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Full Length Article

Experimental Study on Irrigation Characteristics of Wheat under Surge Irrigation

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Abstract

The present study depicts the effects of different surge flow irrigations on water flow speed and the quality of irrigation under the universal siphon device and explore the feasibility of replacing surge flow irrigation in wheat. Four irrigation treatments were implemented in wheat: surge irrigation group (S), alternating surge irrigation group (AS), fixed surge irrigation group (FS), and continuous irrigation group (C). In each treatment, we measured water flow speed, irrigation uniformity, water use efficiency (WUE) and the yield of wheat. The results revealed that under the universal siphon device, the water flow speed of surge flow irrigation was faster than that of continuous irrigation. Among the four kinds of irrigation, surge irrigation was more effective in enhancing irrigation uniformity. The irrigation uniformity of S treatment and AS treatment was 3.01% and 2.04% higher than C treatment, respectively. And AS treatment has better effect to increase the yield of winter wheat compared with the S and FS treatment. AS treatment has a better potential to improve water use efficiency, followed by FS treatment. They were 94.74%, 73.68% higher than C, respectively. Therefore, the use of alternating surge irrigation for winter wheat in Tai'an, can achieve significant water saving and yield-increasing effects. © 2019 Friends Science Publishers

Keywords: Wheat; Surge irrigation; Siphon; Irrigation uniformity; Water use efficiency

Introduction

At present, irrigation methods in China mainly include furrow irrigation, flood irrigation, sprinkler irrigation, drip irrigation and so on. Flood irrigation is a wasteful method of irrigation. Although the drip irrigation water-saving effect is obvious, the irrigation uniformity is poor (Zhang *et al.*, 2018). Controlled alternative irrigation is a new technique of water saving control of farmland proposed. This irrigation method can reduce inefficient transpiration and increase the water use efficiency of the leaves (Wang *et al.*, 2011; Xia *et al.*, 2015). Some people organically combined the two kinds of water-saving irrigation technologies of surge irrigation and low-pressure pipe irrigation, but they have not been field-tested to verify their practicality (Bai *et al.*, 2006).

Relevant studies on drive devices of surge irrigation reversing valves have found that surge valves are suitable for small-scale applications (Hai *et al.*, 2017). But the device is not used in a variety of surge irrigation treatment, nor in the field test has been tested or even promoted. In the growth stages of winter wheat, the cumulative and daily average water consumption increases from the jointing stage to the filling stage. Therefore, ensuring the irrigation amount from the jointing stage to the filling stage contributes to the high yield of winter wheat (Zhang *et al.*, 2016).

At present, there is no combination of surge irrigation and interval irrigation for irrigation experiments. Therefore, two irrigation methods, surge irrigation and interval irrigation, are combined to form alternating surge irrigation and fixed surge irrigation to achieve controlled root zone partitioning. Exploring the impact of surge irrigation, fixed surge irrigation, alternating surge irrigation on the water flow speed, irrigation uniformity, wheat growth and yield to provide a theoretical basis for the promotion of alternate surge irrigation, aiming to develop more efficient water-saving irrigation technology.

Materials and Methods

Experimental Details and Treatments

Study area: The study was conducted in the field of experimental field (36°0′5″N, 117°0′20″E) of Mazhuang Town, Tai'an City, Shandong Province in China from October 2015 to June 2016. The test field was located in a well in the North China Plain. In the irrigation area, the soil type is loam, and the groundwater depth is 6.8 m, so ground water recharge can be ignored. The field water holding capacity was 32.5% (volume water content), the dry volume mass was 1.37 g/cm^3, and the porosity was 57%. Tillage methods are continuous winter wheat and summer corn. The total precipitation during the winter wheat growing season was 432.7 mm, the average annual sunshine time was 2 627.1 h and the average frost-free period was 195 d.

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Treatments

The graphical representation of treatments is shown in Fig. 1. The crucible has a length of 120 m, a crucible width of 1.5 m, and a slope of 2.5‰. Four treatments were set up in the trial, with three replicates per treatment. Each treatment was protected on both sides. A total of 18 field ridges were arranged, of which 1 to 3 were continuous irrigation (C) and 4 to 6 were surge irrigation (S), 7~12 were alternating irrigation (AS) and 13~18 were fixed irrigation (FS). Considering the plant length, soil texture and convenience of popularization and application, the number of irrigation cycles for surge irrigation, fixed surge irrigation and alternate surge irrigation in the experiment is 2. The circulation rate is 0.5. Continuous irrigation time is 40 min, and surge irrigation single cycle irrigation time is 15 min. Consider alternate surge irrigation and fixed surge irrigation is a barrier irrigation, and lateral leakage problem is more serious, single cycle irrigation time takes 20 min. The wheat variety tested was Jimai 22 with a seeding capacity of 1.83 kg/ha and a basic seedling of 43000 plants/ha. Three irrigations were conducted during the seedling, jointing and filling stages. The test flow rate was steadily controlled at 45 m^3/h and the single-width flow rate was 8.33 L/(s •m). Wheat was sown on October 14, 2015 and harvested on June 7, 2016.

The universal siphon device is powered by lifting water flow, siphon timing siphon or disconnection of siphon is completed by means of stabilizing tank and control pool (timer). Then the water supply and the periodic water stop are realized, thus the automatic water control purpose of the device is realized. It is different from other surge irrigation devices. When the siphon is used, no matter how the water supply flow changes, it can ensure that all siphons can form automatically under various water supply flows. A schematic diagram of the device is shown in Fig. 1.

1) Soil water content: Three sampling points were selected at 40, 80, and 120 m along the length of the crucible in each test rake. The portable soil moisture measuring instrument TRIME-PICO TDR manufactured by Germany was used for 3 d before irrigation and 2, 6, 16 and 28 d after irrigation. The soil water content in 0-20, 20-40, 40-60, 60-80 and 80-100 cm soil layers was measured.

2) The velocity of water flow: A stopwatch is used to record the time spent on the flow of 10 m by a stopwatch to calculate the speed of the flow.

3) Production: When the goods are received, the 50 cm range is selected in each of the treatments and the number of spikes is investigated and the yield is measured. 18 of them were selected and the number of spikes and 1000 grain weight were investigated indoors.

4) The evenness of irrigation in the direction of border length: The soil moisture content of 0-100 cm soil layer was measured by the following formula:

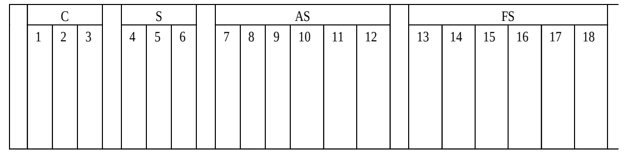


Fig. 1: Graphical representation of treatments

$$Du = (1 - \sum |\Delta H| / H_{avg}) \times 100 \quad (1)$$

$$H_i = \sum \Delta w_i \times \Delta h_i \times 100 \quad (2)$$

$$H_{avg} = \sum H_i / n \quad (3)$$

$$H = H_i - H_{avg} \quad (4)$$

Type：Hi——Calculation of crop root zone border along the border to the direction of I sampling points as the representative of the infiltration depth, mm;
Δwi——Calculation of soil moisture content change;
Δhi——Calculating soil thickness, mm;
H_{avg}——Calculation of field crop root zone average infiltration depth, mm;
n——The number of sampling points in the long side of the border;
ΔH——The difference between the infiltration depth of the root zone and the average infiltration depth of the plot represented by i sampling points, mm;
Du——Calculation of irrigation uniformity

Statistical Analysis

Microsoft Excel 2010 was used for data processing, Origin 8.0 was used for mapping, DPS for statistical analysis, LSD method for significant test.

Results

Water Flow Speed

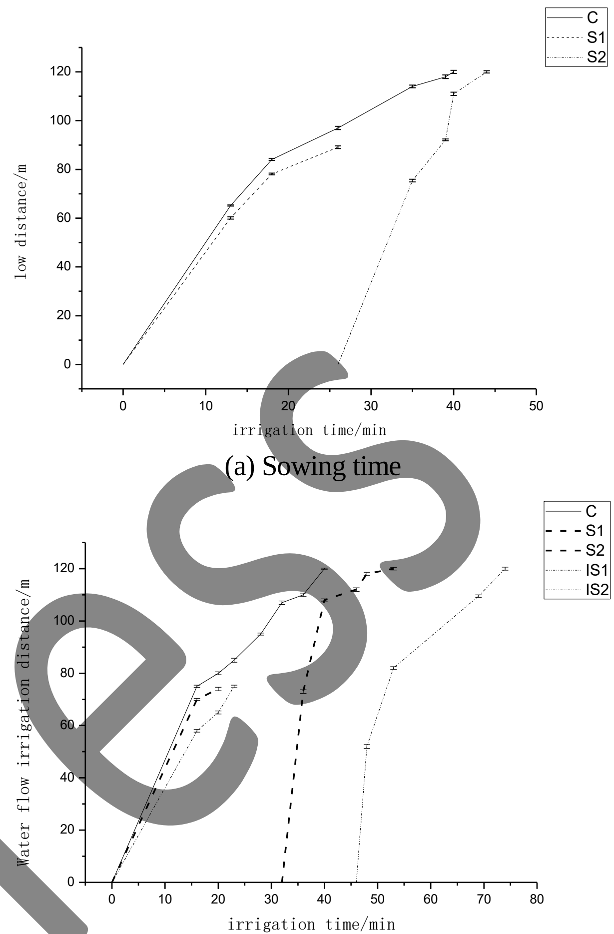
The water flow speed in different periods is shown as shown in Fig. 2. A is a comparison of two kinds of irrigation treatments for continuous irrigation (C) and ordinary surge irrigation (S). In order to avoid the effect of water deficit caused by interval irrigation on the emergence rate of wheat at sowing period, the undifferentiated surge irrigation was used during the sowing period. So in Fig. (2a), we only compare the flow speed of continuous irrigation and ordinary surge irrigation. C represents continuous irrigation treatment. S1 represents the first cycle of surge irrigation, and S2 represents second cycles of surge irrigation. From the comparison, we can conclude that the velocity of water flow in the second period of surge irrigation is faster than that of continuous irrigation.

The main reason for the rapid velocity of water flow in the second period of surge irrigation is that the flow of water on the soil surface after the first period of soil passes through the soil. The microparticle structure of the soil has been changed and the dense layer is formed, which reduces the infiltration of the water. It provides favorable conditions for the advance of water flow, thus speeding up the flow of water.

At jointing stage, the velocity of water flow is treated with the speed of water flow as shown in Fig. (2b). Due to the same irrigation parameters between fixed wave surge irrigation and intermittent alternate surge irrigation during jointing stage, the two kinds of water flow rate at the jointing stage were summed up as the interval surge irrigation (IS). So in the jointing period, three kinds of irrigation water flow speed are compared with continuous irrigation (C), wave surge irrigation (S), and interval surge irrigation (IS). It is shown from the diagram that the flow of water flow in the first and two periods of the interval of surge irrigation is obviously less than that of ordinary surge and continuous irrigation. From the total speed of water flow, the speed of intermittent surge irrigation is 1.2 times that of continuous irrigation, while that of common surge irrigation is 1.3 times that of continuous irrigation. Comparison of sowing and jointing the two maps of the same processing flow advance speed can be obtained, the jointing stage flow advance speed is slightly slower than the sowing period, this is due to the jointing stage of wheat plant height was significantly higher than that of sowing time, which increases the flow drag and weaken the flow advance speed.

Irrigation Uniformity

On the whole, the irrigation uniformity in the two diagram showed a trend of rising and decreasing after irrigation and reached the maximum at about sixth days after irrigation. The increase of irrigation evenness within two days after irrigation was faster than that in the next four days. After reaching the maximum, irrigation uniformity decreased from the sixth day. The trend decreased slowly from 6 days to 16 days, but decreased significantly from 16 days to 28 days. In short time after irrigation, the uniformity of irrigation can be improved continuously, which is the best with ordinary surge irrigation, and the continuous irrigation is the worst. The uniformity of intermittent fixed surge irrigation and interval alternate surge irrigation is lower than that of common surge irrigation. The reason is also that these two interval irrigation methods cause lateral permeability, resulting in uneven irrigation. As a result, the difference of water content between irrigation plot and non-irrigation area is relatively large. However, there is no big difference between the two intervals of alternate interval irrigation, which results in the result of AS>FS (irrigation uniformity). Irrigation uniformity is as follows: S treatment>AS treatment>FS treatment>C treatment (Fig. 3).



(a) Sowing time

(b) Jointing stage

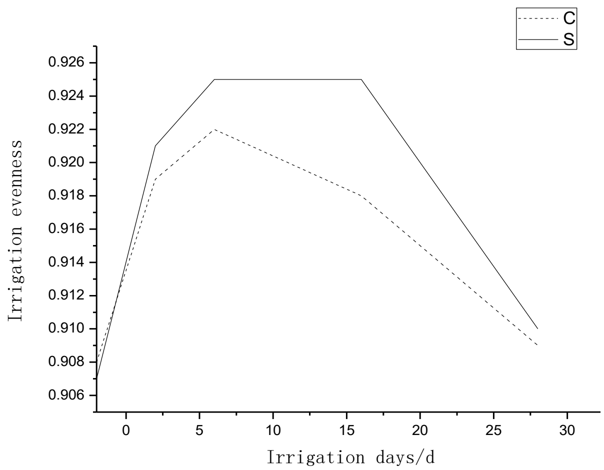
Fig. 2: The speed of water flow in different periods

Dry Weigh

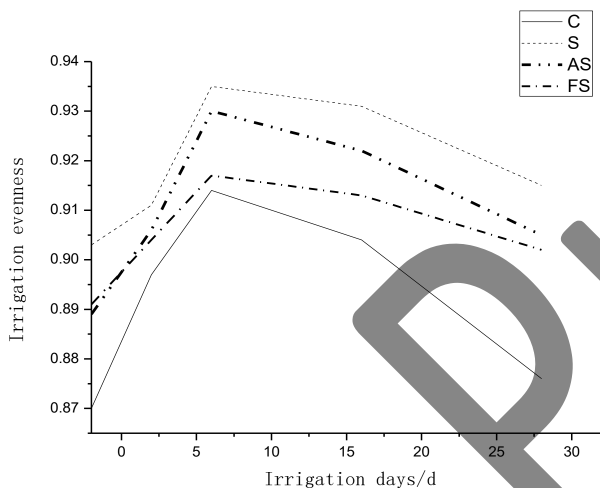
The effect of different treatments on dry matter quality of winter wheat was shown in Table 1. During the four growing periods of wheat, the dry matter quality showed a growing trend. Compared with the C treatment, the dry matter quality of S treatment increased by 55.13%, 25.92%, and 25.28%, respectively. Compared with the C treatment, the AS treatment increased by 51.45%, 19.17% and 22.29% respectively. The overall performance is that S treatment >AS treatment >FS treatment >C treatment, S and AS treatment difference is not significant (Table 1).

Community Growth Rate

The effect of different treatments on the growth rate of winter wheat was shown in Table 2. As we can see from the Table 2, the population growth rate is increased first and then decreased. Compared with C treatment, S treatment increased by 52.94%, 27.12%, and 25.71% respectively.



(a) Sowing time



(b) Jointing stage

Fig. 3: Water content uniformity of 0~100cm soil layers in different periods

Compared with C treatment, AS treatment increased by 52.94%, 20.34% and 22.86% respectively. The overall performance was S treatment >AS treatment >FS treatment >C treatment (Table 2).

Yield and Water use Efficiency

The effects of different treatments on the yield and water use efficiency of winter wheat were shown in Table 3. It is known from Table 3 that C treatment, S treatment and FS treatment are less than AS treatment in the number of spikes. However, S treatment was significantly higher than that of C, AS and FS on the number of spikes, and increased by 68.45%, 22.28%, and 33.06%, respectively. In addition, the S treatment of 1000 grain weight was less than the other three treatments. At the yield level, the AS treatment was the best, the S treatment was second, and the C treatment was the worst. Compared with C treatment, the yield of S treatment,

Table 1: Accumulation of dry matter in different treatments g

Treatment	Green stage	Jointing stage	Heading stage	Maturity of grain filling
C	1.49a	5.17c	11.84b	14.08b
S	1.18b	8.02a	14.91a	17.64a
AS	1.26b	7.83a	14.11a	17.26a
FS	1.28b	5.54b	12.05b	15.66a

Mean ± standard deviation. Values sharing same letters differ non-significantly (*P*>0.05)

Table 2: The growth rate of different treatment groups g·d

Treatment	Green stage	Jointing stage	Heading stage	Maturity of grain filling
C	0.03a	0.17b	0.59b	0.35b
S	0.02a	0.27a	0.75a	0.44a
AS	0.03a	0.26a	0.71a	0.43a
FS	0.03a	0.18b	0.60b	0.39a

Mean ± standard deviation. Values sharing same letters differ non-significantly (*P*>0.05)

Table 3: Yield and water use efficiency of Winter Wheat under different treatments

Treatment	Spike number	Number of spikes	1000 grain weight/g	yield/ (g·m^{-2})	WUE/ (g·m^{-2}·mm^{-1})
C	81.67b	27.07c	36.98a	327.01c	2.85c
S	82.67b	45.60a	24.99c	376.80a	3.84b
AS	92.00a	36.80b	28.60b	387.26a	5.55a
FS	82.33b	34.27b	30.61b	345.47b	4.95a

Mean ± standard deviation. Values sharing same letters differ non-significantly (*P*>0.05)

AS treatment and FS treatment increased by 15.23%, 18.42% and 5.64% respectively. The efficiency of irrigation water conservancy is the best for AS treatment. Compared with the C treatment, the efficiency of AS treatment, FS treatment and S treatment increased by 94.74%, 73.68% and 34.74%, respectively (Table 3).

Discussion

The water flow speed is an important index to measure the effect of irrigation. Studies have shown that the water flow speed of surge irrigation has a significant improvement over continuous irrigation, which is about 1.85 times that of continuous irrigation. In the seedling stage of the experiment, the water flow speed in the first cycle of the S treatment was not significantly different from that of the C treatment. The speed of the second cycle was significantly faster than that of the C treatment, which was 1.19 times and 2.28 times of the C treatment, respectively. Overall, the water flow speed of surging irrigation is 1.74 times that of continuous irrigation. Alternating surge irrigation and fixed surge irrigation flow rate is about 0.85 times that of surge irrigation. The slower water flow speed of fixed surge irrigation and alternating surge irrigation is affected by the lateral permeability of water.

Studies have shown that irrigation uniformity can reflect the depth of irrigation water seepage and the uniformity of soil water redistribution. In this experiment, the irrigation uniformity under the four kinds of irrigation treatment was generally represented by S treatment> AS treatment> FS treatment> C treatment (Nie *et al.*, 2016; Hai *et al.*, 2017). Studies have shown that poor uniformity in continuous irrigation is affected by water evaporation. Continuous irrigation has long irrigation time, large evaporation of soil moisture, small surface soil moisture content and large depth of water infiltration, leading to the poor irrigation uniform. This is consistent with the research results of Sun and others (Huang *et al.*, 2015; Guo *et al.*, 2017).

Studies have shown that the lack of water will inhibit the absorption of nitrogen by wheat, and nitrogen is an important part of wheat chlorophyll, and the lack of nitrogen will affect the photosynthesis of wheat, thus affecting the accumulation of dry matter in wheat (Liu *et al.*, 2012; Xia *et al.*, 2015; Song *et al.*, 2016). In this experiment, dry matter accumulation at the jointing, heading and maturing stages S and AS treatment was significantly higher than other treatments. The reason may be that the water adjustments produced by these two kinds of irrigation treatments can promote the absorption of nitrogen by wheat, thus promoting the accumulation of dry matter quality in wheat. Surge irrigation and alternating surge irrigation alternately show good adaptability to wheat field dense crops.

Water is one of the basic guarantees for high wheat yield. If excessive moisture enters the field, it cannot be absorbed and utilized by wheat. Instead, it will increase the evaporation of water, thus reducing the utilization efficiency of irrigation water. Studies have shown that, as long as the water control is reasonable, alternate furrow irrigation can achieve optimal water use through stomatal adjustment, thus reducing the luxury transpiration of crops and improving water use efficiency (Wang *et al.*, 2011). In this experiment, the yield levels of S treatment and AS treatment were not significantly different, but the water consumption of AS treatment was lower than S treatment. As a result, the water use efficiency of AS treatment was 14.13% higher than that of S treatment. This shows that the moderate water deficit caused by alternate surge irrigation increases the water use efficiency of winter wheat, which is consistent with the results of the findings. The test verified that the water use efficiency of alternating surge irrigation was higher than that of traditional surge irrigation, that is, in the case of water saving, higher yield can be obtained.

Conclusion

Alternating surge irrigation is superior to continuous irrigation, surge irrigation and fixed surge irrigation in terms of panicle number, yield and water use efficiency. Although the alternating surge irrigation is not much different from the surge irrigation at the production level, the water use efficiency is significantly higher than the surge irrigation treatment.

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