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.

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 (Ouedraogo 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 characteristics and might negatively impact on soil quality and sustainability. 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 CumulUstic 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 NH₄OAc-K, 9.96 mg/kg mineral N (NO₃-N and NH₄-N), and an average pH (H₂O) 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
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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% P₂O₅), and 80 kg/ha of K in the form of potassium sulfate (51% K₂O) 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 m² (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 (SOC) (Mg/ha) = SOC (g/kg) × bulk density (Mg/m³) × thickness (m) × 10000 (m²/ha) × 1 kg/1000 g.
- TN storage (TNS) (Mg/ha) = TN (g/kg) × bulk density (Mg/m³) × thickness (m) × 10000 (m²/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 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 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 of treatment and cropping year SOCS and TNS had significant effects 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 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 ($p<0.05$).

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)

| Source of variation | SOC | TN | SOC/TN |
|---------------------|-----|----|--------|
| Treatment           | 0.000 | 0.000 | 0.702 |
| Year                | 0.710 | 0.005 | 0.091 |
| Treatment × Year    | 0.639 | 0.001 | 0.998 |

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).

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 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            |
| 2014       | 8.1c              | 14.7b          | 16.9a                  | 510b        | 603a         | 519b           |
| 2015       | 9.7c              | 13.2b          | 16.8a                  | 524b        | 601a         | 526b           |
| 2016       | 11.0c             | 14.0b          | 16.9a                  | 530b        | 610a         | 532b           |
| Average    | 9.6c              | 14.0b          | 16.9a                  | 521b        | 605a         | 526b           |

Source of variation (p value)

|                      | Treatment | Year | Treatment × Year |
|----------------------|-----------|------|------------------|
|                      | 0.000     | 0.001| 0.602            |

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 14C 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 led 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 (Qu 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 OFM significantly increased maize grain yields across years compared with CK, the average increases in PF and OFM were 45.8% and 76.0%, respectively. Significant increases of 1000-kernel weight were also observed in PF and OFM 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 OFM 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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