

Effect of irrigation frequency during the growing season of winter wheat on the water use efficiency of summer maize in a double cropping system

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Abstract

Our aim was to investigate the potential effects of irrigation frequency during the growing season of winter wheat on the water use efficiency (WUE) of summer maize in a double cropping system. To this end, we conducted a field experiment with winter wheat cultivated with 1, 2, and 3 irrigation applications with 120 mm water at the time of stem elongation, heading, or milking. The results showed that later irrigation applications increased soil moisture before sowing (SMBS) of summer maize. Summer maize grain yield was enhanced in both the common and excessively rainy years with increased SMBS; however, irrigation during the later growing season of winter wheat in rainy years could increase deep percolation of summer maize. In common and rainy years, the more the SMBS, the higher was the grain yield of summer maize. The highest WUE for summer maize was obtained when it was grown after winter wheat irrigated with 120 mm water at milking or 60 mm water at each, the stem elongation and heading stages. Considering the combined WUE of winter wheat and summer maize, the authors think that winter wheat should be irrigated at the stem elongation and heading stages to achieve reasonable WUE and grain yield for both crops.

Keywords: double cropping system, winter wheat, summer maize, irrigation, water use efficiency

Introduction

In North China, the common crops are winter wheat and summer maize, which are cultivated according to a double cropping system (Fang et al, 2006). Precipitation is far less than water consumption during the winter wheat growing season due to the climate in this season. Hence, irrigation is necessary in order to obtain high grain yield. In contrast, surplus precipitation occurs during the summer maize growing season; therefore, irrigation is not necessary when both crops are grown in the same years. As a result, irrigation is typically used during the winter wheat growing season in winter wheat-summer maize double cropping systems in North China (Li et al, 2008).

At present, full irrigation is commonly practiced in North China in order to ensure high and stable grain yield of winter wheat (Zhang et al, 2006); hence, the irrigation frequency is high and the irrigation quantity is excessive. This may potentially lead to overuse of groundwater and, consequentially, serious environmental problems (Xia et al, 2005); in addition, excessive irrigation has disadvantageous effects on grain yield and crop quality. Han et al (2008) found that irrigation frequency and developmental stages at application had significant effects on winter wheat grain yield and quality. In North China, water resources are

very limited. In order to ensure sustainable development of agriculture, water-saving management systems should be adopted. Most research in this region only focused on the water consumption characteristics of winter wheat or summer maize separately (Li et al, 2010; Zhang et al, 2010), and failed to combine water saving measures with double cropping systems. The authors of previous studies on the winter wheat-summer maize double cropping system, however, revealed that irrigation quantity during the winter wheat growing season significantly affected the water consumption characteristics of summer maize (Li et al, 2008; Li et al, 2009). The objective of the current study is to investigate the effect of irrigation frequency during the winter wheat growing season on the water use efficiency (WUE) of summer maize in a double cropping system, with the aim of establishing theoretical and practical water saving techniques in North China.

Materials and Methods

Experimental site

The experiment was conducted during 2006–2007 and 2007–2008 at the Luancheng Agro-Ecosystem Experimental Station of the Chinese Academy of Sciences (114°40'E, 37°50'N), which is located in the northern part of the North China Plain at the

base of Mt. Taihang. The mean annual precipitation at the station is 485 mm, approximately 70% of which received during the summer maize growing season from June to September. The remainder of the region's annual precipitation is received between October and early June, which is the winter wheat growing season. The experimental plots had a loamy soil profile, in which the concentration of organic matter was 1.2% and the concentration of rapidly available phosphorus, potassium, and nitrogen was 15, 150, and 80 mg kg⁻¹, respectively. Field moisture capacity and wilting point were 36.4% and 9.6%, respectively. The winter wheat variety used for the experiment was Kenong 9204, which was sown at the rate of 9.3 g m⁻² on October 12 and October 17 in 2006 and 2007, respectively. At the time of sowing, 54.0 kg ha⁻¹ of P₂O₅, 138.0 kg ha⁻¹ of N, and 41.0 kg ha⁻¹ of K₂O were applied to the soil. The wheat plants were harvested on June 11 and June 12 in 2007 and 2008, respectively. According to the common practice in this area, summer maize was sowed via no-tillage methods immediately after the winter wheat was harvested. The summer maize variety utilized was Zhengdan 958. When the maize plants were at the 5-leaf stage, the final plant density was fixed at 6.75 × 10⁴ plants ha⁻¹.

Experimental design

The authors' previous studies indicated that reasonable grain yield and economic profit could be achieved by 120-mm irrigation of the winter wheat (Li et al, 2008; Li et al, 2009; Li et al, 2010). Hence, in this experiment, all irrigation applications were controlled at 120 mm. The following 7 irrigation regimes were applied during the whole winter wheat growing season: 120-mm irrigation at stem elongation (T1); 120-mm irrigation at heading (T2); 120-mm irrigation at milking (T3); 60-mm irrigation at each, stem elongation and heading (T4); 60-mm irrigation at each, stem elongation and milking (T5); 60-mm irrigation at each, heading and milking (T6); and 40-mm irrigation at each, stem elongation, heading, and milking (T7). Irrigation water was supplied from a pump outlet to the plots via plastic pipes, and a flow meter was used to measure the amount of water supplied. Treatments were randomized using a complete factorial design and replicated 3 times. The area of the plots was 16.0 m². Raised beds were erected around the plots to prevent surface runoff. A 1.5-m wide zone without irrigation was maintained between adjacent plots to minimize the potential effects of adjacent plots on each other. No irrigation water was supplied during the subsequent growing season of summer maize.

Volumetric soil water content

The volumetric soil water content of the cores obtained at every 10 cm from the top down to 180 cm in the planting zone was measured by a CNC503B neutron moisture meter (Super Energy; Nuclear Technology Ltd, Beijing, China). The water content of the top 20-cm soil layer was measured by the oven-drying method. Measurements were performed at approxi-

mately 7-day intervals. After precipitation events, additional measurements were performed.

Evapotranspiration

The evapotranspiration of the summer maize was calculated using the following equation (Istanbulluoglu et al, 2009):

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

In this equation, ET (mm) is the amount of water that underwent evapotranspiration; I (mm) is the amount of irrigation water that was measured using the flow meters; P (mm) is the precipitation amount measured with a standard rain gauge at the weather station; R (mm) is the amount of surface runoff (because there were beds around the plots, and therefore, surface runoff was not assumed to be significant); D (mm) is the downward flux below the crop root zone; and SW (mm) is the change in stored water content of soil profile exploited by summer maize roots. In 2007, deep percolation was negligible; however, in 2008, deep percolation was measured by the water balance method (Gong and Li, 1995; Tracy et al, 1997), due to heavy rain during the growing season of the summer maize. Deep percolation was zero when the soil moisture content at 1.8 m was equal to or less than the field moisture capacity. When the soil moisture content at 1.8 m 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

The WUE of summer maize was defined as follows (Zhang et al, 1998): WUE=Y/ET

Y (g m⁻²) represents grain production, and ET (mm), the amount of water that underwent evapotranspiration.

Data statistics

The treatments were analyzed using analysis of variance (ANOVA). For ANOVA, $\alpha = 0.05$ was set as the level of significance to determine whether significant differences existed between the yearly means of the various treatments. Multiple comparisons were performed for significant effects with the least significant difference (LSD) test at $\alpha = 0.05$.

Results

Precipitation during the growing season of summer maize

Precipitation was measured with a meteorological device (Table 1). Precipitation during the summer maize growing season was 346.1 mm in 2007 and 406.7 mm in 2008. Based on the annual mean precipitation during the growing seasons of summer maize in the study regions (339.5 mm), the years 2007 and 2008 were classified as common and rainy, respectively.

Soil moisture before sowing of summer maize

Irrigation during the growing season of winter wheat could affect the soil moisture before sowing

Table 1 - Precipitation during the growing season of summer maize in 2007 and 2008 (mm).

Year	June	July	August	September	October	Total amount
2007	20.2	98.2	173.2	54.5	0	346.1
2008	102.0	104.0	108.3	57.9	34.5	406.7

(SMBS) in the 1.8-m soil profiles of summer maize significantly (**Table 2**). Under conditions when irrigation was applied only once late during the winter wheat growing season, the SMBS of summer maize increased. The SMBS measurements in T3 and T2 were higher than that in T1 by 54.4 and 27.3 mm, respectively. When the crops were irrigated twice during the winter wheat growing season, the SMBS measurements in T6 and T5 were higher than that in T4 by 38.8 and 20.2 mm, respectively. This result indicated that irrigation timing during the later part of the growing season of winter wheat improved the SMBS of summer maize. Under the conditions of 3 times irrigation during the winter wheat growing season, compared with T5 and T6, the SMBS in T7 was not significantly improved. Hence, in the double cropping system with winter wheat and summer maize, irrigation water that was applied during the growing season of winter wheat was not absorbed completely and some of the water continued to be utilized by the summer maize.

Grain yield

Grain yield (**Table 3**) was significantly affected by

Table 2 - Soil moisture before sowing in the 1.8-m soil profiles of summer maize in 2007 and 2008 (mm).

Treatment	2007	2008	Mean
T1	338.7 ^d	436.3 ^d	387.5 ^d
T2	374.9 ^b	454.2 ^b	414.6 ^b
T3	410.5 ^a	473.2 ^a	441.9 ^a
T4	325.4 ^e	431.8 ^d	378.6 ^e
T5	361.8 ^c	432.5 ^d	397.2 ^c
T6	378.7 ^b	456.0 ^b	417.4 ^b
T7	333.8 ^d	449.9 ^{bc}	391.9 ^{cd}

^awithin a column, values followed by different letters differ significantly among treatments.

the different SMBS measurements during the summer maize growing season. When both crops were grown in the common year, T3 resulted in the highest grain yield, followed by T6, T2, T5, T1, and T7. The lowest grain yield was observed in T4 (6.2 t ha⁻¹), which was significantly lower than that for the other treatments. In the rainy year, T6 resulted in the highest grain yield, but the yield did not significantly differ between T3 and T5. T1 resulted in the lowest grain yield. Considering the results in 2007 and 2008 together, T3 and T6 significantly increased the grain yield of summer maize.

Evapotranspiration

Table 4 shows the changes in precipitation, soil profile depletion, deep percolation, and evapotranspiration of summer maize during the growing seasons of 2007 and 2008. Deep percolation was not evaluated because of less precipitation during the summer maize growing season in 2007, and it was calculated by the water balance method in 2008 (Gong and Li, 1995; Tracy et al, 1997). Results showed that when irrigation was applied only once during the winter wheat growing season, T3 significantly increased deep percolation and accounted for 12.6% of the precipitation. When the crops were irrigated twice during the winter wheat growing season, T6 significantly increased deep percolation. When irrigation was applied 3 times during the winter wheat growing season, compared with T6, T7 did not significantly increase deep percolation. Therefore, in the rainy year, when irrigation was applied only once or twice late during the winter wheat growing season, deep percolation during the summer maize growing season increased. With the increase in SMBS, the soil profile depletion decreased. However, evapotranspira-

Table 3 - Grain yield of summer maize in 2007 and 2008 (t ha⁻¹).

Treatment	2007	2008	Mean
T1	6.3 ^{cd}	5.8 ^c	6.1 ^d
T2	6.6 ^{bc}	6.7 ^b	6.6 ^{bc}
T3	7.2 ^a	7.3 ^a	7.3 ^a
T4	6.2 ^d	6.8 ^b	6.5 ^c
T5	6.5 ^{bcd}	7.1 ^{ab}	6.8 ^b
T6	6.8 ^b	7.4 ^a	7.1 ^a
T7	6.3 ^{cd}	6.9 ^b	6.6 ^{bc}

^awithin a column, values followed by different letters differ significantly among treatments.

tion increased significantly with an increase in SMBS. This finding demonstrates that irrigation during the growing season of winter wheat not only affected the evapotranspiration of winter wheat but also substantially affected that of summer maize.

Water use efficiency

In the winter wheat and summer maize double cropping system, irrigation applied during the winter wheat growing season significantly affected the WUE of summer maize (**Figure 1**). When irrigation was applied only once during the winter wheat growing season, T3 resulted in the highest WUE, followed by

Table 4 - Evapotranspiration of summer maize in 2007 and 2008 (mm).

Treatment	Precipitation	Soil profile depletion	Deep percolation	Evapotranspiration
2007				
T1	346.1	30.3 ^{de}	—	376.4 ^c
T2	346.1	34.6 ^c	—	380.7 ^c
T3	346.1	40.2 ^a	—	406.3 ^a
T4	346.1	24.5 ^f	—	370.9 ^d
T5	346.1	33.9 ^{cd}	—	380.0 ^{cd}
T6	346.1	35.7 ^b	—	391.8 ^b
T7	346.1	29.4 ^e	—	375.5 ^{cd}
2008				
T1	406.7	30.9 ^d	35.9 ^c	391.2 ^b
T2	406.7	29.7 ^d	35.2 ^c	390.7 ^b
T3	406.7	75.4 ^a	51.1 ^a	420.5 ^a
T4	406.7	29.2 ^d	36.3 ^c	389.1 ^b
T5	406.7	50.4 ^c	37.9 ^c	408.7 ^{ab}
T6	406.7	60.6 ^b	43.9 ^b	412.9 ^a
T7	406.7	53.4 ^c	41.7 ^b	407.9 ^{ab}

^awithin a column, values followed by different letters differ significantly among treatments.

T2, and the lowest WUE was observed in T1. When irrigation was applied twice during the winter wheat growing season, no matter in both the common and rainy years, T6 resulted in the highest WUE. When irrigation was applied 3 times during the winter wheat growing season, the WUE in T7 was more significantly lesser than that in T4, T5, and T6. This result indicates that when irrigation was applied only once or twice during the winter wheat growing season, irrigation timing during the later part of the growing season of winter wheat improved the WUE of summer maize. T3 and T6 resulted in the highest WUE for both years; however, there was no significant difference between T4 and T6 in the WUE values.

Discussion

These findings indicate that in the winter wheat and summer maize double cropping system, the soil moisture derived by the irrigation of winter wheat that was present in the soil layers before summer maize sowing increased the productivity of summer maize in common and rainy years.

During the growing season of summer maize in North China, it was estimated from the treatments that approximately 29.4–75.4 mm of stored soil water was available to summer maize in the region, depending on the precipitation. The stored soil water was important for summer maize production. The growing season of summer maize is the rainy season in North China, when the average annual precipitation is approximately 339.5 mm; however, drought often occurs during the seedling stage of summer maize

due to the influence of seasonal wind. Accordingly, the stored soil water at the time of sowing has become an important parameter to obtain stable yield and high WUE for summer maize in this area. Due to the potential influence of drought, additional irrigation is often used. Some previous researchers found that crops used less stored soil water as the amount of irrigation increased (Bandyopadhyay et al, 2005; Li et al, 2010). Therefore, in order to obtain stable grain yield and high WUE during the growing season of summer maize, the stored soil water at the time of sowing should be considered when additional irrigation is applied.

Previous research by the authors of this study indicated that during the winter wheat growing season, 120-mm irrigation was applied; moreover, 60-mm irrigation at each the stem elongation and heading stages achieved the highest grain yield and WUE (Li et al, 2008; Li et al, 2009; Li et al, 2010). This study found that in the winter wheat and summer maize double cropping system, 120-mm irrigation applied during the winter wheat growing season produced significantly higher summer maize grain yield and WUE, which were observed with T3 and T6 than with the other treatments, but the WUE did not significantly differ between T4 and T6. Combining the results obtained for grain yield and WUE, it can be concluded that irrigation at the stem elongation and heading stages of winter wheat results in high grain yield and WUE for the both crops and offers a reliable measurement system for the development of efficient irrigation regimes for double cropping systems with winter wheat and summer maize in North China.

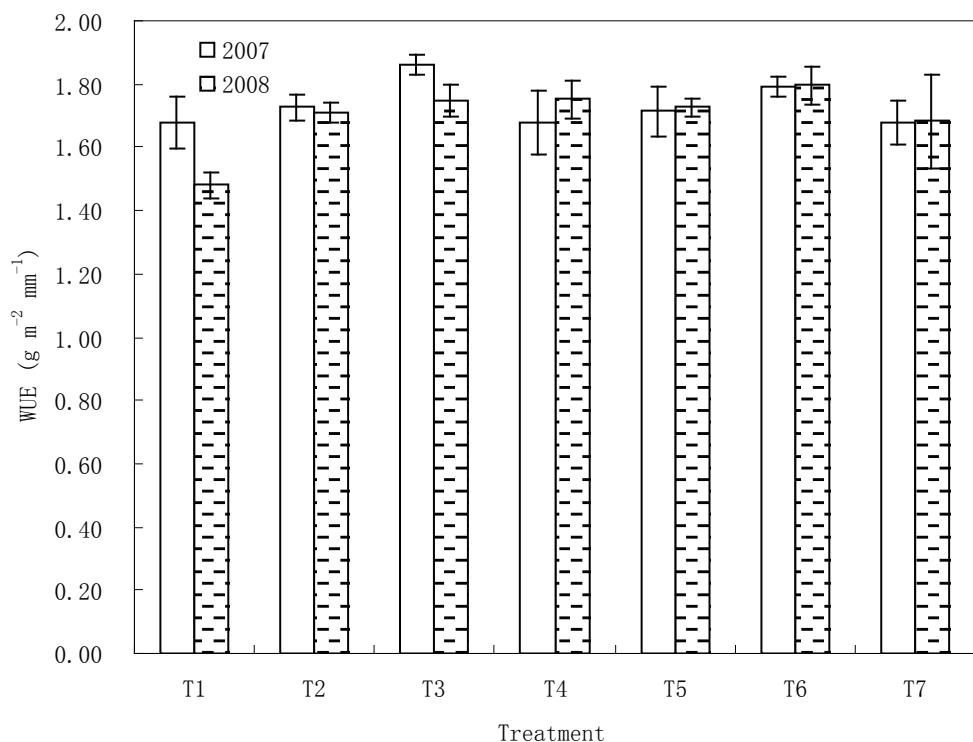


Figure 1 - Effect of irrigation frequency during the growing season of winter wheat on the water use efficiency of summer maize in a double cropping system. Vertical bars are standard errors.

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