GROWTH AND DEVELOPMENT OF COTTON (*GOSSYPIUM HIRSUTUM* L.) IN RESPONSE TO CO_2 ENRICHMENT UNDER TWO DIFFERENT TEMPERATURE REGIMES

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INTRODUCTION

It is well known that the carbon dioxide (CO_2) concentration of the global atmosphere has increased during the last few decades and continues to increase, mainly due to energy consumption from fossil fuels. Since the start of the Industrial Revolution period until today, the atmospheric CO_2 level has increased from 280 ppm to around 365 ppm, and continues to rise at about 1.8 ppm per year. It is expected that it might reach a concentration of 600 to 1000 ppm by the end of this century. Elevated [CO_2] enhances the productivity of C3 plants, including peanut, cotton and wheat. Along with an increase in [CO_2], climate projections indicate changes in other climate factors such as temperature. Elevated [CO_2] together with higher temperature could provide an opportunity to grow crops where currently cold temperatures limit growth of crops, such as cotton. Furthermore, these potential warmer conditions could allow for earlier planting and longer growing seasons where at present low temperatures or late frosts prohibit it. The objective of this study was to evaluate the interactive effects of low and high temperature on growth and development of cotton under different CO_2 concentrations ranging from 400 ppm to 800 ppm.

MATERIALS AND METHODS

The experiment was conducted in 2003 in the controlled-environment chambers of the Georgia Envirotron, located at the College of Agricultural and Environmental Sciences – Griffin Campus of the University of Georgia. Six Conviron growth chambers (model CG72), with a floor space of 93 ft^2 and a height of 7.22 ft, were used in this experiment. A central personal computer allowed for programming of the desired climatic conditions in the chambers and storing the climatic data. Lighting levels were adjustable at five different intensity levels. Carbon dioxide was automatically injected into the chambers and its level in the chambers was controlled using a CO_2 delivery system and chamber vents. An individual LICOR infrared gas analyzer (LI-800 GasHound CO_2 Analyzer, LI-COR, NE, USA) was used to monitor CO_2 levels for each chamber independently. All chambers were also equipped with a drip irrigation system.

The six treatments consisted of all combinations of the two day/night temperatures (77/59 F (T1) and 95/77 F (T2)) and three CO_2 concentrations (400, 600 and 800ppm). The experimental design was completely randomized, with four replicates (plastic pots) per treatment. Twenty eight pots were placed in each chamber. The distance between pots was maintained at 1.15ft x 0.98 ft (0.88 plants/ft^2). Pots were filled with washed sand. Five seeds of cotton, cultivar DP 448B, were sown in each pot and thinned to one plant per pot after emergence. Plants were watered daily with a modified half-strength of Hoagland's solution three or four times a week to provide an adequate supply of water and nutrition.

Growth analysis was conducted weekly during the growing season and at each sampling plant traits, including plant height, number of leaves, number of squares and number of bolls were measured weekly. The number of days to 50% emergence, squaring and flowering were also determined. Leaf area, leaf dry mass, root dry mass, square dry mass, boll dry mass and total above dry mass per plant were also measured at each sampling time.

RESULTS AND DISCUSSION

Table 1 shows the number of days from seeding to emergence, and days from emergence to squaring and flowering. Increasing the temperature from 77/59 F to 95/77 F decreased the days from seeding to emergence by 2 days across all CO_2 levels. On average, the length of emergence to squaring at 95/77 F was 51 days which was 34 days shorter than the number of days from emergence to squaring at 77/59F. The mean days from emergence to flowering for 77/59 F and 95/77 F were 104 and 66 days respectively. As was expected, the warmer environments shortened the duration of each individual development stage.

At both temperatures, increasing [CO_2] to 800 ppm hastened the emergence by 1 day. At 77/59 F, increasing [CO_2] to 600 ppm increased the number of days to squaring, but a further increase of CO_2 to 800 ppm decreased the squaring by 9 days compared to ambient [CO_2]. In this experiment, increasing the [CO_2] (800 ppm) decreased the days from emergence to flowering by 13 days compared with ambient [CO_2] (400 ppm). CO_2 effect as shortening crop growth duration demands possibly a change in farm management planning in the future with respect to crop rotations and timing of inputs, such as fertilizer and irrigation. Table 1 shows that the temperature showed a prominent effect on crop growth duration compared to CO_2. Increasing temperature from 77/59 F to 95/77 F reduced the days to squaring and flowering for all CO_2 levels.

Elevated [CO_2] up to 600 ppm decreased the leaf numbers. However, a further increase of CO_2 increased the leaf numbers at 95/77 F (Table 2). Crop height as another plant parameter showed a proportional change similar to LAI, with exception of 1.3% reduction by increasing CO_2 (600 ppm) at 95/77 F. However, a further increase of CO_2 (800 ppm) increased crop height (2.2%).

Table1. The number of days from seeding to emergence and days from emergence to squaring and flowering under CO_2 enrichment with two different temperature regimes.

Temperature (F) (day/night)	CO_2 level (ppm)	Emergence (DAS) [a)]	Squaring (DAE)[b)]	Flowering (DAE)
77/59	400	5	91	109
	600	5	96	107
	800	4	82	96
95/77	400	3	55	68
	600	3	54	66
	800	2	52	64

a)DAS: days after seeding, b)DAE: days after emergence

Table 2. Final leaf number and R:S ratio, averaged across the whole growing season, in response to CO_2 and temperature.

	CO_2 (ppm)		
	400	600	800
	Final leaf number (per plant)		
77/59 F	20.7	15.2	19.2
95/77 F	37.7	32.7	38.0
	R:S ratio (Root to Shoot weight)		
77/59 F	0.18	0.15	0.19
95/77 F	0.20	0.22	0.22

We found that plant height was more sensitive to temperature than CO_2. Leaf area is the main source for radiation absorbance and affects crop production. Figure 1 shows the trend of the Leaf Area Index (LAI) of cotton plants observed across all CO_2 and temperature levels. Our observed LAI data at the final growth analysis sampling prior to harvest showed that the elevated CO_2 (up to 600 ppm) increased the LAI by 3.1% at 77/59 F and 8.7% at 95/77 F, while a further increase of CO_2 (800 ppm) reduced the LAI by 1.3% and 3.1% at 77/59 F and 95/77 F, respectively. Our data also showed that the change in LAI was different among the three different [CO_2] levels. Increasing [CO_2] for both temperatures showed a positive impact on LAI growth rate. In general, a higher leaf area growth rate would accelerate crop canopy closure. This result might be indicative as taller cotton plants show higher canopy closure rate at elevated [CO_2]. Based on this assumption it is expected that under future climate change conditions cotton canopy closure would occur faster, which would be an advantage for locations facing problems of weed competition and could be considered as disadvantage where water stress would happen towards the end of growing season. Averaged over the entire growing season, temperature also impacted the LAI for all CO_2 levels and increased LAI (Fig. 1) by 6.3% at 400 ppm, 9.5% at 600 ppm, and 9.0% at 800 ppm CO_2. At any CO_2 level, increasing temperature showed a higher impact on LAI than increasing CO_2 at any level of temperature. In other words, when comparing CO_2 and temperature, temperature had a dominant effect on LAI of cotton plants.

Biomass accumulation and partitioning

On average for the entire growing season, increasing CO_2 at 77/59 F increased the total biomass by 50% at 600 ppm and at 70% for 800 ppm [CO_2]. When the temperature was increased to 95/77 F, total biomass for the entire growing season did not show any response to CO_2 at 600 ppm, but it increased 40% at 800 ppm. The increase in total biomass for elevated [CO_2] at both temperatures was higher and not proportional to the change in LAI to CO_2. This may indicate a higher resource use efficiency per absorbing leaf area rather than increasing the area for capturing of resources. The relationship between leaf area as solar radiation absorbing surface and plant biomass production was examined and we found that plants at more or less the same LAI produce higher biomass at elevated [CO_2], which reflects the higher resource use efficiency of plants when exposed to elevated [CO_2]. On average for the entire growing season we found that an increase in temperature increased total biomass by 5.5 times at 400ppm, 7.0 times at 600 ppm, and 5.7 times at 800 ppm of [CO_2].

Increasing the temperature increased the ratio of root to shoot (R:S) (Table 2). This indicated that due to the higher total biomass production at higher temperature plants partition relatively more carbohydrates to the roots and therefore try to explore more resources in the soil. In general, there seems to be a small increase in R:S when CO_2 increased. Temperature also showed a positive impact on root weight. Root weight at 95/77F increased by 41.4% for the 600 ppm and 6.2% for the 800 ppm of CO_2.

Reproductive growth

An increase in temperature and CO_2 up to 600 ppm increased the number of squares at final harvest (Table 3). The number of squares increased by 31.4% at 77/59 F for 600ppm [CO_2] but decreased by 6.6% at 800ppm [CO_2]. At higher temperature (95/77 F) the number of squares decreased by 20.3% at 600 ppm and 0.8% at 800 ppm of [CO_2]. Increasing temperature significantly increased the square numbers. Increasing temperature increased the square number by 433.9% at 400 ppm, 223.9% at 600 ppm and 407.3% at 800 ppm of [CO_2].

At 77/59 F, boll numbers increased by 25.4% at 600 ppm and 14.3% at 800 ppm. At higher temperature (by 95/77 F) boll numbers increased by 413.3% at 600 ppm and 233.3% at 800 ppm compared to ambient. While an increase in temperature increased the number of squares, it actually decreased the number of bolls at any CO_2 level. Boll numbers were reduced by 76.2% at 400 ppm, 2.5% at 600 ppm and 30.6% of [CO_2] by increasing temperature to 95/77 F (Table 3). The reduction of boll numbers due to temperature is because boll retention is highly sensitive to temperature. Breeding for high temperature tolerant cultivars during boll development is a key issue for adaptation to the expected increases in temperature due to climate change. An increase in [CO_2] to 800 ppm did not show any benefit at lower temperature in our experiment as the number of squares was reduced by 28.9% and the number of bolls was reduced by 8.9% respectively when compared to 600 ppm. Both elevated [CO_2] and an increase in temperature increased the boll weight (Table 3), except at the highest temperature 95/77 F and highest [CO_2]. The higher response of boll weight to temperature at 95/77 F might be due to the fact that optimum temperature of cotton, as a warm season tropical crop, is in the range of 78.8 F to 82.4 F. Our higher response to [CO_2] at 95/77 F for boll weight indicated the main role of temperature as promoting or damping the effect of [CO_2] on cotton production. Lint yield showed a similar response to [CO_2] as boll weight. Increasing temperature reduced lint yield at all [CO_2] levels (Table 3).

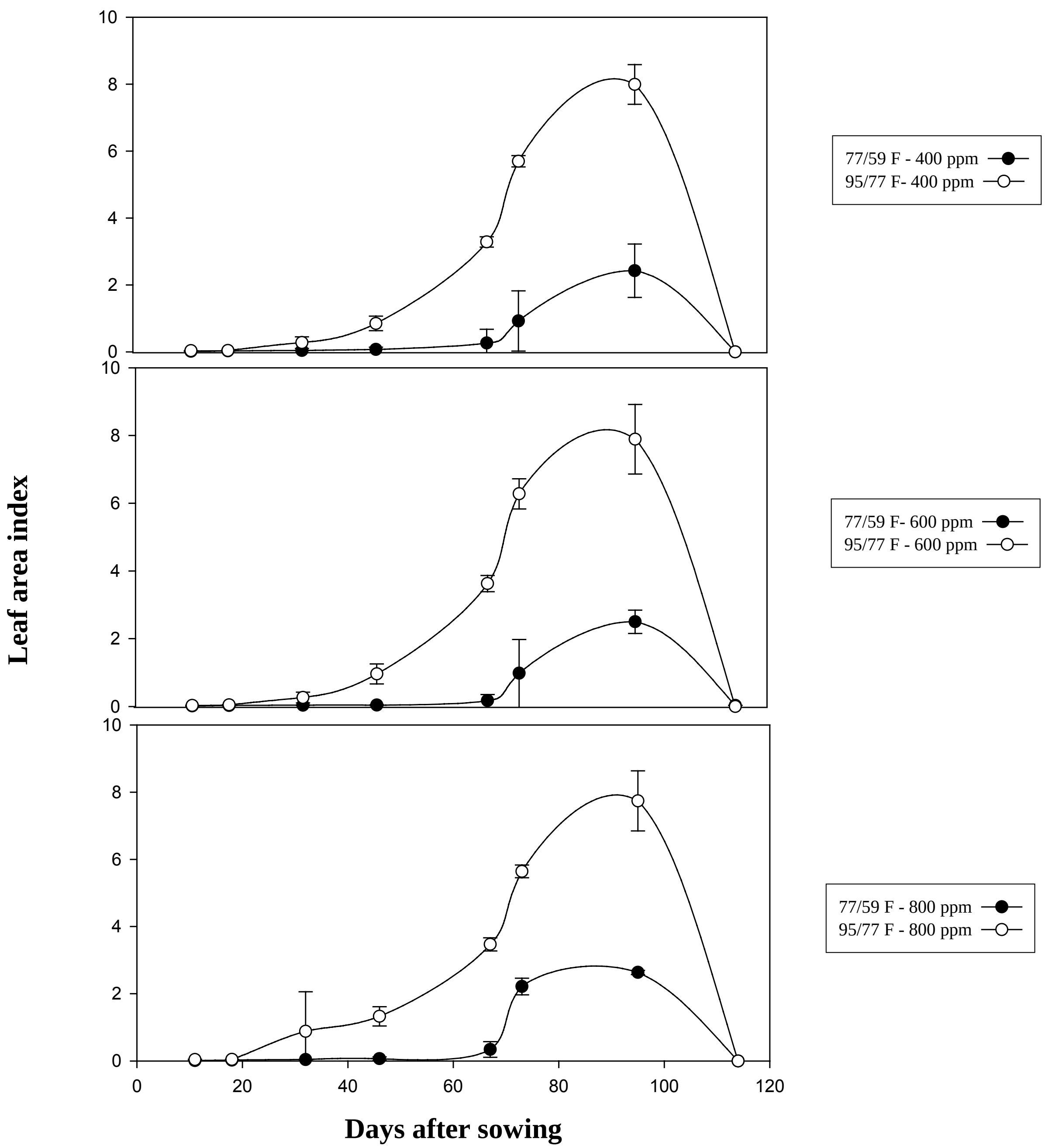

Fig. 1. LAI trend of cotton at two levels of temperature and three levels of CO_2.

Table 3. Square number, boll number and boll weight at final sampling of the growth analysis and seed + lint yield at final harvest in response to CO_2 and temperature

CO_2 (ppm)			
	400	600	800
Square number (per ft^2 ground)			
77/59 F	26.7	35.1	24.9
95/77 F	141.5	113.7	142.6
Boll number (per ft^2 ground)			
77/59 F	13.9	17.4	15.9
95/77 F	3.3	17.0	11.03
Boll weight (lb $acre^{-2}$)			
77/59 F	52.7	84.8	335.8
95/77 F	54.7	1861.0	1277.0
Seed + Lint yield (lb $acre^{-2}$)			
77/59 F	5539.3	5543.7	6384.9
95/77 F	394.7	2524.5	707.2

Conclusion

The response of indeterminate crops such as cotton to CO_2 and temperature is more complicated than determinate crops like rice plants. Increasing the [CO_2] positively stimulated growth and development of cotton with greater response at temperatures close to optimum. The vegetative and reproductive developments were affected by both [CO_2] and temperature, but with a dominant effect of temperature. Increasing CO_2 and temperature did not increase the surface area of absorbing resources, but positively impacted the resource use efficiency of cotton crops. However, the number of days to reach the maximum crop absorbing leaf area surface and subsequently soil cover was higher at higher CO_2 concentrations and higher temperatures. In general, increasing CO_2 and temperature increased the total biomass of cotton plants together with heavier bolls. Seed + lint yield also showed positive response to elevated CO_2, although the increase was higher at the 77/59 F temperature compared to temperature combination of 95/77 F.