Effect of night temperature on boll growth and yield

Milenka Arevalo, Derrick Oosterhuis, Dennis Coker and Scott Brown
Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville Arkansas USA
Correspondence author lareval@uark.edu; oosterhu@uark.edu

ABSTRACT

Earlier research has shown a correlation between low yields and high temperatures during boll filling. Preliminary research comparing boll growth and yields in contrasting environments, Arkansas and Greece, indicated that an 8 ^{0}C higher night temperature during boll development in Arkansas may be a major contributory factor to lower yield in Arkansas. A field experiment was designed to evaluate the effects of night temperature in Arkansas on boll development, fiber yield per seed and selected physiological parameters. PVC frames were constructed with plastic covering over the two middle rows of 4-row plots, and heaters or air conditioners were used to raise or lower night temperatures compared with an ambient temperature control. Temperature treatments were initiated after the third week of flowering in order to have three stages of boll development, i.e. 1, 2 and 3 week old bolls at the time of the temperature treatments were imposed. One week of elevated temperature during the third week of flowering had no significant effect on boll weight or fiber per seed. However, there was a numerical trend for decreased boll weight with elevated night temperature, with fiber weight per seed being the main yield component affected. There was also no significant effect on respiration or photosynthesis. It was concluded that one week of altered temperature was insufficient to significantly affect boll growth because there was sufficient time for subsequent compensatory boll growth prior to maturity. The study will be repeated in 2003 with various modifications including a longer two-week temperature treatment.

Introduction

Cotton yield and total seed cotton production per hectare in Arkansas increased steadily during the eighties, but leveled off in recent years. Also, yields have fluctuated widely from year-to-year, e.g. the 1994 crop was a record high yield, whereas the 1993 and 1995 seasons were extremely disappointing with unusually low yields despite the promise of a good crop at mid-season. Variability in cotton yield is associated with genotype and environment. It is thought that genotypic differences in commercial cotton cultivars in response to stress are relatively small, whereas environmental stress, particularly from water shortages and extreme temperatures are the main cause of lower and variable yields in the Mid-South (Oosterhuis, 1995). Water shortages and high temperatures invariably occur in the Mid-South during late July and August when the main boll load is developing. Metabolism is very sensitive to extreme temperatures (Burke *et al*., 1988), and therefore, growth of the reproductive parts can be expected to be adversely affected by high temperatures.

A strong correlation exists between high temperatures during boll development and low yields in the Mid-South (Oosterhuis, 1995). High temperatures dramatically increases night respiration and affects other processes, and therefore the plant utilizes mechanisms of compensation in order to conserve carbohydrates by setting fewer bolls, decreasing boll size and in the worst case, shedding bolls to compensate for carbohydrate deficiency needed to meet plant demands (Reddy *et al*., 1991). However, there is very limited data available on temperature and cotton yield, possibly because of the difficulty in conducting research in the field with varying temperatures. Information on cotton response to temperature is lacking particularly with regard to the upper temperature threshold and effects on physiological processes and yield. It was hypothesized that when periods of excessively high night temperature occur during boll filling, there is a temporary shortage of carbohydrate, which leads to decreased boll weights. Currently, we do not account for this in our estimations of yield. The main objective of this study was to evaluate and quantify the effect of varying night temperatures on boll growth and development.

Experimental procedure

A field study was designed and conducted to investigate the effects of raised or lowered night temperature on boll growth and boll weight. The experimental plots were located at the University of Arkansas Agricultural Experiment Station in Fayetteville on a Captina silt loam (Typic Fragiudult). Cotton (*Gossypium hirsutum* L.) cultivar Suregrow 215 BR was planted on May 23, 2002 at a row spacing of 0.9 m with 10 plants/m. The experiment was laid out in a randomized complete block design with three replications. Cultural inputs followed University of Arkansas recommendations for cotton production and were consistent across all plots. Temperature shelters (4 x 5 x 1m) were constructed from PVC tubes (2.54 cm diameter) to support a plastic covering over the canopy (Figure 1). The elevated night temperature treatments were achieved using space heaters blowing hot air down the middle two rows of the plots. Similarly, the decreased night temperature treatment was achieved using large air conditioners blowing cool air down the center of the plots. Temperatures in each plot were monitored every 15 minutes using Watchdog 100 temperature sensors (Spectrum Tech. Inc., Plainfield, IL) located in the center of the plot at mid canopy on the main stem of plants. The temperature treatments were imposed for one week at night during the fourth week of flowering from 8:00 PM to 12:00 AM. The plastic cover was drawn over each plot at the time the temperature treatments began and removed the following day at approximately 6:00 AM, i.e., from sun down to sunrise.

Approximately 50 bolls from the first fruiting position were tagged as white flowers in all plots during the first, second and third week of flowering to give three ages of bolls when the temperature covers were first placed over the plots at end of the third week (i.e., at this time the tagged bolls were 3, 2 and 1 week old when the temperature treatment was imposed). Half the tagged bolls were harvested one week after removal of the covers and the remainder of the tagged bolls was collected at harvest along with a 1 m sub sample on each center row for yield and yield components. Fiber and seed weight per boll were measured on all tagged bolls. Total seed number, boll weight (fiber + seed) and fiber weight per seed were recorded on the 2 m harvested.

Measurements were also made of leaf area, dry weight of leaf and petioles, leaf wax concentration, and specific leaf weight at one week after the temperature treatments were imposed. Photosynthesis and night respiration were recorded in the middle of the week of temperature treatment and again one week after treatment using a LICOR 6200 portable photosynthesis system (Licor Inc, Lincoln, NE).

Results and Discussion

Patterns of maximum and minimum temperature and rainfall

The long-term maximum and minimum temperature and rainfall were compiled for the location and compared with the actual 2002 year records as shown in Figure 2. This information was used for interpretation of the results from our field study. Knowledge of the daily and yearly variation in patterns of temperatures permits an estimation of the impact of these factors on the development of the crop and potential yield.

Preliminary temperature study in contrasting environments

A comparative study of yields and temperatures was carried out in 2002 to determine why Greece has considerably higher cotton yields (1456 kg/ha) compared to Arkansas, USA (840 kg/ha) despite most production factors being similar. A comparison of the two production systems revealed that the main factor accounting for the large yield difference was 8 ^{0}C cooler night temperatures in Greece compared to the Mississippi Delta in the USA during boll development (Figure 3). Greek cotton did not experience elevated night temperatures, which leads to increased respiratory loses and reduced boll growth. In addition, humidity is lower in Greece during the summer so that evaporation keeps the leaves cooler during the day than is possible in the humid US Mid-South.

Night temperature study

Night temperatures were raised (space heater) and lowered (air conditioner) to be compared to ambient temperatures in the control (Figure 4). Unfortunately, some sensors placed in the control plots failed to record the respective temperatures, so we could not have a real estimate of this information. The resulting effect on plant growth, physiology and boll growth did not show any significant differences (P=0.05). However, some interesting variations were observed among treatments in the parameters measured. Raising or lowering the night temperature for seven days had no significant (P=0.05) effect on fourth node leaf respiration during the night or on photosynthesis the following day (data not shown). Similarly, there was no subsequent effect on these parameters at one week after the night temperature treatment. The lack of temperature treatment effect on respiration was unexpected due to the sensitivity of this process to temperature. Similarly there was no significant effect of the night temperature treatment on canopy leaf area and plant dry matter, although the cooler night temperature treatment had numerically higher values of leaf area and dry matter (data not shown).

Fiber weight per seed is a fundamental component of yield (Lewis *et al*., 2000) but this parameter was not significantly reduced (P=0.05) by the seven-day period of altered night temperature treatment on the first sampling of tagged bolls taken immediately after the week temperature treatments ended. This applied to bolls 1, 2, and 3 weeks of age experiencing the altered night temperature. In accordance with our hypothesis we expected a decrease in fiber weight from the elevated night temperature. Similarly, we expected an increase in fiber weight per seed from the cool temperature treatment but this was not observed.

There was also no significant (P=0.05) effect of raised or lowered night temperatures on final boll weight or fiber weight per seed at harvest (Figures 5 and 6). However, there was a numerical trend for elevated night temperature to decrease fiber and boll weight, which, although not statistically significant, supports our hypothesis of high night temperatures being detrimental to developing boll weight. Decreased boll weight would presumably be related to a shortage of carbohydrates for boll growth. It has been suggested that this would partly account for lowered yields in Arkansas during periods of high night temperature, but additional research with modifications to the protocol used for this study are needed to prove this hypothesis. High temperatures would be further compounded when coupled with periods of water shortage as invariably occurs in the Mississippi Delta at sometime during boll development in July and early August.

An understanding of what is happening to the boll load will permit the formulation of possible strategies to counteract the problem, e.g. using earlier maturing varieties to escape the hottest and driest part of the season, breeding for temperature tolerance, irrigating at appropriate critical times or possibly using new technologies such as an osmolyte spray to improve plant tolerance.

Conclusions

Raising or lowering night temperatures had no significant (P=0.05) effect on any of the variables evaluated. However, there was a numerical trend for elevated night temperature to decrease final fiber and boll weight, which supports our hypothesis of high night temperatures being detrimental to developing boll weight. Decreased boll weight would presumably be related to a shortage of carbohydrates for boll growth. Authors cited in this paper suggested that this would partly account for lowered yields in Arkansas during periods of high night temperature, but additional research with modifications to the protocol are needed to prove this hypothesis.

The field study will be repeated with some modifications in 2003. The night temperature treatment will be extended to two weeks as one week did not appear to be sufficient and allowed subsequent compensation. We also conclude that extending the treatment duration would more accurately represent the interval of time during boll development when Greece has cooler night temperatures compared to those in Arkansas (Figure 3). Actual boll temperature will be monitored in addition to canopy temperature. The sides of the PVC canopies will also be covered to ensure a more uniform temperature under the plastic covers. The study will also be repeated in the growth chamber using two similar chambers with contrasting night temperatures during boll development. Emphasis will be placed on measurements of boll temperature, respiration and carbohydrate accumulation in leaves and petioles.

References

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Figure 1. *PVC and plastic sheet shelters constructed over the two middle rows of each plot to change night temperature (Fayetteville, Arkansas, 2002.)*

Figure 2. *Long-term 32 years maximum and minimum temperatures and rainfall compared with current 2002 records (Fayetteville, Arkansas).*

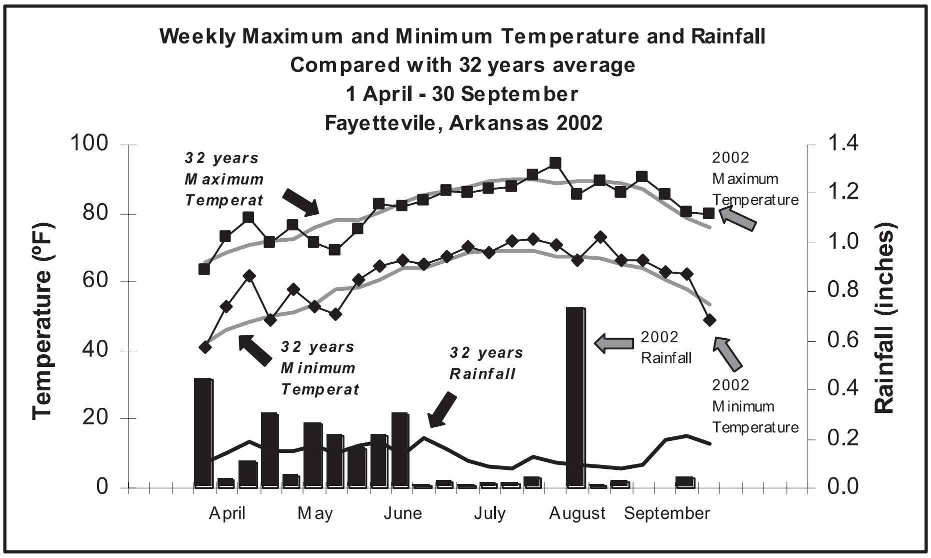

Figure 3. *Arkansas versus Greek temperatures (from Oosterhuis, 2002).*

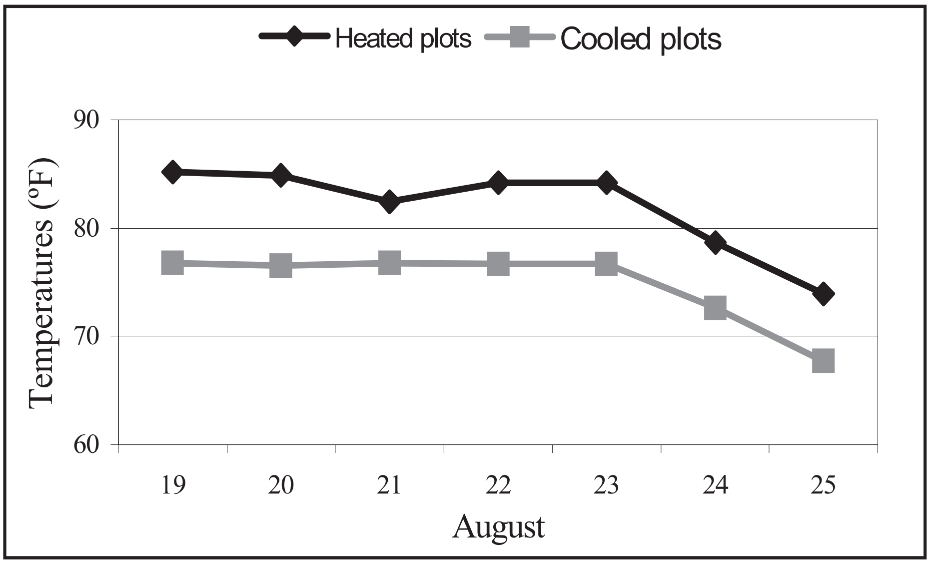

Figure 4. *Daily four-hour temperatures recorded from August 19 to August 25 for heated and cooled plots during the week of temperature treatments (Fayetteville, Arkansas, 2002).*

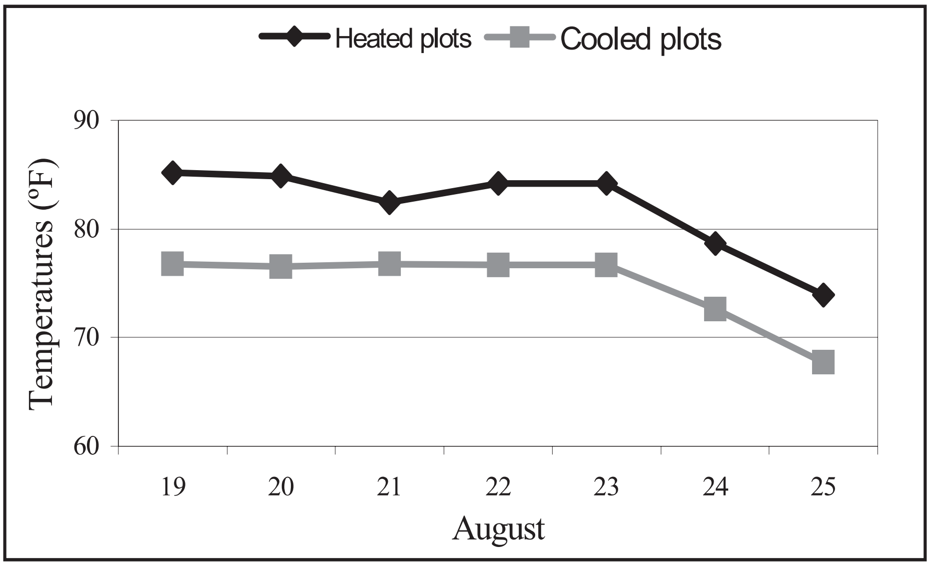

Figure 5. Average boll weight from 2 m length of row at harvest (Fayetteville, Arkansas, 2002).

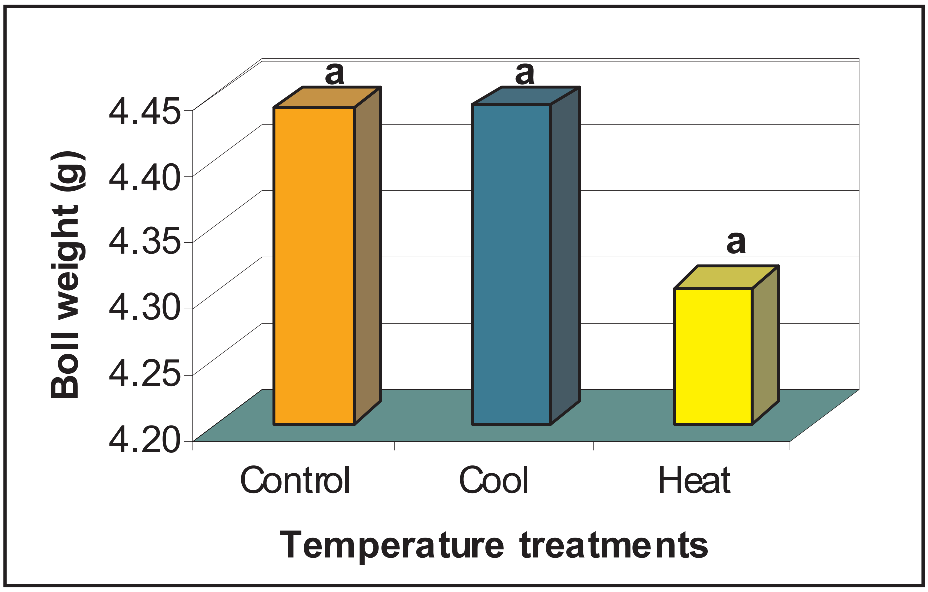

Figure 6. Weight of fiber per seed from 2 m length of row at harvest (Fayetteville, Arkansas, 2002).