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Effects of Fertilization on Growth and Yield of Cotton after Surface Waterlogging Elimination

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Abstract: In the regions vulnerable to surface and subsurface waterlogging, the stage of cotton bud and boll stage set is just in rainy season. Cotton often meets comprehensive stress from surface and subsurface waterlogging. waterlogging during this stage inhibits cotton development and reduces final yield significantly. The objective of this investigation was to evaluate the effects of fertilization after waterlogging elimination on the SPAD value, chlorophyll fluorescence parameter and yield under a short-term waterlogging. Test-pit experiments were conducted with two waterlogging level, namely 4 and 9 days and 4 days waterlogging treatment set 3 level of fertilization, 9 days waterloging treatment set 4 level of fertilization. The results showed that: 1) The SPAD value decreased significantly under the waterlogging and decreased to the lowest value 7 days later. Then, the SPAD value increased significantly after fertilization regulation, the treatment of 4 day waterlogging required more than 20% fertilizer and the treatment of 9 days waterlogging required more than 30% fertilizer. 2) The minimum fluorescence (*Fo*) was increased under the waterlogging, while potential photochemical efficiency of PS||(*Fv*/*Fo*) and the maximum photochemical efficiency of open photosystem(*Fv*/*Fm*) was reduced under the waterlogging, the increased degree of Fo and the reduced degree of *Fv*/*Fo* and *Fv*/*Fm* were enhanced with the increase of waterlogging degree. 3) The hot summer bolls, autumn bolls and the unginned cotton yield decreased significantly under the waterlogging, fertilizer after the waterlogging elimination could raise the unginned cotton yield, there was a significant correlation between the Relative yield (*Ry*) and the duration of surface waterlogging (*Tw*), the duration of subsurface waterlogging (*Tg*) and proportion of Fertilizer (*Fb*), which could represent by the linear relationship.

Keywords: Bud and boll stage, chlorophyll fluorescence parameter, cotton, fertilization regulation, SPAD value, waterlogging

INTRODUCTION

Under the influence of subtropical monsoon climate, there is usually more precipitation in Four-Lake Watershed in Jianghan Plain in summer, easily causing waterlogging disaster in farmland. A research showed that flooding usually inhibits the growth of plant roots, which results in growth reduction of entire plant, unripe fruit abscission, eventually leading to crop yield reduction (Vartapetian and Jackson, 1997). Cotton is known to be poorly adapted to waterlogging (Hodgson and Chan, 1982) which is considered to be one of the major problems in global production (Gillham *et al*., 1995). He root system does not develop functional aerenchyma and endogenous levels of alcohol dehydrogenase, associated with anaerobic metabolism, are low (Dennis *et al*., 1992). There are also many reports about the effects of waterlogging on cotton at home and abroad. Researchers established relevant models, on the basis of which related drainage control index and drainage patterns were proposed (Bange *et al*., 2004; Zhu *et al*., 2003a, b, 2007). But there are few researches on what effective remedial measures should be taken after cotton meets waterlogged stress. This study employed test-pit experiments to create waterlogging environment, adopt remedial measures of timely fertilization after the waterlogging and observe apparent morphological feature and changes of physiological responses of cotton in the process of waterlogged stress and after the timely fertilization to find out the regulation about dressing on growth and yield of cotton after the waterlogging and explore effective remedial measures after cotton suffering from waterlogging.

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MATERIALS AND METHODS

Test facilities: The experiment was conducted in year 2010 at the Irrigation and Drainage Experimental Station of the Four Lake Engineering Management Bureau, Jingzhou, Hubei Province and P.R. China. Which is located in the middle reaches of the Four-lake Watershed, the right bank of main channel of the Four-lake Watershed and the elevation is 29.1-29.8 m which belongs to flat land close to lakes on the micro-landforms. The concrete pits (20×1.5 m) with bottom can provide water supply and drainage freely. Soil is considered to be medium loam, the pH value is 7.6, the field water-holding rate is 26.8%. The arable layer soil contains 69.4 mg/kg available N, 28.7 mg/kg Olsen-P, 118.7 mg/kg available K. The soil thickness was 100 cm), 30 cm sand filter material was lay at the bottom of the pit. Each pit is equipped with a water providing and controlling device (Fig. 1), which can freely control the water level through the gear drive.

Experimental design: Cotton cultivar in the experiment is hybrid cotton E9, which was transplanted on May 22, with 50 cm spacing between plants and 100 cm spacing between rows. The experiment of fertilization after cotton suffering from waterlogging was made in the bud and boll stage and designed according to completely random block.

During cotton plants under waterlogging in bud and boll stage, 5-10 cm of inundated depth was kept, the duration of cotton underwent waterlogging (*Tw*) is 4 and 9 days separately, after waterlogging elimination the groundwater table decline to 70 cm from soil surface within 7 days. The crop under waterlogging started on June 30, 2011.

After Waterlogging elimination, different dosages of fertilization were used for crop nutrient supplement so as to boost crop recovery from waterlogging adversity quickly. Bases on the dosage recommended by Zhou (2004), an adoptable bench mark for cotton fertilization is that 300 kg/hm^2 of N, 108 kg/hm^2 of P_2O_5 and 255 kg/hm^2 of K_2O during the whole growth period of cotton.

In our experiment, base fertilizer consists of the total phosphate fertilizer, 30 N and 25%, respectively K_2O necessary for cotton in whole growth period. The topdressing usually was added at cotton blossoming and boll-forming stage, which normal dosage is pure N of 210 kg/hm^2, pure K_2O of 191.25 kg/hm^2. The normal dosage (100% Q) of the topdressing regarded as a reference, fertilization after waterlogging formed different treatment shown in Table 1. In the use of fertilizer, the potassium fertilizer was applied once only on the fifth day after waterlogging; the nitrogen fertilizer was applied in twice, the first time was in the fifth day after waterlogging, the second time was in the middle of July, the nitrogen ratio both them was 1:3.

Observation and analysis: Selected five strains of cotton that have the same rates of the growth in the process of experiment, to determinate the SPAD value and chlorophyll fluorescence parameter of inverse four leaf (Luo *et al*., 2009). The SPAD readings were taken with a chlorophyll meter (SPAD-502, Minolta, Japan),

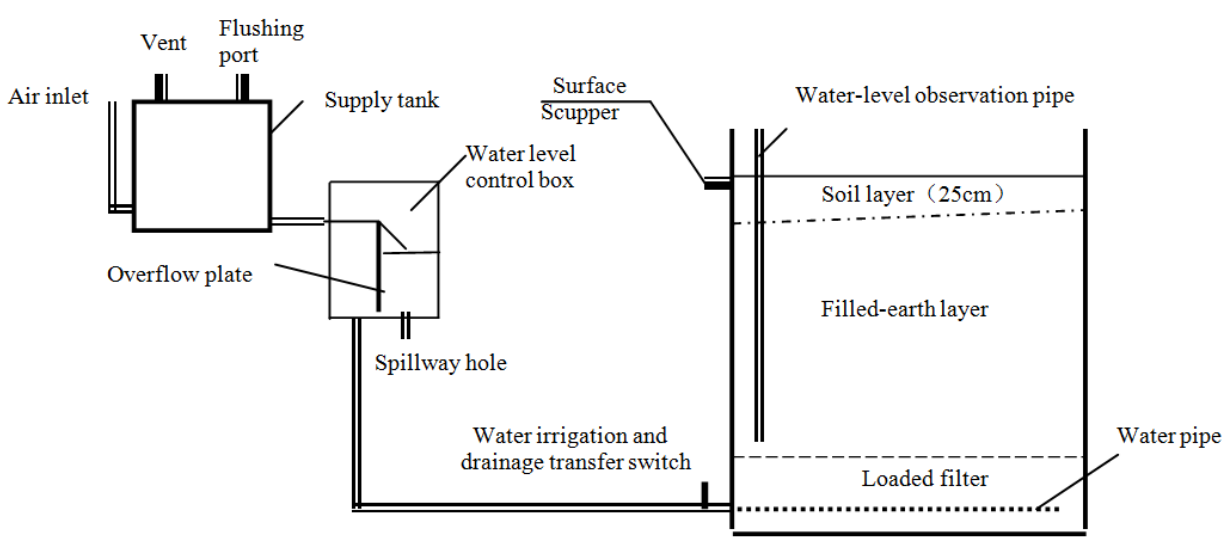

Fig. 1: Sketch of experimental facilities

Table 1: Experimental treatment

Treatment	Waterlogging duration (day)	Fertilization after waterlogging
CK	0	——
T1	4	100% Q
T2	4	120% Q
T3	4	140% Q
T4	9	100% Q
T5	9	115% Q
T6	9	130% Q
T7	9	145% Q

each individual leaf monitor 5 points (take 1 point from the Central lobe of palm leaves of cotton), then the average 5 readings was recorded to represent the SPAD value of a monitoring leaf (R_C). The chlorophyll fluorescence parameter was measured on the same leaves for SPAD value measurement with the chlorophyll fluorometer (OS-30P, OPTI-SCIENCES, USA). The minimal and maximum chlorophyll fluorescence (*Fo* and *Fm*) were determined after full dark-adaptation for 30 min. The potential photochemical efficiency of PS||(*Fv*/*Fo*) and the maximum photochemical efficiency of open photosystem (*Fv*/*Fm*) were calculated according to the method of Li *et al*. (2007). Investigate the pre-hot summer bolls, hot summer bolls and autumn bolls, respectively on July 15th, August 15th and September 15th, the raw cotton collected from each test-pits with multi-harvested was kept to calculate final yield.

RESULTS AND DISCUSSION

The SPAD value dynamic change: The influence of fertilization after water logging on cotton plants recovery is obvious (Table 2). It is easy to get some cognition from Table 2:

- Compared with CK, SPAD value of the plants had a significant declination as cotton plants under water logged stress for 3 days. SPAD value was reduced to minimum if the duration of the waterlogging reached to 7 days and it did not change obviously under continuous waterlogging. The study showed that cotton may be sensitive to waterlogging which happened in early stage to some degree, while it would slowly adapted to waterlogged environment as the duration of waterlogging.
- The SPAD between water logged 4 days and waterlogged 9 days got to significant level when waterlogged 7 days, that showed the heavier the waterlogging is, the harder the chlorophyll synthesis is. Until later experiment, they had a decreasing trend in it; especially waterlogged 9 days with two additional fertilizer of 130 and 140% had no significant differences in comparison with water logged 4 days with 100%, which showed that the cotton would recover the function of chlorophyll synthesis slowly after the after the waterlogging elimination and synthesis speed would be improved by adding fertilizer.
- It had no significant differences in SPAD as water logged 4 days with two additional fertilizers of 12 and 140% until waterlogged 20 days, but got to significant level comparison of 100%; while waterlogged 9 days with two additional fertilizers levels of 130 and 145% had no significant differences, while arrived to significant level comparison of 100 and 115%.

Table 2: Multiple comparison of SPAD value under the influence of water and fertilizer regulation

Treatment	3 days	7 days	10 days	15 days	20 days
CK	42.3±0.72 a	42.1±0.88 a	42.3±0.76 a	42.7±0.69 a	42.3±1.05 a
T1	35.7±0.90 b	32.2±0.64 b	33.5±0.71 b	34.2±0.55 c	35.2±0.85 c
T2	35.8±1.18 b	31.8±0.73 b	32.8±0.99 b	34.5±0.79 c	36.7±0.47 b
T3	35.9±1.25 b	32.1±1.29 b	32.7±1.27 b	35.9±0.74 b	37.0±0.71 b
T4	36.6±0.91 b	30.0±1.15 c	31.8±0.99 c	32.6±1.08 d	33.5±0.93 e
T5	36.4±1.22 b	30.5±0.93 c	31.9±0.91 c	33.2±0.75 d	34.2±0.56 d
T6	36.3±1.00 b	30.1±0.97 c	31.3±0.94 c	33.9±0.62 c	35.2±1.08 c
T7	36.5±1.24 b	30.5±1.04 c	31.6±0.92 c	34.5±0.96 c	35.9±0.51 c

Table 3: The total boll number and unginned cotton yield of each treatment

	The total boll number				
Treatment	Number of boll-bearing in pre-hot summer	Number of boll-bearing in hot summer	Number of boll-bearing in autumn	Unginned cotton yield in 3m^2 (g)	R_y (%)
CK	1.6±0.2 a	25.9±1.6 a	49.8±0.5 a	1153.3±9.0 a	100.0
T1	2.4±0.6 a	14.7±1.9 bc	22.4±3.4 de	873.1±9.3 f	72.7
T2	3.1±1.2 a	14.5±0.8 bc	27.9±1.7 bc	966.3±4.7 d	80.4
T3	2.1±0.8 a	17.4±3.2 b	29.0±4.9 b	1080.0±6.0 b	89.9
T4	2.4±0.4 a	9.4±0.90 d	17.9±0.6 e	836.7±7.3 g	69.6
T5	1.6±0.2 a	11.9±2.2 cd	20.8±3.5 de	881.7±4.1 f	73.4
T6	2.8±1.1 a	12.6±1.3 cd	20.8±1.6 de	956.1±6.3 e	79.6
T7	2.2±1.4 a	13.5±1.4 c	24.0±2.6 cd	994.8±3.1 c	82.8

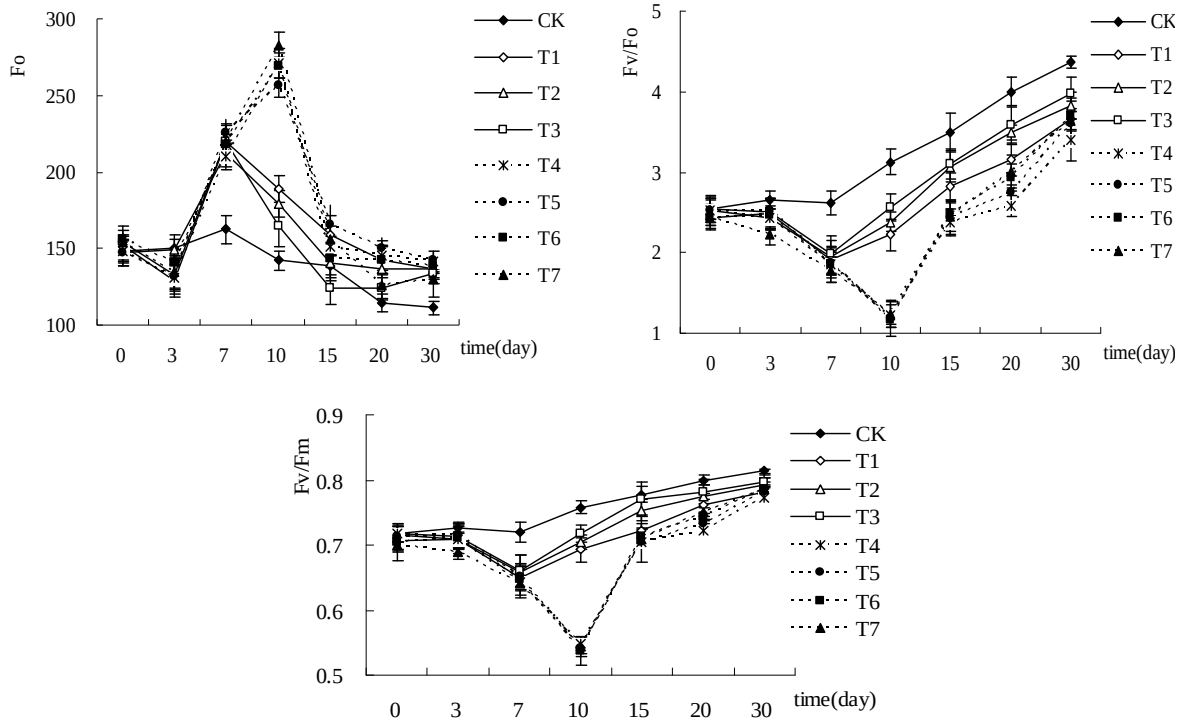

Fig. 2: Change in *Fo*, *Fv*/*Fo* and *Fv*/*Fm* of each treatment

That showed that more than 20% fertilizer should be applied if the duration was 4 days at buds-bolls stage and more than 30% fertilizer if the duration reached 9 days.

Dynamic change of fluorescence kinetics index: The minimum fluorescence (*Fo*) indicates that PSⅡ reaction center is completely open, namely fluorescence level of the original electron Acceptors (QA) when all oxidize, The increase of which reversible or irreversible inactivation may occur in the PS II reaction center of plant leaf, also the plant thylakoid membrane may injure and the more *Fo* increase, the more serious the extent of the damage on the thylakoid membrane will be Schnettger *et al.* (1994) and Pastenes and Horton (1996). In the light of Fig. 2, *Fo* which encounter waterlogging stress treatments constantly rise, *Fo* reaches the maximum value seven days later in the treatment of waterlogged 4 days; and reaches the maximum value ten days later in the treatment of waterlogged 9 days, the heavier the degree of Waterlogging is ,the more *Fo* will increase. With the end of Waterlogging stress and timely fertilization, *Fo* of each treatment continuously decline and there is no significant differences on the 30th day.

Fv/*Fo* represents a potential activity of PSII reaction center; *Fv*/*Fm* represents maximum photochemical efficiency of PSII (Maxwell and Johnson, 2000). As can be seen from Fig. 2, *Fv*/*Fo*, *Fv*/*Fm* which encounter waterlogging stress treatment constantly decline, *Fv*/*Fo*, *Fv*/*Fm* reaches the minimum value 7 days later in the treatment of waterlogged 4 days and reaches the minimum value 10 days later in the treatment of waterlogged 9 days, the heavier the degree of Waterlogging is, the more *Fv*/*Fo*, *Fv*/*Fm* will decline. With the end of Waterlogging stress and timely fertilization, *Fv*/*Fo*, *Fv*/*Fm* of each treatment continuously increases and there are no significant differences on the 30th day.

The total boll number and unginned cotton yield: Table 3 gives about the total boll number and unginned cotton yield research results. From Table 3, some cognition can be gained, that were analyzed as follows:

- There is no difference in bolls among all treatments in the pre-hot summer, each plant has 2.3 bolls on average, accounting for little of overall proportion; while there are some differences in hot summer bolls and autumn bolls, because of the Waterlogging stress, which is definitely below the normal condition, for example, the handling that was water logged for 4 and 9 days without fertilization, of which the hot summer bolls amount is 14.7 and 9.4, respectively, only accounting for 56.8 and 36.3%. The handling that was

waterlogged for 4 and 9 days without fertilization, of which the autumn bolls amount is 22.4 and 17.9, respectively, only accounting for 45.0 and 35.9%. The above shows that the heavier the cotton was water logged during bud and boll stage, the more the hot summer bolls and autumn bolls will reduce.

- Waterlogging stress occurred during bud and boll stage, which will lead to unginned cotton yield reduction largely. The reduction will be 27.3 and 30.4%, respectively for cotton under waterlogged stress for 4 and 9 days, respectively. While timely fertilization is provided after waterlogging, the unginned cotton yield will increase largely, moreover, the large proportion of fertilization is added, the higher the ultimate yield is obtained, but none can reach the standard level, which show that timely fertilization after waterlogging can only ease but not eliminate the adverse influence that water logged stress has on cotton to some extent.

Further analysis showed that R_y and T_w, T_g, F_b have significant correlation, which could be represented by a linear relationship as follow:

$$R_y = -1.19T_w - 3.101T_g + 35.714F_b + 64.28$$
$$(R = 0.993>R0.01)$$

CONCLUSION

Through experimental study and analysis, the following conclusions can be gained:

- Compared with controls, the SPAD value of the cotton under the waterlogging stress was decreased significantly and the function of chlorophyll synthesis was hindered. Statistical analysis showed that the SPAD value was reduced to minimum if the duration of the waterlogging reached to 7 days, which was consistent with the research of Guo *et al*. (2010). After the waterlogging elimination, SPAD value significantly increased with the increase of fertilizer. more than 20% fertilizer should be applied if the duration was 4 days at buds-bolls stage and more than 30% fertilizer if the duration reached 9 days, which showed that the activity of root was not deactivated completely after the stress, moreover it could still absorb the partial nitrogen nutrition from the fertilizers and then transport to leaves used for chlorophyll synthesis. The SPAD value had significantly positive correlation with the total nitrogen content, therefore, we could use the SPAD value to predict the nitrogen content and nitrogen nutrition status (Qu *et al*., 2007; Wang *et al*., 2006). We could get the primary conclusions of the research that there existed the possibility of the nitrogen deficiency in the waterlogging and fertilizer application after the waterlogging elimination was the effective remedial measures. However, the concrete relationship between the SPAD value and the total nitrogen content was not studied after the waterlogging elimination yet and the specific fertilizing quantity was not certain, all of which needed to be researched thoroughly.
- The *Fo* was increased and the *Fv*/*Fo*, *Fv*/*Fm* were reduced under the waterlogging. The increased degree of *Fo* and the reduced degree of *Fv*/*Fo* and *Fv*/*Fm* were enhanced with the increase of waterlogging degree, which showed that the reaction center of PSII in leaves would be reversibly deactivated and the potential reaction center would be damaged because of the Waterlogging. Moreover, the thylakoid membrane would be injured and the photosynthetic primary reaction would be inhibited and the injury would be more serious with the stress degree. Applying additional fertilizer in time after the waterlogging elimination could renewably restore the partial activity of the PSII and increase the light energy conversion efficiency.
- The number of hot summer bolls and autumn bolls were decreased significantly and the unginned cotton yield was remarkably reduced. Fertilization after the waterlogging could raise the unginned cotton yield, there was a significant correlation between the Relative yield (R_y) and the duration of surface waterlogging (T_w), the duration of subsurface waterlogging (T_g) and proportion of fertilizer (F_b), which could represent by the linear relationship:

$$R = -1.109T_w - 3.101T_g + 35.714F_b + 64.286$$
$$(R = 0.993>R_{0.01})$$

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