Heat Stress and Cotton Yields in Arizona

Paul W. Brown

Abstract

Yield of upland cotton was related to heat stress in Yuma, LaPaz, Maricopa, and Pinal Counties for the period 1987-1999. Heat stress during the primary fruiting cycle was assessed using heat stress units (HSU) which were derived from mean daily canopy temperatures computed using a canopy temperature model and local AZMET weather data. Mean lint yields were computed for years with low, intermediate and high levels of HSU. Yields in years with low levels of heat stress were always significantly greater than yields in years with high levels of heat stress. Differences in yield between high and low heat stress years ranged from 100 lb/a in Maricopa County to 254 lb/a in Yuma County and averaged 166 lb/a across all counties. Differences in yield between the low and intermediate stress years, and intermediate and high stress years averaged 86 and 80 lb/a, respectively across all counties; however, these differences were not always significant in individual counties.

Introduction

Heat stress can negatively impact cotton yields in much of central and western Arizona by reducing fruit retention and boll size. Heat stress conditions typically develop during the monsoon season when high air temperatures combine with rising humidity to force canopy temperatures above the optimal range for proper fruit development. Research in both Arizona and Mississippi indicates that reproductive performance of upland cotton declines once mean crop temperature exceed approximately 28-30ºC or 82.4-86ºF (Hodges et al., 1993; Brown & Zeiher, 1997). In this paper, we use a simple canopy temperature model to identify time periods when mean daily canopy temperatures exceed 28°C. We then quantify the stress during these periods in terms of heat stress units (HSU) and then relate cotton yields to accumulation of HSU in Yuma, LaPaz, Maricopa, and Pinal Counties from 1987-1999.

Materials and Methods

An analysis of heat stress conditions was performed for Yuma, LaPaz, Maricopa, and Pinal Counties for the period 1987-1999. Estimates of mean daily canopy temperature were used to assess heat stress conditions each year from June through September. Mean daily canopy temperatures were derived using the model developed by Brown and Zeiher (1998). The model utilizes hourly weather data from AZMET to generate hourly estimates of canopy temperature:

$$CT_h = 0.53 + T_a - 1.43*VPD \quad \text{(Daytime)}$$

$$CT_h = -5.93 + T_a + 1.95*e_a \quad \text{(Nighttime)}$$

Where:

CT_h is the hourly canopy temperature in degrees C
T_a is mean hourly air temperature in degrees C
VPD is the mean hourly vapor pressure deficit in kilopascals
e_a is the mean hourly vapor pressure in kilopascals

This is part of the 2001 Arizona Cotton Report, The University of Arizona of Agriculture and Life Sciences, index at http://ag.ariozna.edu/pubs/crops/az1224/

The model's daytime equation was used when solar radiation for the hour exceeded zero; the nighttime equation was used whenever solar radiation for the hour equaled zero. Weather data obtained from AZMET weather stations located in Yuma Valley, Parker Valley, Litchfield Park, and Maricopa served as input data for the model.

Hourly estimates of CT_h were then converted to mean daily canopy temperatures by computing the mean of the 24 CT_h values for the 24-hr period ending at midnight. Heat stress units (HSU) were then computed for each day by first converting the mean daily canopy temperature data to units of degrees F, then subtracting the lower temperature threshold for heat stress, 82.4°F, from the mean daily canopy temperatures. Negative values of HSU indicate a non-stressful condition and were set equal to zero.

The vulnerability of a given year's crop to heat stress was assessed by determining the number HSU accumulated during the primary fruiting cycle of a representative crop. Planting dates in central AZ were set to the date when the National Agricultural Statistics Service indicated 50% of the crop was planted. Planting dates in Yuma were assumed to occur when heat unit (HU) accumulation after 1 January reached 400. The crop was assumed to develop according to standard HU guidelines and completed the primary fruiting cycle when 2600 HU had accumulated after planting (HUAP) in central Arizona and Parker Valley, and 2800 HUAP in Yuma Valley.

The 13 cotton seasons at each location were divided into three heat stress categories: low, medium, and high. The low category contained the four years with the lowest number of HSU accumulated at the end of the primary fruiting cycle. The high category contained the four years with the highest number of HSU accumulated over the same period, and the intermediate category contained the five remaining crop years with intermediate HSU accumulations. Mean cotton lint yield was then determined for each heat stress category by averaging the countywide yields reported by the Arizona Agricultural Statistics Service for the years assigned to each category. Mean lint yields for the various heat stress categories were then compared using a standard statistical t-test to test the null hypothesis that means did not differ. The null hypothesis was rejected when the probability of exceeding the resulting t value was <0.10.

Results and Discussion

Lint yields for each heat stress category and the results of the statistical comparison of means are presented in Table 1. Mean lint yields for each heat stress category are presented by county in Fig. 1-4. Yields in years with low levels of heat stress were significantly greater than yields in years with high levels of heat stress in all four counties (Table 1). The difference in average lint yield between high and low stress years ranged from 100 lb/a in Maricopa County to 254 lb/a in Yuma County, and averaged 166 lb/a over the four areas studied (Fig. 1-4).

Yield differences between low and intermediate stress years were smaller than similar differences observed between the low and high stress categories. Yields in low stress years were significantly higher than yields in intermediate stress years in only two counties: Yuma and Maricopa (Table 1). The difference in yield between low and intermediate stress years ranged from -10 lb/a in LaPaz County to 141 lb/a in Yuma County and averaged 86 lb/a (Fig. 1-4).

Differences in lint yield between the intermediate and high heat stress years were even less definitive. Yields differences between the intermediate and high stress categories ranged from -28 lb/a in Maricopa County to 148 lb/a in LaPaz County (Fig. 1-4) and averaged 80 lb/a. Only the yield difference observed in LaPaz County proved to be significant.

The results of this study also provide some insight into the vulnerability of a given location to heat stress. Table 2 provides the mean HSU values associated with the low, intermediate, and high heat stress categories at each location. Heat stress clearly increases with decreasing elevation in years with high heat stress; however, this trend does not extend to intermediate and low heat stress years. During these years, Pinal County recorded the lowest HSU values, followed by Yuma, and then either LaPaz or Maricopa Counties. The apparent more favorable heat stress environment in the Yuma area during low and intermediate stress years is a result of the earlier planting dates which help the crop avoid heat stress in July and August. Later planting dates in LaPaz and Maricopa Counties tend to make the crop more vulnerable to heat stress in these areas and account for the higher HSU accumulations observed in intermediate and low heat stress years.

Conclusions

This study represents an initial investigation into the impact of heat stress on cotton yields in Arizona. While the study reveals some rather clear trends regarding the relationship between yield and heat stress, the overall data set relating yield to heat stress is rather noisy. Factors that likely contribute to this noisy data include: year-to-year variation in insect pressures, improving technologies (e.g. Bt cotton, improved whitefly control, and new varieties), varying production practices (e.g. normal variation in planting date vs. use of single representative planting date, replanting in cold springs, top-cropping), accuracy of the canopy temperature model, and accuracy of using weather data from a single weather station to assess heat stress on a countywide basis.

References

Brown, P.W. and C.A. Zeiher. 1997. Cotton heat stress. *In:* Cotton: A College of Agriculture Report. Series P-108. College of Agriculture, Univ. of Arizona, Tucson, AZ. P. 41-48.

Brown, P.W. and C.A. Zeiher. 1998. A model to estimate cotton canopy temperature in the desert southwest. *In:* 1998 Proceedings Beltwide Cotton Conferences. 5-9 Jan. 1998. San Diego, CA. Natl. Cotton Council. Memphis, TN.

Hodges, H.F., K.R. Reddy, J.M. McKinion, and V.R. Reddy. 1993. Temperature effects on cotton. Miss. St. Univ. Exp. Stn. Bulletin 990.

Table 1. Mean lint yields for years defined with low, intermediate and high heat stress conditions, and results from statistical comparisons of means conducted using t-tests.

	LINT YIELDS, lb/a					
	HEAT STRESS CONDITION			COMPARISON OF MEANS, t-TEST		
COUNTY	**LOW**	**INTERM.**	**HIGH**	**LOW vs. HIGH**	**LOW vs. INTERM.**	**HIGH vs. INTERM.**
Yuma	**1419**	**1278**	**1165**	***	**	**ns**
LaPaz	**1310**	**1320**	**1172**	**	**ns**	**
Maricopa	**1314**	**1186**	**1214**	*	*	**ns**
Pinal	**1308**	**1225**	**1137**	**	**ns**	**ns**

*** Significant at p<0.01
** Significant at p<0.05
* Significant at p<0.1
ns: Not Significant

Table 2. Mean HSU accumulations in degree-days (dd) for years defined with low, intermediate, and high heat stress conditions. Elevations represent elevation in feet above mean sea level of the AZMET station used to provide weather data for the HSU computation.

		HEAT STRESS UNITS, dd		
		HEAT STRESS CONDITION		
COUNTY	**ELEVATION, feet**	**LOW**	**INTERMEDIATE**	**HIGH**
Yuma	**105**	**11.9**	**44.6**	**100.6**
LaPaz	**308**	**21.3**	**54.5**	**87.6**
Maricopa	**1014**	**26.6**	**52.7**	**80.0**
Pinal	**1184**	**4.8**	**26.8**	**67.8**

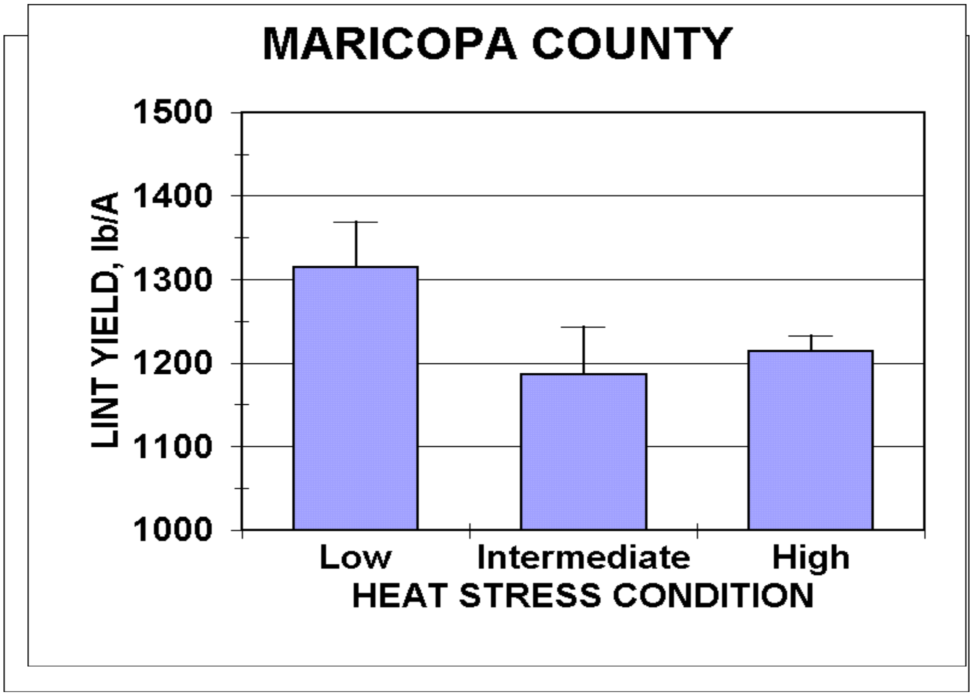

Figure 1. Mean lint yields in Yuma County for years when heat stress was classified as low, intermediate, and high. Error bars represent the root mean square deviation.

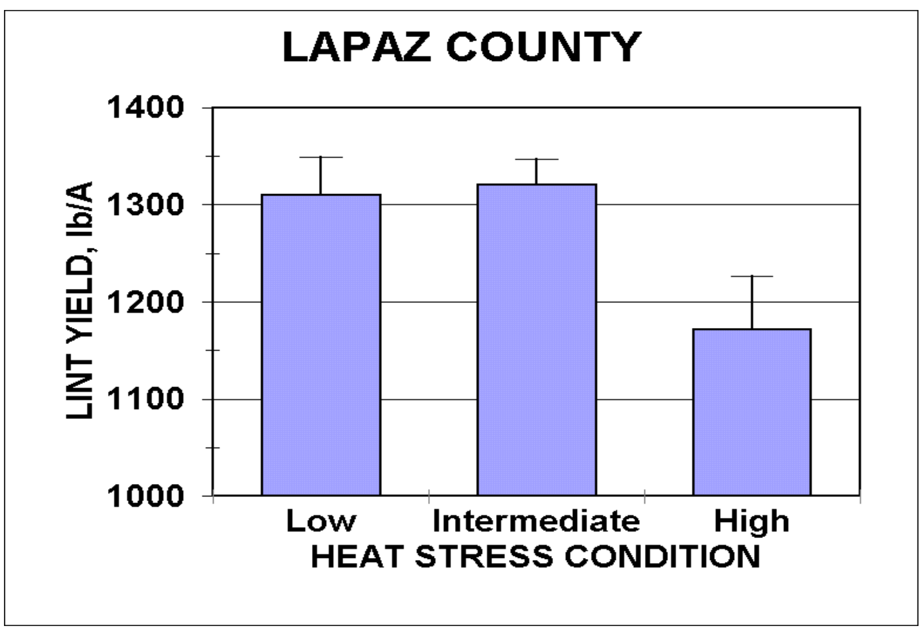

Figure 2. Mean lint yields in LaPaz County for years when heat stress was classified as low, intermediate, and high. Error bars represent the root mean square deviation.

Figure 3. Mean lint yields in Maricopa County for years when heat stress was classified as low, intermediate, and high. Error bars represent the root mean square deviation.

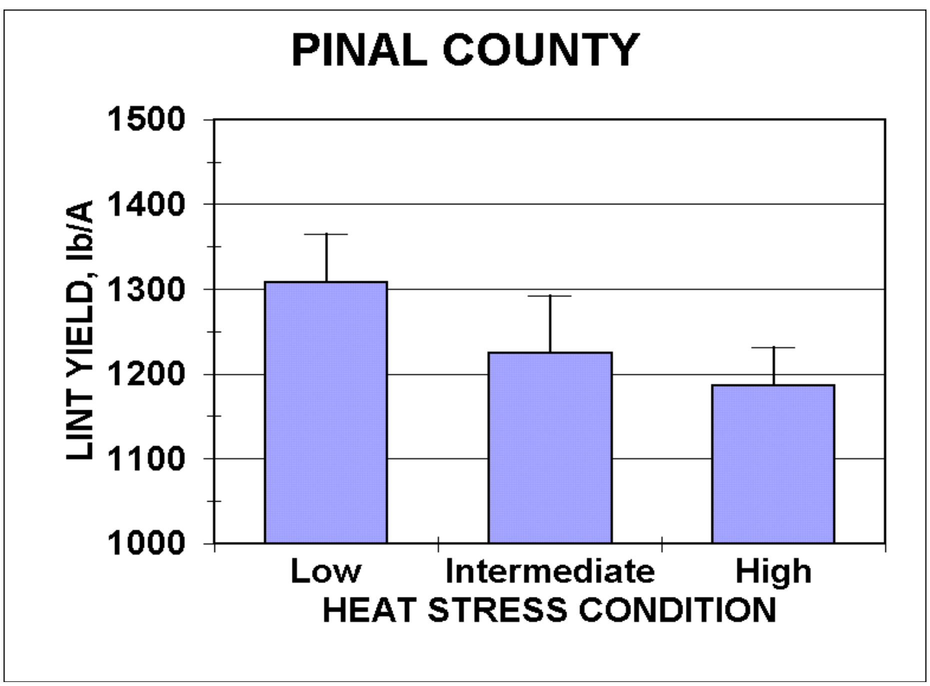

Figure 4. Mean lint yields in Pinal County for years when heat stress was classified as low, intermediate, and high. Error bars represent the root mean square deviation.