COTTON GROWTH AND PHYSIOLOGICAL RESPONSES TO BORON DEFICIENCY

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Abstract

The experiment was conducted in a growth chamber to characterize cotton plant growth and select physiological characteristics during development of boron deficiency at the early growth stage prior to squaring. When B deficiency symptom consisting of dark bands on the petioles were first detected from boron deficient (–B) plants 4 weeks after B removal, the growth and physiology had already been affected significantly. Boron deficiency during the early growth of cotton increased leaf chlorophyll content and cell membrane leakage, decreased leaf stomatal conductance and net photosynthetic rate, and depressed plant growth and dry matter accumulation, resulting in increased fruit abscission and a change in dry matter partitioning after squaring. Therefore, in boron deficient areas, soil or foliar application of boron may improve cotton plant growth and lint yield.

Introduction

Boron (B) has long been known as an essential micro nutrient element required for optimal growth and development of cotton (*Gossypium hirsutum* L.) plants. Boron deficiency is common in highly leached and acidic sandy soils of cotton growing regions in the world. Boron is important in pollen germination and pollen tube growth resulting in successful fruit setting. Therefore, B deficiency during flowering and fruiting may significantly reduce boll retention, resulting in a low yield and poor fiber quality. However, little is known about the effect of B deficiency during the early growth of cotton seedlings prior to squaring on subsequent plant growth and physiology of the plant.

Reports of cotton yield response to soil or foliar application of boron have been inconsistent. Howard et al. (1998) and Woody et al. (1969) reported that soil- or foliar-B application increased yield. In contrast, some studies have shown no positive or negative effect on cotton yield from supplemental B (Heitholt, 1994a, b). These contrasting results may be associated with soil texture, soil pH, soil fertility, or soil B level. The objectives of our study were to determine the effects of B deficiency during early growth on leaf photosynthesis, nonstructural carbohydrate contents of leaves and floral buds, plant dry matter accumulation and partitioning, and plant nutrient status. Additionally, a field study on yield and physiological responses of cotton plants to soil- and foliar-B applications at different soil nitrogen levels was also conducted. The data presented here only focus on the effect of B deficiency on leaf net photosynthetic rate, chlorophyll content, leaf cell membrane leakage, and dry matter accumulation and partitioning, under controlled environmental growth chamber conditions.

Materials and Methods

The experiment was conducted in a controlled environment growth chamber at the Altheimer laboratory, university of Arkansas in Fayetteville. The growth chamber was programmed for a 12-h photoperiod, with day/night temperatures of 30/25 ^{o}C and relative humilities of 60 to 80%. Seeds of cotton (*Gossypium hirsutum* L.) cultivar Suregrow 125 was planted in 2-L pots filled with washed sand. Each pot had a hole of 2 cm in diameter in the base for drainage. After emergence, seedlings were thinned to one plant per pot. All pots watered with half-strength modified Hoagland's nutrient solution during the first two weeks after planting to maintain a sufficient nutrient and water supply.

At 2 weeks after planting, plants of similar size were divided into two identical groups. One group was B sufficient (+B) and continuously received the normal nutrient solution with B. The other group was B deficiency (-B) and the sand medium was flushed with plenty of deionized water to remove B from the pots. Thereafter, the -B treated plants were watered with B free nutrient solution.

During B deficiency, leaf net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, and transpiration rate were recorded weekly using a LI-6200 portable photosynthesis system (Li-Cor Inc., Lincoln, NE). Additionally, at 4 and 5 weeks after B removal when –B plants showed B deficient symptoms (Dark bands on petioles), leaf cell membrane leakage and chlorophyll content were determined. Four plants in each treatment were harvested weekly for five weeks after the initiation of the B deficit treatment. Plant height, the numbers of main-stem nodes, fruiting branches, fruiting sites, fruits (squares + bolls), and fruit shedding of individual plants were recorded. Thereafter, plants were separated in leaves, stems (main stem + branches + petioles), fruits and roots. Leaf area and dry weights of different tissues were measured to determine the effect of B deficiency on plant growth and dry matter partitioning.

The experiment was arranged a completely randomized design with four replications. The *t* test was performed to determine significant ($P \leq 0.05$) differences between treatment means.

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Results and Discussion

Leaf Photosynthesis Characters

Leaf net photosynthetic rates were not different between +B and –B treatments during the first three weeks after removal of B (Table 1). Thereafter, -B-treated plants had significantly lower leaf net photosynthetic rate than the +B control plants ($P \leq 0.05$). Compared to +B plants, leaf photosynthetic rate of –B-treated plants decreased 8% at 4 weeks and 39% at 5 weeks after removal of B. Decreased photosynthetic rate from B deficiency was closely related to a lower stomatal conductance because under severe B deficient conditions (4 and 5 weeks after B removal), leaf photosynthesis, stomatal conductance and transpiration rate decreased simultaneously (Table 1). Furthermore, a significant increase in cell membrane leakage of –B plants may also be one of the causes leading to low photosynthesis (Fig. 2).

Chlorophyll Content

B deficiency did not affect the ratio of chlorophyll *a* to chlorophyll *b* (data not shown), but increased total chlorophyll content per unit leaf area. Although –B plants had a lower photosynthetic rate than +B plants at 4 and 5 weeks after initiation of B deficit, the former showed significantly higher total chlorophyll concentration than the latter (Fig. 1A). Therefore, B deficiency remarkably decreased chlorophyll photosynthetic efficiency (Fig. 1B).

Plant Height and Leaf Area

There were no differences between the two B treatments in plant height, the number of main-stem nodes, leaf area, and number of fruits (squares + bolls) during the first two weeks after removal of B (Fig. 2). However, at 3, 4, and 5 weeks after the start of the B deficit treatments, the number of main-stem nodes, leaf area, and the number of squares of the B deficit plants (-B) were significantly less or smaller than those of the B sufficient plants (+B). B deficiency at 4 and 5 weeks also reduced plant height. Among the four growth parameters, the number of fruits was the most sensitive to B deficiency. The plant height, main-stem nodes, leaf area, and the number of fruits per plant of -B plants were decreased by 30%, 9%, 36%, and 83%, respectively, compared to the +B plants.

Dry Matter Accumulation

During the first three weeks after B removal, no statistical differences were observed in plant dry matter accumulation between +B and -B treatments (data not shown). However, at 4 and 5 weeks after removal of B, total dry matter of -B treated plants decreased 32-37% (Table 2). Depressed dry matter accumulation for -B plants was closely associated with decreases in both leaf area (Fig. 2) and in leaf net photosynthesis (Table 1). Of all the major plant components (leaves, stems, roots and fruits), fruit dry weight exhibited the greatest decrease (69%) and leaf dry weight had the smallest decrease (23%) when averaged over the two sampling dates at 4 and 5 weeks after B removal. Decreased fruit dry weight was closely related to the higher fruit shedding (Fig. 2) and less fruiting sites. The number of fruiting sites was reduced from 40 per plant in the +B treatment to 26 per plant in the -B treatment at 5 weeks after removal of B. At that time, no fruit shedding was observed in the +B plant, but 73% of fruits in the -B plant had shed.

References

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Table 1. Changes in net photosynthetic rate (Pn), stomatal conductance (g_s), and transpiration rate (E) of upper-most expanded main-stem leaves during boron deficiency.

Time†	Pn		g_s		E	
	+B	-B	+B	-B	+B	-B
(weeks)	(μmol m^{-2} s^{-1})		(cm s^{-1})		(mmol m^{-2} s^{-1})	
1	18.4	18.5	2.9	2.7	14.1	12.3
2	20.7	18.9	2.8	3.0	13.7	11.8
3	19.8	18.7	3.8*	2.6	15.1	12.0
4	22.4*	20.7	4.1**	1.8	15.8*	11.5
5	18.9*	11.6	3.8**	1.1	14.0*	4.9

† Measurement times after B was removed from nutrient solution for –B treatment.

* and ** indicate that differences between +B and –B treatments are significant at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

Table 2. Effect of Boron deficiency on dry matter accumulation and partitioning of growth chamber-grown cotton plants

	4 weeks after B removal		5 weeks after B removal	
Tissue	**+B**	**-B**	**+B**	**-B**
	---------- g plant^{-1} ----------			
Leaves	14.64*	10.40	24.09*	20.51
Stems	9.69*	6.07	19.09**	11.81
Roots	6.19*	3.55	8.42*	5.57
Fruits	1.94*	0.97	4.82**	0.60
Total	32.46*	20.63	56.42**	38.49

* and ** indicate that differences between +B and –B treatments are significant at $P \leq 0.05$ and $P \leq 0.01$ levels, respectively.

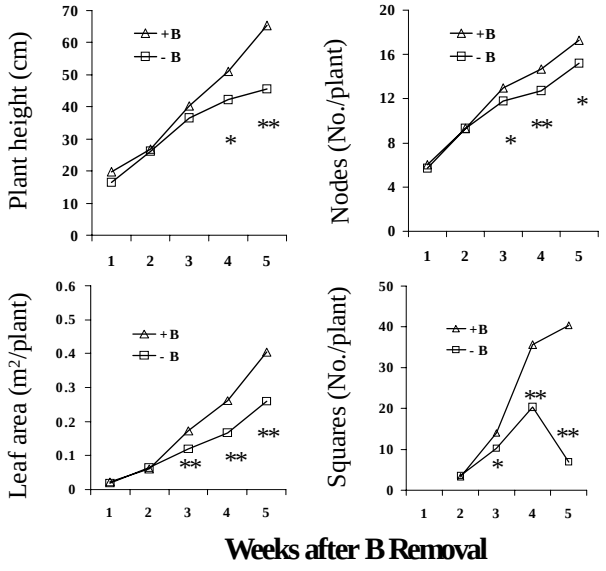

Figure 1. Changes in (A) plant height, (B) number of main-stem nodes, (C) leaf area, (D) number of squares during the onset of boron deficiency. The * and ** indicate significant differences at 0.05 and 0.01 levels, respectively.

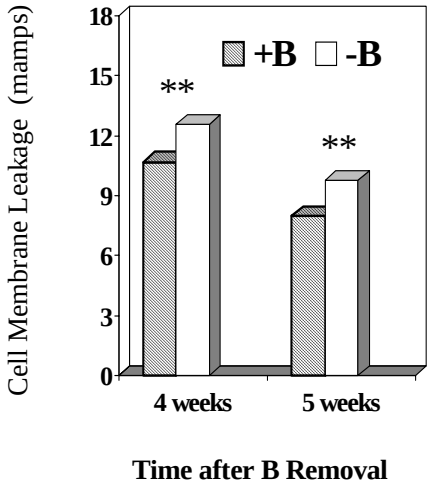

Figure 2. Effect of B deficiency on leaf cell membrane leakage. The * indicates significant difference at 0.01 level between two treatments.

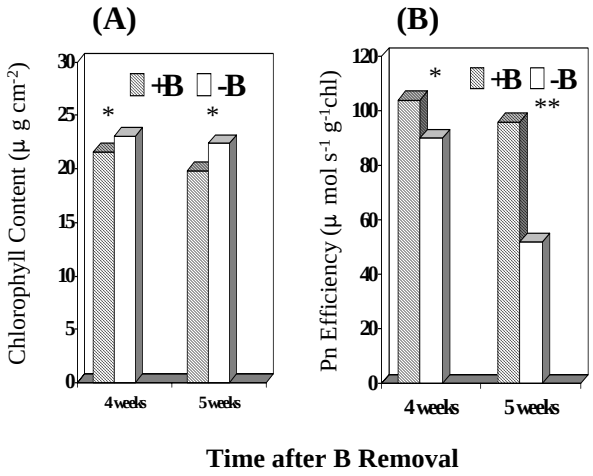

Figure 3. Effect of B deficiency on (A) leaf chlorophy 11 content and (B) chlorophy 11 photosynthetic efficiency. The * and ** indicate that differences are significant at 0.05 and 0.01 levels, respectively.