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Summer maize grain yield and water use efficiency response to straw mulching and plant density

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Abstract

The demand for food security and fresh water due to global warming causes an elevated requirement for food production and water efficiency in the North China Plain (NCP). To establish the optimal summer maize (*Zea mays* L.) planting schedule, a study was conducted to understand the effects of different straw mulching conditions and plant density on grain yield (GY) and water use efficiency (WUE). During 2012 and 2013 summer maize growing seasons, experiments were conducted with two different mulching treatments, *i.e.*, 0.6 kg m^{-2} straw mulching (M) and non-mulching (N), and three plant density conditions, *i.e.*, 10.0 plants m^{-2} (1, high plant density), 7.5 plants m^{-2} (2, medium plant density), and 5.5 plants m^{-2} (3, low plant density). The six treatment combinations were: 10.0 plants m^{-2} density without straw mulching (N1), 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), 7.5 plants m^{-2} density without straw mulching (N2), 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2), 5.5 plants m^{-2} density without straw mulching (N3), and 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3). The results showed medium and high plant density treatments had a significant increase in spike number compared to the low plant density treatment. Straw mulching significantly improved both the GY and WUE of summer maize under low and medium plant density treatments in both dry and normal rainfall years. M2 treatment achieved the highest GY and showed the greatest improvement in WUE of 35.4% over the non-mulching treatment across the three plant densities, and so it will be promoted as an agricultural practice in the NCP

Abbreviations

North China Plain (NCP), Grain yield (GY), Water use efficiency (WUE), Non-mulching treatment (N), 0.6 kg m^{-2} straw mulching treatment (M), 10.0 plants m^{-2} or high plant density (1),7.5 plants m^{-2} or medium plant density (2), 5.5 plants m^{-2} or low plant density (3),Treatment of 10.0 plants m^{-2} density without straw mulching (N1), Treatment of 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), Treatment of 7.5 plants m^{-2} density without straw mulching (N2),Treatment of 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2),Treatment of 5.5 plants m^{-2} density without straw mulching (N3),Treatment of 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3),Evapotranspiration (ET),Precipitation (P),Surface runoff (R),Downward flux below the crop root zone (D).

Introduction

Fresh water shortages and global warming are resulting in the urgent need for sustainable agricultural development in the North China Plain (NCP). The impact of the greenhouse effect on water supply is a considerable concern for researchers. Climate change increases the probability of drought and changes to regional precipitation patterns leading to water stress in many regions (Djebou and Singh, 2016). Decades of changes in stratospheric water vapor have potentially affected recent climate. Extensive efforts have been put into improving crop productivity under water-limiting conditions. The NCP often experiences drought during the summer maize (*Zea mays* L.) growing season with the climate changes observed in recent years (Yan *et al.*, 2017). Improvements in grain yield (GY) and water use efficiency (WUE) have become the key to the development of agriculture in this region and are significant for alleviating the food crisis caused by a growing population.

Soil surface mulching practices can effectively conserve water by reducing surface runoff and increasing water infiltration (Ma *et al.*, 2017), and these practices have a long history of use in field management practices worldwide. Sustainable farming practices using residue

Table 1 - Treatments design in summer maize growing seasons

Straw mulching amount ($kg\ m^{-2}$)	Plant density (plants m^{-2})	Code	Row spacing (cm)
0.6	High plant density: 10	M1	17.1
	Medium plant density: 7.5	M2	22.2
	Low plant density: 5.5	M3	31.7
0	High plant density: 10	N1	17.1
	Medium plant density: 7.5	N2	22.2
	Low plant density: 5.5	N3	31.7

mulching with no-till have been demonstrated in many environments. The need for soil surface protection outside the growing season was confirmed by Kalmár *et al*. (2013). Zheng *et al*. (2002) demonstrated that wheat straw mulching effectively decreased soil surface evaporation and conserved soil water. No-tillage farming and mulching practice conducted in the NCP led to a significant improvement in soil properties over the long-term. Soil surface mulching reduced the sediment yield and runoff by buffering the ground from raindrop action and enhancing infiltration (Babalola *et al*., 2007). The straw-covered soil surface controlled runoff and sediment losses and subsequently decreased nutrient losses (Liu *et al*., 2012).

A rational plant density is required for summer maize to build a good canopy structure and optimize physiological indexes by using solar-thermal resources within the specific ecological environment. Maize responds differently to plant densities under different cultivation practices that greatly influence GY (Li *et al*., 2015). Drought-prone environments need lower plant densities for efficient use of growth resources (Tokatlidis *et al*., 2011). Seeding rates above the optimum result in lower GY because of higher competition between plants. Short duration hybrids should be sown at higher densities to compensate for lower leaf area per plant (Tsimba *et al*., 2013). GY increased with increasing plant density and while the rate of increase declined, the GY was the greatest at the highest plant density (Raymond *et al*., 2008). In general, research related to plant density mostly focuses on crop breeding and crop physiology. How to save water and achieve a high GY of summer maize by using an optimal combination of straw mulching and planting density requires further study.

In this study, we hypothesized that straw mulching and plant density may affect summer maize GY and WUE greatly. The aims of this study were to determine: (i) the effect of straw mulching and plant density conditions on the WUE of summer maize; (ii) to ascertain whether straw mulching and plant density affect GY; and (iii) to determine an optimal combination of straw mulching and plant density.

Material and methods

Experimental site

Experiments were conducted at the Experimental Station of Shandong Agricultural University (36°10"9'N, 117°9"03'E) in the NCP. The study plot was located in a warm and semi-humid region with a continental climate. Average annual rainfall is 786.3 mm, and 65.1% of the local rainfall is concentrated in the summer, which can satisfy the water requirement for all growth stages of summer maize. The soil at the experimental sites is loamy (40.0% sand, 44.0% silt, and 16.0% clay) with 32.4% field water capacity. The experiment was conducted in plots divided by concrete walls, which were 25.0 cm thick and extended 1.5 m beneath the surface. Plot dimensions were 3.0 m × 3.0 m. Visual observations of the experimental plots did not reveal any signs of previous tillage or water erosion.

Experimental design

High-yielding summer maize cultivar "DengHai 661" was used in the experiment. Each plot was irrigated with 0.5 m^3 of water before sowing to make sure all treatments performed under the same original soil moisture conditions. The maize was sown on June 17, 2012 and June 19, 2013, and was harvested on October 3, 2012, and October 2, 2013, respectively. Split plots designed in randomized complete blocks with three replications were used, with two mulching conditions in the main plots and three plant density treatments in the subplots

Treatments

The six treatment combinations were (1) 10.0 plants m^{-2} density without straw mulching (N1); (2) 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1); (3) 7.5 plants m^{-2} density without straw mulching (N2); (4) 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2); (5) 5.5 plants m^{-2} density without straw mulching (N3), and (6) 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3) Table 1. Wheat straw cut into 3.0 – 5.0 cm was spread evenly over the soil surface when the sum-

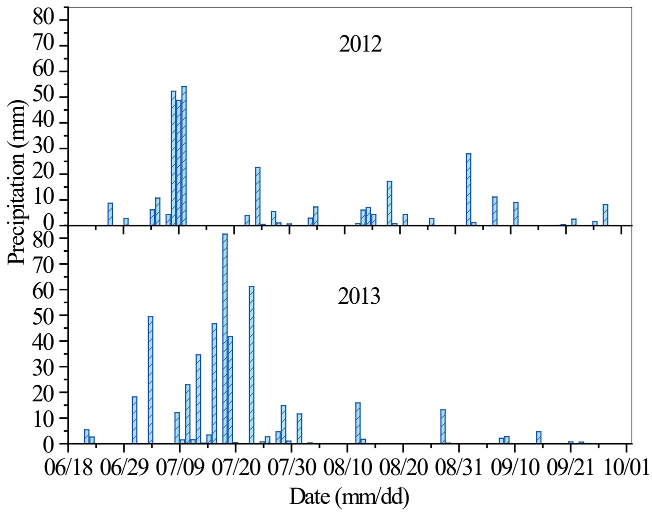

Fig. 1 - Precipitation distribution during 2012 and 2013 summer maize growing seasons in the Experimental Station of Shandong Agricultural University.

mer maize was at the 3 - leaf stage. During both summer maize growing seasons, no irrigation was applied, and other management measures adopted were same to high yield field (Li *et al.*, 2015).

Measurements

Precipitation data were provided by the Tai'an agricultural weather station, situated approximately 100 m from the experimental site.

The soil volumetric water content was measured by a neutron moisture meter (CNC503B, Super Energy, Nuclear Technology Ltd., Beijing, China) access tube, which was buried in each experimental plot. Measurements were taken every 10.0 cm in depth, up to 120.0 cm below ground level. The water content of the top 20.0 cm soil layer was measured by the gravimetric method for calibration. Measurements were performed at approximately 7 days intervals. Before and after precipitation, additional measurements were performed.

Evapotranspiration of summer maize was calculated using the following equation (Yan *et al.*, 2017):

$$ET=P - R - D - SW \quad (1),$$

where ET, evapotranspiration (mm); P, precipitation (mm); R, surface runoff (mm), which was assumed to be not significant because of the concrete walls around each plot; D, downward flux below the crop root zone (mm), deep percolation was zero when the soil moisture content at 1.2 m was equal to or less than the field moisture content; on the other hand, when the soil moisture content at 1.2 m was more than the field moisture capacity, the deep percolation was calculated as the difference between the soil moisture content and field moisture capacity; and SW, water storage change in the soil profile (mm).

The summer maize GY at maturity was measured from the central rows of each plot. Grain was manually removed from the cob and air-dried. Spike number per area, rows per spike, and kernels per row were measured. The 1000-kernel weight was estimated by counting and weighing 500 kernels, with 3 replicates per plot.

Summer maize water use efficiency was calculated as (Yan *et al.*, 2017):

$$WUE = \frac{GY}{ET} \quad (2),$$

where WUE, water use efficiency of ET for the grain yield (kg m^{-3}); GY, grain yield (g m^{-2}); and ET, evapotranspiration (mm), which is calculated from Eq. (1).

Statistical analyses

The Origin 8.0 procedure was used to conduct analysis of variance. Mean values of the treatments were compared using the least significant difference (LSD) at $P \leq 0.05$. Mean values are reported in the tables and figures.

Results and discussion

Precipitation

Precipitation distribution during 2012 and 2013 summer maize growing seasons is shown in Figure 1. During 2012, total precipitation (337.1 mm) was 25.7% lo-

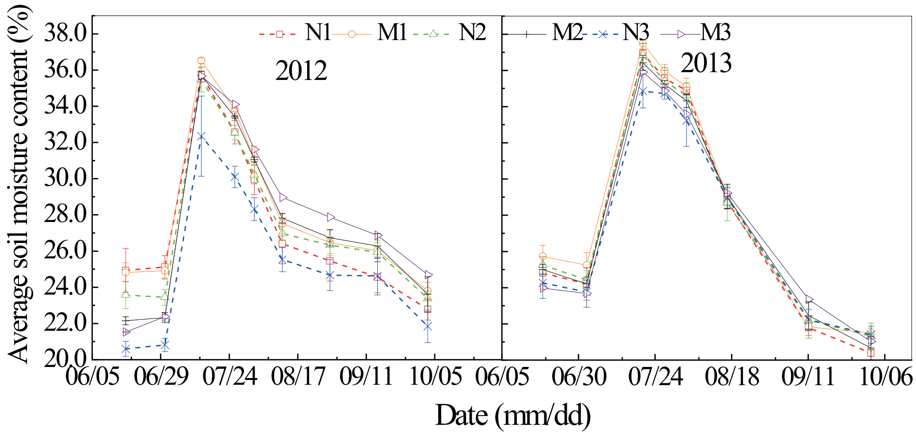

Fig. 2 - Dynamic change of average soil moisture content during 2012 and 2013 summer maize growing seasons. Vertical bars are standard errors. Codes represent 10.0 plants m^{-2} density without straw mulching (N1), 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), 7.5 plants m^{-2} density without straw mulching (N2), 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2), 5.5 plants m^{-2} density without straw mulching (N3), and 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3), respectively.

wer than the average (453.7 mm) for the corresponding period over the past 30 years, even including two times rainstorms (where 50 mm precipitation occurred in less than 24 h). During 2013, total precipitation (461.8 mm), also including two times rainstorm, was closer to the average value. Therefore, the years 2012 and 2013 were classified as dry and normal years, respectively.In both summer maize growing seasons, the precipitation distribution was nonuniform. During 2012, approximately 62.4% precipitation was concentrated in July; while in 2013, it was plentiful before August but scant in the late growing season.

Evapotranspiration and average soil moisture content

Straw mulching and plant densities resulted in different effects on the average soil moisture performance during 2012 and 2013 (Figure 2). The lowest average soil moisture content during 2012 was seen under treatment N3, and the average soil moisture content under mulching treatments was higher than that under non-mulching treatments. However, there was little differences in soil moisture content between different plant densities under the same mulching conditions. During 2013, the average soil moisture content showed no differences between the six treatments.

The performance of ET between mulching and non-mulching treatments was significantly different in all three density conditions during 2012 (Figure 3). ET in mulched plots declined with a decrease of plant density during 2012; however, there were no significant differences in ET between the three plant densities and two mulching treatments during 2013.

There has been a debate about the effect of straw mulching on ET, with some studies observing a lower ET in mulched plots (Zhao *et al*., 2012). In this study, the results indicated that straw mulching had no significant effect on the ET during 2013, in which precipitation distribution was concentrated at an early stage, but that there was a significant decrease in ET in the dry year. ET is significantly affected by the interactions of soil evaporation and plant transpiration (Katerji *et al*., 2011). The increase in vegetation transpiration by mulching was offset by the decrease in soil evaporation, resulting in no significant difference in ET, which could explain why no significant effect of straw mulching on ET was observed (Yan *et al*., 2017).

Grain yield

GY and yield components during 2012 and 2013 are shown in Table 2. The highest GY was found under M2 treatment, with yields of 1255.4 and 1168.9 g m^{-2} during 2012 and 2013, respectively. The GY from mulching treatments was generally significantly higher than that from non-mulched plots, at 13.4% and 26.0% during 2012 and 2013, respectively. Under medium and low plant density conditions, the significantly higher GY under mulching treatment was due to straw mulching increasing the 1000-kernel weight by 8.7% and 6.5% during 2012, and 22.8% and 13.7% during 2013, respectively. Straw mulching showed no significant effect on rows per spike and kernels per row under different plant density conditions; while the effect of plant density on spike number and kernels per row was not. Overall, medium and high plant density treatments resulted in a significant increase in spike number over the low plant density treatment, by 43.3% and 77.7% during 2012, and 40.5% and 82.4% during 2013, respectively; while there was a significant decrease in kernels per

Table 2 - Grain yield and yield components during 2012 and 2013 summer maize growing seasons

Treatment	Spike number (spikes m^{-2})	Rows per spike (rows spike^{-1})	Kernels per row (Kernels row^{-1})	1000-kernel weight (g)	Grain yield (g m^{-2})
2012					
M1	9. 7a	16.8a	27.4d	294.2c	1143.9ab
N1	9.6a	16.1ab	27.8cd	296.7c	1083.5b
M2	7.9b	16.3ab	30.9b	326.0b	1255.4a
N2	7.6c	15.8b	29.5bc	299.8c	1043.5bc
M3	5.4d	16.6ab	35.4a	343.1a	1073. 0b
N3	5.4d	16.7a	33.9a	322.1b	936.1c
M	7. 7a	16.6a	31.2a	321.1a	1157.4a
N	7.6a	16.2a	30.4a	306.2b	1021.1b
1	9.7a	16.4ab	27.6c	295.5c	1113.7a
2	7.8b	16.1b	30.2b	312.9b	1149.5a
3	5.4c	16.6a	34.6a	332.6a	1004.5b
2013					
M1	9.9a	15.4ab	27.5c	309.0b	1140.0ab
N1	9.8a	14.4b	26.9c	296.1bc	969.7bc
M2	7.6b	16.2a	30.2b	325.7ab	1168.9a
N2	7.6b	16.1a	29.3bc	265.3c	906.3c
M3	5.6c	16.3a	35.7a	358.9a	1159.7a
N3	5.2d	16.3a	35.3a	315.8b	878.1c
M	7.7a	16.0a	31.1a	331.2a	1156.2a
N	7.6b	15.6a	30.5a	292.4b	918.0b
1	9.9a	14.9b	27.2c	302.6b	1054.9a
2	7.6b	16.1a	29.7b	295.5b	1037.6a
3	5.4c	16.3a	35.5a	337.4a	1018.9a

Values followed by the same letter in the same column, each year, do not differ significantly (LSD, $P < 0.05$) standard deviation. Codes represent non-mulching treatment (N), 0.6 kg m^{-2} straw mulching treatment (M), 10.0 plants m^{-2} or high plant density (1), 7.5 plants m^{-2} or medium plant density (2), 5.5 plants m^{-2} or low plant density (3), 10.0 plants m^{-2} density without straw mulching (N1), 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), 7.5 plants m^{-2} density without straw mulching (N2), 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2), 5.5 plants m^{-2} density without straw mulching (N3), and 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3), respectively.

row by 20.3% and 12.8% during 2012, and 23.5% and 16.3% during 2013, respectively. There were no significant differences in GY between medium and high plant densities. The decline in spike number under the medium plant density treatment was offset by the increase in kernels per row.

The distribution of seasonal precipitation is an important factor that influences crop production (Kheiri *et al.*, 2017). Even though 2012 was a dry year, summer maize is relatively insensitive to water stress imposed

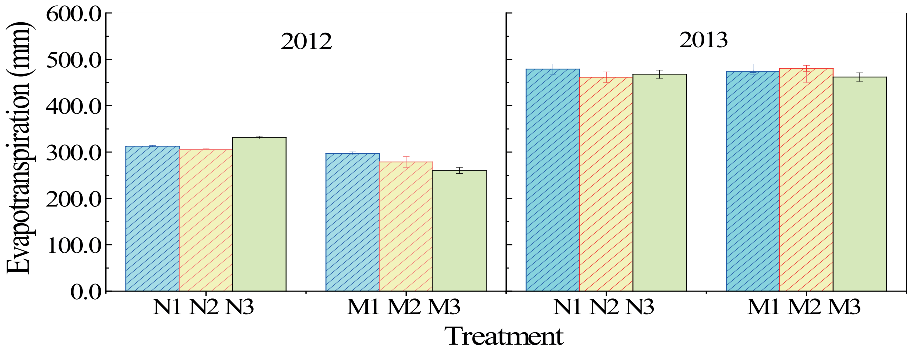

Fig. 3 - Total evapotranspiration during 2012 and 2013 summer maize growing seasons. Vertical bars are standard errors. Codes represent 10.0 plants m^{-2} density without straw mulching (N1), 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), 7.5 plants m^{-2} density without straw mulching (N2), 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2), 5.5 plants m^{-2} density without straw mulching (N3), and 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3), respectively.

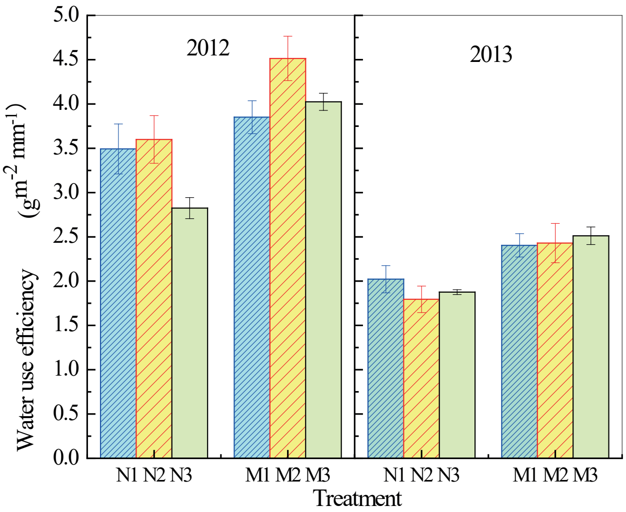

Fig. 4 - The summer maize WUE during 2012 and 2013 summer maize growing seasons. Codes represent 10.0 plants m^{-2} density without straw mulching (N1), 10.0 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M1), 7.5 plants m^{-2} density without straw mulching (N2), 7.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M2), 5.5 plants m^{-2} density without straw mulching (N3), and 5.5 plants m^{-2} density with 0.6 kg m^{-2} straw mulching (M3), respectively

during its early vegetative growth stages, as it can adapt to minimize the effects of subsequent periods of water stress. The precipitation was concentrated at the early vegetative growth stages during 2012 and had no significant effect on the growth of the maize, which could be an explanation as to why the GY of all treatments during 2013 were generally lower than those from 2012. Drought-prone environments require lower plant densities for the efficient use of growth resources (Tokatlidis *et al.*, 2011). The effect of plant density on GY should be studied further across different annual rainfall conditions.

Water use efficiency

Both during 2012 and 2013 summer maize growing seasons, the WUE under different plant density treatments showed no significant differences within the same straw mulching conditions (Figure 4). However, there were significant differences in WUE between the mulched and non-mulched plots. During 2012, the WUE of M2 and M3 was 25.4% and 42.5% higher than that of N2 and N3; during 2013, the WUE of M1, M2, and M3 was 18.9%, 35.4%, and 33.9% higher than that of N1, N2, and N3, respectively. The WUE under all treatments varied considerably in both growing seasons. During 2012, the WUE under all treatments was higher than that during 2013, which corresponds well with the fact that plant water deficit results in a high WUE (Blum, 2009). The lesser soil evaporation in mulched fields would facilitate a higher GY and WUE in a dry year (Ma *et al.*, 2017). Decrease in soil moisture caused by evaporation was partly compensated for by a capillary rise from the deeper soil layers (Hao *et al.*, 2013). The improvement in GY and WUE under straw mulching conditions was attributed to a better topsoil moisture and higher soil temperature in the planting zone. Soil moisture distribution in different layers needs to be studied further. Shading of the soil by the plant canopy and an increase in plant water uptake amounts would change the observed water losses by evaporation (Li *et al.*, 2013). The plant transpiration of different plant types warrants an intensive study.

As has been reported, the increase in total transpiration correlates with a significantly higher GY and enhanced WUE (Tolk *et al.*, 1999). The higher GY and WUE are consistent with this conclusion. Further attention is necessary to discover the response of soil moisture content, ET, and WUE to different precipitation amounts and distribution throughout the year. ET would decrease under global warming, and the degree of the reduction would generally increase with increasing mean global temperature (Tao and Zhang, 2011). Changes in ET affect CO_2 uptake directly and indirectly through the depletion of plant available water (Suyker and Verma, 2010). As CO_2 concentration increases, crop production could be affected by several factors (Liu *et al.*, 2014). The interaction between carbon utilization and ET and their combined effect on GY under global climate change should be studied further.

Conclusions

The results showed medium and high plant density treatments had a significant increase in spike number compared to the low plant density treatment. Straw mulching resulted an effective tool used to improve grain yield by increasing 1000-kernel weight. Plant density had significant effects on spike number and kernels per row; however, there was no significant difference in grain yield. Straw mulching significantly improved both the GY and WUE of summer maize under low and medium plant density treatments in both dry and normal rainfall years. M2 treatment achieved the highest GY and showed the greatest improvement in WUE of 35.4% over the non-mulching treatment across the three plant densities; therefore, it will be promoted as an agricultural practice in the NCP

Acknowledgements

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References

Babalola O, Oshunsanya SO, Are K, 2007. Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (*Zea mays* L.) yields. Soil Till Res 96: 6–18.

Blum A, 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res 112: 119–123.

Djebou DCS, Singh VP, 2016. Impact of climate change on precipitation patterns: a comparative approach. Int J Climatol 36: 3588–3606.

Hao FH, Chen SY, Ouyang W, Shan YS, Qi SS, 2013. Temporal rainfall patterns with water partitioning impacts on maize yield in a freeze–thaw zone. J Hydrol 486: 412–419.

Kalmár T, Bottlik L, Kisić I, Gyuricza C, Birkás M, 2013. Soil protecting effect of the surface cover in extreme summer periods. Plant Soil Environ 59: 404–409.

Katerji N, Rana G, Fahed S, 2011. Parameterizing canopy resistance using mechanistic and semi-empirical estimates of hourly evapotranspiration: critical evaluation for irrigated crops in the Mediterranean. Hydrol Process 25: 117–129.

Kheiri M, Soufizadeh S, Ghaffari A, Aghaalikhani M, Eskandari A, 2017. Association between temperature and precipitation with dryland wheat yield in northwest of Iran. Climatic Change 141: 703–717.

Li J, Xie RZ, Wang KR, Ming B, Guo YQ, Zhang Q, Li SK, 2015. Variations in maize dry matter, harvest index, and grain yield with plant density. Agron J 107: 829–834.

Li SX, Wang ZH, Li SQ, Gao YJ, Tian XH, 2013. Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. Agric Water Manage 116: 39–49.

Li ZX, Liu KC, Liu CX, Zhang XQ, Liu X, Zhang H, Liu SC, Wang QC, Li QQ, 2013. Aboveground dry matter and grain yield of summer maize under different varieties and densities in North China Plain. Maydica 58: 189–194.

Liu Y, Tao Y, Wan KY, Zhang GS, Liu DB, Xiong GY, Chen F, 2012. Runoff and nutrient losses in citrus orchards on sloping land subjected to different surface mulching practices in the Danjiangkou Reservoir area of China. Agric Water Manage 110: 34–40.

Li QQ, Chen YH, Liu MY, Zhou XB, Dong BD, Yu SL, 2007 Effect of irrigation to winter wheat on the soil moisture, evapotranspiration, and water use efficiency of summer maize in North China. Trans ASABE 50: 2073–2080.

Liu QR, Liu XH, Bian CY, Ma CJ, Lang K, Han HF, Li QQ, 2014. Response of soil CO_2 emission and summer maize yield to plant density and straw mulching in the North China Plain. Sci World J Doi: org/10.1155/2014/180219.

Ma CJ, Liu XH, Bian CY, Liu QR, Li QQ, 2017. Straw mulching can realize soil/plants carbon sequestration and yield increasing of summer maize in North China. Rom Agric Res 34: DII 2067-5720 RAR 2017-115.

Raymond FD, Alley MM, Parrish DJ, Thomason WE, 2009. Plant density and hybrid impacts on corn grain and forage yield and nutrient uptake. J Plant Nutr 32: 395–409.

Suyker AE, Verma SB, 2010. Coupling of carbon dioxide and water vapor exchanges of irrigated and rainfed maize–soybean cropping systems and water productivity. Agric Forest Meteorol 150: 553–563.

Tao FL, Zhang Z, 2011. Impacts of climate change as a function of global mean temperature: maize productivity and water use in China. Climatic Change 105: 409–432.

Tokatlidis IS, Has V, Melidis V, Has I, Mylonas I, Evgenidis G, Copandean A, Ninou E, Fasoula VA, 2011. Maize hybrids less dependent on high plant densities improve resource-use efficiency in rainfed and irrigated conditions. Field Crops Res 120: 345–351.

Tolk JA, Howell TA, Evett SR, 1999. Effect of mulch, irrigation, and soil type on water use and yield of maize. Soil Till Res. 50: 137–147.

Tsimba R, Edmeades GO, Millner JP, Kemp PD, 2013. The effect of planting date on maize

grain yields and yield components. Field Crops Res 150: 135–144.
Wang YJ, Xie ZK, Malhi SS, Vera CL, Zhang YB, Wang JN, 2009. Effects of rainfall harvesting and mulching technologies on water use efficiency and crop yield in the semi-arid Loess Plateau, China. Agric Water Manage 96: 374–382.
Yan ZX, Gao C, Ren YJ, Zong R, Ma YZ, Li QQ, 2017. Effects of pre-sowing irrigation and straw mulching on the grain yield and water use efficiency of summer maize in the North China Plain. Agric Water Manage 186: 21–28.
Zhao H, Xiong YC, Li FM, Wang RY, Qiang SC, Yao TF, Mo F, 2012. Plastic film mulch for half growing-season maximized WUE and yield of potato. Agric Water Manage 104: 68–78.
Zheng J, Feng Y, Yu K, Wang Z, Yuan X, 2002. Irrigation with brackish water under straw mulching. Trans CSAE 18: 26–31.