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Effects of cotton field management practices on soil CO_2 emission and C balance in an arid region of Northwest China

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Abstract: Changes in both soil organic C storage and soil respiration in farmland ecosystems may affect atmospheric CO_2 concentration and global C cycle. The objective of this field experiment was to study the effects of three crop field management practices on soil CO_2 emission and C balance in a cotton field in an arid region of Northwest China. The three management practices were irrigation methods (drip and flood), stubble managements (stubble-incorporated and stubble-removed) and fertilizer amendments (no fertilizer (CK), chicken manure (OM), inorganic N, P and K fertilizer (NPK), and inorganic fertilizer plus chicken manure (NPK+OM)). The results showed that within the C pool range, soil CO_2 emission during the whole growing season was higher in the drip irrigation treatment than in the corresponding flood irrigation treatment, while soil organic C concentration was larger in the flood irrigation treatment than in the corresponding drip irrigation treatment. Furthermore, soil CO_2 emission and organic C concentration were all higher in the stubble-incorporated treatment than in the corresponding stubble-removed treatment, and larger in the NPK+OM treatment than in the other three fertilizer amendments within the C pool range. The combination of flood irrigation, stubble incorporation and application of either NPK+OM or OM increased soil organic C concentration in the 0−60 cm soil depth. Calculation of net ecosystem productivity (NEP) under different management practices indicated that the combination of drip irrigation, stubble incorporation and NPK+OM increased the size of the C pool most, followed by the combination of drip irrigation, stubble incorporation and NPK. In conclusion, management practices have significant impacts on soil CO_2 emission, organic C concentration and C balance in cotton fields. Consequently, appropriate management practices, such as the combination of drip irrigation, stubble incorporation, and either NPK+OM or NPK could increase soil C storage in cotton fields of Northwest China.

Keywords: arid region; oasis cotton field; management practices; soil C balance; soil organic C; soil respiration

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The soil C pool is 3.3 times the size of the atmospheric pool and 4.5 times the size of the biotic pool (Lal, 2004a). Soil respiration is a major contributor to soil C flux to the atmosphere (Raich and Tufekcioglu, 2000; Jassal et al., 2008). Even a slight change in soil C cycling may lead to alterations in the C balance between the terrestrial ecosystems and the atmosphere (Johnston et al., 2004; Du et al., 2010). Agricultural soils have great potential to reduce the atmospheric CO_2 concentration and mitigate the greenhouse effect

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(Swift, 2001; Smith, 2008).

Among all the terrestrial ecosystems, the agro-ecosystem is most affected by human activity. Agricultural management practices strongly affect C cycling between the agro-ecosystem and the atmosphere (Sainju et al., 2008; Wise et al., 2009). Irrigation is an important agricultural management practice in arid areas for increasing both crop growth and yield. Irrigation methods can affect both soil structure and physical-chemical properties, leading to changes in both soil respiration (Wichem et al., 2004; Li et al., 2011) and C fixation (Wu et al., 2008). Fertilization, one of the major management practices for increasing crop yield, has significant effects on agro-ecosystem. Manure application can increase soil organic C concentrations. Because organic C is the substrate for soil respiration, respiration rates are generally higher in soils that have received manure application (Han et al., 2008). Generally, nitrogen (N) fertilizer application promotes above- and below-ground biomass production, increases the absorption of water and nutrients, and enhances root respiration (Yang et al., 2005). However, studies have also shown that N fertilizer decreases the distribution of C in the soil, resulting in a negative impact on root and rhizosphere microbial respiration, and a reduction in soil respiration rate (Berthrong et al., 2013). Therefore, greater understanding about the effects of agricultural management practices on soil respiration is needed for identifying how to reduce soil CO_2 emission.

Desertification is a serious problem in Xinjiang, China, an important cotton-producing region. Agricultural production practices in Xinjiang have changed significantly in recent decades. Practices such as drip irrigation under mulch film, increased fertilization application, and long-term crop stubble incorporation have significantly increased crop yield. However, these practices have also caused gradual increases in soil CO_2 emission from agriculture fields in this region. Increased soil CO_2 emission may increase crop production by increasing the CO_2 concentration in the lower plant canopy (Qi et al., 2003). On the other hand, not all of the soil CO_2 emitted can be absorbed by the crop; some of the CO_2 enters the atmosphere, leading to an increase in atmospheric CO_2. Climate warming will further increase soil respiration and release more CO_2 from the soil, thus accelerating the warming (Sánchez et al., 2003) and forming a positive feedback loop between the climate change and the C cycle (Friedlingstein et al., 2003).

Inappropriate agricultural management practices can increase soil CO_2 emission and reduce soil organic matter concentration (Lal, 2004a). In contrast, appropriate agricultural management practices can increase soil C storage in cropland (Lal, 2004b). Many researchers have compared the effects of different agricultural management practices on soil C flux and organic C storage (e.g. Entry et al., 2002; Sainju et al., 2008). However, little is known about the relationship between soil CO_2 emission and organic C concentration in arid cropland. Further, additional information on the effects of agricultural management practices on soil C balance is also needed. The objectives of this study were to analyze the relationship between soil CO_2 emission and organic C concentration in cotton fields under different management practices in an arid region of Northwest China, and to determine the effects of crop management practices on soil C balance in the cotton fields.

1 Materials and methods

1.1 Study area

The experiment was conducted in 2010 and 2011 cotton growing seasons at the Wulanwusu Agrometeorological Experiment Station in the Xinjiang Uygur autonomous region, Northwest China (44°17′N, 85°49′E). The experiment station is characterized by an arid climate, with a mean annual precipitation of 211 mm, a mean annual evaporation of 1,660 mm, and an annual mean temperature of 7.0°C. The annual frost-free period is 170 days, and the mean annual sunshine hour is 2,860 h. The soil type is grey desert soil with a sandy loam texture. Soil chemical properties are shown in Table 1.

Table 1 Soil chemical properties in the study area

Soil chemical property	Soil depth (cm)		
	0–20	20–40	40–60
Organic matter (g/kg)	17.0	15.3	12.8
Total N (g/kg)	1.25	1.08	0.94
Total P (g/kg)	2.04	1.91	1.78
Available N (mg/kg)	84.0	72.8	66.4
Available P (mg/kg)	91.5	84.3	72.1
Available K (mg/kg)	315	288	253

1.2 Experimental design

A split-split plot design was used in this experiment. There are 32 plots (2 irrigation methods×2 stubble management practices×4 fertilizer amendments×2 replicates) in total. Each plot had an area of 3 m×8 m and was measured three times. In the main plot treatment, two irrigation methods were designed: drip irrigation and flood irrigation. The split-plot treatment consisted of two stubble management practices: stubble-incorporated (7,500 kg/hm^2) and stubble-removed. The split-split-plot treatment was composed of four fertilizer amendments: no fertilizer (CK), chicken manure (OM), inorganic N, P and K fertilizer (NPK), and inorganic fertilizer plus chicken manure (NPK+OM). The chicken manure, which was composted before utilization, contained organic matter 235 g/kg, total N 17.8 g/kg, total P 13.7 g/kg and total K 21.8 g/kg. To prevent the movement of water and fertilizer between the plots, plastic film (60 cm width and 1.57 mm thickness) was completely buried between the plots before planting. The total amount of fertilizer applied during the growing season in each irrigation treatment was N 440 kg/hm^2, P_2O_5 420 kg/hm^2, K_2O 270 kg/hm^2 and manure 30 t/hm^2. Of these fertilizer amounts, 30% of the N, 70% of the P_2O_5, and 100% of the K_2O and OM were applied before planting. The remainder of the fertilizer (i.e. 70% of the N and 30% of the P_2O_5) was applied as topdressing. In the drip irrigation treatment, the topdress fertilizer was added to the irrigation water, while in the flood irrigation treatment, the topdress fertilizer was placed in shallow furrows and then covered with soil before the irrigation water was applied. The chemical fertilizers were urea (46% N), diammonium phosphate (18% N and 46% P_2O_5), and sulphate-potassium magnesium (22% K_2O, 5% Mg and 14% S). Specific information about the irrigation date, irrigation amount and topdress fertilizer amount are shown in Table 2.

'Xinluzao 33' cotton (*Gossypium hirsutum* L), the most commonly grown cultivar in the study area, was used in this experiment. In 2010, the cotton was sown on 4 May and harvested on 20 October; while in 2011, the cotton was sown on 17 April and harvested on 4 October. The plant density was 19.8×10^4–21.9×10^4 plants/hm^2 in 2010 and 23.1×10^4–25.0×10^4 plants/hm^2 in 2011. All of the plots were covered with plastic film mulch. Two sheets of plastic film mulch were laid side by side in each plot. There was a 40-cm bare soil belt between the two sheets of plastic film mulch. Each sheet of plastic film mulch had four rows of cotton, at the intervals of 30 cm between rows 1 to 2 and between rows 3 to 4, and 50 cm between rows 2 to 3. Aside from the treatments described above, the plots were managed according to the local management practices.

1.3 Observation indices and methods

1.3.1 Measurements of soil respiration

Soil respiration rates were measured at an interval of approximately ten days during two cotton growing seasons using an LI-8100 automated soil CO_2 flux system (Li-Cor Inc., Lincoln, NE, USA). The measurements began at cotton emergence and were conducted on sunny days between 10:00 and 13:00,

Table 2 Irrigation date, irrigation amount and topdress fertilizer amount applied under two irrigation treatments in 2010 and 2011 cotton growing seasons

Item		Flood irrigation					Drip irrigation							
2010														
Irrigation date (dd/mm)		05/05	17/06	06/07	05/08	24/08	05/05	21/06	06/07	15/07	21/07	04/08	14/08	21/08
Irrigation amount (m^3/hm^2)		45	2,625	1,770	1,410	1,125	45	750	675	825	825	750	675	600
Topdressing amount (kg/hm^2)	N	0	51	104	104	51	0	21	41	62	62	62	41	21
	P_2O_5	0	14	28	28	14	0	5	11	17	18	17	11	5
2011														
Irrigation date (dd/mm)		22/04	10/06	06/07	28/07	23/08	22/04	11/06	22/06	06/07	19/07	28/07	12/08	23/08
Irrigation amount (m^3/hm^2)		54	2,550	1,650	1,425	1,125	54	825	675	750	900	750	750	600
Topdressing amount (kg/hm^2)	N	0	51	104	104	51	0	21	41	62	62	62	41	21
	P_2O_5	0	14	28	28	14	0	5	11	17	18	17	11	5

because soil respiration rates at this time can best represent the daily mean respiration rate (Xu and Qi, 2001). To minimize the disturbance of the soil surface, the LI-8100 respiration chamber was mounted on polyvinyl chloride (PVC) soil collars. The collars (11.5 cm height and 20 cm inner diameter) were sharpened at the bottom and inserted into the soil to a depth of 9.5 cm on the day before the first measurement. The collars were left in the soil during the entire growing season. To reduce the effects of cotton roots on soil respiration, the PVC collars were installed in the bare soil between the two sheets of plastic film mulch in each plot. All weeds and plant litters were removed from within the collars the day before each measurement. Among the treatments, soil respiration measurements were conducted in the same sequence on each sampling day for avoiding the systematic errors. For each treatment combination, there was also a corresponding plot with bare soil where all the cotton seedlings were removed immediately after emergence. The bare soil plots were treated exactly the same as the plots with cotton plants, i.e. irrigation methods, stubble management practices and fertilizer amendments. The methods for soil respiration measurements were the same in both the planted and the bare soil plots.

1.3.2 Calculation of soil CO_2 emission

Total soil CO_2 emission (kg C/hm^2) during the entire growing period in each year was calculated based on the soil respiration rate (1 μmol CO_2/(m^2·s)=1.0368 g C/(m^2·d)) and the total number of days in the cotton growing season.

1.3.3 Measurements of net primary productivity

The above- and below-ground biomass of cotton plants were measured at an interval of 20 days beginning at the seedling stage. Above-ground biomass was determined by clipping five cotton plants at the cotyledonary node on each sampling day, while below-ground biomass was determined by excavating blocks of soil (40 cm wide×70 cm long×60 cm deep) from beneath the cotton plants at the same time. The soil was carefully picked apart and the roots were removed by hand. The plant samples were oven-dried at 105°C for 30 min and then at 80°C for 48 h. The samples were weighed after oven-drying and then the average biomass of each individual plant was calculated. The total biomass per unit land area was calculated by multiplying the individual plant biomass by the plant density. The net primary productivity (NPP, g/(m^2·d)) was calculated according to the equation of Han et al. (2007):

$$NPP=\Delta B/\Delta t=(B_2-B_1)/(t_2-t_1). \quad (1)$$

Where B_1 is the total biomass (g/m^2) at sampling time t_1 (d), and B_2 is the total biomass (g/m^2) at sampling time t_2 (d).

1.3.4 Budget of soil C balance

In this study, we used net ecosystem productivity (NEP, kg C/hm^2) to represent the soil C balance in the cotton field ecosystem. The NEP was calculated using the equation of Lee et al. (2003):

$$NEP=NPP-Rs. \quad (2)$$

Where *NPP* is the net primary productivity, and *R*s is the soil microbial heterotrophic respiration. Before calculating *NEP*, the *NPP* values were multiplied by 0.45 to convert the result to a C content (kg C/hm^2) (Zhang et al., 2009). The *R*s values were the soil respiration rates on the bare soil plots. When *NEP* value is negative, the ecosystem is regarded as a CO_2 source relative to the atmosphere; while when *NEP* value is positive, the ecosystem is regarded as a CO_2 sink, and the higher the value the larger the C pool.

1.3.5 Soil sampling and analyses

Five soil sampling points were selected randomly in an S-shaped pattern within each plot at cotton harvest in early October of 2010 and 2011, respectively. Soil samples were collected at the depths of 0–20, 20–40 and 40–60 cm on each sampling point using a soil drill. Samples from the same depth within each plot were thoroughly mixed and divided into three subsamples, and then these subsamples were air-dried and passed through a 0.149-mm sieve. Soil organic C was determined by the potassium dichromate oxidation method (Yeomans and Bremner, 1988).

1.3.6 Data analyses

Data were expressed as mean±standard error. Three-way ANOVA using General Linear Models (GLM) was used to test the main and interactive effects of irrigation methods, stubble management practices and fertilizer amendments on soil organic C concentration. The least significant difference (LSD) at the 0.05 level of probability was used for comparison of means. All statistical analyses were performed by SPSS 18.0 (SPSS, Chicago, IL, USA) and the figures were prepared with Sigmaplot 10.0.

2 Results

2.1 Characteristics of soil CO_2 emissions in cotton fields

Among the cotton growth stages, soil CO_2 emissions were highest during the bolling stage, followed by the seedling stage, the flowering stage, the budding stage, and then the boll opening stage (Table 3). Irrigation methods, stubble management practices and fertilizer amendments all had significant effects on soil CO_2 emissions in the cotton field (Table 3). Within the C pool range, soil CO_2 emissions in the drip irrigation treatment were significantly larger than those in the corresponding flood irrigation treatment throughout the growing season (P<0.05). Meanwhile, among the drip irrigated plots, soil CO_2 emissions were larger in the stubble-incorporated treatment than in the corresponding stubble-removed treatment within the C pool range; however, the differences between the two treatments were only significant at the seedling stage. Among the flood irrigated plots, soil CO_2 emissions were higher in the stubble-incorporated treatment than in the corresponding stubble-removed treatment at the seedling, flowering and boll opening stages; however, the opposite pattern was observed at the budding and bolling stages. Total soil CO_2 emission during the entire growing season followed a similar pattern as that described above for individual growth stages. Specifically, stubble management had a significant effect on total soil CO_2 emission in the flood irrigation treatment compared with the drip irrigation treatment (P<0.05). Comparison of the effects of fertilizer treatments on soil CO_2 emission indicated that no significant difference in soil CO_2 emission was observed between the OM treatment and the corresponding NPK+OM treatment at any time during the experimental period (P>0.05). In contrast, there was significant difference of soil CO_2 emission between the CK treatment and the corresponding NPK treatment (P<0.05). Soil CO_2 emission at each growth stage was

Table 3 Effects of crop management practices on soil CO_2 emission (kg C /hm^2) in 2011 cotton growing season

Treatment		Growth stage					Total soil CO_2 emission
		Seedling (26 Apr–3 Jun)	Budding (3 Jun–28 Jun)	Flowering (28 Jun–23 Jul)	Bolling (23 Jul–28 Aug)	Boll opening (28 Aug–15 Sep)	
Stubble-incorporated treatment							
Drip irrigation	CK	1,218.6^{bA}	991.9^{bA}	1,026.2^{bA}	1,223.7^{bA}	391.3^{aA}	4,851.7^{bA}
	OM	1,283.8^{aA}	1,016.1^{aA}	1,097.7^{aA}	1,315.4^{aA}	403.7^{aA}	5,116.8^{aA}
	NPK	1,172.6^{cA}	959.9^{bA}	1,003.1^{bA}	1,181.1^{bA}	406.2^{aA}	4,722.9^{cA}
	NPK+OM	1,287.7^{aA}	1,021.7^{aA}	1,123.0^{aA}	1,323.2^{aA}	439.2^{aA}	5,194.7^{aA}
Flood irrigation	CK	1,148.1^{bA}	886.5^{bB}	981.1^{bA}	1,194.4^{bB}	418.7^{aA}	4,628.7^{bB}
	OM	1,205.8^{aA}	1,000.5^{aB}	1,066.6^{aA}	1,299.8^{aB}	426.8^{aA}	4,999.5^{aB}
	NPK	1,130.4^{bA}	892.3^{bB}	969.4^{bA}	1,188.8^{bB}	413.1^{aA}	4,594.0^{cB}
	NPK+OM	1,207.1^{aA}	985.6^{aB}	1,061.4^{aA}	1,340.0^{aB}	460.3^{aA}	5,054.4^{aB}
Stubble-removed treatment							
Drip irrigation	CK	1,114.4^{bB}	955.6^{bA}	999.2^{bA}	1,209.3^{bA}	387.6^{bA}	4,666.1^{bA}
	OM	1,214.8^{aB}	1,002.7^{aA}	1,049.8^{aA}	1,303.9^{aA}	406.2^{abA}	4,977.4^{aA}
	NPK	1,019.1^{cB}	908.1^{cA}	970.7^{cA}	1,172.0^{bA}	391.3^{abA}	4,461.2^{cA}
	NPK+OM	1,197.5^{aB}	1,001.4^{aA}	1,067.3^{aA}	1,315.1^{aA}	421.8^{aA}	5,003.1^{aA}
Flood irrigation	CK	1,079.2^{bB}	882.6^{bA}	953.9^{bB}	1,139.7^{bA}	405.6^{abB}	4,461.0^{bC}
	OM	1,141.3^{aB}	919.5^{bA}	1,038.7^{aB}	1,293.3^{aA}	417.4^{abB}	4,810.2^{aC}
	NPK	1,011.5^{cB}	821.7^{cA}	909.8^{cB}	1,160.2^{bA}	400.6^{bB}	4,303.8^{bC}
	NPK+OM	1,139.3^{aB}	962.9^{aA}	1,054.3^{aB}	1,307.0^{aA}	437.9^{aB}	4,901.4^{aC}

Notes: CK, no fertilizer; OM, chicken manure; NPK, inorganic N, P and K fertilizer; NPK+OM, inorganic fertilizer plus chicken manure. Different lowercase letters within a column indicate significant differences (P<0.05) among the four fertilizer treatments under the same irrigation method and stubble management practice. Different capital letters within a column indicate significant differences (P<0.05) between the two stubble management practices under the same irrigation method and fertilizer amendment.

highest in the NPK+OM treatment, followed by the OM treatment, the CK treatment, and then the NPK treatment. Total soil CO_2 emission during the entire growing season followed the same pattern as was observed at individual growth stages.

2.2 Changes in soil organic C concentrations in cotton fields

Soil organic C concentrations decreased as soil depth increased in both cropping seasons (Table 4). Soil organic C concentrations were higher in the stubble-incorporated treatment than in the corresponding stubble-removed treatment; however the differences between the two treatments were not significant (P>0.05). In the soil depth of 0–60 cm, soil organic C concentrations were highest in the NPK+OM treatment, followed by the OM treatment, the NPK treatment, and then the CK treatment under the same irrigation method and stubble management practice; however the differences among the four treatments were not significant. Soil organic C concentrations in the 0–60 cm depth were significantly higher in the flood irrigation treatment than in the corresponding drip irrigation treatment (P<0.05).

2.3 Relationship between soil organic C concentration and soil CO_2 emission

We conducted regression analysis to understand the relationship between soil organic C concentration and soil CO_2 emission in the study area. There was a highly significant positive correlation between soil CO_2 emission and soil organic C concentration in the 20–40 cm soil depth (R^2=0.6970, P<0.01; Fig. 1). Soil CO_2 emission was also positively correlated with soil organic C concentration in the 0–20 cm soil depth (R^2=0.5797, P<0.05) and in the 40–60 cm soil depth (R^2=0.5693, P<0.05). These indicated that soil CO_2 emission had a strong relationship with soil organic C concentration, especially in the 20–40 cm depth.

2.4 Soil C balance in cotton fields

Results of this study showed that the soil in the cotton field acted as a C pool (Table 5). Furthermore, the size of the soil C pool was affected by agricultural management practices (Table 5). Soil C pool was significantly larger in the drip irrigation treatment than in the corresponding flood irrigation treatment (P<0.05). However, soil C pool in the stubble-incorporated treatment was not significantly different from that in the corresponding stubble-removed treatment. Among the four fertilizer treatments, the sizes of the soil C pools declined in the order of NPK+OM>NPK>OM>CK.

The NPP for the entire crop growing season was larger in the drip irrigation treatment than in the corresponding flood irrigation treatment (Table 5). The values of NPP were also higher in the stubble-incorporated treatment than in the corresponding stubble-removed treatment. Comparisons of the four fertilizer treatments under the same irrigation method

Table 4 Effects of crop management practices on soil organic C concentration (g/kg) in 2010 and 2011 cotton growing seasons

Soil depth (cm)	Drip irrigation				Flood irrigation			
	CK	OM	NPK	NPK+OM	CK	OM	NPK	NPK+OM
Stubble-incorporated treatment in 2010								
0–20	9.68±0.47[b]	11.30±0.11[a]	9.72±0.42[b]	11.46±0.12[a]	9.70±0.13[b]	11.35±0.13[a]	9.80±0.17[b]	11.53±0.11[a]
20–40	8.04±0.25[b]	9.03±0.19[a]	8.24±0.34[b]	9.08±0.19[a]	8.57±0.28[b]	9.63±0.23[a]	8.57±0.31[b]	9.73±0.43[a]
40–60	6.53±0.23[b]	7.58±0.34[a]	6.53±0.37[b]	7.65±0.19[a]	6.54±0.35[b]	7.26±0.37[a]	6.60±0.37[b]	7.80±0.28[a]
Stubble-incorporated treatment in 2011								
0–20	9.53±0.24[b]	11.55±0.19[a]	9.82±0.19[b]	11.62±0.19[a]	9.57±0.12[b]	12.27±0.33[a]	9.84±0.25[b]	12.31±0.08[a]
20–40	7.56±0.37[b]	8.46±0.28[a]	7.85±0.09[b]	8.96±0.12[a]	7.63±0.09[b]	8.63±0.35[a]	7.93±0.36[b]	9.21±0.37[a]
40–60	6.53±0.28[b]	6.80±0.09[b]	6.60±0.28[b]	7.40±0.37[a]	6.60±0.33[b]	6.90±0.24[b]	6.53±0.34[b]	7.74±0.09[a]
Stubble-removed treatment in 2011								
0–20	9.36±0.11[b]	11.34±0.13[a]	9.58±0.28[b]	11.47±0.28[a]	9.46±0.29[b]	12.01±0.19[a]	9.61±0.09[b]	12.08±0.28[a]
20–40	7.16±0.19[b]	8.13±0.09[a]	7.37±0.19[b]	8.14±0.23[a]	7.35±0.19[b]	8.18±0.15[a]	7.50±0.37[b]	8.44±0.28[a]
40–60	6.05±0.17[a]	6.26±0.19[a]	6.00±0.37[a]	6.33±0.09[a]	6.12±0.09[b]	6.37±0.09[b]	6.15±0.56[b]	6.66±0.19[a]

Note: The lowercase letters are indicated as in Table 3.

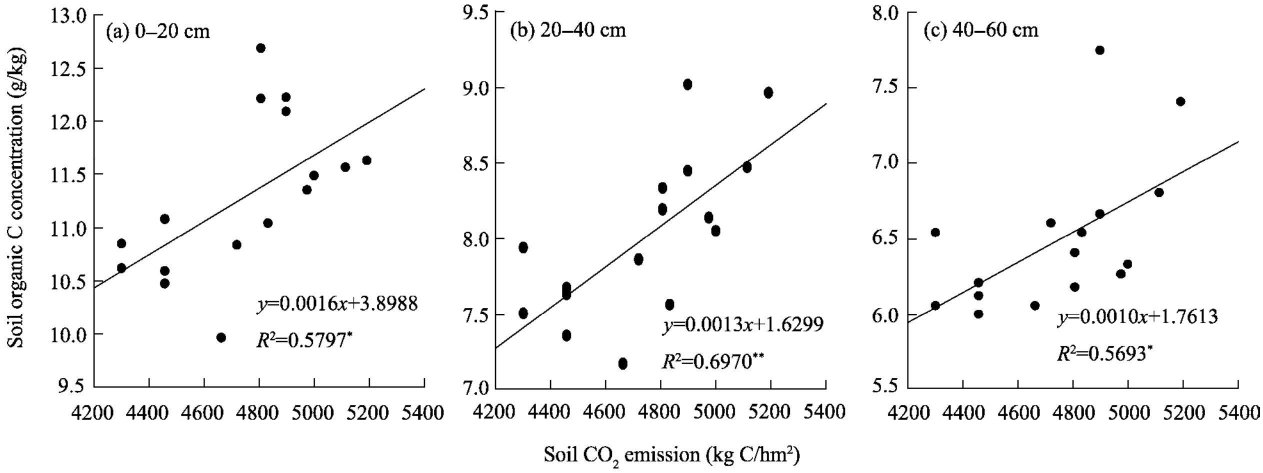

Fig. 1 Regression analysis between soil CO_2 emission and soil organic C concentration in different soil depths (n=16). * and ** mean significance at the 0.05 level and 0.01 level, respectively.

Table 5 Effects of crop management practices on soil C balance in 2011 cotton growing season

Item	Drip irrigation				Flood irrigation			
	CK	OM	NPK	NPK+OM	CK	OM	NPK	NPK+OM
				Stubble-incorporated treatment				
NPP	6,873^{dA}	7,297^{cA}	7,588^{bA}	8,206^{aA}	5,449^{dB}	6,061^{cB}	7,207^{bB}	7,678^{aB}
Rs	2,638^{bA}	2,705^{aA}	2,475^{cA}	2,706^{aA}	2,605^{aA}	2,681^{aA}	2,480^{bA}	2,697^{aA}
NEP	4,235^{dA}	4,591^{cA}	5,013^{bA}	5,500^{aA}	2,844^{dB}	3,381^{cB}	4,727^{bB}	4,980^{aB}
Rt	4,852^{bA}	5,117^{aA}	4,723^{cA}	5,195^{aA}	4,629^{bB}	5,000^{aB}	4,594^{cB}	5,054^{aB}
NPP/Rt	1.42^{bA}	1.43^{bA}	1.61^{aA}	1.58^{aA}	1.18^{bB}	1.21^{bB}	1.57^{aA}	1.52^{aA}
				Stubble-removed treatment				
NPP	6,475^{dA}	6,769^{cA}	7,128^{bA}	7,651^{aA}	4,663^{bB}	5,409^{bB}	6,810^{aB}	7,129^{aB}
Rs	2,678^{bA}	2,741^{aA}	2,533^{cA}	2,672^{bA}	2,273^{bB}	2,428^{aB}	2,194^{cB}	2,377^{aB}
NEP	3,797^{dA}	4,027^{cA}	4,595^{bA}	4,979^{aA}	2,390^{dA}	2,981^{cA}	4,616^{bA}	4,752^{aA}
Rt	4,666^{bA}	4,977^{aA}	4,461^{cA}	5,003^{aA}	4,461^{bB}	4,810^{aB}	4,304^{cB}	4,902^{aB}
NPP/Rt	1.39^{bA}	1.36^{bA}	1.60^{aA}	1.53^{aA}	1.05^{bB}	1.12^{bB}	1.58^{aA}	1.45^{aA}

Note: NPP, net primary productivity (kg C/hm^2); Rs, soil microbial heterotrophic respiration (kg C/hm^2); NEP, net ecosystem productivity (kg C/hm^2); Rt, total soil respiration (kg C/hm^2). NPP/Rt represents the potential effect of crop management practice on soil C storage. The lowercase and capital letters are indicated as in Table 3.

and stubble management practice indicated that NPP was highest in the NPK+OM treatment, followed by the NPK treatment, the OM treatment, and then the CK treatment.

3 Discussion

3.1 Effects of crop management practices on soil CO_2 emission

Irrigation methods have significant effects on soil CO_2 emission (Li et al., 2011). In our study, the increase of soil CO_2 emission lies with drip irrigation rather than with flood irrigation within the C pool range (Table 3). One explanation is that water supply is less intense and water movement is slower in drip irrigation than in flood irrigation (Chai et al., 2008), resulting in less destruction of soil structure and increase of air movement in the drip irrigated soil. The soil of crop root zone under drip irrigation is looser than that under flood irrigation, and the soil water status is generally optimal for microbial activity (Chen et al., 2003). All of these factors could cause higher soil respiration rates in the drip irrigated soil within the C pool range.

The incorporation of cotton stubble increased soil CO_2 emission within the C pool range (Table 3). This is probably because stubble incorporation increased organic C concentration in the soil (Table 4). Malhi et al. (2011) reported that soil microbial respiration increased when sufficient substrate (organic C) was provided. Han et al. (2010a) attributed the increases in soil CO_2 emission after residue incorporation to a reduction in soil bulk density and an increase in porosity; both factors would promote soil respiration. In contrast to these findings, Al-Kaisi and Yin (2005) reported that crop residue on the soil surface reduced soil CO_2 emission by serving as a barrier between the soil and the atmosphere.

In the drip irrigation treatment, both NPK+OM and OM treatments increased soil CO_2 emission within the C pool range (Table 3). In contrast, only NPK treatment reduced soil CO_2 emission. The most likely explanation is that the NPK+OM and OM treatments increased the substrate for microbial activity, then resulting in an increase in microbial respiration.

3.2 Effects of crop management practices on soil organic C concentration

Our results indicated that the NPK+OM or OM treatment alone promoted the accumulation of soil organic C. In contrast, the application of NPK did not significantly increase soil organic C accumulation (Table 4). This suggested that the application of OM was key to the build-up of soil organic C in this agro-ecosystem. Malhi et al. (2011) reported that the application of NPK can reduce the C:N ratio in the soil. In this study, we observed that under the same fertilizer application and stubble management practice, flood irrigation increased soil organic C concentration in the 0–60 cm depth compared with drip irrigation (Table 4). Our results can probably be attributed to the differences in soil water contents between the two irrigation methods. Because the volume of water in a single flood irrigation was large (Table 2), the 0–60 cm soil layer was damp or even saturated after irrigation. This condition reduced organic matter decomposition in the soil (Han et al., 2010b), resulting in higher soil organic C concentration. Conversely, in the drip irrigation treatment, less water was applied at more frequent intervals (Table 2), so the area of damp soil was small and mainly localized near the emitters. Because of the differences in soil water contents, soil temperatures were also likely to be higher in the drip irrigated soil than in the flood irrigated soil. Overall, soil moisture and temperature conditions in the drip irrigation treatment were more favorable for organic matter decomposition, resulting in a decline in soil organic C concentration.

Soil organic C concentration is the most important factor affecting CO_2 emission in agricultural soils (Priess et al., 2001). In our study, soil CO_2 emission was significantly positively correlated with soil organic C concentration in the 20–40 cm soil depth (Fig. 1). Similar results were reported in the grasslands of Inner Mongolia (Li et al., 2004). However, indirect correlation between soil CO_2 emission and organic C concentration in forest ecosystems was also observed in previous studies (Xu and Qi, 2001). Burke and Raynald (1994) found that the density of cotton fine roots was higher in the 20–40 cm soil depth. We supposed that these fine roots could be closely related to soil CO_2 emission in two ways. Firstly, the roots are physiologically active, resulting in the release of significant amounts of CO_2 due to root respiration. Secondly, the decomposition of these roots would also result in the release of CO_2.

3.3 Effects of crop management practices on soil C balance

Agro-ecosystems undertake C regulation in a relatively short time scale (Han et al., 2008). The C sequestration potential of agricultural soil was estimated to account for 20% of the total in China (Zheng et al., 2011). Studies in Europe have shown that appropriate agricultural management practices and policies can increase C storage in agricultural soils (Freibauer et al., 2004). Previous researches in the US also indicated that changes in agricultural land use and management practices between 1982 and 1997 created a C pool for atmospheric CO_2 (Ogle et al., 2003). In our study, agricultural soil was a C pool under certain agricultural management practices. In addition, drip irrigation significantly increased the size of the C pool in the cropland (Table 5). In the drip irrigation system, a relatively small amount of water was applied at frequent intervals, making the soil environment relatively favorable for root development. Although drip irrigation increased soil CO_2 emission within the C pool range (Table 3), the NPP was generally greater in the drip irrigation treatment than in the flood irrigation treatment (Table 5). Under the same irrigation method and stubble management practice, NEP was highest in the NPK+OM treatment, followed by the NPK treatment, the OM treatment, and then the CK treatment (Table 5). Furthermore, under the same irrigation method and fertilizer application, the value of NEP in the stubble-incorporated treatment was higher than that in the stubble-removed treatment (Table 5). Therefore, the combination of drip irrigation, stubble incorporation and NPK+OM increased the size of the soil C pool most, followed by the combination of drip irrigation, stubble incorporation and NPK. Stubble incorporation and appropriate fertilizer application can increase both soil C storage and soil C pool intensity (Wang et al., 2004).

4 Conclusions

Agricultural management practices have significant impacts on soil CO_2 emission, organic C concentration and C balance. In this study, the combination of appropriate agricultural management practices can increase soil organic C concentration, making the agricultural soil as a C pool. In addition, within the C pool range, soil CO_2 emission under flood irrigation was smaller than that under drip irrigation, while soil organic C concentration under flood irrigation was larger than that under drip irrigation. Soil CO_2 emission had a highly significant relationship with soil organic C concentration in the 20–40 cm soil depth. Calculation of NEP showed that the combination of drip irrigation under plastic film mulch, stubble incorporation and either NPK+OM or NPK treatment promoted the C sequestration and increased the size of the soil C pool in the plough layer of a cotton field in Northwest China.

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