RESPONSES OF FIELD-GROWN COTTON TO SHADE: AN OVERVIEW

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Abstract

A 3-year field study was conducted to determine the effects of an 8-day period of shade (63% light reduction) at four growth stages; pinhead square (PHS), first flower(FF), peak flower (PF) and boll development (BD) on cotton (*Gossypium hirsutum* L.) carbohydrate composition, mineral nutrient status, lint yield, yield components and fiber quality. Shading for 8 days at the early square stage did not significantly affect cotton growth and yield. Shade during flowering and fruiting significantly increased fruit abscission, and decreased lint yield and fiber quality. The detrimental effect of shade on yield increased with later growth stages. At all four stages, shade significantly decreased leaf photosynthetic rate (43-55%) and nonstructural carbohydrate concentration (47-71%), and increased concentrations of chlorophyll and mineral nutrients. Effects of shade on carbohydrates and mineral nutrients of bracts and floral buds were also determined in this study. Shade during plant reproductive growth significantly reduced leaf photosynthesis and total nonstructural carbohydrate (TNC) concentrations, and affected mineral nutrient status and C/N ratio of cotton, resulting in increased fruit abscission and decreased lint yield and fiber quality.

Introduction

Light is a major factor limiting yield in cotton. Cloudy, overcast weather in the Mid-South region of the USA frequently occurs during the cotton growing season, and it is often speculated that these overcast periods have a detrimental effect on yield. Although the effect of shade on cotton yield has been documented in earlier studies, little is known about the physiological and yield responses of field-grown cotton to the timing of shade. Effects of low light stress at different growth stages on cotton growth and yield may be quite different because of the indeterminate growth habit of cotton plants. Therefore, a better understanding of the effects of shade at different growth stages on leaf photosynthesis, concentrations of nonstructural carbohydrates, and mineral nutrients of different parts of field-grown cotton plants may help to explain yield variability in cotton production and to improve management efficiency. Objectives of this study were: (1) To determine the effects of shade at four growth stages on cotton yield, yield components and fiber quality, (2) To quantify the effects of shade at different stages on leaf photosynthesis and chlorophyll concentration, and on nonstructural carbohydrates in leaves, bracts and floral buds of field-grown cotton, and (3) To investigate changes in mineral nutrient status of cotton plants to low light intensity.

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Materials and Methods

Plant Culture

The experiments were conducted in the field at the Arkansas Agricultural Research and Extension Center, University of Arkansas in Fayetteville in 1993-1995. Cotton (cv. Deltapine 20) was planted on 26 May 1993, 17 May 1994 and 15 May 1995. A plot consisted of five rows spaced 1-m apart, oriented in a south-north direction, and hand thinned to nine plants m^{-1} row when the seedlings had three true leaves. Control of insects and weeds, fertilizer, and furrow irrigation were given as needed during the growing seasons according to Arkansas cotton production recommendations.

The shade shelters (5 X 5 m and 1.9 m tall) were framed with PVC pipe and covered with black shade cloth providing an approximately 63% reduction in photosynthetic photon flux density (PPFD).

Experimental Treatments

The 5 treatments in 1993 and 1994 consisted of a no-shade control and four 8-d periods of shade of beginning at 4 growth stages including PHS, FF, PF and BD (Table 1).

Two experiments were conducted in 1995 (Table 2). The first experiment focused on shade during the squaring period only, to investigate the effect of shade at different stages prior to flower on square development and lint yield. The second experiment was to investigate the effect of duration of the shade interval during boll development (91 DAP) on cotton yield and fiber quality.

The experiments were arranged in a randomized complete block design with three replications.

Measurements

At 2, 4, 6 and 8 days after the initiation of shade in 1993 and 1994, the net photosynthetic rate, dark respiration rate and chlorophyll concentrations of the uppermost fully-expanded main-stem leaves were measured between 1100 and 1300 h. Thereafter, the petioles and blades of 6 leaves used for photosynthesis measurement were sampled. Additionally, ten 20-day-old squares at the first fruiting position of sympodial branches from each plot were collected 8 days after the initiation of shade treatments. The methods of Cornish et al. (1991) were used to extract and to determine leaf chlorophyll contents.

The samples of squares were separated into bracts and floral buds. The bracts, floral buds, petioles and leaves were dried for determining contents of nonstructural carbohydrates and mineral nutrients. The methods of Hendrix (1993) were used to extract and to determine nonstructural carbohydrates in plant tissues. The sum of hexose, sucrose and starch was defined as total nonstructural carbohydrate (TNC). Petiole NO_3-N, P, K and S, as well as total mineral nutrient concentrations in leaves, bracts and floral buds, were determined by the University of Arkansas Soil Testing and Research Laboratory, Marianna, AR.

Seedcotton samples were harvested by hand from 2 m of the center row of each plot. Boll numbers, seedcotton weight, and lint weight were determined. Average boll weight, lint percentage, and lint yield were calculated to analyze effects of the timing of shade on boll retention, lint yield and yield components. Fiber quality (HVI) was determined in 1994 and 1995.

Results and Discussion

I. Lint Yield and Fiber Quality

Lint Yield and Yield Components

Lint yield did not differ statistically between unshaded control and plants shaded at PHS (1994 and 1995) and FF stages (1993) (Table 3), whereas yield was significantly decreased by shade at the PF and BD stages. The reduction in lint yield from shaded cotton increased with progressive by later growth stages.

Among the three yield components of boll numbers, boll weight and lint percentage, effect of shade on the number of bolls was the greatest (Table 3). The decrease in lint yield for shaded cotton was mainly associated with a decrease in the number of harvestable bolls. Shade at PHS, FF or PF stage did not decrease average boll weight. Both boll numbers and boll weight were decreased by shade at the BD stage. No significant differences in lint percentage were found among shade treatments.

In 1995 (experiment 1), shade prior to flowering did not significantly affect lint yield and yield components (data not shown). In the 1995 study of the duration of shade intervals (experiment 2), all three shade treatments of 1-, 2- and 4-day intervals during boll development decreased lint yield significantly (by 19, 41 and 34%, respectively) (Table 4).

Fiber Quality

In the 1994 study, all shade treatments significantly decreased fiber micronaire values by 8-16% ($P \leq 0.05$) (data not shown). Shade at the PF and BD stages exhibited the greatest effect on fiber micronaire value.

In the 1995 (experiment 1), these fiber quality parameters were not significantly affected by shade during the squaring period (data not shown). In the 1995 experiment with shade intervals during boll development, fiber micronaire was significantly decreased by all three shade-treatment intervals ($P \leq 0.05$) compared to unshaded control. Results of fiber micronaire response to low light in our study agree with the observations of Pettigrew (1995). Our results revealed that fiber micronaire was the most sensitive to low PPFD during boll development among the five fiber quality parameters measured; but shade also had effects on fiber uniformity index and strength. The responses of fiber length and elongation to shade during boll development were relatively small.

II. Photosynthesis and Chlorophyll

Photosynthetic and Respiration Rates

Leaf net photosynthetic rate was significantly decreased by shade ($P \leq 0.001$) (Fig. 1). At 2, 4 and 8 days after initiation of shade at the FF stage, net photosynthetic rates of shaded cotton declined by 52, 43 and 42% compared to unshaded control plants (Fig. 1A). Shade had similar effects on leaf net photosynthetic rate at all growth stages (Fig. 1B). The leaf dark respiration rate did not statistically differ between the no-shade control and shaded plants.

Chlorophyll Concentration

Shade at all growth stages significantly increased leaf chlorophyll concentration (Fig. 2). Of the three growth stages of FF, PF and BD, shade at the FF stage caused the greatest increase in chlorophyll concentration (data not shown). During shading treatment, the difference in chlorophyll concentrations between no-shade control and shaded cotton leaves increased as the number of shade days increased, particularly on a DW basis. The relative increase in chlorophyll *b* was much greater than in chlorophyll *a*. Therefore, the ratio of chlorophyll *a/b* for shaded plants significantly declined ($P \leq 0.01$~0.0001) as the shading period increased.

III. Nonstructural Carbohydrates

In general, nonstructural carbohydrate concentrations in leaves, bracts and floral buds were affected significantly by shade and growth stage, but less affected by year. No interaction was found between year and shade. Sucrose appeared to be the most sensitive to both shade and growth stage among the three nonstructural carbohydrates.

Leaves**:** Specifically, of the three nonstructural carbohydrates, averaged over the four stages of 2 years, starch exhibited the greatest decrease (61%), followed by sucrose (45%) and hexose (6%) compared to no-shade control plants (Table 5).

Bracts**:** The TNC concentration in bracts was only 25-40% of that in leaves (Table 5), but the proportions of hexose and sucrose in bracts were much higher than those in leaves. Low bract TNC may be associated with a lower photosynthetic rate of bracts than leaves (Wullschleger and Oosterhuis, 1990). High fractions of soluble sugar in bracts are probably beneficial for carbohydrate translocation from bracts to fruits (Benedict and Kohel,1975). Shade significantly decreased carbohydrate concentrations in bracts.

Floral Buds**:** Shade at the FF and PF stages did not affect TNC concentration of floral buds (Table 5). The floral buds of shaded plants at the BD stage, however, exhibited significantly lower TNC (20%) than that of unshaded control plants. During boll development, insufficient carbohydrate supply under low PPFD conditions was a major factor which increased fruit abscission and decreased yield.

IV. Plant Mineral Nutrient Status

NO_3-N, P, K and S Concentrations in Petioles

Shading at any growth stage significantly increased petiole NO_3-N, P and K concentrations except petiole K at FF (Fig. 3). Petiole S concentration of shaded plants increased 43% at FF , was not different at PF, and significantly decreased at DB compared to the no-shade control plants.

Mineral Nutrients in Leaves

The response of leaf total N, P and K concentrations to shade was similar to that of petiole NO_3-N, P and K concentrations. Shade at any growth stage increased leaf total N (17-21%), P (18-39%) and Mg (11-24%) concentrations (Fig. 4). Leaf K concentration for shaded cotton was also significantly higher than that of unshaded control plants except for the treatment of shading at the FF stage. Shading at the PHS, FF and PF stages also increased the leaf S, Ca and Mg concentrations, but shading at the BD stage did not significantly affect the concentrations of these three elements in leaves.

Mineral Nutrients in Floral Buds and Bracts

Floral buds had higher total N, P K and Mg, and lower S and Ca concentrations than the subtending bracts (data not shown). The floral buds of shaded cotton plants had significantly higher K and Ca concentrations compared with those of the no-shade control plants. Ca in the bracts of shaded cotton was higher than that in the bracts of unshaded control plants. There were no statistical differences between the two shading treatments for other mineral nutrients in the buds and bracts. In contrast, the total N concentrations in floral buds and bracts of shaded plants were decreased by about 6%. The results of the increased leaf N and decreased floral bud N of shaded cotton illustrated that shade affected N partitioning in plants, and under low light, more N was allocated into the vegetative tissues (leaves).

Conclusions

An 8-d period of shade at all stages after first flowering significantly increased cotton fruit abscission, and decreased lint yield and fiber quality. The reduction in lint yield of shaded cotton increased when the shade was exposed at progressively later growth stages. Of the three main components of yield, the number of bolls per unit area was the most sensitive to shade. The reduction in lint yield of shaded cotton was mainly attributed to low boll retention. Of the five major cotton fiber quality properties, micronaire was the most sensitive to shade at flowering and fruiting. Shade during the boll development period significantly decreased fiber micronaire value, strength and uniformity index, but did not affect fiber length and elongation.

Under shade conditions, cotton leaf chlorophyll concentration significantly increased, leaf net photosynthetic rate decreased, but the dark respiration rate did not change significantly. Shade at all growth stages caused the greatest declination in TNC concentration of leaves, a smaller decrease in that of bracts, and the smallest decrease in that of floral buds. Leaf nonstructural carbohydrate concentrations were the most sensitive to shade at the PF stage, whereas carbohydrate concentrations in the bracts and floral buds were the most sensitive to shade at the BD stage.

Shade significantly increased concentrations of petiole NO_3-N and leaf total N, but only caused a numerical decrease in total N of bracts and buds. Under shade conditions, the P, K and S concentrations in plant components increased, and C/N ratio decreased. Increased mineral nutrient concentrations of shaded cotton were closely associated with the significantly decreased TNC concentrations. Insufficient carbohydrate supply and a decreased C/N ratio are probably the major factors correlated with increased fruit abscission, and the decreased lint yield and fiber quality of shaded cotton. The results of our studies showed that carbohydrates and mineral nutrient status of field-grown cotton plants were very sensitive to light conditions. The weather conditions and time of sampling must be considered when taking tissue samples for plant nutrient diagnoses.

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Table 1. Treatments showing the time when shade was imposed in 1993 and 1994.

Treatments	Growth stages[†]			
	PHS	FF	PF(FF+12 d)	BD(FF+24 d)
1. Control	----[‡]	----	----	----
2. Shade at PHS	S[§]	----	----	----
3. Shade at FF	----	S	----	----
4. Shade at PF	----	----	S	----
5. Shade at BD	----	----	----	S

[†] PHS, FF, PF and BD are pinhead square, first flower, peak flower and boll development stages, respectively.

[‡] No-shade. [§] Duration of an 8-day period of shade.

Table 2. Treatments showing the times when shade was exposed for the two experiments in 1995.

Experiment 1

Treatments	Time of beginning shade after PHS (days)		
	0	9	17
No-shade control	- - - - - - - -[†]	- - - - - - - -	- - - - - - - -
Shade at PHS	SSSSSSSS[‡]	- - - - - - - -	- - - - - - - -
Shade at 8 DAPHS[§]	- - - - - - - -	SSSSSSSS	- - - - - - - -
Shade at 16 DAPHS	- - - - - - - -	- - - - - - - -	SSSSSSSS

Experiment 2

Treatments	Time of beginning interval shade at 91 DAP (days)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No-shade control	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-d shade interval	S	-	S	-	S	-	S	-	S	-	S	-	S	-	S	-
2-d shade interval	S	S	-	-	S	S	-	-	S	S	-	-	S	S	-	-
3-d shade interval	S	S	S	S	-	-	-	-	S	S	S	S	-	-	-	-

[†] No-shade. [‡] S = one day of shade.

[§] DAPHS = days after pinhead square.

Table 3. Effects of an 8-day shading (63% of light reduction) period at four different growth stages on lint yield and yield components of field - grown cotton in 1993 and 1994.

Treatments	Lint yield	Boll number	Boll weight	Lint fraction
	kg ha^{-1}	no. m^{-2}	g boll^{-1}	%
			(1993)	
Control	810	61	3.4	40
Shade at FF	661	50	3.4	39
Shade at PF	534	40	3.5	38
Shade at BD	384	36	2.6	41
LSD(0.05)	216	12	0.4	NS†
			(1994)	
Control	1103	70	4.0	39
Shade at PHS	1025	61	4.3	40
Shade at FF	903	60	4.0	38
Shade at PF	878	54	4.1	40
Shade at BD	779	53	3.8	40
LSD(0.05)	163	8	0.4	NS

[†] NS = not significant (P>0.05).

Table 4. Effects of length of shade intervals during boll development on lint yield and yield components of field-grown cotton in 1995.

Treatments[†]	Lint yield	Boll number	Boll weight	Lint fraction
	kg ha^{-1}	no. m^{-2}	g boll^{-1}	%
Control	977	62	4.7	34
1-d shade interval	791	59	3.9	35
2-d shade interval	576	44	3.8	35
4-d shade interval	645	45	3.9	37
LSD(0.05)	133	8	0.3	2

[†] Total shade of eight days for three shade treatments.

Table 5. Effects of shade at different growth stages on nonstructural carbohydrate concentrations of leaves, bracts and floral buds. Data are the means of 1993 and 1994.

Stage	Leaves		Bracts		Floral buds	
	Check	Shade	Check	Shade	Check	Shade
			--------------- g mg^{-1} DW -----------------			
			(Hexose)			
PHS	23	16*	---†	---	---	---
FF	12	17 ns	7	5**	4	4 ns
PF	13	11 ns	7	4**	6	7 ns
BD	9	5*	11	3**	4	4 ns
			(Sucrose)			
PHS	15	7****	---	---	---	---
FF	22	14***	23	15**	11	8*
PF	15	9**	27	12**	8	5***
BD	10	4**	5	4 ns	4	3*
			(Starch)			
PHS	259	131****	---	---	---	---
FF	209	92****	39	25****	77	68 ns
PF	178	59****	49	31****	71	70 ns
BD	167	52****	51	24****	77	63****
			(TNC)			
PHS	297	154****	---	---	---	---
FF	243	123****	70	45***	91	80 ns
PF	206	79****	83	47****	85	82 ns
BD	185	61****	66	32****	85	70****

† Not available.

The ns is not significant. *, **, *** and **** are significant at P<0.05, 0.01, 0.001 and 0.0001 level, respectively.

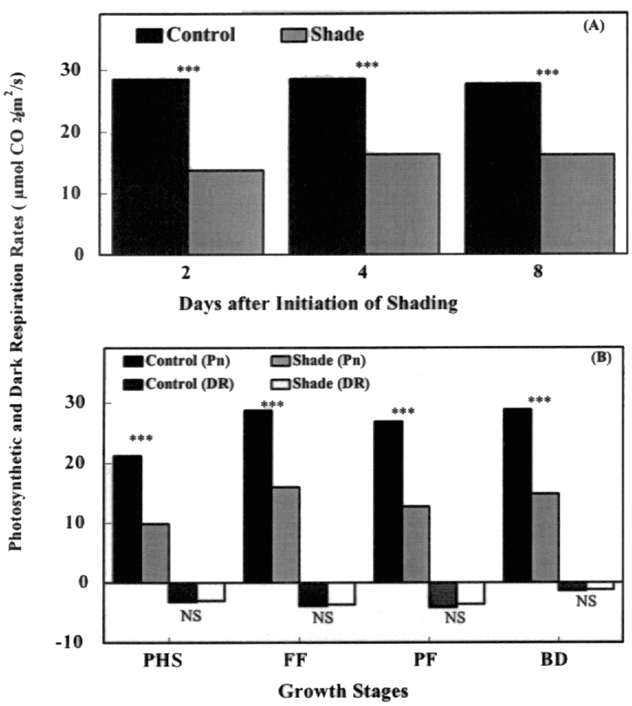

Figure 1. (A) changes in leaf net photosynthetic rate during 2-, 4-, and 8-day periods of shade imposed at the FF stage, and (B) effects of an 8-day shade period on photosynthetic rate (Pn) and dark respiration (DR) of field-grown cotton at the PHS, FF and BD stages. NS=not significant, and *** is significant at P<0.001 level.

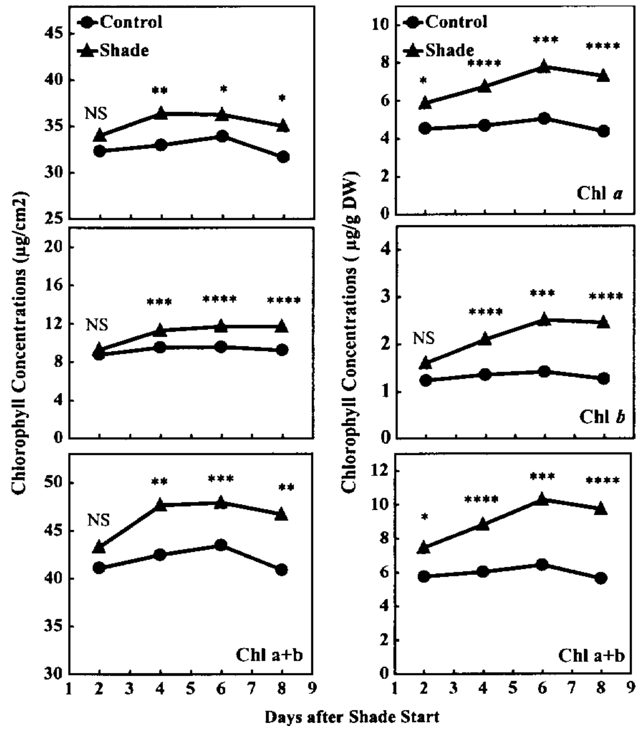

Figure 2.

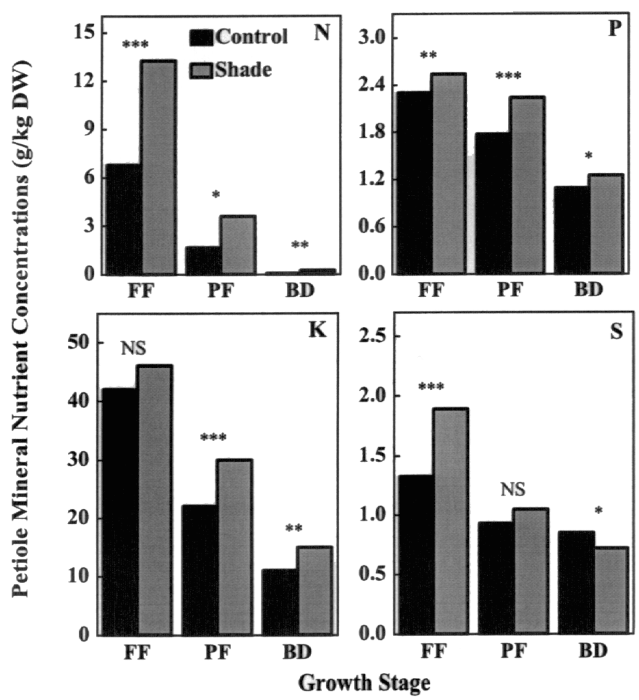

Figure 3. Effects of shade at different growth stages on petiole NO_3-N, P, K and S concentrations. Each data point is the mean 12 samples over 4 sampling times (2,4,6 and 8 days) in 3 replications. NS=not significant (P>0.05), *=P<0.05, **=P<0.01 and ***=P<0.001.

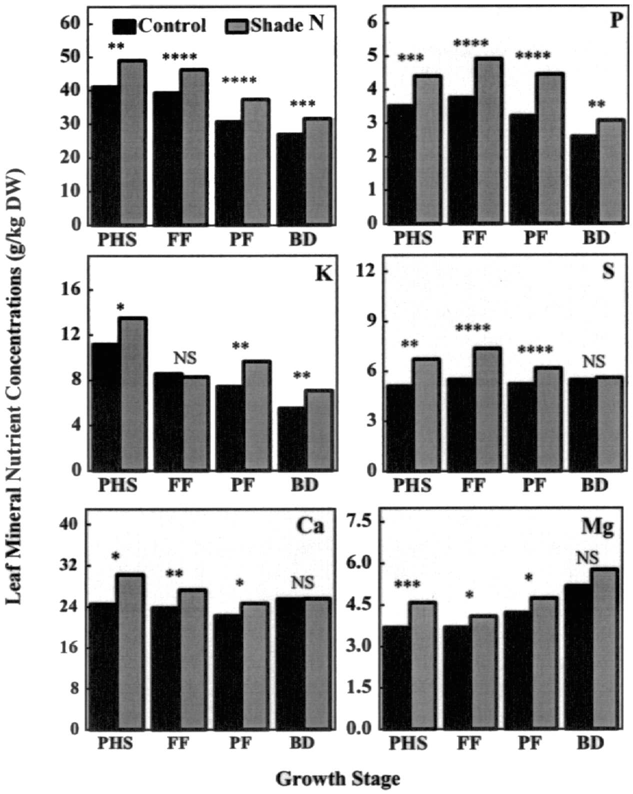

Figure 4. Effects of shade at different growth stages on leaf N, P, K, S, Ca and Mg concentrations. Each data point is the mean 12 samples over 4 sampling times (2,4,6 and 8 days) in 3 replications. NS=not significant (P>0.05), *=P<0.05, **=P<0.01 and ***=P<0.001.