crop yields.

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