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The effects of short-term waterlogging on the lint yield and yield components of cotton with respect to boll position

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ABSTRACT

The objectives of this study were to determine the influence of waterlogging on the lint yield and yield components, biomass accumulation and distribution in the cotton boll with respect to boll position. Cottons were subjected to waterlogging 66 days after the seedlings were transplanted into ponds created by maintaining 1–2 cm of water on the soil surface for 0, 3, 6, 9 or 12 d. The ponds were then drained to allow recovery. The tap root and main stem biomass were significantly reduced and the plant biomass decreased resulting from decreased biomass in fruiting branch 1–8 (FB$_{1–8}$) after waterlogging. The vegetative and reproductive biomass of FB$_{9–16}$ increased by altered fruiting dynamics resulted from previous waterlogging, and the highest biomass was measured in 6 days of waterlogging (WL$_6$). Waterlogging of 3, 6, 9 and 12 d resulted in a 16.0%, 24.1%, 39.5% and 50.2% reduction in lint yield, due to decreased boll number. Altered fruiting dynamics after waterlogging increased the contribution of bolls at position 3 on FB$_{9–16}$ to the total yield due to an increase in boll number. The proportion of the boll wall and the seed biomass increased, while the proportion of the fiber biomass and the fiber/seed ratio decreased progressively with waterlogging duration. Insufficient assimilates were preferred compensation in boll number to boll biomass. These findings demonstrate that the bolls at various positions differed in their response to waterlogging and that even short periods (3 d) of waterlogging can have considerable long-term effects on the growth of cotton.

1. Introduction

Waterlogging is a major abiotic stress that severely constrains crop growth and productivity in many regions (Ahsan et al., 2007; Jackson and Colmer, 2005). During waterlogging, O$_2$ in the soil is rapidly depleted, resulting in hypoxic or anoxic conditions within a few hours. This results in a severe decrease in the energy status of the root cells, affecting important metabolic processes of plants (Sairam et al., 2009). Cotton (*Gossypium hirsutum* L.) is an important economic crop with poor adaptation to waterlogging (Hodgson and Chan, 1982). Waterlogging is considered to be a major problem in global cotton production (Gillham et al., 1995). Waterlogging occurs frequently in the Yangtze River Valley in China, especially during the flowering and boll formation stages (Yang et al., 2012), and can greatly influence the growth and yield of cotton (Bange et al., 2004; Hodgson and Chan, 1982).

Previous researches demonstrated that waterlogging can reduce cotton yield by 10% (Bange et al., 2004) to 40% (Hodgson, 1982). Field experiments with waterlogged cotton (>16 h) reported reductions in lint yield resulting from a decrease in boll number (Bange et al., 2004; Hodgson, 1982; Hodgson and Chan, 1982). The decreased boll number under waterlogged occurred mainly in response to a decreased overall growth (i.e., height, nodes, leaf area) and lower radiation use efficiency (Bange et al., 2004). In addition, waterlogging can cause significant reductions in cotton stem elongation, shoot mass, root mass and leaf number (Christianson et al., 2010) and can alter the foliar nutrient concentrations (Conaty et al., 2008). Waterlogging has been observed to promote fruit shedding because of inadequate aeration of the roots (Longnecker and Erie, 1968). Studies on cotton revealed that waterlogging significantly decreased the photosynthetic rate (Conaty et al., 2008; Meyer et al., 1987). Milroy and Bange (2013) observed that the radiation use efficiency (RUE) did not recover from a single large waterlogging event early in cotton development and remained low for the rest

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Abbreviations: CV(%), coefficient of variation; DPA (d), days post anthesis; FB, fruiting branch; MDT (°C), mean daily temperature; MDTmin (°C), mean daily minimum temperature; MDTmax (°C), mean daily maximum temperature; *Pn*, net photosynthetic rate; RSWC (%), relative soil water content; WL, waterlogging.

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of the season. However, the response of the lamina net photosynthetic rate (*Pn*) to repeated waterlogging suggested some degree of acclimation.

The indeterminate growth habits of cotton result in the formation of bolls on different fruiting branches at different times and under different environmental conditions and therefore different rates of growth and development (Bondada and Oosterhuis, 2001). Previous reports indicated that fruiting position 1 (the first sympodial position closest to the main stem) contributed more to the total cotton yield than other fruiting positions on the same sympodial branch (Boquet and Moser, 2003; Heitholt, 1993; Jenkins et al., 1990; Pettigrew, 2004). However, in the Yangtze River Valley of China, where high seed cotton yields (7657 kg ha^{-1}) were measured, the boll retention rate on the distal sites (i.e., fruiting position 3 and higher) was as high as 58.8% (Gu et al., 2010). Thus, the high boll retention rate of the distal fruiting positions may be key to improving the fiber yield of cotton under conditions of high yield potential.

Because cotton is an indeterminate crop, bolls on different fruiting branches and positions exist at different stages of development. Therefore, should waterlogging occur during flowering or boll development, the indeterminate growth of cotton may result in differences in the response to waterlogging. Many previous studies have focused on the effects of waterlogging on the yield of the entire cotton plant. There is no information available on the effects of waterlogging on cotton yield or yield components with respect to boll position. Therefore, the objectives of this study were to determine the influence of waterlogging on the lint yield and yield components, biomass accumulation and distribution in the cotton bolls with respect to boll position.

2. Materials and methods

2.1. Plant materials and growth conditions

Cotton (*G. hirsutum* L.) (cv. Siza 3) seeds were sowed on 8 April 2011 and 2012 at the experimental station of Nanjing Agricultural University in Nanjing (32°02′N and 118°50′E), Jiangsu Province, China. Individual healthy and uniform seedlings with three true leaves were transplanted into 4-m-long, 4-m-wide and 1.5-m-high ponds on 10 May. The ponds were covered with a transparent waterproof film above the crop canopy to exclude the effects of rainfall during waterlogging. Each pond contained five rows of seedlings; the row and plant spacing was 75 × 25 cm.

2.2. Experimental design and treatments

The experiment consisted of five waterlogging treatments (i.e., 0, 3, 6, 9 and 12 days of waterlogging) with three replicates laid out in a randomized complete block design. The irrigation of the experimental ponds was controlled manually and was determined using the relative soil water content (RSWC) method outlined by Weatherley (1950). The plants were well-watered before and after the waterlogging event, and the soil water content was maintained between 70% of field capacity (the lower soil water limit) and 80% of field capacity (the upper soil water limit).

Five soil water treatments were established on 15 July, 66 days after transplanting the seedlings into the ponds before the plants had cut-out. Hence, the plants were still actively growing and producing new flowers while boll development was occurring at the lower nodes. The groups consisted of a well-watered control (WL_0) with RSWC maintained at 70–80% of field capacity and four soil waterlogging treatments comprised of waterlogging for 3, 6, 9 and 12 d (i.e., WL_3, WL_6, WL_9 and WL_{12}, respectively). Waterlogging was achieved by maintaining a 1–2 cm water layer on the soil surface until the evening of the 3rd, 6th, 9th and 12th day, when the water was removed by draining the ponds.

The soil surface temperature was measured using a thermometer at noon before the waterlogging treatments were imposed and on the day the waterlogging was terminated. Three thermometers were installed in each pond at a soil depth of 5–10 cm located i) adjacent to a row of plants, ii) in the middle of two rows of plants, and iii) between positions i) and ii). At the same time and positions, the soil oxidation–reduction potential (Eh) was measured using a combined platinum–calomel electrode (FJA-4; Nanjing Zhuandi Instrument Cor.-Ltd., Nanjing, China).

2.3. Morphological indices

The bolls were mapped by fruiting branch and position. The first sympodial position closest to the main stem was designated as fruiting position 1, and successive boll positions were designated as fruiting position 2 and fruiting position 3. The bolls with position numbers higher than three were classified as fruiting position 3. The plant height, number of fruiting branches, number of fruiting positions and number of bolls were determined on eight plants per pond every 7 days from the initiation of squaring to boll opening. The rate of boll shedding was also calculated for these eight plants.

2.4. Lint yield, yield components, biomass accumulation and distribution

Measurements related to yield and biomass were conducted on the same day across the waterlogging treatments at maturity, and thus, a different number of days following the termination of waterlogging occurred in different treatments and different fruiting branches. In addition, measurements were all taken after the waterlogging event had been terminated, and thus, the plants may have been able to recover from the waterlogging event.

Eight mature plants from each pond were slowly uprooted, and the taproot and large lateral roots were retained. Next, the plants were separated into the root, main stem, vegetative organs (leaves, petioles and branches) and reproductive organs (squares, flowers and bolls). The vegetative and reproductive organs were classified according to the fruiting branches (i.e., $FB_{1\text{-}4}$, $FB_{5\text{–}8}$, $FB_{9\text{–}12}$ and $FB_{13\text{–}16}$). The samples were placed in an electric fan-assisted oven at 105 °C for 30 min and then dried to a constant mass at 80 °C before being weighed.

The lint yield of $FB_{1\text{–}4}$, $FB_{5\text{–}8}$, $FB_{9\text{–}12}$ and $FB_{13\text{–}16}$ was determined using data obtained from the biomass harvest above and boll number from each corresponding fruiting branch. All indices were determined on eight representative plants of each replicate. The lint yield (g m^{-2}) was calculated as the total lint biomass in one square meter.

Using the same plants, tagged cotton bolls on $FB_{2\text{–}3}$, $FB_{6\text{–}7}$, $FB_{10\text{–}11}$ and $FB_{14\text{–}15}$ were hand-harvested according to the fruiting branch and position and were separated into boll walls, seed and fiber. The boll walls and seed were placed in an electric fan-assisted oven at 105 °C for 30 min and were dried at 70 °C to a constant mass before weighing. The fiber was dried at 50 °C to a constant mass before weighing. The total biomass and the proportion of the boll walls, seed and fiber at different fruiting branches and positions were calculated. The fiber and seed biomass were measured to calculate the lint percentage.

2.5. Weather data

The mean daily temperature (MDT), mean daily maximum temperature (MDTmax), mean daily minimum temperature (MDTmin) and the day degrees from May to October during the two growing seasons were collected from a local weather station adjacent to the