MATEC Web of Conferences **25**, 01010 (2015)
DOI: 10.1051/matecconf/20152501010

Research on the Effects of Water Stress on Growth Traits and Water Use Efficiency of Winter Wheat

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ABSTRACT: This research about the effects of water stress at different growth stages on the crop growth traits has a practical significance in guiding water-saving irrigation. The box test method is adopted to test the water stress of winter wheat at different stages, observe the plant height, leaf area and yield, and analyze the water use efficiency under the condition of water stress. The results show that the water stress in each growth period will play an inhibiting role in the plant height and leaf area of winter wheat; the water stress duration at a single stage is relatively short, and rehydration crop has a certain compensatory growth without making a big difference; the continuous water stress stage plays a significantly inhibiting role in the plant height and leaf area.; water stress has a largest effect on the plant height in the elongation period; the heading period suffers from water stress, so the leaf area decreases rapidly; water stress at a single stage in the appropriate period can increase water use efficiency. Regulated deficit irrigation can reduce luxury water consumption, which has a little effect on the yield and plays a guiding role in water saving and stable yield.

Keywords: winter wheat; growth period; water stress; plant height; leaf area; water use efficiency

1 RESEARCH BACKGROUND

Water resources shortage is a major limiting factor in the agricultural development in the arid and semi-arid areas, while short water supply is a main factor to cause crop failures [1, 2]. Drought and water shortage has become a major stress factor to restrict agricultural production. In addition to pay attention to improve the coefficients of water delivery and irrigation part, to improve the water use efficiency (WUE) is also an important part in agricultural water saving. However, China's current agricultural water use efficiency is very low [3]. The problem to be solved is how to optimize agricultural irrigation water in accordance with local water resources conditions and crop water requirements, so as to meet comprehensive requirements of water saving, stable yield and efficiency increase. The crop growth has different sensitivities to the water stress. Many scholars have researched the effects of water stress on crop yield, and in turn guided the regulated deficit irrigation. Therefore, the research on the water shortage at different growth stages on the crop growth traits has a practical significance in guiding water-saving irrigation. In the filling period and the whole growth period, China's main producing areas of wheat suffer from frequent drought disasters [4, 5], which adversely affect the growth of wheat.

The water use efficiency (WUE) of crops is a comprehensive physiological and ecological index to evaluate the suitability of plant growth. It actually reflects the relationship between the water consumption of the plant and the amount of dry matter, which refers to the amount of dry matter generated from the water consumption of the plant. One of the goals of real water-saving agriculture is to improve the water use coefficients of crops. The water use efficiency can be divided into three categories based on the difference in the scale of research object: For the leaf scale, WUE is a ratio between photosynthetic rate and transpiration rate; for the individual plant, WUE = dry matter quantity / evapotranspiration; for the plant population, WUE = dry matter quantity / water consumption. It is very difficult to measure the plant transpiration amounts and the evaporation among plants, so the authors measure the water use efficiency at each growth stage in a population scale.

Relevant scholars have researched the effects of water deficit on the growth, physiological characteristics, root system and various yield factors of winter wheat [6-9]. Drawing on past experience, the box test method is adopted in the test area to isolate the upper and lower water supply and the lateral seepage of underground water, so as to ensure the control of water content in the box. They also have researched the

Table 1. Design table of soil water content at each stage of winter wheat

Processing Number	Returning green stage	Elongation stage	Heading stage	Filling stage	Maturation stage
1	Drought	Normal	Normal	Normal	Normal
2	Normal	Drought	Normal	Normal	Normal
3	Normal	Normal	Drought	Normal	Normal
4	Normal	Normal	Normal	Drought	Normal
5	Normal	Normal	Normal	Normal	Drought
6	Normal	Drought	Drought	Normal	Normal
7	Normal	Drought	Drought	Drought	Normal
CK	Normal	Normal	Normal	Normal	Normal

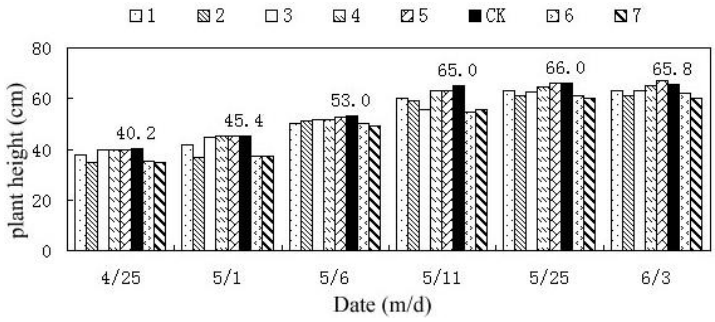

Figure 1. Changes of plant height over time

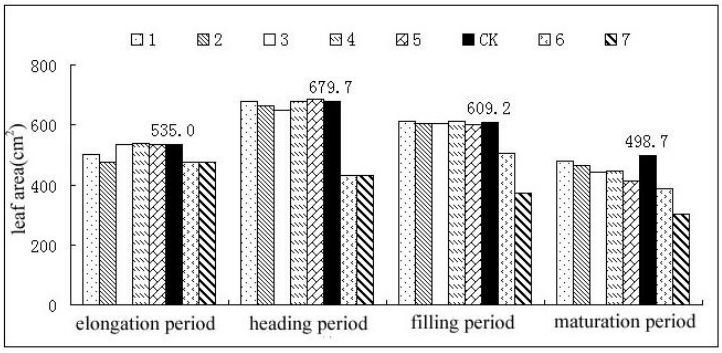

Figure 2. Changes of leaf area over the growth period

effects of water stress in different growth periods on crop growth traits, so as to provide a theoretical basis for the research on the mechanism of crop water stress.

2 MATERIALS AND METHODS

2.1 *Test material*

The variety of winter wheat selected in the test is Xiaoyan 60 with drought-enduring and saline-alkaline tolerance. The box test has been carried out in the test base of agricultural water saving research center in West Campus of Tianjin Agricultural University in 2013–2014. The soil in the test area is medium loam soil; the average dry density of the soil layer of 0–60cm is 1.42g/cm^3; the soil field capacity is in the range of 23%–25%; the wilting water level is in the range of 9%–10% (all the aforementioned is the weight water content). The test area is equipped with an activity canopy, which is closed in case of rain to prevent the effects of rainfall on the test. The previous crop in the test area is summer corn.

2.2 *Experimental treatment and methods*

The box test adopts the method of burying the plastic box into the test field, so as to prevent the effects of lateral seepage and the upper and lower water supply. The soil layer of 0–50cm concentrates 90% of the root system of winter wheat, which is a main soil layer for winter wheat to absorb and use water, so the soil depth

of 0–60cm is selected in this research. The specification of the selected plastic box is as follows: The length is 0.98 m, the width is 0.76m, and the depth is 0.67m. The top edge of the plastic box is 7cm higher than the field surface; the soil surface inside the box is equal to the soil surface of the filed, so that the soil density inside the box is consistent with that in the field. Water stress is given to five major growth periods of winter wheat (namely, period of seeding establishment, elongation period, heading period, filling period and maturation period). The soil in each test box shall be tested before sowing, and the fertilizing amount in the field is a standard fertilization. Top-dressing is done in the period of seeding establishment. This test sets up seven processes and one control study in total. Each processing is repeated for three times with a total of 24 plots. The specific water treatment scheme is shown in Table 1. ("Normal" represents the full irrigation of soil: Its lower limit is 70% of field capacity, and its upper limit is the field capacity; "drought" represents the stage of water stress: Its lower limit of soil water content is 45% of field capacity, and its upper limit is 80% of field capacity.)

2.3 *Sampling and determination method*

Non-destructive sampling is done in different growth periods. The representative 15 types of plants are selected in each box, and the plant height is measured with a ruler: Before jointing, we measure the plant height from the soil surface to the highest leaf apex of the measured plant leaf after which extends; after jointing, we measure the plant height to the basal pulvinus of the extending leaf at the uppermost; after the heading stage, we measure it to the top of panicle, excluding the awn length. Measurement of leaf area: measure the wheat leaf length and intermediate leaf width with a ruler, and then multiply both products with the coefficient of 0.8. The water consumption at this stage is calculated by the use of water balance method.

3 CONCLUSION ADN ANALYSIS

3.1 *Effects of water stress in different growth periods on plant height*

Effects of different treatments on plant height of wheat are shown in Figure 1.

As can be seen from Figure 1, the amount of growth increases with the advance of the growing process,; after the period of seeding establishment, winter wheat enters into the rapid growth stage, and the plant height constantly increases; in the filling period, the plant height no longer increases, and the height is basically stable. No matter which growth period suffers from water stress, the plant height of wheat before the maturation period is lower than the control group of normal water supply, indicating that the water stress in any growth period will inhibit the growth of winter wheat. Water stress at a single stage in different growth periods has different effects on the plant height. Water stress has a largest effect on the plant height in the elongation period, which is 6cm lower than that of the normal water supply; water stress has a least effect on the plant height in the maturation period, which is 0.8cm lower than that of the normal water supply; the stress at other stages has insignificant differences in the inhibition on the plant height. Continuous drought at these stages has a greater effect on the plant height. The longer the drought is, the greater the effect on the plant height is. The plant height in continuous drought at three stages is 8cm lower than that of the normal water supply.

3.2 *Effects of water stress in different growth periods on leaf area*

Effects of different treatments on leaf area of wheat are shown in Figure 2.

As can be seen from Figure 2, the leaf area has a rapid growth process in the jointing and heading period. The leaf area is the largest in the heading period; the leaf area decreases in the filling period; in the maturation period, the leaf area will rapidly decrease with the aging of leaf. The leaf area of drought-stricken winter wheat is different in different growth periods. The drought-stricken leaf area at a single stage with different treatments has insignificant differences when the leaf area is the largest in the heading period, mainly because of a shorter time of stress. Except that the wilting leaf area decreases during stress due to water shortage of leaf, the leaf area has insignificant differences at other non-stress stages; however, when the leaf area becomes aging in the maturation period, the leaf area of drought-stricken wheat in this period becomes aging rapidly. Continuous stress has a greater effect on the leaf area of winter wheat, and the leaf area is about 30% smaller than that of the normal supply.

3.3 *Effects of water stress in different growth periods on water use efficiency*

The water use efficiency (WUE) of crop is calculated by the Formula (1)

$$WUE=Y_a/ET_a \quad (1)$$

Where: Y_a is the actual yield under different conditions of water shortage in the growth periods (kg/hm^2);

ET_a is the actual water consumption in the whole growth periods (mm).

The actual water consumption in different treatments can be obtained by the water balance. Compared with the actual yield, the changes of water use efficiency in different treatments in the whole growth periods are shown in Table 2.

As can be seen from Table 2, the water stress in different periods leads to different water use efficiency. The water use efficiency of full irrigation is 1.17

Table 2. WUE in different treatments

Treatment No.	Total water consumption (mm)	Total yield (kg/hm^2)	Water use efficiency (kg/m^3)
1	546.80	6634.00	1.21
2	513.21	5921.62	1.15
3	501.93	5316.60	1.06
4	520.51	5401.83	1.04
5	542.71	6323.68	1.17
6	490.93	5122.25	1.04
7	430.44	4280.53	0.99
CK	583.80	6824.08	1.17

kg/m^3; the maximum water use efficiency is up to 1.21 kg/m^3 in case of water stress in the period of seeding establishment; the minimum drought-stricken water use efficiency is 1.04kg/m^3 in the filling period; the drought-stricken water use efficiency and full irrigation have insignificant differences in the elongation period and maturation period. The minimum water use efficiency in continuous water shortage at three stages is 0.99 kg/m^3. And the test results indicate the water use efficiency in water stress at a single stage in the proper period.

4 CONCLUSION

(1) Effects of different processes of water deficit in the entire growth period of crop on the plant height: Winter wheat enters into a rapid growth stage after the period of seeding establishment, and the plant height constantly increases; in the filling period, the plant height no longer increases, and the height is basically stable.

(2) The plant height and leaf area visually reflects the effects of water stress on the morphological index of crop. The stage of water stress plays a certain inhibiting role in the plant height of winter wheat; the water stress has a largest effect on the plant height in the elongation period; the water stress duration at a single stage is relatively short, so the rehydration crop has a certain compensatory growth; drought at a single stage in other growth periods has a little effect on the plant height, but continuous drought has a great effect on the plant height. The longer the drought is, the greater the effect on the plant height is. So drought at a single stage in other growth periods has a little effect on the plant height. Continuous drought at these stages has a greater effect on the plant height. The longer the drought is, the greater the effect on the plant height is. The plant height in continuous drought at three stages is 8cm lower than that under the condition of normal water supply.

(3) The leaf area has a rapid growth process in jointing and heading period, and it is the largest in this period; the leaf area decreases in the filling period; in the maturation period, the leaf area will rapidly decrease with the aging of leaf.

(4) The drought-stricken leaf area at a single stage with different treatments has insignificant differences when the leaf area is the largest in the heading period; continuous stress has a greater effect on the leaf area of winter wheat, and the leaf area is about 30% smaller than that of the normal supply, because the winter wheat starts the self-adaptation mechanism of water deficit; the luxury water consumption can be reduced by reducing the evaporation and transpiration on the leaf surface as much as possible.

(5) The water use efficiency of wheat is different in case of water stress in different periods. The water use efficiency is the largest in case of water stress in the period seeding establishment, while the water use efficiency is minimum in continuous water shortage. The test results indicate that the water stress at a single stage in the proper stage can improve the water use efficiency; the deficit irrigation is an effective way of real field water-saving, which can realize the stable yield and water saving.

ACKNOWLEDGEMENT

This paper is financially supported by the Bohai Sea Granary Technology Engineering—Tianjin Grain Yield Increase Technology Integration and Demonstration in Bohai Sea Rim Area of the Planning Subject of “The Twelfth Five-year-plan” in National Science and Technology for the Rural Development in China (No. 2013BAD05B00) and its subproject the Comprehensive Utilization Technique of Multiple Water Sources (No. 2013BAD05B08) and the Key Technologies R & D Program of Tianjin — “Unconventional Development of Agricultural Water Resources and the Safe and Efficient Irrigation Technique Research” in 2014(No. 14ZCZDNC00001).

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