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EFFECTS OF STRAW MULCHING ON DRY MATTER DISTRIBUTION AND GRAIN YIELD OF SUMMER MAIZE

C.J. Ma[1], C.Y. Bian[1], X.H Liu[1], Z.X Yan[1], C. Gao[1], Y.J. Ren[1], Q.R Liu[1], Q.Q. Li[1] and H.F. Han[2*]

[1]College of Water Conservancy and Civil Engineering, Shandong Agricultural University, Tai'an, Shandong, P.R. China, 271018
[2]State Key Laboratory of Crop Biology, Shandong Key Laboratory of Crop Biology, Shandong Agricultural University, Tai'an, Shandong, P.R. China, 271018
[*]Corresponding author: hhf@sdau.edu.cn, sdaumcj@163.com

ABSTRACT

The limited land resources are compelling the farming community to implement high-yielding measures. Straw mulching is an effective way to sustain soil fertility and increase summer maize grain yield. To evaluate the effect of straw mulching on summer maize productivity, field experiments were conducted during 2010 and 2011 at Experimental Station of Shandong Agricultural University. The experiment adopted a split plot design arranged in randomized blocks with three replications. Main plots were plant type, including compact type, Chaoshi1 (C), and flat type, Danyu86 (D); subplots consisted of straw mulching amount: 0, 0.6, and 1.2 kg/m^2, treatments consists of C0, C0.6, C1.2; D0, D0.6 and D1.2. The results indicated that straw mulching increased LAI at the earlier growing stage but decreased LAI at the later growing stage; there was a significant effect on PAR capture ratio for Danyu6 but not in Chaoshi1, the capture ratio was significantly higher in D0.6 and D1.2 than D0, and the increasing the proportion were by 8.3% and 11.0%, respectively. Straw mulching increased both cob dry matter and stems and leaves dry matter in Danyu86; however, straw mulching increased cob dry matter and decreased stems and leaves dry matter in Chaoshi1. Results support the application of straw mulching in combination with plant types for maximizing summer maize grain yield in the North China Plain.

Keywords: straw mulching; leaf area index; PAR capture ratio; yield compositions; summer maize.

INTRODUCTION

With the development of Chinese society and the improvement of people's living standards, the demand for food has been growing. However, the area of land under cultivation was greatly threatened (Deng *et al.*, 2015; Islam *et al.*, 2013) and the food security faced great challenges (Cordell *et al.*, 2009) because of the development of industry and agriculture and the accelerating process of urbanization in recent years. For this reason, the method by expanding cultivated area to improve the total grain output has been difficult to sustain before; oppositely, improving unit grain yield has become the only path to ensure China's food security.

North China Plain, covering an area of 3.2×10^5 km^2, is suitable for food production (Zhang *et al.*, 2010). Cultivated land in the North China Plain reaches 18.3% of the Chinese total cultivated land area, and the grain production of the Plain reaches 1/4 of national food production (Zhao *et al.*, 2013). The Plain occupies a pivotal position in the grain production in China and has huge potential for increasing grain production. Because of the climate factors, the region adopts a winter wheat and summer maize double cropping system in a year (Li *et al.*, 2015, Ning *et al.*, 2009). In particularly, summer maize being C4 crop is more high-yielding and multipurpose than wheat which is C3 crop (Yuan *et al.*, 2008; Pepó *et al.*, 2016). Predecessors have taken various measures to achieve stable and high production of summer maize, such as breeding fine varieties (Liu *et al.*, 2015; Wang, *et al.*, 2014), choosing appropriate sowing date (Florio *et al.*, 2014; Verma, *et al*, 2012), applying fertilizer rationally (Ma *et al.*, 2015; Xu *et al.*, 2014), implementing protective cultivation methods (Zhang *et al.*, 2015), reasonable close planting (Nyakudya *et al.*, 2014; Zhang *et al.*, 2014), reasonable irrigation (Sampathkumar *et al.*, 2013; Paredes *et al.*, 2014), and so on. Dry matter accumulation is closely related to the summer maize grain yield, in other words, the level of crop economic output is determined by the amount of dry matter accumulation. However, it is rarely reported that the research on the measures to increase the grain yield by improving the dry matter accumulation and the distribution efficiency.

In recent years, with the improvement of the level of agricultural mechanization, about 90% of the winter wheat is reaped by the combined harvester in the North China Plain; therefore, a large amount of winter wheat straw is left over in the field after harvested, which providing a convenience for applying straw mulching technology in the next summer maize planting (Shen *et al.*, 2012). Straw mulching has been relatively deeply studied and widely applied, because it possesses many advantages. Chen' *et al.* (2015) indicated that winter wheat grain yield varied with rainfall and drought indexes among years, but the plastic film combined with straw mulching invariably increased grain yield. José *et al.* (2014) tested the effects of straw mulching and herb seeding on soil erosion after fire in a gorse shrubland, the result showed that straw mulching significantly reduced soil erosion in the first year after fire. Zhao *et al.* (2014) found that soil moisture at the 0–40 cm depth was higher in straw mulching treatments than in non-mulching treatments. Kishor *et al.* (2008) indicated that straw mulching and reduced tillage significantly lowered annual and pre-monsoon soil and nutrient losses. In the North China Plain, 3 types of summer maize are widely grown, i.e., compact, half of the compact, and flat. Different plant types of summer maize have different characteristics. However, the effects of straw mulching on above ground dry matter distribution and summer maize grain yield in different plant types have not been understood thoroughly.

Dry matter accumulation of summer maize largely comes from leaves, because photosynthesis mainly occurs in the maize leaves, and leaf area index (LAI) determines the plant state of summer maize. Summer maize growth is dependent on the ability of the canopy to intercept incoming radiation and convert it into new biomass (Gifford *et al.*, 1984). At present, the dry matter accumulation and distribution character of different summer maize plant states is not very clear and uniform. But on the one hand, dry matter accumulation in a certain range is closely related crop economic output; on the other hand, the distribution rate of summer maize dry matter to stem, leaves and kernels determines the dry matter utilization efficiency in the yield formation process. Therefore, it is important to master the dry matter accumulation and distribution of summer maize (Karlen *et al.*, 1987). Since summer maize grain yield forms after silking stage, but not all of the dry matter is gathered to maize kernel (Ning *et al.*, 2013), it is hypothesized that in straw mulching conditions, dry matter accumulation and distribution in different plant types maybe different from that in non-mulching conditions, resulting in different grain yield. Therefore, it is very necessary to find effective straw mulching measures which can both increase summer maize dry matter accumulation and improve dry matter distribution to grain yield.

Therefore, the purposes of this study were to determine (i) the effect of straw mulching and plant types on LAI and PAR capture ratio in the canopy, (ii) aboveground dry matter accumulation and distribution and grain yield of summer maize. Addressing the above questions could provide a theoretical basis and practical support for development of an efficient straw mulching method for summer maize production in the North China Plain.

MATERIALS AND METHODS

Experimental Site: The experiment was conducted at the Experimental Station of Shandong Agricultural University (36°10’ N, 117°09’ E) in the North China Plain during 2010 and 2011 summer maize growing seasons. The experiment site located in temperate continental semi-humid monsoon climate zone which rain and heat are over the same period and the average annual rainfall can meet the requirements of summer maize growth. At the site, average annual rainfall is 697 mm, approximately 70% of which was concentrated from July to September in the summer maize growing season. The experiment was conducted in plots (9.0 m^2) divided by concrete walls (25.0 cm thick) that extended 1.5 m beneath the ground surface and 10.0 cm above the ground surface. Alkaline hydrolysis nitrogen, available potassium, and available phosphorus in 0–20 cm soil were 108.1, 92.4, and 16.1 mg/kg, respectively. There was no groundwater recharge and no water loss and soil erosion during the study.

Experimental Design: The experiment adopted a split plot design arranged in randomized blocks with three replications. Main plots were plant type, including compact type, Chaoshi1, and flat type, Danyu86; subplots consisted of straw mulching amount: 0, 0.6, and 1.2 kg/m^2. At summer maize three-leaf stage, straw mulching was carried out by applying winter wheat straw that was chopped into 3–5 cm pieces by manual. The planting density of Chaoshi1 and Danyu86 were 7.5×10^4 and 5.25×10^4 plants/ha, respectively, the crops were planted on June 16, 2010, and June 18, 2011, and harvested on October 3, 2010, and October 2, 2011. No additional irrigation was applied in the both summer maize growing seasons. Other managements were same as high-yielding field.

Measurements

Leaf area index (LAI): 3 typical summer maize plants of every plot were selected to be measured by straightedge at jointing, tasseling-silking, and maturity stages. Leaf area was calculated by the method of length and width coefficient. Leaf area per plant was as follows:

$$S = \sum(L \times B) \times 0.75 \qquad (1)$$

In equation (1), ∑ is sum of the leaves, L is length of the leaves (cm), and B is max-width of the leaves (cm)

$$LAI = (\sum S) \div S' \qquad (2)$$

In equation (2), ∑ is sum of the plants, S is leaf area per plant (cm^2), and S’ is the area occupied by 3 summer maize plants (cm^2).

Photosynthetic active radiation (PAR): PAR capture ratio was measured by SunScan Canopy Analysis System (Delta T Devices Ltd., Cambridge, UK) on typical sunny days from tasseling-silking stage to maturity stages. The SunScan was placed parallel to the row direction on soil surface of each plot in the middle of each summer maize row. The average value of the 3 repeated data was used as transmitted radiation. Meanwhile, the incoming solar radiation above the canopy was also monitored. The amount of solar radiation intercepted by the canopy by calculating the difference between the above canopy and soil surface solar radiation was measured (Li *et al.*, 2012).

Aboveground dry matter weight: At jointing, tasseling-silking, or maturity stages, typical summer maize plants were selected in the central plots; stem, leaves, and cobs were separated and put into envelope. The specimen were placed in the drying oven for 30 min at 105℃, then turned to 85℃ until to be constant weight, and finally were weighed by the electronic balance whose precision is 0.01.

Grain yield and yield composition: When the summer maize had reached maturity stage, 6 cobs were selected at random in every experiment plot to measured ear rows per cob, kernels per row, 1000-grain weigh, and grain yield. Before harvested, cobs number of every plot was measured.

Precipitation: The precipitation and temperature data was provided by the weather station which was closed to the Experimental Station of Shandong Agricultural University (Table 1).

Statistical Analysis: Microsoft Excel 2007 and Origin 8.0 were applied to data processing and mapping, and the analysis of variance (ANOVA) was used to determine if significant differences existed among treatments means (α = 0.05). Multiple comparisons were conducted for significant effects using the least significant difference (LSD) test at α = 0.05.

RESULTS AND DISCUSSION

Precipitation: Total precipitation amounts in 2010 and 2011 summer maize growing seasons were 479.2 and 606.2 mm (Table 1), which was classified as normal year and wet year, respectively.

In 2010 summer maize growing season, the precipitation mainly concentrated in August and September and the amount reached 348.6 mm which accounted for 72.7% of the whole summer maize growing season. In 2011 summer maize growing season, the precipitation distribution was relatively uniform and mainly concentrated in July, August, and September which occupied 31.7%, 27.4%, and 34.6% of the whole summer maize growing season, respectively. The maximum temperatures of 2 years were 31.9℃ on June 30, 2010 and 30.3℃ on July 24, 2011; The minimum temperatures of 2 years were 14.5℃ on September 23, 2010 and 14.9℃ on October 2, 2011.

Leaf area index: LAI in 2010 and 2011 summer maize growing seasons was shown in Figure 1. On July 11, 2010, the LAI was significantly lower in Danyu86 at the straw mulching amount of 1.2, 0.6 and 0 kg/m^2 (D1.2, D0.6, D0) than Chaoshi1 at the same mulching amount (C1.2, C0.6, C0) by 45.6%, 33.7%, and 53.6%, respectively. The LAI was significantly lower in D1.2 than in D0.6 by 58.0%; similarly, the LAI was significantly lower in C1.2 and C0.6 than in C0 by 48.8% and 50.0%, respectively. On August 4, 2010, the LAI was significantly lower in D0.6 than in C0.6 by 9.8%, and in D0 than in C0 by 17.5%, respectively. The LAI was significantly higher in D1.2 and D0.6 than in D0 by 20.5% and 13.9%. On July 28, 2011, the LAI was significantly lower in D1.2 than in C1.2 by 14.9%, in D0.6 than in C0.6 by 24.6%, and in D0 than in C0 by 26.4%, respectively. The LAI in C1.2 was significantly lower than in C0.6 and C0 by 11.0% and 11.7%. On August 15, 2011, the LAI were significantly lower in D1.2 than in C1.2 by 14.7%, and in D0 than in C0 by 14.4%, respectively. As for Chaoshi1, the LAI was significantly higher in C1.2 than in C0.6 by 9.8%.

LAI is an important index to study the structure and function of farmland ecosystem and crop canopy structure, and the size of LAI affect biological and grain yield directly (Verger *et al.*, 2014; Feng *et al.*, 2013). In this experiment, at jointing stage, because of crop varieties and planting densities, the LAI was lower in Danyu 86 than in Chaoshi1. At jointing stage, the LAI at the mulching rate of 1.2 kg/m^2 in the both varieties was lower than the LAI at the rate of 0.6 and 0 kg/m^2, which indicated that straw mulching at the rate of 1.2 kg/m^2 would inhibit the growth and development of summer maize LAI in the former growth stage; however, in the later growth stage, the LAI was higher at the rate of 1.2 kg/m^2 than at the rate of 0.6 and 0 kg/m^2, which indicated that straw mulching at the rate of 1.2 kg/m^2 promoted the growth and development of summer maize LAI. Therefore, straw mulching (especially straw mulching at the rate of 1.2 kg/m^2) inhibited the summer maize LAI in the earlier growth stage; however, promoted the summer maize LAI in the later growth stage. Hence, finally, there was no significant difference in LAI was found between mulching and non-mulching treatments in the both varieties. In the range of 0-40℃, the higher the soil temperature, the more beneficial to the growth of crop root (Kaspar *et al.*, 1992). But straw mulching has a dual function on soil temperature, it reduced the soil temperature under the condition of high temperature and improve soil temperature under the condition of low temperature (Li *et al.*, 2008). Because the early growth period of summer maize was in high temperature stage, mulching treatments soil temperature may be lower; oppositely, mulching treatments soil temperature may rise instead in the late growth period of summer maize.

PAR capture ratio: There was significant difference in PAR capture ratio in the both growing seasons (Table 2). In 2010 summer maize growing season, with straw mulching rate increased, the PAR capture ratio in Danyu86 increased, and the capture ratio was significantly higher in D0.6 than D0 by 8.3% and in D1.2 than D0 by 11.0%, respectively; however, there was no significant difference in PAR capture ratio in C1.2, C0.6, and C0. Therefore, there was a significant effect on PAR capture ratio in Danyu6 but not in Chaoshi1. In addition, as for plant variety, the PAR capture ratio was significantly higher in Chaoshi1 than in Danyu86 by 6.0%; and for straw mulching rate, there was a trend that with straw mulching rate increased, the PAR capture ratio increased significantly. In 2011 summer maize growing season, there was no significant differences in all treatments; however, the PAR capture ratio was significantly higher in Chaoshi1 than in Danyu86 by 3.4%.

Under field conditions, PAR was intercepted, absorbed or reflected, scattered by plant canopies, LAI has a direct impact on PAR absorption ratio, the ability of the crop canopy to intercept the solar radiation determines its growth conditions (Gifford *et al.*, 1984), previous research result indicated that there was a good logarithmic relationship between LAI and PAR capture ratio (Daughtry *et al.*, 1992). The PAR controlled the carbon exchange between the crop canopy and atmosphere (Anatoly *et al.*, 2015) and had a certain impact on the production formation. In this experiment, the highest PAR capture ratio appeared in C1.2 in the both growing seasons. In addition, the differences in the PAR capture ratios for the summer maize canopies were due to dynamic LAI variations and alterations in vertical distributions (Pl´enet *et al.*, 2000; Li *et al.*, 2012). In this experiment, as for summer maize variety, the significant difference in the PAR capture ratios appeared between Chaoshi1 and Danyu6 in both growing seasons, which was because of plant-type structure and density; however, as for straw mulching rate, the mulching treatment significantly increased the PAR capture ratio but no significant difference was found in 2011, the reason maybe that too much precipitation in 2011 promoted the growth of stem and leaves of summer maize and thus enhanced the PAR capture ratio.

Aboveground dry matter accumulation and distribution: At jointing stage on July 13, 2010, the aboveground dry matter accumulation was significantly lower in D1.2 than in C1.2 by 59.4%, in D0.6 than in C0.6 by 41.0%, and in D0 than in C0 by 57.4%, respectively (Figure 2). The aboveground dry matter accumulation was significantly lower in D1.2 than in D0.6 by 67.6%; however, there was no significant difference was found between D0.6 and D0. As for Chaoshi1, the aboveground dry matter accumulation was significantly lower in C1.2 than in C0.6 and C0 by 53.0% and 55.8%. At tasseling-silking stage on August 14, 2010, the aboveground dry matter accumulation was significantly lower in D1.2 than in C1.2 by 10.3%, in D0.6 than in C0.6 by 20.0%, and in D0 than in C0 by 24.7%, respectively. Compared with D0, the dry matter accumulation in D1.2 was significantly increased by 9.2%. The dry matter accumulation was significantly lower in C1.2 than in C0.6 and C0 by 8.6% and 8.4%. At jointing stage on August 7, 2011, the aboveground dry matter accumulation was significantly lower in D1.2 than in C1.2 by 26.7%, in D0.6 than in C0.6 by 27.8%, and in D0 than in C0 by 34.2%, respectively. On August 24, 2011, the aboveground dry matter accumulation was significantly lower in D1.2 than in C1.2 by 5.8%, and in D0 than in C0 by 12.5%; however, there was no significant difference was found between D0.6 and C0.6. The dry matter accumulation was significantly higher in D1.2 than in D0 by 5.9%, the sequence was D1.2＞D0.6＞D0. The dry matter accumulation was significantly lower in C0.6 than in C1.2 and C0 by 7.7% and 9.2%; however, there was no significant difference was found between C1.2 and C0.

In 2010 summer maize growing season, cobs dry matter was significantly higher in D0.6 than in D0 by 7.8%, stems and leaves dry matter was significantly increased in D1.2 and D0.6 than in D0 by 28.8% and 12.4%; the total aboveground dry matter was significantly increased in D1.2 and D0.6 than in D0 by 13.2% and 9.9%. The cobs dry matter was significantly higher in C1.2 and C0.6 than in C0 by 19.6% and 6.2%, the stems and leaves dry matter was significantly lower in C1.2 and C0.6 than in C0 by 9.9% and 23.6%; the total aboveground dry matter was significantly increased in C1.2 than in C0 by 5.2%; however, the total aboveground dry matter was significantly lower in C0.6 than in C0 by 8.2%. In 2011summer maize growing season, the cobs dry matter were significantly higher in D1.2 and D0.6 than in D0 by 19.8% and 18.6%, the stems and leaves dry matter were significantly increased in D1.2 and D0.6 than in D0 by 54.9% and 17.9%; the total aboveground dry matter was significantly increased in D1.2 and D0.6 than in D0 by 38.0% and 18.2%. The cobs dry matter was significantly higher in C1.2 and C0.6 than in C0 by 31.4% and 17.6%, the stems and leaves dry matter was significantly increased in C1.2 than in C0 by 24.2%; the total aboveground dry matter was significantly increased in C1.2 and C0.6 than in C0 by 27.4% and 9.8%, respectively(Fig. 3).

Dry matter accumulation is both an important indicator of crop growth and material basis for the forming grain yield. In most cases, because of plant type that dry matter accumulation was significantly lower in Danyu86 than in Chaoshi1; however, in 2010, at tasseling-silking stage, Danyu86 was more sensitive when the dry matter accumulation in Danyu86 was increased with straw mulching rate. In 2011, at tasseling-silking stage, the variation rate of dry matter accumulation was slower than at jointing stage because that reproductive growth of summer maize instead of vegetative growth. It was obvious that the difference value of dry matter accumulation between the both varieties was decreasing, though the average dry matter accumulation was lower in Danyu86 in mulching treatments than in Chaoshi1 by 4.0%; therefore, the growth rate in Danyu86 was faster than in Chaoshi1. The effect of straw mulching on the both plant types was not uniform, there was an auxo-action in Danyu86 that dry matter of mulching treatments were increased highly than non-mulching treatments; as for Chaoshi1, the auxo-action was not obvious even reduced that dry matter of mulching treatments were not always increased even decreased than non-mulching treatments. Previous research in this respect had different conclusions, Wang *et al.* (2015) studied the effect of straw mulching on the maize biomass production, found that biomass yield was improved with the increasing straw application level at different summer maize stages in semi-arid China; conversely, Tanaka *et al.* (1990) found that straw mulching restrained the growth of rice in flooded soil. The reason for different consequences may lie in soil characteristics, precipitation, and plant varieties, etc.

Previous researcher had studied the dry matter distribution in summer maize (Ning *et al.*, 2013); however, the effect of straw mulching on aboveground dry matter distribution of summer maize in different plant types was scanty. After analyzed the aboveground dry matter distribution at maturity stage, it was obvious that the effect of straw mulching on the both varieties was different. Straw mulching increased both cobs dry matter and stems and leaves dry matter in Danyu86; however, straw mulching increased cobs dry matter and decreased stems and leaves dry matter in Chaoshi1. The result indicated that the aboveground dry matter distribution in Chaoshi1 had changed, more dry matter transfer to cobs; hence, resulted in the grain yield increased. Because of too much precipitation in 2011 summer maize growing season, the stems and leaves dry matter was higher than that in 2010 summer maize growing season, and the cobs dry matter in Chaoshi1 under straw mulching was higher than under non-mulching by 17.0%; therefore, straw mulching promoted dry matter to transfer to cobs in Chaoshi1 when precipitation was excess.

Grain yield and yield compositions: Grain yield and yield compositions in Danyu86 and Chaoshi1 in 2010 and 2011 summer maize growing seasons were presented in Table 3. In 2010 summer maize growing season, the grain yield was significantly higher in C1.2 than in C0 and C0.6 by 21.5% and 13.1%, the reason mainly due to kernels per row was significantly increased; the grain yield was significantly higher in D0.6 than in C0 by 12.1%. The sequence of grain yield in 2010 was C1.2 > C0.6 > C0, and D0.6 > D1.2 > D0. There was no significant difference in grain yield and yield compositions were found between the two plant types, because that the ears were significantly higher in Chaoshi1 than in Danyu86; however, kernels per row were opposite. As for straw mulching rate, the grain yield was significantly higher in mulching treatments than in non-mulching treatments, because that straw mulching increased the kernels per row. Therefore, straw mulching was an effective means to increase summer maize grain yield. In 2011 summer maize growing season, the grain yield was significantly higher in C0.6 and C1.2 than in C0 by 15.8% and 26.4%, and in D0.6 and D1.2 than in D0 by 27.3% and 27.0%, respectively, the reason mainly due to that kernels per row was significantly increased. The sequence of grain yield in 2011 was C1.2 > C0.6 > C0, and D0.6 > D1.2 > D0. As for the two plant types, there was a significant difference between the grain yield in Danyu86 and Chaoshi1; the grain yield was significantly higher in Chaoshi1 than in Danyu6 by 8.2%, the reason mainly due to the ears and rows per ear were significantly increased. As for straw mulching rate, the grain yields were significantly higher at the rate of 1.2 and 0.6 kg/m^2 than at the rate of 0 kg/m^2 by 26.7% and 21.2%, respectively, the reasons mainly due to that straw mulching increased the rows per ear, kernels per row, and 1000-grain weight.

There was a significant effect of plant types and straw mulching on summer maize grain yield and yield compositions. As for plant types, Xue *et al*. (1995) indicated that compact plant type possess a greater yield potential. In this experiment, there was no significant difference between the two plant types in 2010, but the grain yield in compact type Chaoshi1 was significant higher than in flat type Danyu86 in 2011. The LAI, PAR caption ratio, aboveground dry matter accumulation and distribution were significantly higher in Chaoshi1 than in Danyu86, which resulted in the increasing of grain yield in Chaoshi1, especially in wet year. The result may lie in root system composition and dry matter accumulation in different plant types was different (Zhang *et al.*, 2013); of course, further research is needed in the future. As for straw mulching, the experiment indicated that grain yield was significantly higher in mulching treatments than in non-mulching treatments. Straw mulching increased summer maize PAR caption ratio and aboveground dry matter distribution; hence, resulted in grain yield increased. Wang *et al.* (2011) found that the summer maize grain yield was significantly higher in straw mulching treatment than in non-mulching treatment in northern China. The reason of the yield-improving effects of straw mulching may be that mulching reduced the loss of soil moisture (Li *et al.*, 2013), increased the organic matter (Mupangwa *et al.*, 2013) and humic substances(Szczepanek *et al.*, 2016), soil carbon concentration (Kahlon *et al.*, 2013), and improved the field microclimate (Li *et al.*, 2008); however, the mechanisms needed further studied. In addition, the grain yield in the both growing seasons was significantly different. The average grain yield was lower in 2011 than in 2010 by 34.0%, the first reason maybe that too much precipitation affected summer maize pollination at tasseling-silking stage in 2011. The pollination period in 2011 summer maize growing season was between August 14 and 21, continuous precipitation appeared at the later pollination period, which led to the loss of vitality of some male cob pollen and affected pollination, then bald tip of grain appeared. Continuous precipitation also led to too low temperature, some research indicated that low temperature was a main factor for bald tip of grain. The required appropriate temperature was 24–28℃ during the flowering stage, in comparison, during filling stage the temperature was a little low at 20–24 ℃(Zhao *et al.*, 2015). If continuous low temperature (＜16 ℃) continued too long (>20 h) between jointing stage and filling stage, the phenomenon of bald tip of grain would appeared more. The precipitation at flower season and the low temperature caused by precipitation reduced the grain yield of summer maize. Straw mulching could keep heat and reduce the influence of temperature changing on the crops (Li *et al.*, 2008). Table 3 showed that straw mulching reduced bald tip of grain by increasing kernels per row. The average grain yield was lower in 2011 than in 2010 by 34.0%, the second reason maybe that too much precipitation affected summer maize's reproductive growth and vegetative growth in 2011. Combined with the previous data, too much precipitation resulted in too much vegetative growth that more dry matter was distributed to leaves and stem and decreased reproductive growth which reduced 1000-grain weight. But the 1000-grain weight was significantly increased in mulching treatments, and the reason remained to be further studied. Therefore, even in adverse environmental conditions, straw mulching could promote the growth of summer maize, and improve the grain yield.

In recent years, annual rainfall in North China Plain has not been consistent (Sun *et al.*, 2010). In this experiment, straw mulching increased summer maize grain yield by increasing kernels per row in different rainfall years, and even also increased the rows per ear and 1000-grain weight in wet year. The further reason of increasing grain yield effect of straw mulching was that mulching treatments increased the aboveground dry matter accumulation and distribution efficiency. Hence, the results support the application of straw mulching in combination with plant types for achieving the purpose of efficient distribution of dry matter and high yield of summer maize in the North China Plain.

Table 1. Precipitation (mm), minimum and maximum air temperature (℃) during 2010 and 2011 summer maize growing seasons.

Growing seasons	June	July	August	September	October	Total	Min-temp	Max-temp
2010	36.2	94.4	226.9	121.7	0	479.2	14.5	31.9
2011	38.7	192.0	165.8	209.7	0	606.2	14.9	30.3

The precipitation of June in 2010 and 2011 summer maize growing seasons was calculated the sum of rainfall from sowing date to the end of the month. The precipitation of October in 2010 and 2011 summer maize growing seasons was calculated the sum of rainfall from 1 October to harvest date. The minimum and maximum air temperature is the average temperature of the day.

Table 2. PAR capture ratio in 2010 and 2011 summer maize growing seasons

Treatment	Capture ratio (%)	Reflection ratio (%)	Penetration ratio (%)
2010			
By mulching rate			
1.2	0.89a	0.03a	0.08b
0.6	0.85ab	0.04a	0.11a
0	0.83b	0.05a	0.12a
P value	*0.020*	*0.342*	*0.063*
By varieties			
D	0.83b	0.05a	0.11a
C	0.88a	0.02b	0.09a
P value	*0.004*	*0.020*	*0.142*
Interaction			
D1.2	0.87ab	0.04ab	0.09bc
D0.6	0.85b	0.05ab	0.11abc

D0	0.78c	0.08a	0.14a
C1.2	0.91a	0.02b	0.07c
C0.6	0.86ab	0.02b	0.12ab
C0	0.88ab	0.03b	0.10abc
P value	*0.006*	*0.109*	*0.089*
2011			
By mulching rate			
1.2	0.90a	0.03a	0.07a
0.6	0.89a	0.03a	0.08a
0	0.90a	0.02a	0.08a
P value	*0.909*	*0.586*	*0.879*
By varieties			
D	0.88b	0.03a	0.10a
C	0.91a	0.02a	0.06b
P value	*0.017*	*0.103*	*0.022*
Interaction			
D1.2	0.88a	0.03ab	0.10a
D0.6	0.87a	0.03a	0.10a
D0	0.88a	0.03a	0.09a
C1.2	0.92a	0.03a	0.05a
C0.6	0.91a	0.03ab	0.06a
C0	0.91a	0.02b	0.07a
P value	*0.217*	*0.033*	*0.208*

Table 3. Effect of straw mulching on grain yield and yield compositions in 2010 and 2011 summer maize growing seasons.

Treatments	Ears (ear /m^2)	Rows per ear (ear/ rows）	Kernels per row (Particle / line)	1000-grain weight (g)	Grain yield (g/m^2)
2010					
By mulching rate					
1.2	6.5a	15.1a	38.9a	377.4a	1268.9a
0.6	6.5a	15.4a	37.3ab	377.2a	1253.9a
0	6.4a	15.2a	35.9b	379.4a	1141.0b
P value	*0.527*	*0.758*	*0.023*	*0.974*	*0.040*
By varieties					
C	7.3a	15.2a	32.3b	383.1a	1203.0a
D	5.6b	15.2a	42.4a	372.8a	1239.5a
P value	*0.000*	*0.905*	*0.000*	*0.271*	*0.368*
Interaction					
C0	7.3a	15.3a	29.9c	381.9a	1097.1b
C0.6	7.3a	15.2a	31.8c	387.7a	1178.9b
C1.2	7.4a	15.2a	35.3b	379.8a	1332.9a
D0	5.5b	15.1a	41.9a	376.9a	1184.9b
D0.6	5.7b	15.6a	42.8a	366.6a	1328.8a
D1.2	5.5b	15.0a	42.5a	374.9a	1204.9ab
P value	*0.000*	*0.923*	*0.000*	*0.826*	*0.028*
2011					
By mulching rate					
1.2	5.9a	15.5a	37.2ab	312.2ab	879.1a
0.6	5.9a	15.0ab	38.1a	337.9a	841.3a
0	5.9a	14.8b	35.7b	280.1b	694.0b
P value	*0.811*	*0.084*	*0.044*	*0.012*	*0.000*
By varieties					
C	6.9a	15.4a	32.9b	278.7b	836.5a
D	4.9b	14.8b	41.1a	341.4a	773.1b

P value	*0.000*	*0.023*	*0.000*	*0.000*	*0.025*
Interaction					
C0	7.0a	15.3ab	30.7d	260.6c	733.4bc
C0.6	6.9a	15.3ab	33.3c	292.1bc	849.3a
C1.2	6.7a	15.7a	34.6c	283.3c	926.9a
D0	4.7b	14.3c	40.8ab	299.5bc	654.6c
D0.6	4.9b	14.7bc	42.8a	383.6a	833.4ab
D1.2	5.0b	15.3ab	39.7b	341.2ab	831.4 ab
P value	*0.000*	*0.070*	*0.000*	*0.002*	*0.001*

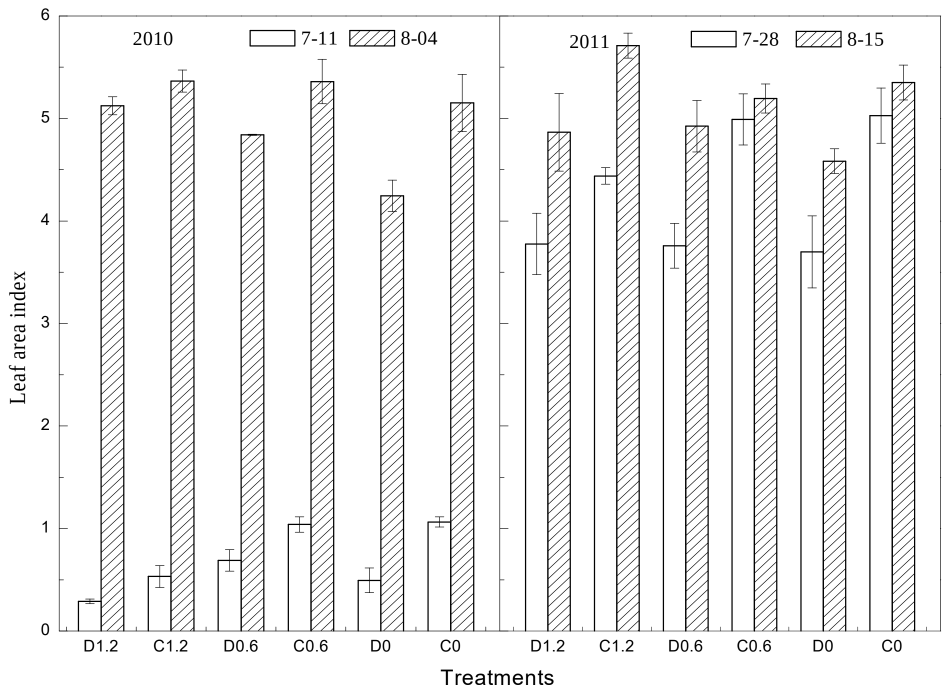

Figure 1. LAI on July 11 and August 4, 2010, and on July 28 and August 15, 2011.

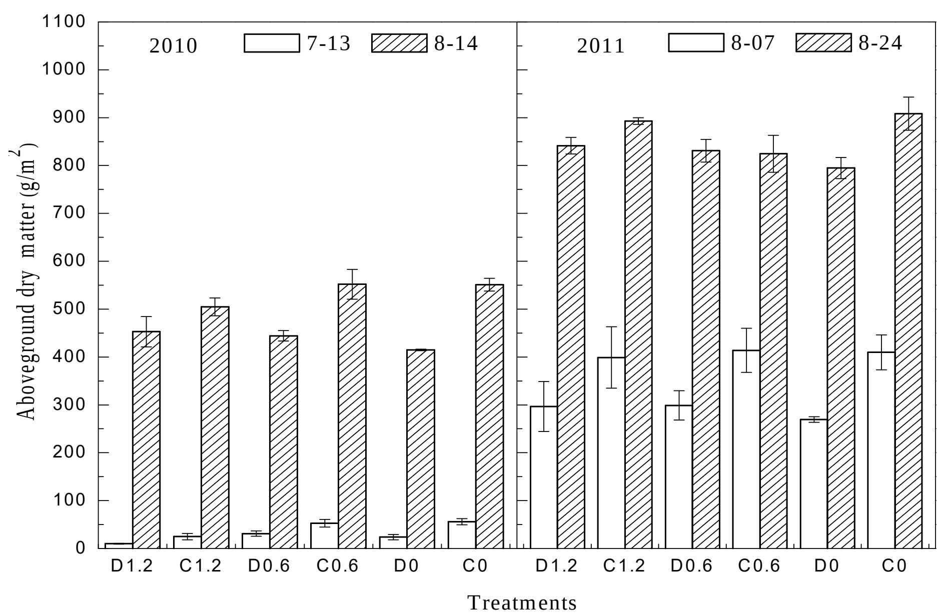

Figure 2. Aboveground dry matter accumulation on July 13 and August 14, 2010, and on August 7 and August 24, 2011.

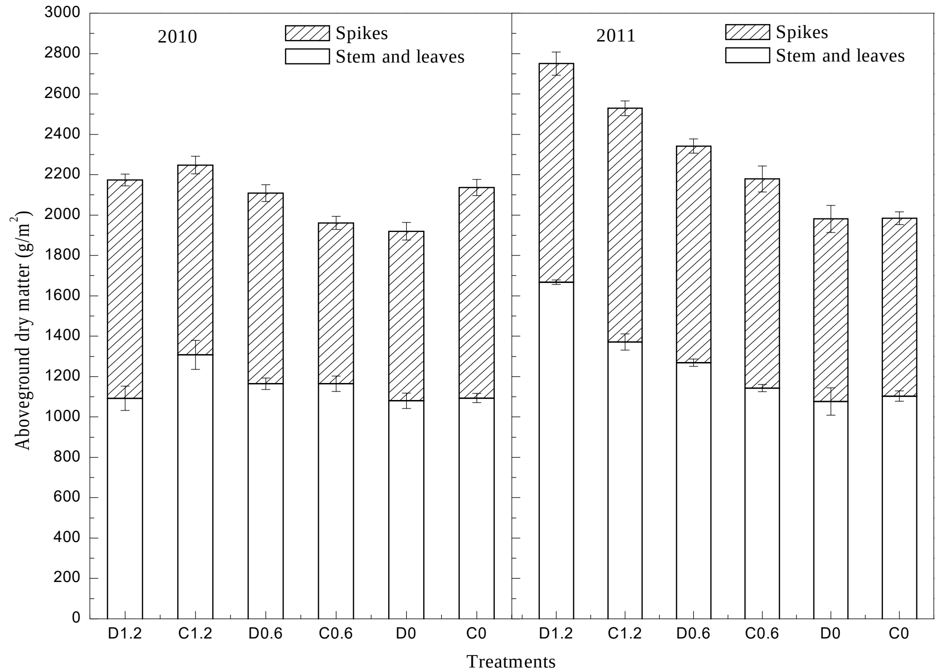

Figure 3. Aboveground dry matter distribution at maturity stage in 2010 and 2011 summer maize growing seasons.

Conclusion: Straw mulching increased LAI at the former growing stage but decreased the LAI at the later growing stage and significantly affected the PAR capture ratio in Danyu86 but not in Chaoshi1. Straw mulching increased both cobs dry matter and stems and leaves dry matter in Danyu86; however, increased cobs dry matter and decreased stems and leaves dry matter in Chaoshi1. Straw mulching increased grain yield through increasing kernels per row and straw mulching treatment of C1.2 realized the maximum grain yield in the North China Plain.

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