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RESPONSE OF SUMMER MAIZE GRAIN YIELD AND PRECIPITATION-USE EFFICIENCY TO STRAW MULCHING IN NORTH CHINA PLAIN

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ABSTRACT

The limited water resources have compelled the farming community to implement water-saving measures in rain-fed farmland. In 2009, 2010 and 2011 summer maize growing seasons, 0, 0.6, and 1.2 kg/m^2 straw mulching rates were employed to evaluate the effect of straw mulching on the contribution of dry matter remobilization to grain yield (CDMRG), grain yield (GY), and precipitation-use efficiency (PUE) of summer maize in rain-fed farmland. The results indicated that both 0.6 and 1.2 kg/m^2 straw mulching rates resulted in a significantly increased aboveground dry matter accumulation at maturity stage. Thus, compared to 0 kg/m^2 straw mulching rate, the CDMRG was significantly increased in both 0.6 and 1.2 kg/m^2 straw mulching rates. With regard to GY, no matter in moderate or humid years, straw mulching increased the summer maize GY, mainly due to the fact that 1000-kernels weight or rows per ear were significantly enhanced. In moderate years, regardless if precipitation was concentrated in the early or the late summer maize growth stages, the PUE in 1.2 or 0.6 kg/m^2 straw mulching rates were significantly higher than without mulching; in humid year, the PUE in both 0.6 and 1.2 kg/m^2 straw mulching rates were significantly higher than in 0 kg/m^2 straw mulching rate. Hence, no matter in moderate or humid years, straw mulching in summer maize growing season not only achieved the highest GY, but also the highest PUE. The results of this study suggest that, in rain-fed farmland, straw mulching facilitates better summer maize production in North China Plain.

Key words: straw mulching, growth stage, yield composition, dry matter, rain-fed maize.

INTRODUCTION

The North China Plain, which covers an area of 1.445 million km^2, was reported to provide about one-fifth of the total state food (Li et al., 2013). However, the Plain has only 7.2% of the total national water resources (Zhang et al., 2007). In this region, the widely planted crops are winter wheat and summer maize. The evapotranspiration in winter wheat growing season is approximately 400-500 mm, but annual precipitation typically does not exceeded 200 mm (Li et al., 2008). Therefore, additional irrigation is required for the winter wheat GY; however, the summer maize growing season is in a rainy season, so how to efficiently use precipitation resources in summer maize growing season is a key measure to support agricultural sustainable development in this area.

In recent years, approximately 90% of winter wheat is harvested by combine harvesters in North China Plain (Shen et al., 2012); therefore, the ground is mulched with winter wheat straw. Wang et al. (2011a) found that crop residue mulching treatment increased soil water storage, thus showing potentials for drought mitigation and economic use of fertilizers in drought-prone rain-fed conditions. Other studies indicated that straw mulching could increase crops GY by enhancing nitrogen use efficiency (Patra et al., 1993; Sharma et al., 2010), improving soil quality (Arora et al., 2011; Kong, 2013), and controlling temperature (Tuo et al., 2007). However, Zhang et al. (2011) suggested that crop residue mulching combined with no-tillage is not recommended for spring maize in the Loess Plateau of China; instead, use of ridges mulched with plastic film combined with crop

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residues in furrows may be an efficient measure to increase crop GY. Hence, under different climate conditions, the effects of straw mulching on the maize GY are different.

In North China Plain, due to the influence of seasonal wind and climate change, drought has often occurred in summer maize growing seasons; therefore, precipitation have become important resources to obtain a stable and high summer maize GY. However, few studies have reported the integrated effects of straw mulching when combined with precipitation-use efficiency (PUE) in North China Plain. Further, the effect of straw mulching on PUE of summer maize is not completely understood. This study aims to determine (1) aboveground dry matter accumulation and the contribution of dry matter remobilisation to grain yield (CDMRG), (2) GY and yield composition, and (3) PUE of summer maize under straw mulching conditions. Clearly the above questions will provide a theoretical basis and practical support for the development of an efficient precipitation-use pattern in North China Plain.

MATERIAL AND METHODS

Experimental site

The study area was located at the Experimental Station of Shandong Agricultural University (36°10′19″, 117°9′03″), in North China Plain, where the mean precipitation is 697.0 mm, of which approximately 454.4 mm falls from June to September - the summer maize growing season. Agriculture in this area is intensified by a winter wheat and summer maize double cropping system. In 2009, the experiment was conducted in field conditions, the rapidly available phosphorus, potassium, and nitrogen in 0-20 cm soil layer were 15.2, 81.8 and 65.2 mg/kg, respectively; in both 2010 and 2011, the experiment was conducted in plots divided by concrete walls 25 cm thick that extend 1.5 m beneath the surface, the rapidly available phosphorus, potassium, and nitrogen in 0-20 cm soil layer were 16.1, 92.4 and 108.1 mg/kg, respectively.

Experimental design

This experiment was randomised complete block design, 3 straw mulching rates were employed in summer maize growing season as follows: 0 (T0), 0.6 (T0.6) and 1.2 (T1.2) kg/m^2. At the summer maize 5-leaf_stage, straw mulching was carried out by applying winter wheat dry straw that was chopped to 3-5 cm. In 2009, the area of every plot was 5.0 × 6.0 m^2, each plot consisted of ten rows with 60 cm row spacing; in both 2010 and 2011, the area of experimental plots was 3.0 × 3.0 m^2, each plot consisted of five rows with 60 cm row spacing. Treatments were randomised and replicated 3 times. The summer maize cultivar used for the experiment was "Danyu 86". The maize plants were manually planted on June 12th, June 16th, and June 18th in 2009, 2010, and 2011, and were harvested on October 2nd, 3rd, and 2nd in 2009, 2010 and 2011, respectively. At sowing, rapidly available phosphorous, potassium, and nitrogen were applied at a rate of 7.5, 11.3 and 15.0 g/m^2, respectively. When the maize plants were at the 5-leaf stage, the plant density was fixed at 5.3 plants/m^2. In summer maize growing seasons, no irrigation was applied.

Measurements

Precipitation was measured by the meteorological stations near the experimental sites 50 m. Aboveground dry matter was determined by sampling consisting of 3 consecutive plants from the central rows at the jointing, flowering, and maturity stages. The sampling areas were spaced to avoid the effects of previous samplings. Dry matter was determined after drying at 80°C for 72 h.

CDMRG was calculated using the following equation (Li et al., 2010):

$$\mathrm{CDMRG} = \frac{\mathrm{DMR}}{\mathrm{GY}} \times 100,$$

where: CDMRG (%), the contribution of dry matter remobilisation to GY; DMR (kg/m^2), dry matter remobilisation, was the difference between aboveground dry matter at the flowering and maturity stages; GY (g/m^2), grain yield, was measured at the maturity on an area of 8 m^2 in 2009 and two central lines of each plot in 2010 and 2011. The ear numbers, rows per ear, and kernels per row were measured. The 1000-kernels weight was estimated by counting and weighing 500 grains on 2 replicates per plot.

PUE was calculated using the following equation (Nel, 2009):

$$PUE = \frac{GY}{P},$$

where: GY (g/m^2), grain yield, and P (mm), precipitation in summer maize growing seasons.

Statistical analysis

The treatments were run as an analysis of variance (ANOVA). The ANOVA was performed at $\alpha = 0.05$ level of significance to determine whether differences existed among treatments means. The multiple comparisons were done for significant effects with the LSD test at $\alpha = 0.05$.

RESULTS

Precipitation

Precipitation in 2009, 2010 and 2011 summer maize growing seasons was 476.0, 488.7 and 606.2 mm, respectively (Table 1).

Table 1. Precipitation in 2009, 2010 and 2011 summer maize growing seasons

Growing seasons	June	July	Aug.	Sept.	Oct.	Total
2009	71.7[a]	239.4	131.2	34.3	0.0[b]	476.0
2010	45.7	94.4	226.9	121.7	0.0	488.7
2011	38.7	192.0	165.8	209.7	0.0	606.2

[a] Precipitation in June was the mean monthly from sowing day to June 30th ;
[b] Precipitation in October was the mean monthly from October 1st to harvesting day.

The annual mean precipitation in summer maize growing seasons in the study region is approximately 454.4 mm; hence, both 2009 and 2010 were classified as moderate years, and 2011 was humid year. However, in 2009 summer maize growing season, precipitation occurred mainly in June and July, and the precipitation in this period accounted for 65.2% of the total precipitation; in 2010 summer maize growing season, precipitation occurred mainly in August and September, and the precipitation in this period accounted for 71.3% of the total precipitation.

Aboveground dry matter accumulation

Figure 1 shows the effect of straw mulching on the aboveground dry matter accumulation in 2009, 2010 and 2011 summer maize growing seasons.

The result indicated that at the jointing stages, straw mulching had no significant effect on the aboveground dry matter accumulation; however, at the maturity stages, when straw mulching rate increased, the aboveground dry matter accumulation was enhanced significantly. Compared to T0 treatment, the aboveground dry matter accumulation in both T0.6 and T1.2 treatments were significantly enhanced. The three-growing seasons average in T0.6 and T1.2 treatments were 2141.2 and 2335.6 g/m^2, respectively, which were more than that in T0 treatment by 231.2 and 425.6 g/m^2. This finding demonstrated that both T0.6 and T1.2 treatments did not enhance aboveground dry matter accumulation at the summer maize jointing stages; however, at the maturity stages, both T0.6 and T1.2 treatments resulted in a significant increase in aboveground dry matter accumulation.

Contribution of dry matter remobilisation to grain yield

As shown in Figure 2, in 2009 summer maize growing season, the CDMRG in T1.2 treatment was 53.6%, which was significantly higher than those in T0.6 and T0 treatments by 2.6% and 3.5%, respectively. In 2010 and 2011 summer maize growing seasons, the CDMRG in both T0.6 and T1.2 treatments were all significantly higher than that in T0 treatment. This result indicated that more of the accumulated dry matter was transported from stems and leaves to the grains in both T0.6 and T1.2 treatments than in T0 treatment. The variation in CDMRG could affect summer maize GY and yield composition.

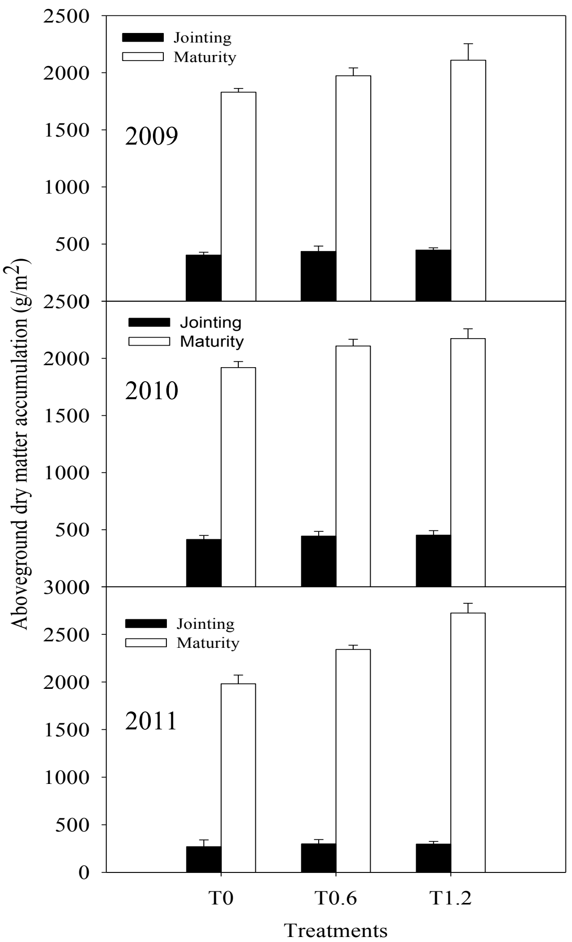

Figure 1. Aboveground dry matter accumulation in 2009, 2010 and 2011 summer maize growing seasons (T0, T0.6, and T1.2 treatments represent straw mulching rate at 0, 0.6, and 1.2 kg/m^2, respectively.Vertical bars are standard errors)

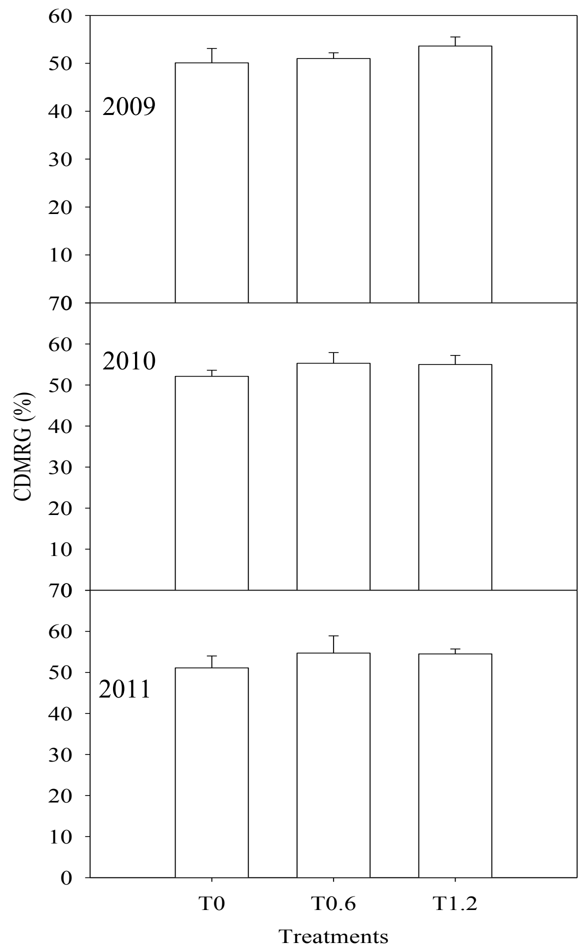

Figure 2. The contribution of dry matter remobilization to grain yield (CDMRG) in 2009, 2010 and 2011 summer maize growing seasons

Grain yield and yield components

Table 2 shows the GY and yield components in 2009, 2010 and 2011 summer maize growing seasons. In 2009 summer maize growing season, T1.2 treatment resulted in the highest GY (1086.0 g/m^2), which was significantly higher than those in both T0.6 and T0 treatments.

The highest 1000-kernels weight was found in T1.2 treatment, which was significantly higher than those in both T0.6 and T0 treatments. As for kernels per row, T1.2 treatment resulted in the highest, but it was not significantly higher than that in T0.6 treatment, and the lowest was found in T0 treatment.

Effect of straw mulching on ear number and rows per ear was not statistically significant. In 2010 summer maize growing season, the highest GY was found in T0.6 treatment, but it was not significantly different from that in T1.2 treatment; and the lowest GY was found in T0 treatment, which was significantly lower than that in T0.6 treatment. Compared to both T1.2 and T0 treatment, T0.6 treatment resulted in significantly higher kernels per row and rows per spike. The effect of straw mulching on spike numbers and 1000-kernels weight was not statistically significant. In 2011 summer maize growing season, the GY in both T1.2 and T0.6 treatments were significantly higher than that in T0 treatment. This result was mainly due to 1000-kernels weight and rows per spike were significantly improved. Therefore, selecting straw mulching under rain-fed conditions is of great importance to improve summer maize GY potential.

Table 2. Grain yield and yield compositions in 2009, 2010 and 2011 summer maize growing seasons

Growing seasons	Treatments	Ear numbers (ears/m^2)	Rows per ear (rows/spike)	Kernels per row (kernels/row)	1000-kernels weight (g)	Grain yield (g/m^2)
2009	T0	4.3a	15.8a	29.6b	328.2b	871.3b
	T0.6	4.6a	15.1a	31.2ab	319.8b	886.0b
	T1.2	4.4a	16.0a	32.9a	354.1a	1086.0a
2010	T0	5.5a	15.1b	41.9c	376.9a	1184.9b
	T0.6	5.7a	15.6a	42.8a	366.6a	1328.8a
	T1.2	5.5a	15.0b	42.5b	374.9a	1204.9ab
2011	T0	4.7a	14.3c	40.8b	299.5c	654.6b
	T0.6	4.9a	14.7b	42.8a	383.6a	833.4a
	T1.2	5.0a	15.3a	39.7b	341.2b	831.4a

In each growing season, values followed by different letters are significantly different among treatments.
T0, T0.6, and T1.2 treatments represent straw mulching rate at 0, 0.6, and 1.2 kg/m^2, respectively.

Precipitation-use efficiency

As shown in Figure 3, in 2009 summer maize growing season, compared to both T0.6 and T0 treatments, the PUE in T1.2 treatment was significantly enhanced.

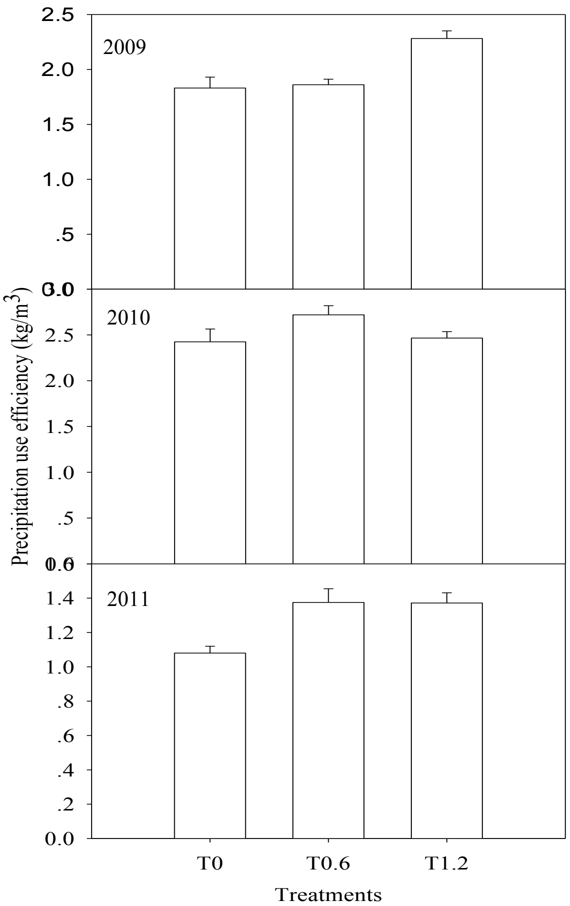

Figure 3. Precipitation-use efficiency (PUE) in 2009, 2010 and 2011 summer maize growing seasons

(T0, T0.6, and T1.2 treatments represent straw mulching rate at 0, 0.6, and 1.2 kg/m^2, respectively. Vertical bars are standard errors)

In 2010 summer maize growing season, compared to both T1.2 and T0 treatments, the PUE in T0.6 treatment was significantly enhanced. In 2011 summer maize growing season, compared to T0 treatment, the PUE in both T0.6 and T1.2 treatments was significantly enhanced. Hence, both in moderate and humid years, straw mulching in summer maize growing seasons not only achieved the highest GY but also the highest PUE.

DISCUSSION

In North China Plain, the actual summer maize GY was only approximately 70% of the potential yield, implying that the region has room to increase the yield by improving crop managements (Wang et al., 2011b).

In this study, straw mulching did enhance summer maize GY, no matter in moderate or humid years. In 2009, precipitation occurred mainly in June and July. In September, precipitation was only 34.3 mm, so in the late summer maize growth stage, drought occurred. T1.2 treatment resulted in the highest GY and PUE may be due to the following reasons: firstly, soil moisture content was improved for higher mulching rate; secondly, a moderate water deficit in the late growth stage could enhance the remobilisation of stored assimilates and accelerate grain-filling of crops (Yang et al., 2001), this maybe the main reason why T1.2 treatment resulted in the highest CDMRG, 1000-kernles weight, and GY. In 2010, drought occurred in the early summer maize growth stage. In North China Plain, the late June and early July is the summer maize booting stage. Compared with jointing and filling stages, the effect of water stress at the booting stage on reducing GY was the largest, which was mainly due to the reduction of the number of kernels per ear (Zhang et al., 1995). In this study, T0.6 treatment resulted in the highest GY maybe due to its effect on alleviating drought stress at this stage. In 2011, compared with T0 treatment, the GY and PUE in both T0.6 and T1.2 treatments were significantly increased, this maybe due to the following reasons: firstly, soil organic matter content increased. Shahla et al. (2013) suggested that straw mulching exerted a significant influence on soil organic matter. Straw mulching may affect soil organic matter through decomposition and soil moisture preservation (Montoya-González et al., 2009; Youkhana and Idol, 2009). Secondly, mulching may reduce run-off from a soil prone to crusting. Mirás et al. (2009) found that total concentrations of the studied elements decreased exponentially due to the effect of maize straw on soil loss. Therefore, straw mulching could improve soil quality (Nele et al., 2011). Thirdly, the ground surface covered by crop residues may reduce the run-off velocity and give the water more time to infiltrate. Hence, the PUE was improved.

Although many researchers suggested that straw mulching could improve soil moisture (Chakraborty et al., 2008; Zhang et al., 2009), some studies indicated that straw mulching could decrease winter wheat GY. Chen et al. (2007) found that compared with non-mulched treatment, straw mulching treatment reduced the final GY by 7%. Li et al. (2008) found that this was mainly due to the fact that straw mulching reduced soil temperature, so the number of tillers after spring was decreased; hence, resulting in lower spike numbers. Maize is a non-tillering crop cultivar, so the negative effect of straw mulching does not exist.

CONCLUSIONS

In North China Plain, in rain-fed farmland, straw mulching facilitates better summer maize production. No matter in moderate or humid years, straw mulching in summer maize growing season achieved both the highest grain yield and the highest precipitation-use efficiency.

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