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Effect of Water Logging Stress on Cotton Leaf Area Index and Yield

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Abstract

In rainy and humidity region of south China, cotton usually suffers from water logging stress in growing stage. It is of great significance to reveal the effect of water logging stress on cotton growth and yield for appraisal of agricultural disaster caused by water logging and disaster reduction. The problem of cotton suffering from waterlogged stress was studied. Analysis showed that *LAI* in the cotton bud period stage and flowering and boll-setting stage is restrained by water logging stress, which is opposite to *LAI* in the cotton boll opening stage. The degree of water logging can be described by the water logging factors such as $SFEW_{30}$. There is a significant linear relationship between the cotton relative yield R_y and the water logging factors such as $SFEW_{30}$ in different growth period, and the cotton yield under water logging condition is the most sensitive in the flowering and boll-setting stage.

Keywords: Water logging stress; Cotton; Leaf area index; Farmland drainage; Water logging factor

1. Introduction

Influenced by the subtropical monsoon climate, in south of China, the rainfall is concentrated, abundant and long-lasting during the cotton growth period. Meanwhile, the water logging stress disaster tends to form with the rainy weather, which conducts a great influence on the growth and yield of cotton. Getting a good understanding of the response mechanism of cotton to water logging stress is of great significance on drainage management, drainage facilities scientific scheduling and decision–making on disaster prevention and mitigation. In the early 1980s, Rojas [1] established the relationship between yield

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reduction and water logging stress, which regards the period of time when soil ventilation reaches 10% and water logging stress time as the total time. In this mode, both of sub-surface water logging stress prevention and surface water logging stress prevention are considered in the drainage engineering design. But the results turn out to be unpractical. A. L. Cowie[2] found that the yield of Chickpea seeds would reduce during any period when the crop is confronted with water logging stress. And the ability of crop to revive or regrow after suffering water logging stress tends to be weaker when crop grows older. Although domestic researchers in this field started late, remarkable progresses have been made both abstractly and practically. For instance, Shen Rongkai et al [3-4] put forward a theory that combines two water logging indexes together and establish the relationship between the combined indexes and crop yield. One factor in the combined index is surface water logging index based on the condition of the crop under water logging stress. The other is sub-surface water logging index based on the movement of underground water. And after that, they came up with the conception of equivalent time of water logging. Tang Guangmin[5] put forward the conception of water logging stress lasting days and the water logging weight factor as well as the solving method of the two factors. Mo Chunhua and Wu Lin[6-7] made a preliminary analysis on the influence of water logging stress on physiological parameters of cotton, such as plant height, stem thick and *LAI*. Zhu Jianqiang [8-10] studied a successive water logging process of cotton in his experimental station to find the influence of water logging stress on agronomic traits and crop yield. Then he established a drainage index mode in water logging field. This article, makes full use of the data from water logging stress experiments, analyzes regular pattern of yield and cotton response to water logging stress, and provides certain reference for planting and managing of cotton, as well as drainage engineering design, drainage operation of pumping station, and draining management of cotton field under water logging stress.

2. Materials and methods

Experiments were carried out in 22 lysimeters at Irrigation and Drainage Comprehensive Experimental Station in Wuhan University from year 2008 to 2010. There is a net area of $4m^2$ (2m×2m) with a depth of 3.0m for each lysimeter, including 0.3m of filter layer in the bottom of the lysimeter, while and the remaining 2.7m space are filled with disturbed light loam soil with the dry bulk density of $1.41g/cm^3$. The soil surface is about 0.1m away from the top of lysimeter sleeve. Cotton is the study plant, they are transplanted into every lysimeter in late May, and there are 6 plants in each lysimeter.

2.1. Study Methods

Two soil moisture conditions are considered in the present study, which are surface water logging and subsurface water logging condition. In this experiment, different water logging stress treatments were carried out in different lysimeters. All treatments to lysimeters in the year 2008 and 2009 are presented in Table 1. The 'surface' column in the table represents the lasting days where there is 10-cm surface water in relative lysimeters. And the 'subsurface' column represents the lasting days where the water table is in the depth of 20-cm from the soil surface in relative lysimeters. In the first two years of experiment, cottons in treatment 3 and 5 which are under 3 and 5 days' of water logging stress shows non-significant law in the physiological parameters so we increased the lasting time under subsurface water logging stress treatment, and the control time are also changed into 4 and 7 days in 2010.

2.2. Observation Contents

The observation content included groundwater depth, crop height, leaf area, stem diameters, dry matter weight of sample plant and cotton yield. Groundwater depth were observed every day from the starting time of water logging stress till the water table dropped blow 80cm from the soil surface. Leaf area, crop height and stem diameter were measured every 10 days during crop growing period. Leaf area was calculated by leaf's length and width which was measured using band taps. Crop height and stem diameter were measured by band tap and calipers. After each measurement, the cotton off the plots was chosen as the sample plants, whose height and stem diameter was close to some of the representative plants (plants that show the average physiological level of each treatment), and their dry matter of cotton was measured every 10 days. During the boll opening stage, seed cotton on every plot is collected for weighting the yield.

Table 1. The water logging stress conditions in the experiment of 2008 and 2009

Treatments	Bud stage		Flowering and Boll-Setting stage		Boll Opening stage	
	Surface (d)	Subsurface (d)	Surface (d)	Subsurface (d)	Surface (d)	Subsurface (d)
1	1	3	0	0	0	0
2	3	5	0	0	0	0
3	0	0	1	3	0	0
4	0	0	3	5	0	0
5	0	0	0	0	1	3
6	0	0	0	0	3	5
7	1	3	1	3	1	3
8	3	5	3	5	3	5
9	0	0	0	0	0	0

3. The affection of different level water logging stress on leaf area index

Leaf area index (*LAI*), or named as coefficient of leaf area, is referred to the ratio of gross leaf area and floor space, that is, *LAI* equals gross leaf divided by floor space.

LAI is a dynamic indicator of the growth state of treatment crop. In some extend, crop production increases with *LAI*, when *LAI* rise to some limits, the production goes down on the contrary. That is because the covering of branches and leaves reduces light in the field and it also lower the photosynthetic efficiency.

In the experiment, the *LAI* of cotton was calculated through measuring the area of leaves. And the formula is shown as follows:

$$LAI = \frac{A_0 \times N}{A} \tag{1}$$

Where *LAI* is the leaf area index of cotton planted in one measuring plot; A_0 is the representative of cotton leaf area in one measurement plot; *N* is the number of cotton planted in one measuring plot; *A* is the area of one measurement plot.

Table 2 is based on the reference treatment 9 to figure out the varied quantity of different treatment compared with to reference treatment in different growth periods.

Table 2. The variation of *LAI* in different treatment from 2008 to 2010

Treatments	Bud stage			Flowering and Boll-Setting Stage			Boll opening stage		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
1	-1.571	-0.747	-0.071						
2	-1.516	-1.277	+0.023						
3				-2.068	-0.269	-0.068			
4				-3.042	-0.091	-0.954			
5							+1.536	+1.081	-0.663
6							+2.824	+2.377	-1.070
7	-0.857	+0.234	+0.045	-0.738	-0.223	-0.544	+0.320	+0.379	+0.351
8	-2.412	-1.598	+0.023	-1.889	-0.106	-0.550	-0.632	+0.277	+0.558

'+' Represents the augment compare to reference treatment, '-' Represents reduction compare to reference treatment, and the variation of treatment 9 is zero

The *LAI* of each treatment used in table 2 is the average value of every plot which is under the same treatment. Indicated by table 2, the *LAIs* changed largely in different growth period. From the year of 2008 to 2010, the *LAI* in bud stage of treatment 1 was averagely declined 0.796 compared with the reference treatment. And the *LAI* of treatment 2 in buds stage was averagely 0.923 smaller than reference treatment. It illustrates that water logging stress in buds stage restrained the increasing of *LAI* in the same period, and the more serious water logging stress, the more obvious of restraining.

During the year from 2008 to 2010, the *LAI* in blooming period of treatment 3 was meanly 0.802 lower than that of the reference treatment, as well as treatment 4 that the *LAI* had dropped 1.362 in the same period compare to reference treatment. And it can be concluded from this phenomenon that if cotton had been waterlogged in blooming period, then the increasing of *LAI* in the same growth stage would be blocked and the measurement of damage is raised with the measurement of water logging stress.

On the contrary, from the year of 2008 to 2010, the *LAI* in open bolls stage of treatment 5 did not decline; it even increases 0.651 evenly every year. And the variation of treatment 6 was uniformed to treatment 5. This convince us that water logging stress in open bolls stage would not restraint the increasing of *LAI* but boost the growing of branches and leaves. At this time, cotton was in its fading stage, too much water would stimulate the sprout of new leaves, especially on the stem close to root where spring up a quantity of little leaves and that is the reason of the increasing of *LAI*.

Treatment 7 was under water logging stress in three growing stages. From the year of 2008 to 2010, the *LAI* in bud stage decreased 0.193 averagely than reference treatment; meanwhile it was 0.502 lower in blooming stage and 0.350 higher in bolls stage. The *LAI* of treatment 8 is 1.329 lower than the reference treatment in bud stage, 0.848 lower in blooming period and 0.068 higher in bolls stage. It is showed that the growing of leaves would be blocked in bud and blooming stage if cotton is under water logging stress in three periods. The longer cotton be waterlogged, the more serious the damage is. And the reaction in blooming stage is more sensitive.

4. The affection of different level water logging stress on amount of dry matter of cotton

From table 3 which is a gathering of relative quantity of cotton seed yield in three years from 2008 to 2010. The corresponding relative quantity of four treatments which cotton were under water logging stress in bud, blooming, bolls and all those three stages are 0.936, 0.790, 1.016, and 0.706, respectively. So, the R_{y1} of which was under water logging stress in buds stage is bigger than the R_{y1} which cotton was under water logging stress in blooming period, and the R_{y1} of which was under water logging stress in bolls stage is bigger than the R_{y1} of which was under water logging stress in blooming period, the R_{y1} of which was under water logging stress in blooming stage is bigger than the R_{y1} of which was under water logging stress in all growing period. And in the same treatment, the longer water logging stress lasted, the lower relative quantity is.

Table 3. The relative quantity of every treatment from 2008 to 2010

Treatments	Relative cotton seed yield R_{y1}				Relative cotton dry matter R_{y2}			
	2008	2009	2010	Average	2008	2009	2010	Average
1	0.735	1.088	1.107	0.936	0.691	1.015	1.133	0.906
2	0.677	1.025	0.981		0.687	0.944	0.964	
3	0.751	0.861	0.990	0.790	0.806	0.973	1.083	0.878
4	0.482	0.825	0.831		0.524	0.999	0.882	
5	1.026	1.171	0.969	1.016	0.823	1.012	1.076	0.942
6	0.880	1.027	1.024		0.644	1.001	1.095	
7	0.571	0.935	0.917	0.706	0.619	0.894	0.974	0.753
8	0.261	0.790	0.762		0.421	0.750	0.858	
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Relative quantity equals to the quantity under corresponding treatments divided by the quantity under reference treatment.

The total dry matter is referred to the weight of organic matter under condition of intensive drying. It is an important index on measuring plant's organic matter accumulation and the amount of nutrient. Figure 1 shows the relationship between cotton seed yield and total dry matter accumulation, and they have a linear relationship.

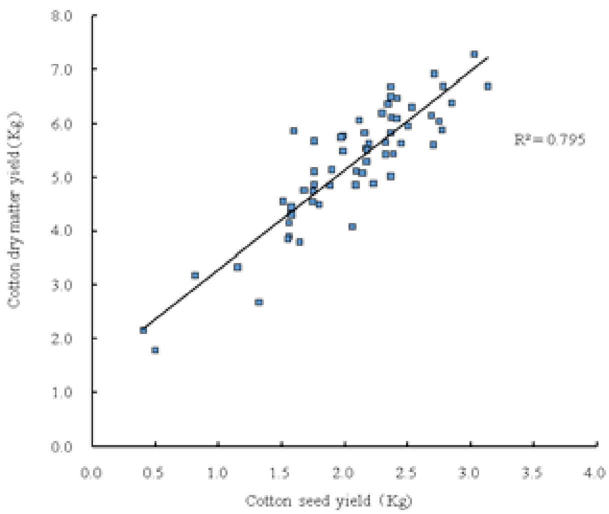

Fig. 1. Relationship between cotton seed yield and cotton dry matter yield

$$X_y = 1.843X_x + 1.429 \quad (2)$$

Where X_y and X_x referred to harvested cotton dry matter yield and the cotton seed yield, respectively.

From the year of 2008 to 2010, the rules of cotton seed yield of every treatment are corresponding to total dry matter yield basically, the higher the cotton seed yield, the more accumulation of dry matter yield. The cotton seed yield and dry matter yield of every treatment are of good linear relationship. So their responses to the same water logging stress are similar.

5. Relationship between the cotton relative yield and the water logging factors

The degree of water logging stress can be reflected by the water logging factors of Cotton. Table 3 and 4 show the test results between relative yield (R_y) and $SFEW_{30}$ under different water logging stress. According to the tables, relative yield reduces with the incensement of the $SFEW_{30}$. Relative yield reduces under water logging stress. The cotton relative yield has extremely close relationship with the comprehensive water logging factors ($SFEW_{30}$). Regression analysis of relative yield and $SFEW_{30}$ are carried out by experiment data from three successive growing seasons (2008-2010). The affection of water logging stress on the crop yield various in different growth period. So $SFEW_{30}$ in each growth period are used as influence factors in the regression analysis Fitting equations are listed in table 5 by trinomial one time regression according to the model (3).

$$R_y = 1 - \sum_{i=1}^{n} \alpha_i SFEW_{30,i} \quad (3)$$

Table 4. The comprehensive water logging stress factors under different treatments in different developmental stage from 2008 to 2010

Treatments	$SFEW_{30}$ in bud stage			$SFEW_{30}$ in flower period stage			$SFEW_{30}$ in open bolls stage		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
1	178.4	113.7	87.7	0.0	0.0	0.0	0.0	0.0	0.0
2	251.9	223.0	257.3	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	211.5	130.0	194	0.0	0.0	0.0
4	1.8	0.0	0.0	342.9	214.7	199.4	7.5	0.0	0.0
5	9.3	0.0	0.0	10.0	0.0	0.0	118.8	105.3	89.0
6	0.0	0.0	0.0	0.0	0.0	0.0	242.1	221.4	266.3
7	142.4	106.1	58.1	263.8	132.4	116.2	185.7	106.0	111.5
8	284.9	223.2	169.9	301.2	205.7	203	223.3	208.4	235.2
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

From table 5, the negative correlation between the cotton relative yield and the comprehensive water logging factors is obvious. The regression result is good. The negative correlation between the cotton relative yield and $SFEW_{30}$ is obvious in bud period and flower period stage, except for the open bolls stage. From the relationship between the cotton relative yield and $SFEW_{30}$ in different stage, the coefficient ratio in bud period, flower period stage and open bolls stage is 5:8:1. So the coefficient ratio in flower period stage is largest and the influence on relative yield is biggest. It is a better agreement with the above analysis that the yield is the most sensitive to waterlogged stress in the flower period stage.

Table 5. Relationship between the cotton relative yield and the comprehensive water logging factors in different developmental stage

Year	Relationship between the cotton relative yield and $SFEW_{30}$ in different developmental stage	Correlation coefficient R	Significant level α
2008	$R_y = 1 - 0.001359 SFEW_{30,1} - 0.001241 SFEW_{30,2} + 0.00016 SFEW_{30,3}$	0.9565	0.001
2009	$R_y = 1 - 0.0000223 SFEW_{30,1} - 0.00104 SFEW_{30,2} + 0.00022 SFEW_{30,3}$	0.7099	0.001
2010	$R_y = 1 - 0.0000589 SFEW_{30,1} - 0.00069 SFEW_{30,2} - 0.000138 SFEW_{30,3}$	0.6401	0.01
2008-2010	$R_y = 1 - 0.000592 SFEW_{30,1} - 0.001082 SFEW_{30,2} - 0.00013 SFEW_{30,3}$	0.7944	0.001

The comparison between relative yield calculated by fitting equation from 2008 to 2010 and relative yield measured is shown in figure 2.

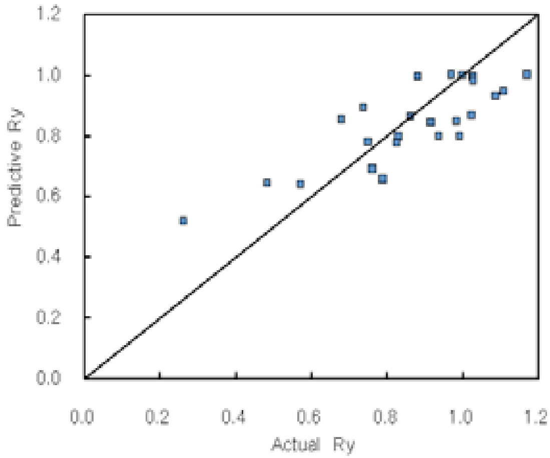

Fig. 2. Relationship between measured and calculated relative yield

According to figure 2, relative yield measured and calculated distributes over two sides of line with the slope 45°. It shows that measured relative yield is quite closely related to calculated relative yield and the difference is little. So the predicted relative yield of the model is reasonable.

6. Conclusion

1. Cotton leaf area index is sensitive to water logging stress in bud stage and flowering and boll-setting stage, and it is restrained by water logging stress in every stages, the inhibited effect of water logging stress is especially significant in flowering and boll-setting stage. The inhibition to *LAI* is more obvious with the aggravation of water logging stress. Water logging stress in open bolls stage improves growth of the softwood, and increases cotton leaf area. But it still inhibits dry matter accumulation and crop yield.

2. The most sensitive stage that cotton seed yield responses to water logging stress is the flowering and boll-setting period stage. The positive correlation between dry matter accumulation and cotton seed yield is good.

3. The negative correlation between the cotton relative yield and $SFEW_{30}$ is obvious in bud stage and flowering and boll-setting stage, except for boll opening stage. The coefficient ratio in bud stage, flowering and boll-setting stage and boll opening stage is 5:8:1. The coefficient ratio in flowering and

boll-setting stage is largest and the influence of water logging stress in this stage on relative yield is the biggest.

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