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RESEARCH ARTICLE

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Film mulching combined with cow manure increases soil C and N

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Abstract

Aim of study: A field study was conducted to assess responses of soil organic C (SOC) and total N (TN) to film mulching and manure, which were important in identifying the changes of SOC and TN.

Area of study: A semiarid area in northwestern China.

Material and methods: The field (soil classified as CumuliUstic Isohumosol) has been planted with spring maize (*Zea mays* L.) for years. Three treatments were: 1) NPK fertilization and no film mulching (CK), 2) NPK fertilization and film mulching (PF) and 3) film mulching and NPK fertilization combined with cow manure (OMF).

Main results: Compared with CK, OMF significantly increased SOC and TN, while no significant effect was observed under PF. The average increases of SOC storage in OMF were 39.2% in 0-10 cm layer and 34.3% in 10-20 cm layer. The average increases of TN storage were 37.6% in 0-10 cm layer and 31.3% in 10-20 cm layer, relative to CK. Compared with the initial SOC (8.86 g/kg) and TN (0.99 g/kg), CK and PF decreased 1.4% and 6.9% of SOC, and 9.1% and 17.2% of TN, whereas OMF increased SOC and TN. The SOC/TN was not affected by treatments but slight increase was observed since the beginning of experiment. Both PF and OMF significantly increased maize grain yields (on average 45.8% and 75.7%, respectively) compared with CK.

Research highlights: Manure combined with film mulching significantly increased soil C and N, ameliorating harmful effects of plastic film mulching, improving soil fertility in the long term and increasing crop yields.

Additional keywords: soil organic C; total N; agricultural practices; maize yield.

Abbreviations used: CK (NPK fertilization and no film mulching); LAI (leaf area index); OMF (film mulching and NPK fertilization combined with cow manure); PF (NPK fertilization and film mulching); SOC (soil organic C); SOCS (soil organic C storage); TN (total N); TNS (total N storage).

Authors' contributions: Conceived, designed and performed the experiments: YS, SL, and LZ. Analyzed the data: JC and LZ. Wrote the paper: LZ, YS and JC. All authors read and approved the final manuscript.

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Introduction

Soil organic C (SOC) plays a key role in maintaining soil properties and sustaining productivity of agro-ecosystems. Conservation of the quantity and quality of SOC is considered to be a component of sustainable soil management and maintenance of soil quality (Ouédraogo *et al.*, 2007). What's more, SOC is of vital importance in global C cycling (Chappell *et al.*, 2013). Therefore, maintain the SOC at a higher level in farmland would be benefit to sustaining food productivity and mitigating climate change (Wang *et al.*, 2015).

However, the SOC level in any given soil is determined by the balance between the organic C inputs and outputs. The different agricultural practices would cause changes of SOC via affecting soil temperature, soil water content and bulk density (Smith, 2008). Plastic film mulching has been widely adopted to increase crop yield and biomass production (Mabh *et al.*, 2010; Dong *et al.*, 2018), primarily via increasing soil temperature and soil water retention (Mabh *et al.*, 2010; Bu *et al.*, 2013; Kader *et al.*, 2017). However, the favorable temperature and moisture conditions under plastic mulching would also affect the decomposition of SOC (Trumbore *et al.*, 1996) via changing the soil biological chacteristics and might negatively impact on soil quality and sustainbility. Thus, it is not surprising that studies examining SOC under film mulching have yielded different results, increased SOC (Munoz *et al.*, 2017) was observed and decreased SOC (Cuello *et al.*, 2015; Zhang *et al.*, 2015) or no changes of SOC (Wang *et al.*, 2016) were also reported. Maintenance of satisfactory level of SOC is necessary for crop productivity and sustainable agro-ecosystems. Therefore, it is necessary to critically examine the effects of film mulching on SOC to assess the changes in soil quality.

It has been shown that the application of manure can increase SOC and soil productivity, and the increase of SOC is directly related to the amount of manure applied to maize (Martínez *et al.*, 2017). A 23-year field experiment in a rice (*Oryza sativa* L.) -barley (*Hordeum vulgare* L.) rotation system clearly showed that manure treatment and manure combined with chemical fertilizers increased 11% and 16% of SOC storage, respectively, compared with the initial SOC stock (Wang *et al.*, 2015). Liu & Zhou (2017) also showed that concentrations of SOC and TN in soil receiving sheep manure were significantly higher. However, detailed information is not available on the processes of SOC and TN changes in a relative long term, and soil sustainability under film mulching remains not clear. Therefore, it is important to quantify composite effects of film mulching and manure on SOC and TN, which is essential to determine the sustainability of an agro-ecosystem.

The ratio of SOC to TN is also an important indicator of soil fertility, reflecting the interaction or coupling between SOC and TN. Though generally varies in a narrow range, the ratio SOC/TN can also be influenced by agricultural management (Dalal *et al.*, 2011), soil conditions (Yamashita *et al.*, 2006) and vegetation types. Studies have shown that manure application could increase the value of SOC/TN (Yang *et al.*, 2015; Liu & Zhou, 2017). Notably, the SOC/TN ratio has received little attention, though SOC and TN have been widely investigated in soil with film mulching (Luo *et al.*, 2015). Additionally, the changes of SOC/TN ratio in soil with film mulching combined with manure are also not clear in the studied area.

Many studies have shown that film mulching changes the soil water content in the field, creating good water, fertilizer and heat conditions, which are beneficial to crop growth and development. In case of plants tolerant to high temperature, the increase effects of film mulching on yields are significant (Yaghi *et al.*, 2013). However, film mulching does not always increase crop yields. Wang *et al.* (2011) showed a decreased yield of potato under late-stage mulching. Zhang *et al.* (2008) also reported that film mulching reduced spring maize yield due to low antecedent soil moisture and nutrient depletion. Thus, more studies are needed to assess the maize yields under film mulching for the entire growing season.

Based on a long-term field experiment, the objective of this study was to investigate changes of SOC, TN and SOC/TN in soil mulched with plastic film after 6-8 years of cultivation and application of manure. The maize grain yields were also determined in the experiment. This information will be useful for establishing sustainable agricultural practices to enhance soil productivity in semiarid land in northwest China.

Material and methods

Experimental site

A long-term field experiment was established in April 2009 at the Changwu Agricultural and Ecological Experimental Station (35.28ºN, 107.88ºE, 1200 m above sea level) on the Loess Plateau of China. The field had been cultivated for more than 50 years before 2009, when the study started. The common regional cropping system involves harvesting one rain-fed crop of maize (*Zea mays* L.) or wheat (*Triticum aestivum* L.) per year. The annual mean air temperature in the area is 9.2 °C. The average annual precipitation is 548 mm, with about 73% occurring during the maize growth season from May to September. The soil at the field site is classified as CumuliUstic Isohumosol (Gong *et al.*, 2007) with a loam texture of 13% sand, 72% silt, and 15% clay. In 2009, prior to the start of the experiment, the main properties of the initial soil were: 8.76 g/kg SOC, 0.99 g/kg TN, 6.6 mg/kg Olsen-P, 127.1 mg/kg NH_4OAc-K, 9.96 mg/kg mineral N (NO_3^--N and NH_4^+-N), and an average pH (H_2O) of 7.9 (soil:water= 1:2.5) for topsoil layer (0-20 cm). Five replicates of the initial soil samples in April 2009 were well kept for the analysis of SOC and TN changes.

Experimental design and treatments

Three fertilization treatments were included: 1) no film mulching applied with NPK fertilization (CK), 2) film mulching applied with NPK fertilization (PF) and 3) film mulching applied with NPK fertilization and cow manure (OMF). The experiment lasted 8 years and the field experimental design consisted of a randomized completely block design with three replicates, with an area of 7 m × 8 m for each individual plot. All plots planted with spring maize had alternating row spacing: 60 cm and 40 cm, and the space between two adjacent plots was 60 cm. PF and OMF treatments were mulched with a transparent plastic film (0.005 mm thick, 1.2 m wide) after the basal fertilizer application and before each year sowings. In each plot, the maize was planted in April at a depth of 5 cm and a density of 65,000 plants/ha and was harvested in September of each year. Chemical fertilizers were evenly broadcast over the soil; 225 kg/ha of N in the form of urea (46% N) was applied for each treatment each year. Nitrogen fertilizer in the form of urea (46% N) was applied three times. A basal dressing of 40% of the urea was broadcast over the soil before sowing and then plowed into the subsurface; 30% was applied at the jointing stage, and the remainder was applied at the silking stage using a hole-sowing machine. Additionally, 40 kg/ha of P in the form of calcium super phosphate (16% P_2O_5), and 80 kg/ha of K in the form of potassium sulfate (51% K_2O) were applied before sowing. For each year cow manure was evenly broadcast on the soil surface and integrated into the 0-20 cm layer with basal fertilizers before sowing to provide pure N at a rate of 25 kg/ha in OMF treatment. The manure had an average content of 320.1 g/kg organic C, 12.0 g/kg total N, 2.0 g/kg total P and 1.5 g/kg total K on a dry-weight basis during the 8 years. In all experiments, natural rainfall was the sole source of water supplied to the plots. Manual weeding was undertaken as required during the maize growing season. The maize straw aboveground at each plot was cut and removed after harvest. In order to facilitate tillage, the maize roots for each plot were also removed utilizing a moldboard plow.

Plant and soil sampling

At each site, the maize was harvested in late September. At harvest, plant samples were divided into grain and straw. The maize grain was harvested from an area of 10 m^2 (four rows each 2.5 m long) in the middle of each plot were manually harvested to determine the grain yield and yield components (kernel numbers per ear and 1000-kernel weight) from 2014 to 2016. All plant samples were dried to a constant weight in an oven at 80 °C, and grain yield was calculated at 15.5% moisture content (Otegui *et al.*, 1996).

Soil was sampled in April 2009 before sowing and in September after harvesting each year from 2014 to 2016. At each plot, the soil at all sites was randomly sampled from each soil depth (0-10 cm, 10-20 cm and 0-20 cm) using an auger. The subsamples from the same replicate plot were composited, placed in polyethylene bags in the field after removing all visible plant debris. Then the soil samples were air-dried and ground to pass through a 0.15-mm sieve for SOC and TN. The soil samples in 0-10 cm and 10-20 cm layers were measured to analyze the contents of SOC and TN from 2014 to 2016 annually, soil samples in 0-20 cm layer were used to analyze the changed SOC and TN in 2016 compared with that in 2009.

Chemical analyses and calculation

The bulk density was determined at 0-10 cm, 10-20 cm and 0-20 cm soil depths each year at each sampling time using a conventional core method (Blake, 1965). SOC was determined by dichromate oxidation using the Walkley–Black dichromate oxidation method (Nelson & Sommers, 1996). Soil TN was determined by steam distillation methods (Bremner & Edwards, 1965) using a Kjeltec N analyzer (Sweden FOSS Kjeltec 2300 analyzer unit, Sweden). After ascertaining the SOC and TN content of each soil, the storages of SOC and TN were calculated with the following equation:

—SOC storage (SOCS) (Mg/ha) = SOC (g/kg) × bulk density (Mg/m^3) × thickness (m) × 10000 (m^2/ha) × 1 kg/1000 g.

—TN storage (TNS) (Mg/ha) = TN (g/kg) × bulk density (Mg/m^3) × thickness (m) ×10000 (m^2/ha) × 1 kg/1000 g.

The changed SOC and TN were determined by concentrations of SOC and TN in September 2016 subtracted that in April 2009.

Statistical analyses

All statistical analyses were performed with the SPSS 19.0 for windows (SPSS Inc., Chicago, IL, USA, 2010). Two-way analysis of variance (ANOVA) with repeated measures was used to examine the effects of different treatments, time intervals and their interactions on related parameters. The differences between the treatment means were compared by using least significant difference (LSD) test and were deemed to be significant if $p<0.05$. Relationships between SOC and TN in 0-20 cm layer were quantified using Pearson's correlation coefficients. Soil data were log 10-tranformed prior to ANOVA and Pearson's correlation analysis in order to meet normality.

Results

Contents of SOC, TN and SOC/TN

The contents of SOC and TN were significantly influenced by treatment, while no significant effects of treatment were observed for SOC/TN (Table 1). The SOC was generally lower under CK and PF treatments in 2015 than in 2014 and 2016, while SOC under OMF treatment was higher in 2015. In contrast to CK, the average SOC in the three years under OMF significantly increased 47.8% and 39.2% in 0-10 cm and 10-20 cm layers, respectively. The averaged SOC across years followed the trend of OMF > CK > PF in both soil layers. The TN was generally higher in 2015 than in 2014 and 2016. Compared with CK, the averaged TN under PF significantly decreased 4.3% in 10-20 cm layer, while the increases of average TN under OMF were 45.0% in 0-10 cm layer and 34.8% in 10-20 cm layer ($p<0.05$). The averaged TN across years of CK, PF and OMF were, respectively, 8.50 g/kg, 8.11 g/kg and 12.56 g/kg in the 0-10 cm layer and 7.79 g/kg, 7.60 g/kg and 10.84 g/kg in the 10-20 cm layer. The averaged TN across years in both soil layers followed the trend OMF > CK > PF. Ranging from 7.82 to 9.24, SOC/TN showed no differences between treatments.

Storages of SOC and TN

The storages of SOC and TN were significantly affected by different treatments (Table 2). Interactions of treatment and cropping year SOCS and TNS had significant effects on on the SOCS and TNS, except for SOCS in the 10-20 cm layer. However, no significant influence of treatment and cropping year was observed for SOCS/TNS. Compared with CK, the average SOCS under OMF treatment significantly increased 39.2% and 34.3% in 0-10 cm and 10-20 cm layers, respectively. Ranging from 1.19 Mg/ha to 1.72 Mg/ha, OMF treatment significantly increased the average TNS by 37.6% in 0-10 cm layer compared with CK. The averaged TNS in 10-20 cm layer followed the trend of OMF (1.72 Mg/ha) > CK (1.31 Mg/ha) > PF (1.25 Mg/ha). Ranging from 8.46 to 8.75, the average SOCS/TNS showed no difference among the three treatments. In 2014 and 2015, SOCS was significantly increased by 3.99 Mg/ha and 5.16 Mg/ha in OMF treatment compared with that of CK in the 10-20 cm layer, but no difference was observed between CK and OMF in 2016 in the same layer. Similar to SOCS, the TNS under PF showed no difference when compared with CK, except for TNS in 10-20 cm layer in 2016. The increases of TNS under OMF treatment in 2016 were 35.3% and 27.8% in 0-10 cm layer and 10-20 cm layer, respectively ($p<0.05$).

Changes of SOC and TN

The SOC and TN were changed in the three treatments in the 0-20 cm layer in 2016, over 8 years of cultivation (Table 3). The SOC and TN decreased by 0.12 g/kg and 0.09 g/kg in CK since the beginning

Table 1. Effects of different agricultural practices on contents of SOC (soil organic C) and TN (total N) in two soil layers.

Layer	Year	SOC (g/kg)			TN(g/kg)			SOC/TN		
		CK	PF	OMF	CK	PF	OMF	CK	PF	OMF
0-10 cm	2014	8.16b	8.27b	12.57a	0.98b	0.97b	1.42a	8.84a	8.62a	8.85a
	2015	8.41b	8.10c	12.74a	1.07b	1.04b	1.56a	7.84a	7.82a	8.17a
	2016	8.48b	8.17b	12.38a	0.95b	0.91b	1.37a	8.98a	8.95a	9.22a
	Average	8.50b	8.11b	12.56a	1.00b	0.97b	1.45a	8.54a	8.38a	8.74a
10-20 cm	2014	7.73b	7.69b	11.04a	0.89b	0.88b	1.27a	8.65a	8.74a	8.71a
	2015	7.49b	7.52b	11.69a	0.98b	0.93b	1.30a	7.95ab	8.11b	8.99a
	2016	7.84b	7.58b	9.77a	0.88b	0.82c	1.16a	8.92a	9.24a	8.41a
	Average	7.79b	7.60b	10.84a	0.92b	0.88c	1.24a	8.50a	8.69a	8.70a

	Source of variation (*p* value)					
	SOC		TN		SOC/TN	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Treatment	0.000	0.000	0.000	0.000	0.702	0.728
Year	0.710	0.005	0.004	0.000	0.091	0.025
Treatment × Year	0.639	0.001	0.897	0.249	0.998	0.008

CK = NPK fertilization and no film mulching; PF = NPK fertilization and film mulching; OMF = film mulching and NPK fertilization combined with cow manure. Means followed by different lower-case letters are significantly different between treatments ($p<0.05$).

Table 2. Effects of different agricultural practices on stocks of SOC and TN in two soil layers.

Layer	Year	SOCS (Mg/ha)			TNS (Mg/ha)			SOCS/TNS		
		CK	PF	OMF	CK	PF	OMF	CK	PF	OMF
0-10 cm	2014	10.71b	10.20b	14.71a	1.22b	1.19b	1.67a	8.84a	8.62a	8.85a
	2015	10.40b	9.91b	14.82a	1.33b	1.27b	1.81a	7.84a	7.82a	8.17a
	2016	10.60b	9.96b	14.61a	1.19b	1.11b	1.61a	8.98a	8.95a	9.22a
	Average	10.57b	10.02b	14.71a	1.25b	1.19b	1.72a	8.55a	8.46a	8.75a
10-20 cm	2014	11.13b	11.07b	15.12a	1.28b	1.26b	1.75a	8.65a	8.74a	8.71a
	2015	10.99b	10.70b	16.15a	1.39b	1.32b	1.80a	7.95b	8.11b	8.99a
	2016	11.22ab	10.84b	13.49a	1.26b	1.17c	1.61a	8.92a	9.24a	8.41a
	Average	11.11b	10.87b	14.92a	1.31b	1.25b	1.72a	8.51a	8.70a	8.70a

	Source of variation (*p* value)					
	SOCS		TNS		SOCS/TNS	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Treatment	0.000	0.000	0.000	0.000	0.746	0.757
Year	0.364	0.007	0.007	0.000	0.090	0.018
Treatment × Year	0.555	0.001	0.969	0.331	0.996	0.005

CK, PF, OMF: see Table 1. SOCS, storage of SOC; TNS, storage of TN. Means followed by different lower-case letters are significantly different between treatments ($p<0.05$).

of this experiment in 2009, respectively. Compared with SOC and TN in 2009, the decreases of SOC and TN under PF treatment in 2016 were 0.61 g/kg and 0.17 g/kg, respectively. SOC and TN under OMF treatment in 2016 were increased by 2.45 g/kg and 0.22 g/kg, respectively, compared with that in 2009. The average rates of changed SOC [from -75.78 mg/kg·yr to 306.70 mg/kg·yr] and TN [from -20.86 mg/kg·yr] to 27.48 mg/kg·yr] from 2009 to 2016 showed a similar trend with that of changed SOC (from -0.61 g/kg to 2.45 g/kg) and TN (from -0.17 g/kg to 0.22 g/kg). Different from SOC and TN, SOC/TN changed less under OMF treatment compared with that of CK and PF. SOC/TN increased by 0.65 under CK and 0.62 under PF in 2016, respectively, compared with that in 2009.

Grain yield and its components

Treatment and cropping year had significant effects on the grain yield, kernel numbers per ear and 1000-kernel weight (Table 4). Significant interactions between treatment and cropping year were observed for grain yield and 1000-kernel weight. Averaging across years from 2014 to 2016, the grain yield under CK was 9.6 t/ha and increased to 14.0 t/ha (45.5%) under PF and to 16.9 t/ha (75.7%) under OMF. The kernel numbers per ear also increased by 16.0 under PF while the number of kernels/ear was 521 under CK. Similar to grain yield, the average 1000-kernel weight under CK was 232 g and increased by 25.2% and 36.1% under PF and OMF, respectively.

Discussion

Film mulching effects on soil C and N

The SOC level is the result of organic C inputs and outputs from the soil, which is usually affected by agricultural practices. The improved soil hydrothermal conditions in mulched soil generally increased root

Table 3. Changes of SOC and TN after the 8-year study (2009-2016) under three different treatments in 0-20cm soil layer.

Treatment	Changed SOC		Changed TN		Changed SOC/TN	
	(g/kg)	Average rate (mg/kg·yr)	(g/kg)	Average rate (mg/kg·yr)	(-)	Average rate (-)
CK	-0.12b	-15.22b	-0.09b	-11.76b	0.65a	0.08a
PF	-0.61c	-75.78c	-0.17c	-20.86c	0.62a	0.08a
OMF	2.45a	306.70a	0.22a	27.48a	0.25b	0.03b

CK, PF, OMF: see Table 1. Different letters followed by numbers in a column indicated significant differences between treatments ($p<0.05$).

Table 4. The maize grain yield, kernel numbers per ear and 1000-kernel weight at harvest in different treatments from 2014 to 2016.

	Grain yield (t/ha)			Kernel no./ear			1000-kernel weight (g)		
	CK	PF	OMF	CK	PF	OMF	CK	PF	OMF
2014	8.1c	14.7b	16.9a	510b	603a	519b	195c	290b	311a
2015	9.7c	13.2b	16.8a	524b	601a	526b	248c	289b	315a
2016	11.0c	14.0b	16.9a	530b	610a	532b	252c	291b	320a
Average	9.6c	14.0b	16.9a	521b	605a	526b	232c	290b	315a
	Source of variation (*p* value)								
Treatment	0.000			0.000			0.000		
Year	0.001			0.011			0.000		
Treatment × Year	0.000			0.602			0.000		

CK, PF, OMF: see Table 1. Means followed by different lower-case letters are significantly different between treatments ($p<0.05$).

biomasses of maize (Li *et al.*, 2013; Eldoma *et al.*, 2016), which would decay more easily compared with no mulched plots, and contribute to SOC content. Based on ^{13}C pulse-labeling, An *et al.* (2015) indicated that plastic film mulching significantly increased the flow of fixed C into the bulk soil organic C relative to soil without mulching. However, continuous use of plastic mulch may also accelerate the decomposition of soil organic matter (Ma *et al.*, 2018). In our study, compared with the CK treatment, mulching practices leaded to a similar (PF treatment) or increase (OMF treatment) SOC content in both soil layers across years. The SOC stocks in both soil layers also did not vary significantly between CK and PF. These results suggested that the increase in the C input from roots due to the improved maize growth in PF treatment was counterbalanced by the increased mineralization of SOC (Wang *et al.* 2016). Compared with the initial SOC content, the SOC under PF treatment had a tendency to decrease at the 0-20 cm layer, which was consistent with Dong *et al.* (2018). The reason might be that roots for each plot were removed each year, which decreased the C input derived from maize root. This result indicated that film mulching alone might accelerate mineralization of SOC and threaten the maintenance of soil fertility. The improved hydrothermal conditions in soil alone with film mulching depleted the SOC due to increased soil mineralization (Liu *et al.*, 2014; Zhang *et al.*, 2015), indicating that plastic film mulching may not be a long-term solution in managing the soil. Differently, SOC in OMF treatment has increased from 8.76 g/kg in 2009 to 12.38 g/kg in 2016. The higher amount of organic C in manure (C content in manure 320.10 g/kg) and the increase in C input of both above and below ground would result in increase of SOC in OMF treatment after long-term of cultivation (Rainergeorg *et al.*, 2010).

Soil TN is an important indicator of soil health. In the present study, little changes in TN were found from 2014 to 2016 among three treatments. It ranged from 0.82 g/kg to 1.56 g/kg in the three treatments; the TN content in the studied soil was relatively low. Compared with the initial TN, the TN under CK and PF treatments demonstrated some tendency to decrease after the 8 years of study, while an increase tendency for the TN was visible in OMF treatment. The results indicate that long-term film mulching without manure application aggravated the loss of soil N, resulting in depletion of TN in the soil. Higher temperature and soil water content in plastic film mulched soil might favor mineralization of organic N (Wilson & Jefferies, 1996). Additionally, crop growth, enhanced by promoted soil conditions, would need more available N; this would accelerate the mineralization of soil N. It is possible that long-term plastic film mulching might cause a depletion of soil N pool, especially when soil received no other organic material. Unavoidably, decrease of SOC would result in a corresponding decrease in soil TN.

The SOC/TN reflects the stability of soil organic matter and is relative stable in a specific soil (Qiu *et al.*, 2010). No significant difference of SOC/TN was observed among the three treatments in our study. However, after several years of cultivation, SOC/TN showed a tendency to slight increase in the three treatments. Qiao (2012) also showed that SOC/TN increased in soil planted with maize after 15 years of cultivation. More organic residues were retained and mineralization of N was aggregated in soil applied with chemical fertilizer and plastic film, both of which would contribute to the increase of SOC/TN (Qiao, 2012). However, the increase of SOC/TN might restrain soil microbial activity and deplete soil nutrients in CK and PF treatments, which was unfavorable to crop growth and caused the soil fertility dropped down. Differently, the increase of SOC/TN in OMF treatment was attributed to a higher increase in SOC and a relative lower increase in TN, thus, it was of great benefit to soil quality in the long term.

Film mulching effects on maize yield

The plastic mulch changed the albedo of the ground surface, producing complex changes in the crop microclimate environment and accelerating crop development (Tarara, 2000). Several studies have reported that plastic film can effectively improve the yield in southeastern Nigeria with annual mean air temperature above 20 °C (Anikwe *et al.*, 2007) and in Northeastern China with annual mean air temperature of 3.6 °C (Zhang *et al.*, 2018). However, some studies have pointed out that increases of crop yield under film mulching were based on the consumption of SOC, which may have negative effects on the soil ecosystem and be not sustainable (Wilson & Jefferies, 1996; Gao & Li, 2009). Our analysis also showed a slight decrease in SOC and TN under PF treatment, which may be of importance regarding the ideal ratio of soil N and C. In our study, the averaged maize grain yields were significantly increased by plastic film with or without cow manure. This might be attributed to higher water transpiration (Vial *et al.*, 2015). Moreover, improved root growth, increased nutrient absorption capacity and increased fertility level of soil surface layer under plastic mulching (Li *et al.*, 2013; Eldoma *et al.*, 2016) would also contribute to the yield. The greater rate of photosynthetic assimilation of dry mass as indicated by leaf area index (LAI) and leaf chlorophyll content, would have been able to fuel grain growth (Bu *et al.*, 2013), which ultimately produced higher grain yield. Zhang *et al.* (2018) also showed that plastic film mulching significantly increased the maximum LAI in Harbin with a relative low mean annual air temperature of 3.6 °C in Northeastern China, which would increase photosynthesis of the crop and improve maize yield.

In conclusion, both PF and OMF significantly increased maize grain yields across years compared with CK, the average increases in PF and OMF were 45.8% and 76.0%, respectively. Significant increases of 1000-kernel weight were also observed in PF and OMF treatments. SOC and TN were affected by treatment and cropping years in the studied area. Film mulching without manure generally had no significant effect on contents and stocks of SOC and TN, while significant increases of SOC and TN in both soil layers were detected in soil applied with manure when compared with CK treatment. After 8 years of cultivation, SOC and TN had a tendency to decrease under CK and PF, but increases of SOC and TN was observed in OMF treatment. Thus, manure application alleviated the harmful effects of film mulching on soil C and N, plastic film mulching combined with manure is a suitable option to increase in maize yield and improve soil quality in semiarid farmland.

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