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Improved yield and water storage of the wheat-maize rotation system due to double-blank row mulching during the wheat stage

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ABSTRACT

Mulching techniques have been widely used in dryland regions in northern China. It is necessary to develop water-saving cultivation techniques in irrigation regions in northern China to relieve water scarcity. Planting and mulching on separate rows has been widely used to improve wheat yield and involves a pattern of a double row of planting and a blank row of mulching. However, whether the mulching pattern during the wheat season can be applied to the wheat-maize system to increase the yield of both crops and to reduce the use of irrigation water remains unclear. Three mulching practices (conventional planting (CP), conventional planting with mulching (CPM) and double-blank planting with mulching (DPM)) during the wheat season were conducted to verify the potential roles of DPM in increasing wheat and maize yields, improving soil temperature and enhancing water storage under the DPM practice. The results show that the DPM practice significantly increased the efficiency spike number, aboveground biomass and grain yield (7.8% higher than CP and 11.3% higher than CPM) of wheat. The heat conservation effect of the DPM practice was stronger in the early stage of growth and was more effective in minimizing fluctuations in soil temperature in the wheat season compared with CPM. The development and yield of maize that was sowed in the mulching lines of DPM were less improved, although the amount of aboveground biomass at the maturity stage was higher. Additionally, the soil temperature of the maize season under DPM showed a narrowing trend of changes during the early stage with slight effects in the middle stage and a resumption of heat conservation in the late stage. Compared with CP, both mulching patterns decreased soil evaporation during the two crops' seasons by an average 5.3% in CPM and 7.8% in DPM, which is particularly evident when the crops' leaf area index was low. Therefore, the DPM pattern could more effectively optimize soil temperature and water storage. Furthermore, this pattern may have positive effects on the yields of winter wheat and on reducing the soil water requirement of the maize season.

1. Introduction

The rotation of winter wheat and summer maize is a commonly seen cultivation method in North China (Guo et al., 2016; Liu et al., 2017a,b). Wheat and maize productivity in this semi-arid area of China depends primarily on the seasonal amount of rainfall and its distribution during crop growth stages. Water deficiency is the main constraint of crop production in this rotation system. The amount of water required for growing winter wheat and summer maize in the double cropping system is over 850 mm (Chen et al., 2007). The long-term average annual precipitation in North China is between 450 and 650 mm, of which 70% occurs intensively during the growth stage of maize, which is between July and September. Unpredictable precipitation is the main constraint of maize production (He et al., 2016), and certain characteristics of this precipitation have negative effects on maize crops, such as low utilization rate of water from rainfall of less than 6 mm, which is prevalent in semi-arid and arid areas, and the threat to maize yield caused by soil erosion due to surface runoffs during the commonly occurring heavy downpours (Li et al., 2017). Therefore, rainfall during the maize season is often characterized by huge downpours within a short period and by low utilization efficiency (Sidhu et al., 2007). On the other hand, rainfall accounts for 25%–40% of the water requirement for winter wheat growth and cannot meet its full demand (Ahmadzai et al., 2017), resulting in seasonal drought (He

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et al., 2016). Thus, it is crucial to implement effective practices to fully utilize the natural rainfall to improve crop production and water use efficiency. Otherwise, the conventional wheat–maize double cropping system will be confronted with a perennial lack of sustainable water supply.

Mulching can be an effective measure to conserve water, as there is an enormous amount of straw left behind after the harvest of winter wheat and maize in the double-cropping system, which provides a reliable supply of raw materials (Li et al., 2012). Although extensive maize-straw mulching has been found to decrease water loss, it also decreases the soil temperature in spring, impedes plant growth and inhibits the permeation of rainfall (Ahmadzai et al., 2017). The low soil temperature delays the root recovery in the early spring and thus inhibits the above-ground biomass formation (Li et al., 2008; Ahmadzai et al., 2017) and yield of winter wheat (Chen et al., 2007). A recent study showed that the production of winter wheat can be enhanced without posing any threat to the natural environment through the combination of straw mulching and wide-precision planting (Liu et al., 2017a,b), as the latter probably generates more winter wheat spikes that can counteract the reduced yield resulting from the straw mulching. However, farmers who practice the double-line planting method using plastic-film mulch in the south of Shanxi Province have been troubled by the high soil temperature in the late stage (after April). The impacts of ridge–furrow treatment in combination with straw or plastic mulch on the crop yield of maize and wheat have been widely studied and indicate that this treatment can produce higher yields in the two crops compared with the conventional cultivation method, probably due to the desirable coordination between soil moisture and temperature (Li et al., 2007, 2013).

The blank line method with mulching materials has been presented and adopted in previous studies and is one of the most efficient methods for water storage under low-intensity precipitation (Liu et al., 2010). Additionally, the positive effects of double-blank line mulching on wheat production have been thoroughly evaluated in our previous studies (Yan et al., 2018). However, little is known regarding the effects of this mulching pattern in the wheat stage on maize production. Therefore, in this study, different mulching patterns were conducted in winter wheat seasons, and the effects on the yield of winter wheat and fallowed summer maize growth, which are related to their responses to soil temperature and water storage, were determined to identify a suitable cultivation practice to effectively improve the productions of wheat and maize.

2. Materials and methods

2.1. Site of the experiment

The experiment was carried out at Han village in Shanxi Province, North China (36°19′N, 111°49′E) for three years from 2013 to 2016. The climate of this area is semi-arid with a mean annual temperature of 12.6 °C and a total of 190 frost-free days. The average yearly precipitation is approximately 657 mm, and approximately 70% of the rainfall coincides with the growing seasons of summer maize (July to September). The distribution of monthly precipitation and mean air temperature are shown in Table 1, where the precipitation in 2013–2014 was abundant followed by a drier year in 2014–2015 and a normal year in 2015–2016. The average air temperature in the seasons of the two crops showed no obvious difference among the years. The rainfall was concentrated between late July and October, implying the necessity of reducing the evaporation and runoff of rainwater during the post-harvest period of wheat in North China.

The soil of the experimental site is a Calcareous cinnamon. The top soil (0–20 cm) have the following properties: pH 8.13 (soil: water = 1:5), electrical conductivity 141.40 μs cm^{-1}, total nitrogen 1.28 g kg^{-1}, organic matter 15.20 g kg^{-1}, alkaline-N 86.69 mg kg^{-1}, Olsen-P 13.64 mg kg^{-1} and available K 101.0 mg kg^{-1}. The loamy soil has moderate draining properties with a deep soil profile.

2.2. Experimental design and method

The experiment was conducted from June 2013 to October 2016 with a split-plot design. The main plot consisted of two patterns: conventional planting (CP) and double-blank line planting (DP; one blank in every two rows of wheat), while the sub-plot comprised two rates of maize straw mulching: no mulch and 9.0 t ha^{-1}. The main plot dimensions were 2.5 m (width) by 120 m (length), and the sub-plot was 2.5 m (width) by 20 m (length), resulting in three replicates. A wheat-maize planting order was set as the crop rotation within a year. The descriptions of treatments are shown in Table 2.

Mechanically harvested maize straw chopped down to a size of 5–20 cm was manually applied to the ridge as the surface mulch material at the tiller stage of wheat. The wheat cultivar Linyuan 8 was planted at a seeding rate of 225 kg ha^{-1} on 3 October 2013, 7 October 2014 and 10 October 2015. The CP treatment was plowed with a row spacing of 20 cm and 12 rows in each plot, while the DP treatment had one blank line for each two rows with 8 rows per plot. The schematic diagram of planting and mulching is shown in Fig. 1.

Basal fertilizer 150 kg ha^{-1} N (in the form of urea), 120 kg ha^{-1} P and 60 kg ha^{-1} K were applied into the top 15–20 cm soil layer ten days before sowing. The mulch was applied between wheat rows at the tiller stage. The crops were not irrigated manually throughout the entire experiment. 3% Sigma and 3.6% Sigma Broad were sprayed to prevent weeds before overwintering stage (November 15) of wheat. In the booting stage (May 15), a mixture of Tebuconazole, Imidacloprid, Rogor, and Potassium Phosphate Monobasic was sprayed to prevent diseases and pests, so as to enhance wheat resistance. Wheat was harvested on 9 June 2014, 12 June 2015 and 10 June 2016. The wheat straw was left with a height of 25 cm as mulching material. The maize cultivar Xianyu 335 was sown in the blank lines of the double planting and mulching treatment after wheat harvest at a rate of 6.75×10^4 plants ha^{-1} without tillage and with an interval of 60 cm and a depth of 5 cm. The herbicide mixed with acetochlor and atrazine was sprayed after maize sowing.

2.3. Measurements and methods

2.3.1. Soil temperature

Soil temperature was recorded by an intelligent digital recorder (L93-4, Hangzhou Logger Technology Co., Ltd., China) that was placed in the planting row of each plot in the surface 20 cm soil layer, recording soil temperature automatically at one-hour intervals during the whole growth period.

2.3.2. Soil water storage

The amount of soil water stored in a 100 cm profile was equal to the product of soil profile depth and mean soil volumetric water content as below.

$$W = w \times \rho s \times h \times 10/100 \quad (1)$$

where W (mm) represents the soil water storage, w (%) is the percentage of soil water content by weight. The soil water content of different soil layers (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm and 80–100 cm) was measured by oven-drying at 105 °C for 48 h. The soil bulk density, ρs (g cm^{-3}), in each soil layer was obtained using the intact core method. Variable h represents soil depth. Three cores measuring 100 cm^3 in volume were collected within the 0–20 cm depth for each replicate. The content of gravimetric moisture was obtained by drying the cores at 105°C for 24 h.

2.3.3. Soil evaporation

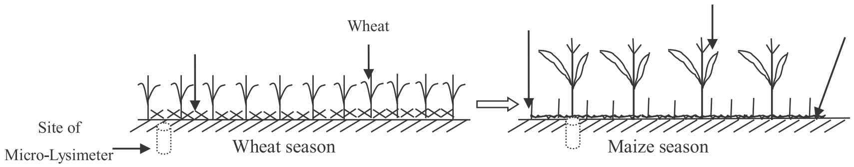
Soil evaporation was measured using a manufactured Micro-

Table 1
Distribution of monthly precipitation (P, mm) and mean air temperature (T, °C) at the experimental site during years of.2013–2016.

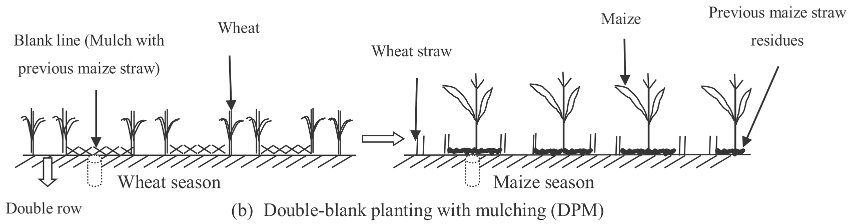
Index	Year	Wheat growing season										Maize growing season			
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Spr.	May	June	Total	July	Aug.	Sep.	Total
P	2013-2014	23.8	28.1	0	0	23.2	11.3	65.3	71.3	32.8	255.8	62.4	140.4	182.4	385.2
	2014-2015	17.7	7.1	0	7.7	7.7	4.8	39.2	33.5	34	151.7	41.2	25.4	43.1	109.7
	2015-2016	61.3	58.3	0.5	0	2.2	3.5	37.7	49.1	49.8	262.4	149.7	25.8	11.7	187.2
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Spr.	May	June	Average	July	Aug.	Sep.	Average
T	2013-2014	15.5	6.9	−0.45	0.93	1.53	11.4	15.8	20.9	25.4	10.87	27.4	24.1	20.1	23.9
	2014-2015	15.3	7.7	−0.28	0.95	3.80	10.4	15.9	21.4	25.0	11.13	27.7	26.2	21.7	25.2
	2015-2016	14.5	7.7	1.2	−1.9	2.5	10.2	17.6	20.1	25.6	10.83	27.2	27.9	22.8	26.0

Table 2
Treatment descriptions during the years.2013–2016.

Treatments	Description of Mechanical and mulch management	
	Wheat seasons (October 5-June 10)	Maize seasons(June 15-October1)
CP (Conventional planting)	i) Rotary tillage with maize straw mixed into 0-20 cm soil layer. ii) Wheat at a sowing rate of 225 kg hm^{-2}, a row space of 15 cm	No tillage with wheat straw left on the ground. Maize at a sowing rate of 6.75 × 10^4 plant hm^{-2}, a row space of 60 cm.
CPM (Conventional planting with mulching)	i) Mechanical crushing maize straw were moved to ridge. ii) Rotary tillage and wheat at a sowing rate of 225 kg hm^{-2}, a row space of 15 cm. iii) Mulching with the crushed maize straw at each row when tiller stage.	No tillage with wheat straw leaved. Maize at a sowing rate of 6.75 × 10^4 plant hm^{-2}, a row space of 60 cm.
DPM (Double-blank planting with mulching)	i) Mechanical crushing; maize straw were moved to the ridge. ii) Rotary tillage and wheat at a sowing rate of 225 kg hm^{-2}, a row space of 15 cm. iii) Mulching with the crushed maize straw at each row at tillering stage.	No tillage with wheat straw leaved. Maize at a sowing rate of 6.75 × 10^4 plant hm^{-2}. Maize was sowed at the blank line containing mulching materials from the wheat season.



(a) Conventional planting with mulching (CPM)



(b) Double-blank planting with mulching (DPM)

Fig. 1. Schematic diagram for conventional planting with mulching (CPM) and double-blank planting with mulching (DPM) during.2013–2016.

Lysimeter according to the methods of Chen et al. (2007). The PVC pipes used to make the Micro-Lysimeter have a 10-cm inner diameter and are 15 cm long. A sleeve (with a slightly bigger diameter and the same length) was made to provide a location within crops that could be inserted into the PVC cylinder. The sleeve, capped with gauze at the base to allow water and heat exchange, was vertically pressed into the soil in wheat rows with mulched and non-mulched treatments. The micro-Lysimeters were first removed from the soil carefully and cleaned according to the methods of Balwinder-Singh et al. (2011) and later weighed and returned to the sleeve every day between 16:00-17:00, with synchronized measurement times being employed for all sample sites. The amount of daily evaporation was the difference between the results of two consecutive days measured using an electronic scale with a resolution of 0.1 g. The soil was replaced every 3–5 days or within 1–2 days after the rainfall redistribution of soil water, which was similar to the approach used by Eberbach and Pala (2005).

2.4. *Plant growth of wheat and maize*

2.4.1. *Aboveground biomass*

Wheat plants of 1-m row length were collected at the tillering, re-growth, booting and maturity stages. Three representative maize plants were sampled at the seedling, bell-mouthed, and maturity stage. The fresh plants were oven dried at 105 °C for 30 min and later at 75°C until reaching a constant weight.

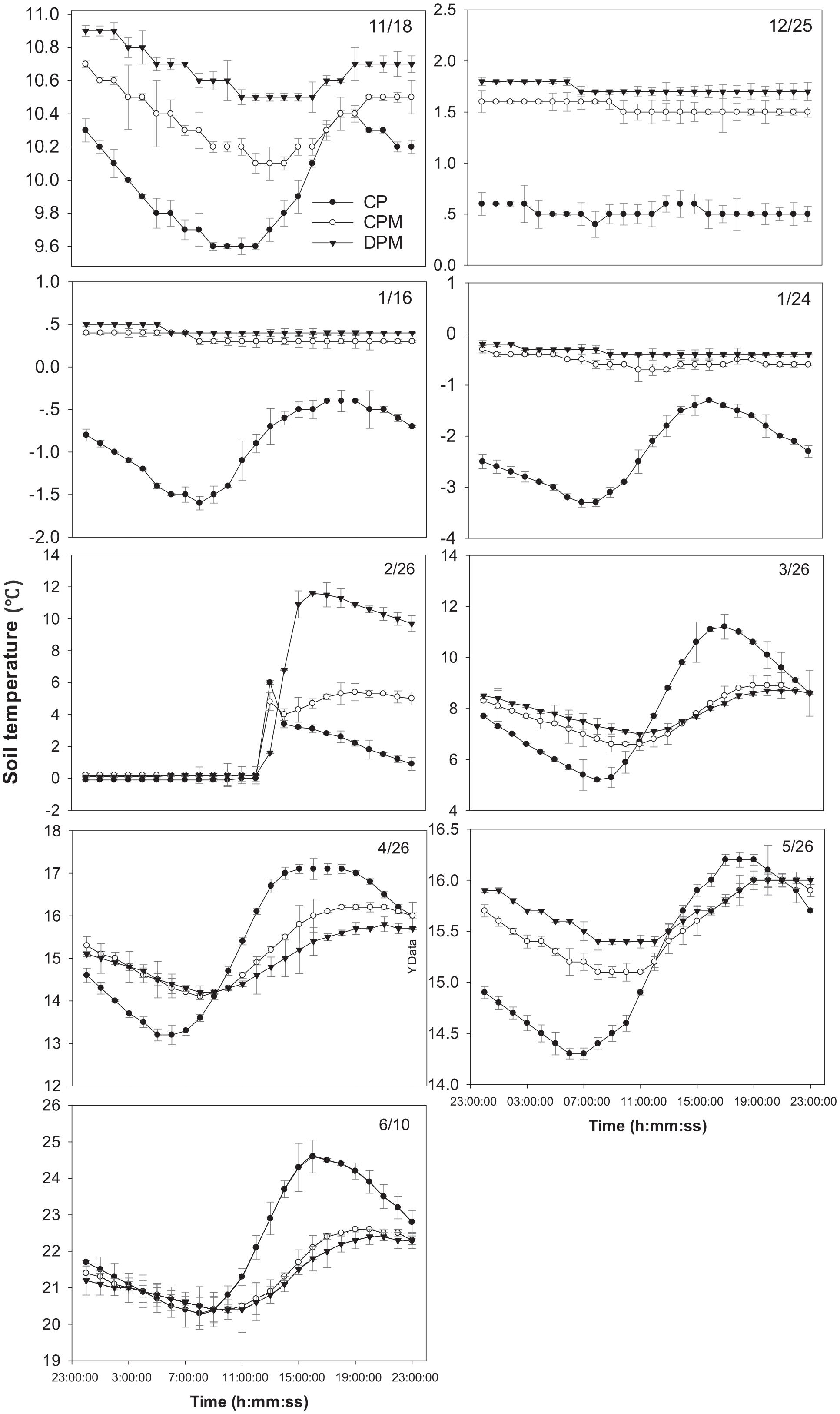


Fig. 2. Soil temperature at the depth of 20 cm of the winter wheat growing season during 2014-2016. The error bars indicate standard deviations. CP represents conventional planting with no mulching, CPM represents conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represents double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

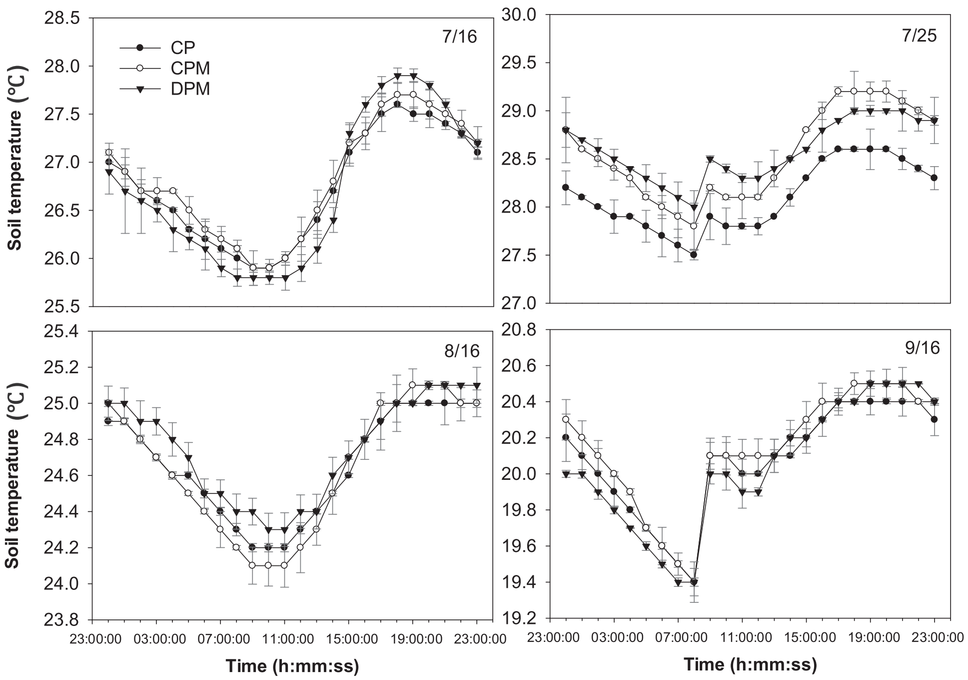


Fig. 3. Soil temperature at the depth of 20 cm during the maize growing season of 2014-2016. The error bars indicate standard deviations. CP represents conventional planting with no mulching, CPM represents conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represent double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

2.4.2. *Yield and its components*

At maturity, 1 m^2 of wheat plants in each plot were harvested randomly by hand to determine the grain yield with the grain standard moisture content of 13% fresh weight. Within the same 1 m^2, the spike numbers were counted, and twenty representative spikes in each plot were harvested to estimate the kernel per spike, spike length and 1000-kernel weight.

At maturity, twenty 20 maize ears at the center of each plot were harvested randomly by hand to determine the grain yield with the standard moisture content of 14% fresh weight. The weight per ear, ear diameter and ear length of the twenty ears were counted as well.

2.4.3. *Leaf area index*

Twenty representative plants of winter wheat were marked and counted at the jointing, heading, and filling stages, while ten representative plants of maize were sampled at the seedling, bell-mouthed and maturity stages. Subsequently, the leaf area was calculated based on their maximum width and length as described previously (Zhao et al., 2013). The leaf area for each plant was the sum of all leaves' area. Each leaf area (LA) was determined with the leaf length (L) and width (W) by the in situ regressed relationship (Liu et al., 2017a,b):

$$\text{Leaf area (LA)} = \text{Leaf length (L)} \times \text{Leaf width (W)} \times 0.72$$

where the length of the leaf referred to the distance between its tip and base, and the width was determined by measuring its widest part.

Leaf area index (LAI) was computed using the mean total leaf area of each plant divided by the field area occupied by a plant (Siegmann and Jarmer, 2015).

3. Results

3.1. *Precipitation*

Table 1 indicates that the amount of precipitation during the wheat season was 255.8, 151.7 and 262.4 mm in the 2013–2014, 2014–2015 and 2015–2016, growing seasons, respectively. The growing season in 2014–2015 was drier compared to the other two years. Less rainfall occurred from December to March between years, which correspond to the stages of overwintering and regrowth. The amount of precipitation received during the maize growing season was relative higher in 2014 followed by 2016 and was the least in 2015.

Air temperature in wheat growing season was consistent during the 2013–2014 and 2014–2015 growing seasons. Warmer air temperature in December, and cooler air temperature was obtained in the 2015–2016 growing season. Air temperature in the maize growing seasons were nearly identical.

3.2. *Soil temperature*

Fig. 2 shows the soil temperature between treatments at the depth of 20 cm in different stages. With the decrease in soil temperature from October to late February, the daily variation of soil temperature increased in both mulching patterns compared with the CP treatment. Soil temperatures in the DPM treatment were higher than those under CPM in this period. Soil temperature began to increase starting from the late February with larger fluctuations. The mulching pattern narrowed the range of soil temperature, reducing the maximum temperature while raising the minimum diurnal soil temperature.

In the maize season, the previous DPM treatment during the wheat season contributed to maintaining soil heat when the temperature was low at night and decreasing the soil temperature when it was high in the day from mid-June to late July (Fig. 3). With decreasing soil temperatures, the heat preservation effect became more obvious. Slight or no differences could be found in the soil temperatures between CP and CPM treatments. After August, there were slight variances in soil temperature between the different treatments. After September, with the decreasing soil temperature, the heat preservation effect under DPM became more obvious again.

3.3. *Soil water storage in the 0–100 cm layer*

We determined the water storage levels across the 0–100 cm soil profile in the tillering, regrowth, booting and maturity stages of winter wheat (Fig. 4). Soil water storage of the 0–100 cm layer in the mulching groups increased, as opposed to that in the CP treatment. During the growing season of 2013–2014, soil water storage increased by 41.8, 17.3 and 48 mm under DPM, and 49.5, 14.1 and 14.6 mm under CPM in contrast to CP in the overwintering, booting and maturity stages, respectively. During the growing season of 2014–2015, the soil water storage increased by 7.9 and 8.2 mm under CPM and 5.9 and 2.8 mm

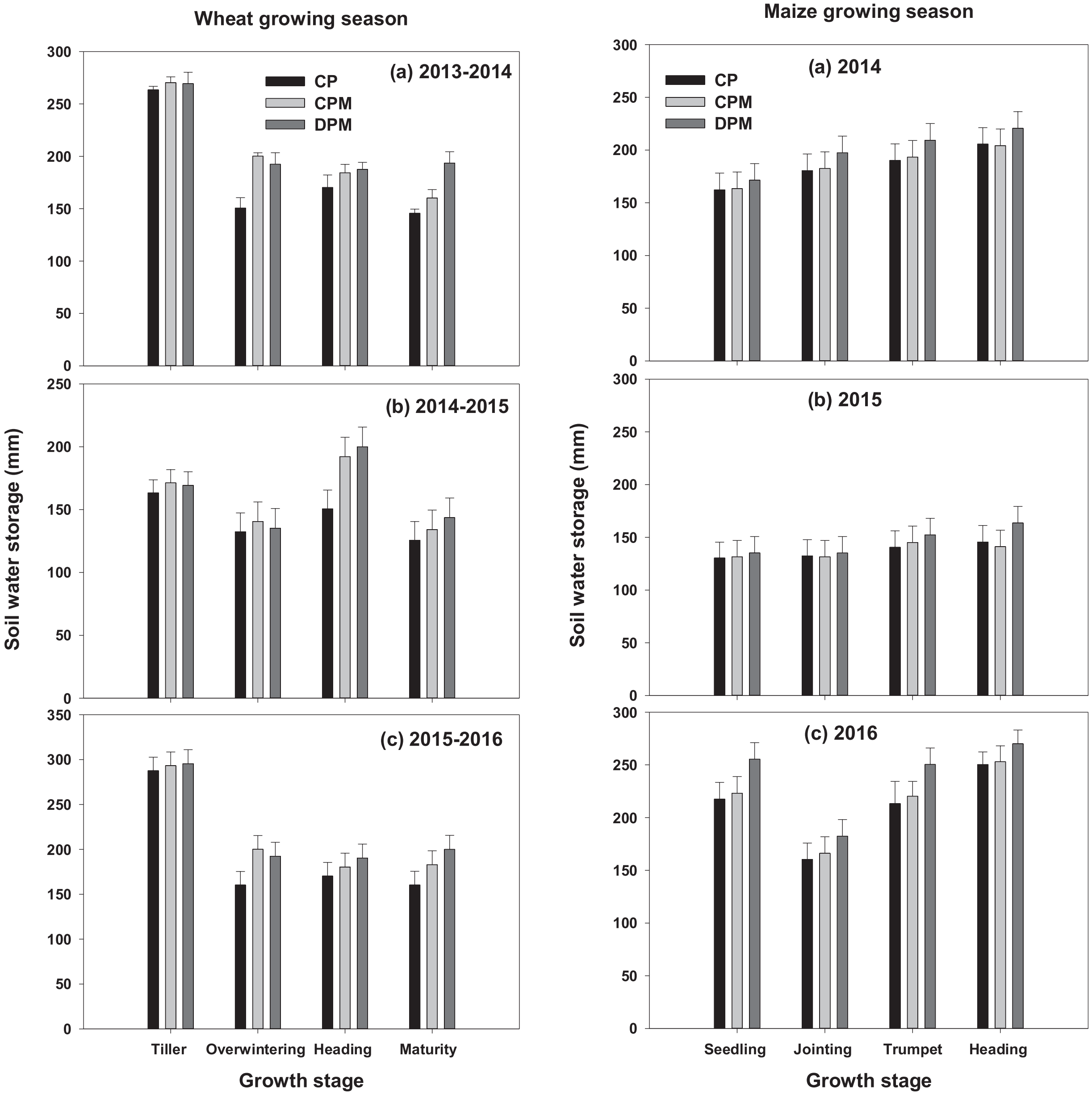


Fig. 4. Soil water storage (mm) in the 0–100 cm soil layer with different treatments at four growth stages during 2014-2016. The error bars indicate standard deviations. CP represents conventional planting with no mulching, CPM represent conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represent double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

under DPM in the tillering and overwintering stages, respectively. In the heading stage, soil water storage increased by 41.5 mm under CPM and 49.4 mm under DPM.

In maize season between 2014 and 2015, soil water storage under the DPM treatment increased significantly by 9.1, 16.9, 19.1 and 15.0 mm in the seedling, jointing, bell and heading stages, respectively, in 2014, and by 4.8, 2.8, 11.8 and 18.0 mm, respectively, in 2015. No obvious difference was found between soil water storages under CP and CPM treatments. In 2016, soil water storage slightly increased under CPM by 5.6, 5.8, 7.0 and 2.7 mm in the seedling, jointing, bell and heading stages, respectively; and by 37.8, 22.1, 37.1 and 19.7 mm, respectively, under DPM. The mean soil water storage under DPM was 15.0, 9.4 and 29.2 mm greater than that of CP in 2014, 2015 and 2016, respectively (Fig. 4).

3.4. Soil evaporation

Compared with CP, the CPM and DPM methods inhibited soil water evaporation more effectively in the wheat growing season (Fig. 5). In the early stage, compared with CP, soil evaporation was reduced by 12.3% and 14.5%, respectively, under CPM and DPM treatments. In the tillering stage, the reduced evaporation effect was more obvious under CPM than under DPM. The average rate of soil evaporation was 1.12 mm d^{-1} for CP, 0.45 mm d^{-1} for CPM and 0.34 mm d^{-1} for DPM treatment of wheat. No significant difference was found in soil water evaporation levels between CP and CPM treatments during and after the jointing stage. In the maize growing season, evaporation reduction under the CPM treatment was the same or less than that of the CP treatment (Fig. 5). However, compared with CP and CPM treatments, soil evaporation under DPM was more inhibited. Additionally, the inhibition effect was weaker during the maize growing season. Compared with no mulch, mulching decreased soil evaporation of the two crop

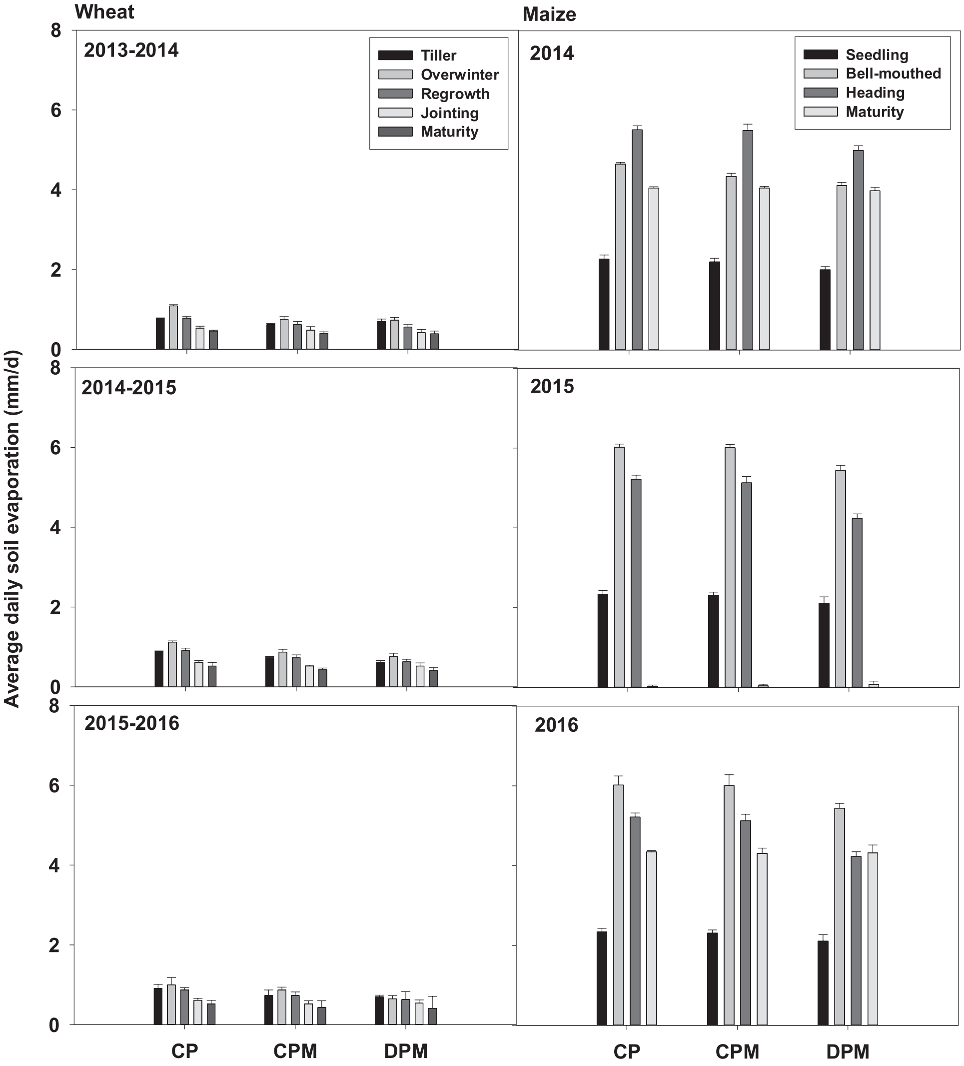


Fig. 5. Average daily soil evaporation (mm/d) among treatments during different growth stages during 2012–2013 and 2013–2014 growing seasons. The error bars indicate standard deviations. CP represent conventional planting with no mulching, CPM represent conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represent double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

seasons by an average of 5.3% under CPM and 11.8% under DPM.

3.5. *Growth of the two crops*

3.5.1. *Wheat*

Similar levels of above-ground biomass of wheat were found in different stages between treatments in all the years (Table 3). In the tillering stage, mulching slightly improved biomass formation. In the re-greening stage, biomass under CPM was reduced significantly, while biomass under DPM was significantly higher than those in the CP and CPM treatments. This trend persisted thereafter until the maturity stage. Effective spike number of winter wheat was inhibited under CPM but promoted significantly under DPM. Similarly, the grains per spike decreased under CPM but increased slightly under DPM. The 1000-kernel weight under mulching treatment was reduced somehow. CPM caused no increase (in 2013–2014) or reduction (in 2014–2015 and 2015–2016) in the yield of winter wheat. Higher yield of wheat was obtained under DPM, increasing by 11.2% in 2014, 14.5% in 2015 and 21.6% in 2016.

Mulching reduced the leaf area index (LAI) in the jointing stage. With the growth of wheat, the LAI under CPM was consistently lower than that under CP, both of which were lower than that under DPM (Fig. 6).

3.5.2. *Maize*

Above-ground dry biomass (shoot + leaf) between treatments were slightly different in the three growing seasons. There was no significant difference in ear diameter and length between treatments. Compared with the CP treatment, yield under DPM increased during the three years but with no significant difference. Maize yield in the 2013–2014 growing season was significantly higher than those in 2014–2015 and 2015–2016 under the same treatment (Table 4).

Maize LAI under CP plots was almost the same as that under CPM, while the LAI under DPM differed little from the other treatments in the seedling stage. However, this value was significantly higher in the trumpet and heading stages under CP and CPM while showing no significant difference in the maturity stage (Fig. 6).

4. Discussion

The DPM practice has been reported in a previous study on the yield increase of wheat under no irrigation (Yan et al., 2018). The practice can narrow the amplitude of variation and provide continuous maintenance of soil temperature before the regrowth stage of wheat. The presence of a blank row within wheat rows is likely to enable crops to utilize solar energy more effectively, and contributes to the modification of soil temperature (Liu et al., 2017a, 2017b). Soil water storage under DPM practice was clearly higher in the late growth stage of growth when the wheat leaf area index was high. The grain yield of wheat under DPM increased by 12.4% in 2014, 2.2% in 2015 and 13.5% in 2016. The yield increases were more obvious in the wetter years of 2013–2014 and 2015–2016. Moreover, the effect of the interaction between years and mulches on wheat yield was significant ($P < 0.05$). For maize, the DPM practice had an obvious warming effect on soil temperature under high soil temperature conditions, while soil temperature differences between treatments were not obvious in other stages. DPM practice did not affect maize development and yield significantly; only a slight amount of the aboveground biomass increased during the maturity stage. However, the average soil evaporation rate under DPM decreased significantly. As a whole, the DPM practice enhanced water storage and lowered soil water evaporation in both wheat and maize seasons.

With the same mulching rate, the DPM pattern produced a thicker mulching layer, and stronger effects in inhibiting soil water evaporation and soil temperature modification. Although the modification of soil temperature under mulching has been reported previously (Chen et al., 2007; Cheng et al., 2016), the effect of soil temperature on crop development has been inconclusive. The delay in the rise of soil temperature in regrowth stage under CPM may decelerate dry matter accumulation. In the present study, the stronger warming effect under DPM was favorable to wheat regrowth and root activity regeneration. The adoption of mulch practices could increase the soil water content and reduce drought problems during the wheat growing season (Zhang et al., 2015b), which is consistent with our findings. The CPM treatment maintained the optimum water content in the early growth stage of wheat; it is possible that practicing mulching under CPM than DPM could inhibit soil water evaporation to a greater degree. Since straw decays and air dries at the time, a relatively thinner mulching layer was formed under CPM, especially after the dry winter season in North China, thereby weakening the water storage ability of CPM and minimizing its effect on the water content in the late growth stage.

Continuous cropping is a pressing issue because it results in soil physical degradation and a reduction in crop yields. However, a less stringent implementation of planting zones in soils has been determined to be more environmentally friendly (Shah et al., 2013). When maize is sown on the mulching row of the previous wheat season, the rows offer the optimum level of humidity and a beneficial microbial community (Yin et al., 2016a,b). In the maize season, the soil temperature changed less under mulching compared to the wheat season. The soil temperature at 20 cm depth increased most markedly under mulching conditions in 25 July. Under film mulching conditions, the average soil temperature of the maize crop increased by 2.3 °C before July and by nearly 1.2 °C after July (Wang et al., 2015). Soil under the mulching material was humid and loose, which is beneficial for the deep growth of maize roots (Yu et al., 2004; Zhang et al., 2016). Otherwise, root development and distribution under mulching changed with irrigation methods (Lv et al., 2010). Moreover, maize row spaces were filled with wheat straw residues from the previous season, leading to a high row planting density, which acted as a natural mulching material and prevented soil water evaporation. Wheat straw mulching reduces the soil water requirement and irrigation for maize (Liu et al., 2010; Li et al., 2017). The stability of soil temperature under mulch leads to decreased soil water evaporation (Chen et al., 2007; Cheng et al., 2016) and increased water storage in surface shallow soil layers (Fan et al., 2014). Compared with CP, both mulching patterns decreased soil evaporation of the two crop seasons by an average of 5.3% under CPM and 11.8% under DPM, and this effect was particularly obvious in the case of a low leaf area index (LAI) when the crops were starting to grow. The practice of alternate planting between wheat and maize largely provides spare time for soil management (Yin et al., 2016a,b), and the use of the straw of crops as mulching materials for the next crop rotation is a better approach for sustainable straw utilization (Tueche and Hauser, 2011).

The improvement of the grain yield of wheat under maize straw

Table 3
Growth parameters under each treatment in different stage of winter wheat.

Year	Treatment	Aboveground dry biomass ($g\ m^{-2}$)				Efficiency spike numbers ($plant\ m^{-2}$)	1000-kernel weight (g)	Kernels per spike	Spike length (cm)	Yield ($kg\ hm^{-2}$)
		Tiller stage	Regrowth stage	Booting stage	Maturity stage					
2013-2014	CP	62.3 ± 2.4c	88.3 ± 4.3b	969.4 ± 11.4b	889.3 ± 31.2b	423 ± 4.2ab	43.6 ± 1.2a	35.2 ± 0.9b	7.8 ± 0.03a	6130.3 ± 32.1b
	CPM	68.9 ± 4.3b	78.9 ± 3.2bc	867.3 ± 33.2a	745.2 ± 19.8c	398 ± 4.1b	42.3 ± 1.4a	36.4 ± 2.1a	7.9 ± 0.06a	6013.1 ± 45.6c
	DPM	69.9 ± 3.9a	109.3 ± 3.5a	1007.1 ± 43.2a	989.3 ± 63.1a	489 ± 3.2a	43.2 ± 2.1a	37.5 ± 0.8a	8.0 ± 0.08a	6890.5 ± 53.7a
2014-2015	CP	59.4 ± 2.8c	90.1 ± 2.3b	879.3 ± 23.1b	834.2 ± 44.2b	439 ± 3.3b	44.5 ± 3.1a	38.1 ± 1.3b	8.3 ± 0.04b	5678.6 ± 33.8ab
	CPM	63.2 ± 4.3b	86.4 ± 3.5b	823.4 ± 22.1b	810.3 ± 37.8b	377 ± 4.4c	42.3 ± 3.2b	40.3 ± 1.1a	8.3 ± 0.09b	5321.2 ± 67.5b
	DPM	67.3 ± 4.1a	109.8 ± 2.7a	908.1 ± 26.7a	892.3 ± 36.1a	484 ± 2.3a	41.6 ± 2.5b	41.4 ± 1.0a	9.0 ± 0.05a	5805.3 ± 62.3a
2015-2016	CP	60.3 ± 3.1b	91.2 ± 5.6ab	934.2 ± 21.9b	867.4 ± 29.8b	398 ± 3.6b	39.5 ± 3.1a	37.5 ± 3.1b	8.1 ± 0.06a	5980.4 ± 64.3b
	CPM	61.2 ± 3.2a	87.3 ± 2.1b	895.6 ± 22.5c	766.4 ± 22.7c	400 ± 4.1b	38.4 ± 3.2a	38.1 ± 2.1b	8.3 ± 0.05a	5781.6 ± 67.8bc
	DPM	62.0 ± 2.8a	99.4 ± 4.3a	1034.2 ± 21.4a	926.3 ± 17.6a	456 ± 3.5a	38.4 ± 4.1a	40.5 ± 0.7a	8.7 ± 0.05a	6520.7 ± 67.9a
F test (M)		*	*	**	*	**	ns	*	ns	**
F test (Y)		ns	*	ns	ns	*	ns	ns	ns	*
F test (M×Y)		ns	ns	ns	ns	ns	ns	ns	ns	*

Mean ± standard deviation followed by the same letter in a column for each cultivar are not significantly different according to LSD (0.05). Letters indicate comparisons between three planting and mulching patterns (M) and between three years (Y).

** Significant differences at $P < 0.01$.

* significant differences at $P < 0.05$; ns indicates non-significant difference.CP represent conventional planting with no mulching, CPM represent conventional planting with a rate of $9.0\ t\ ha^{-1}$ maize straw mulching, DPM represent double-blank planting with a rate of $9.0\ t\ ha^{-1}$ maize straw mulching.

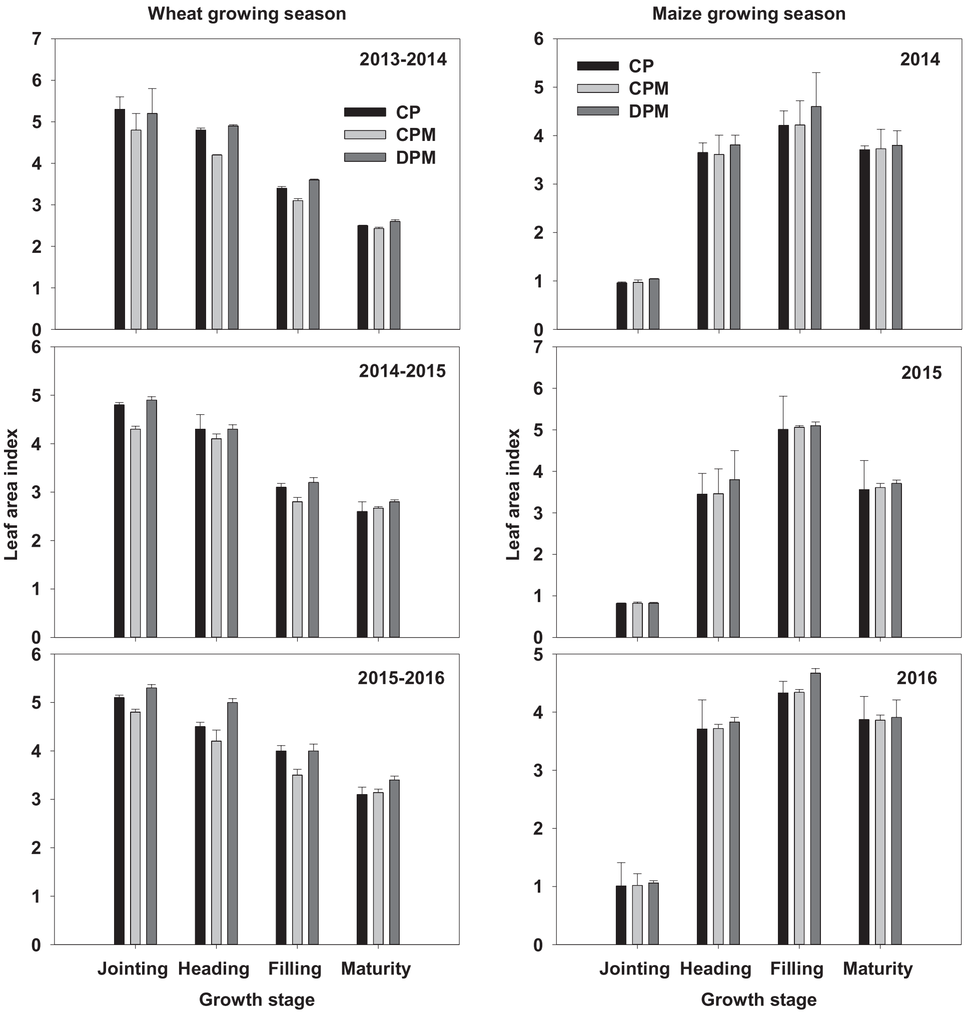


Fig. 6. Leaf area indexat different stages of wheat and maize in 2013–2016. The error bars indicate standard deviations. CP represent conventional planting with no mulching, CPM represent conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represent double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

Table 4
Growth parameters under each treatment in different stage of summer maize.

Year	Treatment	Aboveground dry biomass (g m^{-2})			Grain weight per ear(g)	Ear diameter (mm)	Ear length (cm)	Yield (kg hm^{-2})
		Seedling stage	Bell stage	Maturity stage				
2013-2014	CP	2.7 ± 0.06b	747.8 ± 12.3a	1074.2 ± 33.2b	154.5 ± 5.4b	50.8 ± 3.1b	15.3 ± 0.9b	9545.4 ± 67.8b
	CPM	2.8 ± 0.04b	742.6 ± 31.2a	1181.8 ± 45.6b	151.3 ± 4.3b	50.2 ± 2.9b	15.4 ± 0.8b	9621.1 ± 10.5.6b
	DPM	3.1 ± 0.03a	752.8 ± 32.3a	1303.1 ± 26.7a	160.7 ± 3.4a	51.3 ± 2.7a	18.4 ± 0.7a	9773.5 ± 78.4a
2014-2015	CP	3.1 ± 0.04a	609.3 ± 18.7a	987.3 ± 31.4b	136.7 ± 3.2bc	50.3 ± 4.5b	13.2 ± 0.6b	6568.2 ± 112.4a
	CPM	3.1 ± 0.06a	620.1 ± 16.4a	1004.3 ± 30.2b	140.2 ± 2.1b	50.7 ± 4.4b	13.5 ± 0.5b	6619.3 ± 97.4a
	DPM	3.1 ± 0.05a	614.5 ± 12.3a	1056.7 ± 37.8a	151.8 ± 1.9a	51.0 ± 4.3a	15.7 ± 0.4a	6735.4 ± 74.5a
2015-2016	CP	3.0 ± 0.07a	604.5 ± 21.4b	1003.1 ± 44.1b	141.4 ± 3.2b	50.4 ± 3.2a	14.3 ± 0.7b	7145.3 ± 62.3ab
	CPM	3.1 ± 0.06a	616.7 ± 10.5ab	1045.7 ± 47.8a	142.2 ± 3.2b	50.1 ± 2.1a	14.2 ± 0.6b	7234.1 ± 55.6a
	DPM	3.1 ± 0.05a	615.6 ± 9.7a	1056.8 ± 50.2a	149.6 ± 3.6a	50.9 ± 1.9a	15.8 ± 0.5a	7273.1 ± 51.0a
F test (*M*)		ns	ns	*	*	ns	*	*
F test (*Y*)		ns	ns	*	ns	ns	ns	*
F test (*M* × *Y*)		ns	ns	ns	ns	ns	ns	ns

Mean ± standard deviation followed by the same letter in a column for each cultivar are not significantly different according to LSD (0.05). Letters indicate comparisons between three planting and mulching patterns (*M*) and between three years (*Y*). **Significant differences at $P < 0.01$.

* significant differences at $P < 0.05$; ns indicates non–significant difference. CP represent conventional planting with no mulching, CPM represent conventional planting with maize straw mulching at a rate of 9.0 t ha^{-1}, DPM represent double-blank planting with maize straw mulching at a rate of 9.0 t ha^{-1}.

mulching has been inconclusive, which is based on mulching time, mulching pattern and irrigation conditions (Ram et al., 2013; He et al., 2016). The physical barrier formed by mulched straw can influence crop development such as leaf formation and biomass (Yin et al., 2015).

In the present study, a lower leaf area index characterized all growth stages under CPM. A large mulch area under CPM functioned as a huge barrier, interfering with seedling growth. Yang et al. (2005) noted that maize straw can have the strongest allelopathic effect on wheat seedlings, which reduced the wheat biomass by 60.8%. In addition, mulching is likely to induce light reflection, thereby decreasing leaf photosynthesis (Li et al., 2008). Decreasing the mulching areas using an interlacing mulching pattern in wheat was also reported by Zhang et al. (2015a). The implementation of DPM in the blank line can weaken the barrier of mulching on wheat plants and increase the amount of the above-ground biomass and the efficiency spike number. Liu et al. (2017a,b) confirmed that grain yield losses can be substantially offset by the increase in spike number due to the wide-precision planting/mulching treatment.

The DPM practice can be used in the wheat growth season of northern China. In the present study, we observed that wheat development improved under DPM practice, and the aboveground biomass, spike number and grain yield all increased. Therefore, this practice can be used to improve wheat productivity. Although a slight effect on maize plant development was observed under DPM practice, its effect on reducing water evaporation was more clear. However, further research is required to study the water irrigation requirement and financial benefits. Therefore, DPM practice can benefit crop rotation of maize and wheat.

5. Conclusions

Compared to conventional planting and mulching, DPM practice warmed soil temperature to a greater degree before the regrowth stage of wheat; it warmed soil temperature at night and cooled soil temperature in the daytime in the late stage of wheat, and this effect persisted in the maize season. The amount of soil water storage under DPM increased mostly in the late stage of wheat and during all of the growth stages of maize due to the lower daily soil evaporation compared to CPM practice. DPM practice improved wheat yields significantly through the years and also increased the aboveground biomass, the efficiency spike numbers and the leaf area index. However, the DPM pattern during wheat season had only a slight effect on maize yields compared with CP and CPM patterns. Therefore, double-blank line mulching in the wheat season can be a better practice for the winter wheat-summer maize rotation system due to its contribution to water-saving and higher yields.

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