Effects of straw mulching on water consumption characteristics and yield of different types of summer maize plants

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ABSTRACT

To develop rainfed agriculture in northern China, we conducted field experiments with three straw mulching rates (0, 6, and 12 t/ha) on two plant types (a compact type, Chaoshi1, and a flat type, Danyu86) during the summer maize-growing season in 2009 and 2010 to study soil moisture content, evapotranspiration, grain yield, and water-use efficiency (WUE). The results indicated that straw mulching could significantly (*LSD*, $P < 0.05$) improve soil moisture content at a depth of 20–80 cm below the ground surface during the anthesis-silking stage; however, at maturity, straw mulching decreased the soil moisture content at a depth of 0–60 cm below the ground surface. In 2009, straw mulching at the rate of 12 t/ha significantly (*LSD*, $P < 0.05$) increased the evapotranspiration in Chaoshi1 and Danyu86. In 2010, straw mulching at the rate of 6 t/ha significantly (*LSD*, $P < 0.05$) increased evapotranspiration in Danyu86 alone. The grain yields of Danyu86 in 2009 and Chaoshi1 in 2010 were significantly (*LSD*, $P < 0.05$) higher with straw mulching at the rate of 12 t/ha than on the application of other treatments. Irrespective of whether precipitation was concentrated during the beginning or the latter half of the summer maize growing stage, straw mulching increased the WUE of Chaoshi1, but not of Danyu86. These results indicated that under rainfed conditions in northern China, straw mulching could increase the grain yield and WUE of compact-type maize.

Keywords: variety; rainfed; plant type; soil-profile depletion; zero tillage

Northern China is one of the most important agricultural regions in China; its food production accounts for approximately one-fifth of the national food production. In this region, double cropping of winter wheat with summer maize is the most important planting pattern (Fang et al. 2007). Summer maize is grown during the rainy season in northern China when the average annual precipitation is approximately 325 mm, which is sufficient to meet the water consumption requirements of summer maize. However, with the climate changes in recent years, this region often experiences drought during the summer maize-growing season (Li et al. 2007). Hence, water has become an important factor in obtaining a stable grain yield.

In recent years, combine harvesters were used to harvest approximately 90% of the winter wheat crop in northern China; therefore, the ground was mulched with straw. Straw mulching can improve soil nitrogen availability, increase plant growth (Fang et al. 2011), and influence the physical and chemical properties of the soil (Govaerts et al. 2007). Hence, many researchers consider straw mulching for enhancing maize productivity. In the sub-mountainous northwestern Himalayan regions of India, Sharma et al. (2010) observed that mulching is very beneficial for enhancing moisture

Supported in part by the Special Scientific Research Fund for Public Benefit Industries (agriculture) of China, Project No. 200903003; by the National Natural Science Foundation of China, Project No. 31101127; by the Natural Science Foundation of Shandong Province, P.R. China, Project No. ZR2010CQ009, and by the State Key Program of Basic Research of China, Project No. 2009CB118602.

and nutrient conservation, resulting in increased productivity and improved soil conditions for the maize-wheat cropping system. Monneveux et al. (2006) indicated that residue conservation decreased the anthesis-silking interval and increased the carbon concentration as well as the microbial biomass organic carbon content of the soil during the maize-growing season. Verhulst et al. (2011) observed that zero tillage with residue retention resulted in the highest soil water content, and this effect was more pronounced during the extended, erratic drought periods during the summer maize-growing season. During the same experiment, Govaerts et al. (2009) observed that zero tillage with residue retention increased aggregate distribution, stability, and direct infiltration, especially when compared to zero tillage without residue retention, and to a lesser extent when compared to conventional tillage with or without residue retention. Kolawole et al. (2004) observed that maize yield increased by 37% on burning and by 47% on mulching of *Pueraria* residues.

In northern China, three types of summer maize are widely grown, i.e., compact, half of the compact, and flat. In the aforementioned reports, only one type of plant was studied. Further, the effect of straw mulching on crop evapotranspiration is not completely understood. This study aims to determine the effect of straw mulching on the water consumption characteristics and grain yield of summer maize, which can vary with plant types, under rainfed conditions.

MATERIAL AND METHODS

Experimental site. The study area was located at the Experimental Station of the Shandong Agricultural University (36°10'19'', 117°9'03'') in northern China, where the mean precipitation is 697 mm, approximately 65.2% of which is received from June to September. The winter wheat-summer maize double-cropping system is the dominant agricultural activity in this region. In 2009, the experiment was conducted in light, loamy soil. The concentrations of rapidly available phosphorus, potassium, and nitrogen at a depth of 0–20 cm below the ground surface were 15.2, 81.8, and 65.2 mg/kg, respectively. In 2010, the experiment was conducted in a measuring pit, and the concentrations of rapidly available phosphorus, potassium, and nitrogen at a depth of 0–20 cm below the ground surface were 16.1, 92.4, and 108.1 mg/kg, respectively.

Experimental design. The experiment involved two types of summer maize: a flat type, Danyu86, and a compact type, Chaoshi1. Straw mulching was applied throughout the summer maize growth cycle at three different rates: 0, 6, and 12 t/ha. An outline of the details regarding treatment application is presented in Table 1. During the summer maize five-leaf stage, straw mulching was carried out by applying winter wheat straw that was chopped into 3–5 cm pieces. In 2009, the area of each plot was 30.0 m^2; in 2010, that of the measuring pit was 9.0 m^2. The treatments were randomized using a complete factorial design and were applied in three replications. The maize plants were manually planted after harvesting winter wheat on June 12, 2009, and June 16, 2010. At the beginning of July, the level of rapidly available phosphorous, potassium, and nitrogen were applied at a rate of 75, 112.5, and 150 kg/ha, respectively, depending on the rain. When the maize plants were at the five-leaf stage, Chaoshi1 and Danyu86 were fixed at the rate of 7.5×10^4 and 5.3×10^4 plants/ha, respectively. During the summer maize-growing season, the sites were not irrigated.

Measurements. The volumetric water content of the samples taken from every 10 cm of the top 120 cm depth in the planting zone was measured by a neutron moisture meter (CNC503B, Sper Energy, Nuclear Technology Ltd., Beijing, China). The water content of the top 20 cm of the soil layer was measured by the gravimetric method. Measurements were performed at approximately seven-days intervals. After precipitation, additional measurements were performed.

Evapotranspiration of summer maize was calculated using the following equation (Li et al. 2010):

Table 1. Treatments with the variety, plant types, and straw mulching rates for summer maize in 2009 and 2010

Treatment	Variety	Plant types	Straw mulching rates (t/ha)
C0	Chaoshi1	compact	0
C6	Chaoshi1	compact	6
C12	Chaoshi1	compact	12
D0	Danyu86	flat	0
D6	Danyu86	flat	6
D12	Danyu86	flat	12

C0, C6, and C12 – Chaoshi1 at the straw mulching rates 0, 6, and 12 t/ha, respectively; D0, D6, and D12 – Danyu86 at the straw mulching rates 0, 6, and 12 t/ha, respectively

$$ET = I + P - R - D - SW$$

Where: ET – evapotranspiration (mm); I – irrigation amount (mm); P – precipitation (mm), R – surface runoff (mm); D – downward flux below the crop root zone (mm); and SW – water storage change in the soil profile (mm).

In this experiment, the sites were not irrigated; therefore, I was equal to zero. The measured surface runoff was negligible during the study years. Because of the heavy rain during the summer maize-growing season, deep percolation was observed, and measured by the water balance method (Tracy et al. 1997). Deep percolation was zero when the soil moisture content at a depth of 120 cm was equal to or less than the field moisture capacity (at the experimental site, 120 cm field moisture capacity was 32.4%); on the other hand, when the soil moisture content at this depth was more than the field moisture capacity, deep percolation was calculated as the difference between the soil moisture content and field moisture capacity.

Water-use efficiency was defined as follows (Zhou et al. 2011):

$$WUE = Y/ET$$

Where: Y – grain production (kg/ha).

The maize plants were harvested on October 4, 2009, and October 3, 2010. After air drying, the dry weight of the grain was measured and evapotranspiration was calculated using the above mentioned equation.

Data statistics. Analysis of variance (ANOVA) was used to analyze the effects of the different treatments. ANOVA was performed at a 0.05 level of significance to determine whether the treatments were different. Multiple comparisons were made between the significant effects using the least significant difference (*LSD*) test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Precipitation. Precipitation during the summer maize-growing season was 476.0 and 488.7 mm in 2009 and 2010 (Table 2), respectively; the precipitation amount was the same in both years. However, in 2009, precipitation occurred mainly during June and July, and the precipitation during this period accounted for 65.2% (310.5 mm) of the total precipitation; in 2010, precipitation occurred mainly during August and September, and the precipitation during this period accounted for 71.3% (348.6 mm) of the total precipitation.

Soil moisture content. The soil moisture content during the anthesis-silking and maturity stages of summer maize in 2010 are shown in Figure 1. Corresponding values for 2009 are not shown because they are similar to those for 2010. During the anthesis-silking stage, the soil moisture content was much higher on the application of the straw mulching treatments than on the application of the non-mulching treatments; soil moisture content increased with the rate of straw mulching. Moreover, straw mulching significantly (*LSD*, $P < 0.05$) improved the soil moisture content at a depth of 20–80 cm below the ground surface. At maturity, soil moisture content at a depth of 0–60 cm below the ground surface was much lower on the application of the straw mulching treatments than on the application of the non-mulching treatments. During the summer maize-growing season, the soil moisture content in different soil layers did not significantly (*LSD*, $P < 0.05$) differ between the plant types (Figure 1).

The leaf area index (LAI) during the beginning of the summer maize-growing season was much lower than that during the latter half of the season; therefore, the evaporation ratio in the beginning of the season was higher than that during the latter half of the season. Li et al. (2008) showed that straw mulching reduced the latent heat flux, thereby decreasing soil evaporation. Hence, a large amount of soil moisture could be retained by the soil with straw mulching, and this soil moisture could be absorbed by summer maize during the latter half of the growing season. The LAI during the latter half of the growing season was higher on the application of the mulching treatments than on the application of the non-mulching treatments; thus, the transpiration ratio and phase evapotranspiration increased with mulching. As a result, the soil moisture content at maturity was much lower on the application of the mulching treatments than on the application of the non-mulching treatments.

Evapotranspiration. The details of evapotranspiration during the summer maize-growing season in 2009 and 2010 are presented in Table 3. In 2009, evapotranspiration was significantly (*LSD*, $P < 0.05$) higher on the application of C12 and D12 than on the application of the other treatments, and the increased evapotranspiration resulted from a much higher soil-profile depletion on the application of

Table 2. Precipitation (mm) during the summer maize-growing season in 2009 and 2010

Year	June	July	August	September	Total
2009	71.1	239.4	131.2	34.3	476.0
2010	45.7	94.4	226.9	121.7	488.7

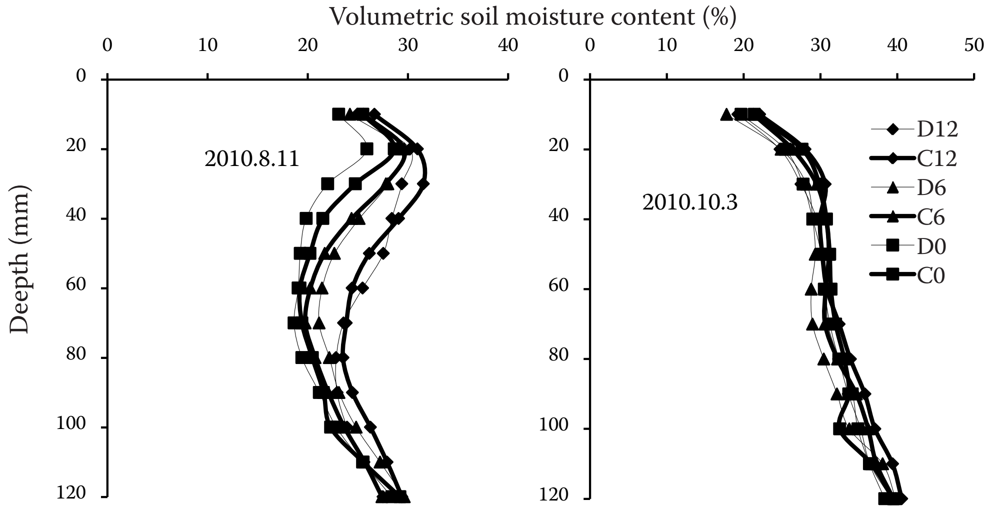

Figure 1. Soil moisture content during anthesis-silking and maturity stages of summer maize in 2010. C0, C6, and C12 – Chaoshi1 at the straw mulching rates 0, 6, and 12 t/ha, respectively; D0, D6, and D12 – Danyu86 at the straw mulching rates 0, 6, and 12 t/ha, respectively

these treatments. Soil-profile depletion was negative, implying that the soil moisture content was higher at maturation than before sowing. In 2010, straw mulching did not significantly (*LSD*, $P < 0.05$) affect evapotranspiration in Chaoshi1; however, evapotranspiration was significantly (*LSD*, $P < 0.05$) higher on D6 application than on the application of the non-mulching treatments; this increase, too, was observed because of a much higher soil-profile depletion on D6 application. A particular straw mulching rate did not elicit significantly (*LSD*, $P < 0.05$) different effect on Chaoshi1 and Danyu86. These findings show that straw mulching during the summer maize-growing season could increase soil-profile depletion and enhance evapotranspiration. Evapotranspiration was higher in 2009 than in 2010; this observation may be related to the period of precipitation. In 2009, the precipitation was received uniformly before the anthesis-silking stage; however, in 2010, most of the precipitation was received after the anthesis-silking stage. Deep percolation was significantly (*LSD*, $P < 0.05$) higher in 2010 than in 2009. This increase may have two possible reasons: higher precipitation in 2010 than in 2009 by 12.7 mm

Table 3. Evapotranspiration during the summer maize-growing season in 2009 and 2010

Year	Treatment	Soil-profile depletion (mm)	Precipitation (mm)	Deep percolation (mm)	Evapotranspiration (mm)
2009	C0	–38.6^{b}	476.0	0^{a}	437.4^{b}
	C6	–40.9^{b}	476.0	–0.1^{a}	435.0^{b}
	C12	–20.2^{a}	476.0	–1.2^{bc}	454.6^{a}
	D0	–46.1^{b}	476.0	–0.6^{abc}	429.3^{b}
	D6	–37.9^{b}	476.0	0^{a}	438.1^{b}
	D12	–23.7^{a}	476.0	–1.6^{c}	450.7^{a}
2010	C0	–113.6^{b}	488.7	–22.3^{b}	352.8^{b}
	C6	–90.2^{ab}	488.7	–23.6^{bc}	375.0^{ab}
	C12	–92.9^{ab}	488.7	–26.6^{de}	369.3^{ab}
	D0	–117.4^{b}	488.7	–20.2^{a}	351.2^{b}
	D6	–55.0^{a}	488.7	–24.5^{c}	409.2^{a}
	D12	–81.5^{ab}	488.7	–23.8^{bc}	383.4^{ab}

Values followed by the same latter in the same column, each year, do not differ significantly (*LSD*, $P < 0.05$) standard deviation. C0, C6, and C12 – Chaoshi1 at the straw mulching rates 0, 6, and 12 t/ha, respectively; D0, D6, and D12 – Danyu86 at the straw mulching rates 0, 6, and 12 t/ha, respectively

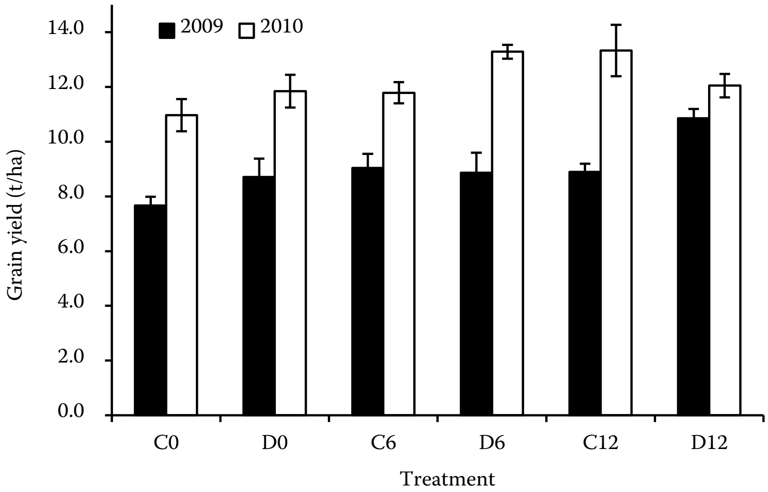

Figure 2. Grain yields of summer maize in 2009 and 2010. Vertical bars are standard errors. C0, C6, and C12 – Chaoshi1 at the straw mulching rates 0, 6, and 12 t/ha, respectively; D0, D6, and D12 – Danyu86 at the straw mulching rates 0, 6, and 12 t/ha, respectively

and restraint to water movement because in 2010, the experiment was conducted in a measuring pit with concrete walls.

Grain yield. In 2009, the grain yield was lower on C0 application than on the application of C6 and C12 by 17.7% and 16.1%, respectively, but there was no significant (*LSD*, $P < 0.05$) difference between any two treatments; however, the grain yield was significantly (*LSD*, $P < 0.05$) higher on D12 application than on the application of D0 and D6 (Figure 2). Straw mulching rates of 0 and 6 t/ha did not elicit any significant (*LSD*, $P < 0.05$) difference between the grain yield of Chaoshi1 and Danyu86; however, straw mulching at the rate of 12 t/ha resulted in a significantly (*LSD*, $P < 0.05$) higher grain yield of Danyu86 than of Chaoshi1. In 2010, the grain yield was significantly (*LSD*, $P < 0.05$) higher on C12 application than on the application of C0 and C6; further, the grain yield was significantly (*LSD*, $P < 0.05$) higher on the application of D6 and D12 than on D0 application. However, the grain yield did not significantly (*LSD*, $P < 0.05$) differ on the application of C12, D6, and D12. These results suggest that under rainfed conditions in northern China, straw mulching can significantly increase the grain yield of summer maize, irrespective of the type of plant, i.e., compact or flat.

Water-use efficiency. The change in the WUE of summer maize during the growing season in 2009 and 2010 is shown in Figure 3. In 2009, the WUE was significantly (*LSD*, $P < 0.05$) higher on the application of C6 and D12 than on the application of the other treatments. In 2010, WUE on C12 application was the highest, significantly (*LSD*, $P < 0.05$) higher than that on the application of C0 and C6, followed by that on D0 application; however, the differences between WUE on the application of D0, D6, and D12 were not statistically significant. Hence, irrespective of whether precipitation was concentrated in the beginning or the latter half of the summer maize-growing season, straw mulching can increase WUE in compact plant types.

In 2010, the grain yield on D6 application was significantly (*LSD*, $P < 0.05$) higher than that of Chaoshi1, but the evapotranspiration on the application of D6 and D12 was higher than that in Chaoshi1 by 9.12% and 9.17%, respectively. In this experiment, the authors found that the LAI was higher in Danyu86 than in Chaoshi1 during the

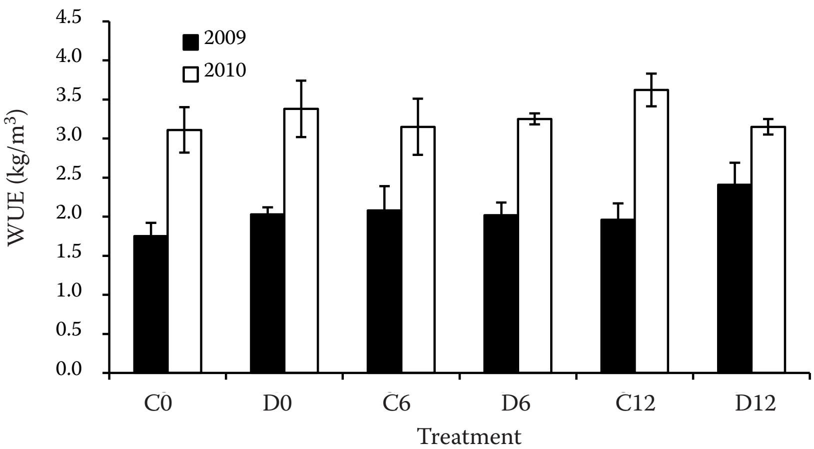

Figure 3. Water use efficiency (WUE) of summer maize in 2009 and 2010. Vertical bars are standard errors. C0, C6, and C12 – Chaoshi1 at the straw mulching rates 0, 6, and 12 t/ha, respectively; D0, D6, and D12 – Danyu86 at the straw mulching rates 0, 6, and 12 t/ha, respectively

latter parts of the growing season. Under conditions of high soil moisture content, the transpiration ratio of Danyu86 was much higher than that of Chaoshi1, and luxurious transpiration was probably exited. Hence, the WUE of Danyu86 decreased.

The WUE of summer maize was determined by transpiration and root water-absorbing capacity. Hence, the essence of efficient water use was root and shoot equilibrium (Gao et al. 2007). Straw mulching affects not only the soil moisture content but also soil temperature and soil nutrient accumulation and distribution (Yan et al. 2007, Li et al. 2008, Malhi et al. 2011). Therefore, to understand the water consumption characteristics of summer maize with straw mulching more clearly, the regulation and control mechanisms of root and shoot equilibrium, as well as its interaction mechanisms under different soil and water conditions should be studied. Understanding these mechanisms is not only essential for understanding the water consumption characteristics with straw mulching but also provides theoretical and practical water-saving techniques applicable to northern China.

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Received on July 16, 2011

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