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THERMAL IMAGING OF COTTON CANOPIES

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Abstract

Canopy temperature is a good indicator of crop water stress and can also be used for making timely irrigation scheduling decisions for center pivot and subsurface drip irrigation systems. A study was conducted in 2001 in which cotton (Gossypium hirsutum L.) canopy temperature was measured with infrared thermocouples and a thermal scanner in field plots irrigated by surface drip irrigation. Two water levels were established that included full evapotranspiration replacement (HW) and the other water level, which applied 50 % of the HW amount, was designated as (LW). The purpose of the study was to compare canopy temperature measured from a small canopy area using infrared thermocouples with that obtained from a larger area by thermal scanning. Canopy temperatures in the HW and LW cotton were measured on eight days during a 20 day period that started at first bloom and include four days during one irrigation cycle. In the HW level there were significant temperature differences between the two sensors on 25 % of the days, but the differences were only slightly greater than the measurement accuracy of the two sensors. In LW cotton, temperatures of the two sensors were significantly different on all days, probably due to the infrared thermocouples observing some soil surface through the canopy. Differences in canopy temperature measured by the two sensors averaged 0.2 °C in HW cotton and 3.2 °C in LW cotton. The largest canopy temperature differences measured during the irrigation cycle between HW and LW cotton was 6.75 °C and 9.1 °C, respectively, for the thermal scanner and infrared thermocouple. These results indicate that when canopy size is sufficient to mask the soil, background canopy temperatures measured from a small area by infrared thermocouples are comparable to those from a larger area sensed by a thermal scanner.

Introduction

In previous studies of crop water stress we have measured canopy temperatures of cotton using infrared thermocouples (Wanjura and Upchurch,1991; Wanjura and Upchurch, 1994; Wanjura and Mahan, 1994) to quantify stress level for the purpose of scheduling irrigation. Continuous monitoring of crop temperature is performed by remote sensing using infrared thermal sensors positioned to observe a small area of canopy. These sensors have also been attached to center pivot irrigation systems and measured a fixed circular transect during an irrigation.

While the infrared sensing of temperature of a small area of canopy provides an accurate temperature for the area observed, the question arises about how representative this measurement is of a larger area of canopy measured with a thermal imaging sensor. Obviously one factor that affects this question is the precision of measurement of the two different sensors and the spatial variability of canopy temperature in a field. Infrared thermocouple accuracy varies with the deviation of the target temperature from the calibrated temperature of the sensor; ie, from ± 0.2 % for a target deviation of ± 3 °C to ±1 % at a deviation of ±12 °C. Thus it is important to select an infrared thermocouple whose calibrated temperature is at or near the center of the range of temperatures being measured. Thermal scanners are calibrated over a wide temperature range, but when spectral response is measured in the 8 to 14 μm(longwave) region and "earth" temperatures (- 20 °C to 50 °C) are measured, accuracy is about 0.5 °C.

Thermal imaging has been used to measure field crop temperatures for many years. A study by (Bartholic et al., 1972) used an airplane mounted thermal scanner to measure irradiance in the 8 to 14 μm wavelength interval. From measurements of cotton plots with a wide range of water stress, they concluded that infrared imagery had potential for distinguishing water-stressed and nonstressed fields in addition to evaluating uniformity of irrigation. A review of image-based remote sensing by (Moran et al., 1997) addressed the potential of image-based remote sensing for providing spatially and temporally distributed information for precision crop management. Current limitations of image-based remote sensing applications include sensor attributes, such as restricted spectral range, coarse spatial resolution, slow turnaround time, and inadequate repeat coverage.

Infrared thermometry has been used to measure canopy temperature at a single location in plots where the area viewed ranged from a circular diameter of 4 inches early in the growing season to 12-18 inches when cotton attains maximum vegetative growth. The purpose of this study was to compare canopy temperature measured from a small canopy area using infrared thermocouples with that obtained from a larger area with thermal imaging.

Materials and Methods

The cotton variety Paymaster HS2326 was planted on 9 May 2001 (DOY 129) into the beds of rows oriented north to south and spaced at 1 m. Previous rainfall provided sufficient moisture for germination and emergence. Initial emergence date was 14 May (DOY 134). A pre-emergence herbicide application of 1.75 $l\ ha^{-1}$ of Prowl was applied.

A thermal scanner was mounted on a 40 ft self propelled Z-Boom. Equipment for thermal imaging included the thermal scanner (Inframetrics, Model 600L), a TV with built-in VCR, and a portable generator. Measurements were taken over cotton (2 water levels) planted in 40-inch spaced rows in a north-south row orientation. Plot size for each water level was 12 rows wide by 170 m long. At the beginning of the study three locations were selected along the row length and marked with flags in order to return to the same sites on different measurement dates. At each location, one row and two row sites were marked. The three locations were 25, 50, and 75 m from the south end of the field.

Thermal scans over one row viewed a 2.5 ft row length which was obtained by positioning the thermal scanner 9.5 ft above the ground surface and 2 rows viewed a 5 ft row length with the thermal scanner at a19 ft height. Single row scans were made over the third row and the two row scans were taken above the third and fourth rows from the outside of the plot. Thermal scans were always started at approximately 1345 hours in the high water (HW) cotton which was irrigated to replace 100 % of potential evapotranspiration (PET). This was followed by thermal scans in the low water (LW) cotton which was irrigated to replace 50% of PET. If clouds covered the sun, we waited for 1-min after the cloud cleared the sun before making a scan.

Thermal Image Analysis

After completing the field thermal scan measurements, the VCR was connected to the USB port on a PC in the laboratory and the video tape of images taken in the field was played through the PC. Images from of each location in each crop were copied and stored in the PC in JPEG format.

The JPEG image was then opened in Adobe Photo Shop for analysis.

Each image was converted to a gray scale of 0-255 luminosity with 0 being black and 255 being white. Each image had the range of temperatures represented in the image stamped on it by the thermal scanning unit. An attempt was made to capture each image within a 10 °C range.

When the image was opened in PhotoShop it was cropped to remove extraneous portions of the image, leaving the canopy and furrows on each side for single rows and two adjacent canopies with outside furrows for two rows. The Rectangular Marguee Tool was used to select the single row canopies in the image with a minimum of bare soil included. A histogram was then generated and the statistics of the histogram was recorded, ie; mean, standard deviation and median of luminosity, and number of pixels in the canopy image.

IRT Temperature

In each water level of cotton two infrared thermocouples (Model IRt/c .2 G -K -80F/20C) were mounted over adjacent rows near the location of the thermal scan readings nearest to the south end of each plot. The canopy temperatures measured with the infrared thermocouples (Irt/c) were saved as 15 min averages in a Campbell Scientific CR7 datalogger. The canopy temperatures measured by the Irt/c were compared to those from the thermal scanner.

Biomass estimates were made by sampling five representative plants in the vicinity of each location on each date of thermal scanning. Midday leaf water potential was measured along with thermal scanning by sampling three leaves at each field location with a pressure bomb.

Results

Growth Stages & Dates

Thermal scans of HW level cotton canopies were taken from a nadir viewpoint on nine days between first square (DOY 162) and mid-bloom stage (DOY 204). Four of these scans were made on successive days of one irrigation cycle beginning with the day when irrigation was applied on DOY 199 and ending on DOY 202, the last day before the next irrigation application. Thermal scans during the irrigation cycle were made over both HW and LW levels.

Leaf Orientation

Leaf shape, distribution around the mainstem, and vertical orientation differs among crop plants and affects the distribution and penetration of solar radiation below the top surface of canopies. This results in different patterns of leaf temperatures at the top surface of the canopy and vertically within the canopy that may affect temperatures measured by infrared thermocouples and thermal images obtained with scanning instrumentation. Cotton azimuth and vertical leaf angles are compared with corn in Table 1. The average leaf azimuth angle for both crops was approximately 189 degrees on both dates indicating that the distribution of the top five leaves was uniformly distributed about the mainstem in the horizonal plane. The azimuth angles of vertically adjacent leaves varied indicating that their positions in the horizontal plane were also different. On both measurement dates vertical angles of cotton were oriented 20 to 30 degrees below the horizontal plane in contrast to corn leaves which were 60 degrees above the horizontal plane.

Biomass

Plants were harvested on four dates during the period of thermal scanning and plant height and leaf area data are summarized in Table 3. Plant leaf area and leaf area index values indicate the development and size of canopies. Between DOY 184 and DOY 206 for cotton and DOY 186 and DOY 206 for corn there was little change in canopy size. Leaf area per plant and leaf area index values on DOY 206 indicate that LW cotton canopies were about 50 % smaller than those of HW cotton. The cotton began to set bolls on DOY 183. Corn began to tassel on DOY 186 and gradually declined afterwards as lower leaves dried and abscised. There was no significant difference due to location along the row for plant leaf area or leaf area index for corn or cotton. Thus uniformity of water application by the drip irrigation system was assumed to be relatively high.

Leaf Water Potential

Midday leaf water potential (LWP) values were different on each day during the period of one irrigation cycle from July 18 through July 21, Table 2. The cotton had large negative LWP values for both irrigation levels were high during the irrigation cycle, even on the day that irrigation was applied. The irrigation well pump had experienced intermittent problems for several weeks which interfered with the normal irrigation cycle and quantities applied. Maximum air temperature of 40.6 °C also occurred in the days immediately before the beginning of the irrigation cycle. Midday LWP values for well watered cotton would normally be in the range of -15 to -18 bars. Even so, these differences in LWP values for cotton in the two water levels resulted in different levels of vegetative growth.

Comparisons of IRt/c and Thermal Scanner Canopy Temperatures

Canopy temperatures for the HW and LW levels were measured by infrared thermocouples and the thermal scanner for eight days including those during the irrigation cycle beginning on DOY 199, Figs. 1a and 1b. During the four days (DOY 199 - DOY 202) of the irrigation cycle canopy temperature differences between the LW and HW levels were greater for measurements made by infrared thermocouples than those measured from the thermal scanner. The pattern of canopy temperature differences during the four days was similar for both types of sensors. The largest canopy temperature difference between the two water levels which occurred on DOY 200 was 6.75 °C and 9.1 °C, respectively, for the thermal scanner and infrared thermocouple.

A comparison of canopy temperatures within each water level measured by each thermal sensor is shown in Figs. 2a and 2b. Canopy temperatures measured by the sensors agreed more closely in the HW level than in the LW level. In the HW level there were significant temperature differences between the two sensors on only two days (DOY 193 and DOY 199) out of a total of 8 days. These differences of 0.8 °C and 0.6 °C are slightly greater than the accuracy of measurement by the infrared thermocouples and the thermal scanner. In LW cotton, temperature differences of the two sensors were significantly different on each of the 4 days, ranging from 2.1 °C to 4.6 °C. Infrared thermocouple temperatures in the LW level were abnormally high probably due to observing some soil surface through the canopy. The difference in canopy temperature measured by the two sensors (TC - TS) were both positive and negative in HW cotton but always positive in LW cotton. The infrared thermocouples appeared to correctly measure temperature since during the night time, temperatures were similar in both water levels, but different during midday, Fig. 3. During the 4 day irrigation cycle differences in temperature measured by the two sensors averaged 0.18 °C in the HW level and 3.16 °C in the LW level.

The canopy temperatures measured by the infrared thermocouples and the thermal scanner were linearly correlated in both water levels, Fig. 4. The linear regression coefficient was 1.43, 1.06, and 1.40 for the LW, HW, and the combined water levels. The canopy temperatures measured by the two sensors agreed mostly closely in the HW level as indicated by its regression coefficient which was closer to 1.0 than in the LW level.

Summary

Canopy temperatures for the HW and LW cotton were measured by infrared thermocouples and a thermal scanner on eight days including four days during one irrigation cycle. The largest canopy temperature differences measured between HW and LW cotton were 6.8 °C and 9.1 °C, respectively, for the thermal scanner and infrared thermocouple. In the HW level there were significant temperature differences between the two sensors on 25 % of the days. In LW cotton, temperatures of the two sensors were significantly different on all days, probably due to the infrared thermocouples observing some soil surface through the canopy. Differences in canopy temperature measured by the two sensors averaged 0.2 °C in HW cotton and 3.2 °C in LW cotton. These results indicate that when canopy size is sufficient to mask the soil background canopy temperatures measured from a small area by infrared thermocouples are comparable to those from a larger area sensed by a thermal scanner.

Disclaimer

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Table 1 Leaf angles in the upper portion of cotton and corn canopies.

Date		**Leaf number below mainstem terminal**				
Crop	**Average**	**1**	**2**	**3**	**4**	**5**
			Azimuth Angle, degrees _1/			
DOY 163						
Cotton	182	161	235	162	192	158
Corn	186	176	178	210	175	194
DOY 183						
Cotton	179	134	198	212	144	216
Corn	164	111	237	126	204	135
			Vertical Angle, degrees _2/			
DOY 163						
Cotton	124	130	123	129	118	118
Corn	26	18	22	23	30	38
DOY 183						
Cotton	111	110	113	111	119	113
Corn	35	17	23	27	31	39

_1/ Azimuth angles were measured in the horizontal plane in a clockwise direction from north.
_2/ Vertical angles were measured between a vertical line and the surface of the leaf blade.

Table 2 Leaf water potential values during one irrigation cycle for two irrigation levels of cotton, 2001.

		Leaf Water Potential, bars	
DOY 199	Irrigation day	-23.3 b _1/	-30.5 a
DOY 200	Irrigation day + 1	-26.0 b	-32.8 a
DOY 201	Irrigation day + 2	-26.3 b	-32.3 a
DOY 202	Irrigation day + 3	-31.1 b	-33.9 a

_1/ Values in the same row followed different letters are statistically different at the 0.001 probability level according to Duncan's New Multiple Range Test.

Table 3 Plant height, leaf area, and leaf area index, 2000.

Date		Location		
Crop	Average	1	2	3
		Plant Height, cm		
DOY 184				
HW Cotton	61	60 a _1/	61 a	63 a
DOY 186				
Corn	184	186 ab	168 b	198 a
DOY 193				
Corn	195	200 a	191 a	193 a
HW Cotton	69	61 b	71 a	75 a
DOY 206				
Corn	196	199 a	189 a	201 a
HW Cotton	79	73 b	75 b	89 a
LW Cotton	64	61 a	67 a	63 a
		Plant Leaf Area, cm^2 / plant		
DOY 184				
HW Cotton	1654	1489 a	1683 a	1790 a
DOY 186				
Corn	6023	6128 a	5523 a	6418 a
DOY 193				
Corn	5396	5627 a	5403 a	5157 a
HW Cotton	1373	1413 a	1233 a	1472 a
DOY 206				
Corn	4800	5335 a	4352 a	4713 a
HW Cotton	1681	1689 a	1665 a	1690 a
LW Cotton	907	738 a	1059 a	925 a
		Leaf Area Index		
DOY 184				
HW Cotton	2.4	2.2 a	2.4 a	2.6 a
DOY 186				
Corn	4.4	4.5 a	4.1 a	4.7 a
DOY 193				
Corn	4.0	4.1 a	4.0 a	3.8 a
HW Cotton	2.0	2.0 a	1.8 a	2.2 a
DOY 206				
Corn	3.5	3.9 a	3.2 a	3.5 a
HW Cotton	2.4	2.4 a	2.4 a	2.4 a
LW Cotton	1.3	1.0 a	1.5 a	1.3 a

_1/ Values in the same row followed different letters are statistically different at the 0.05 probability level according to Duncan's New Multiple Range Test.

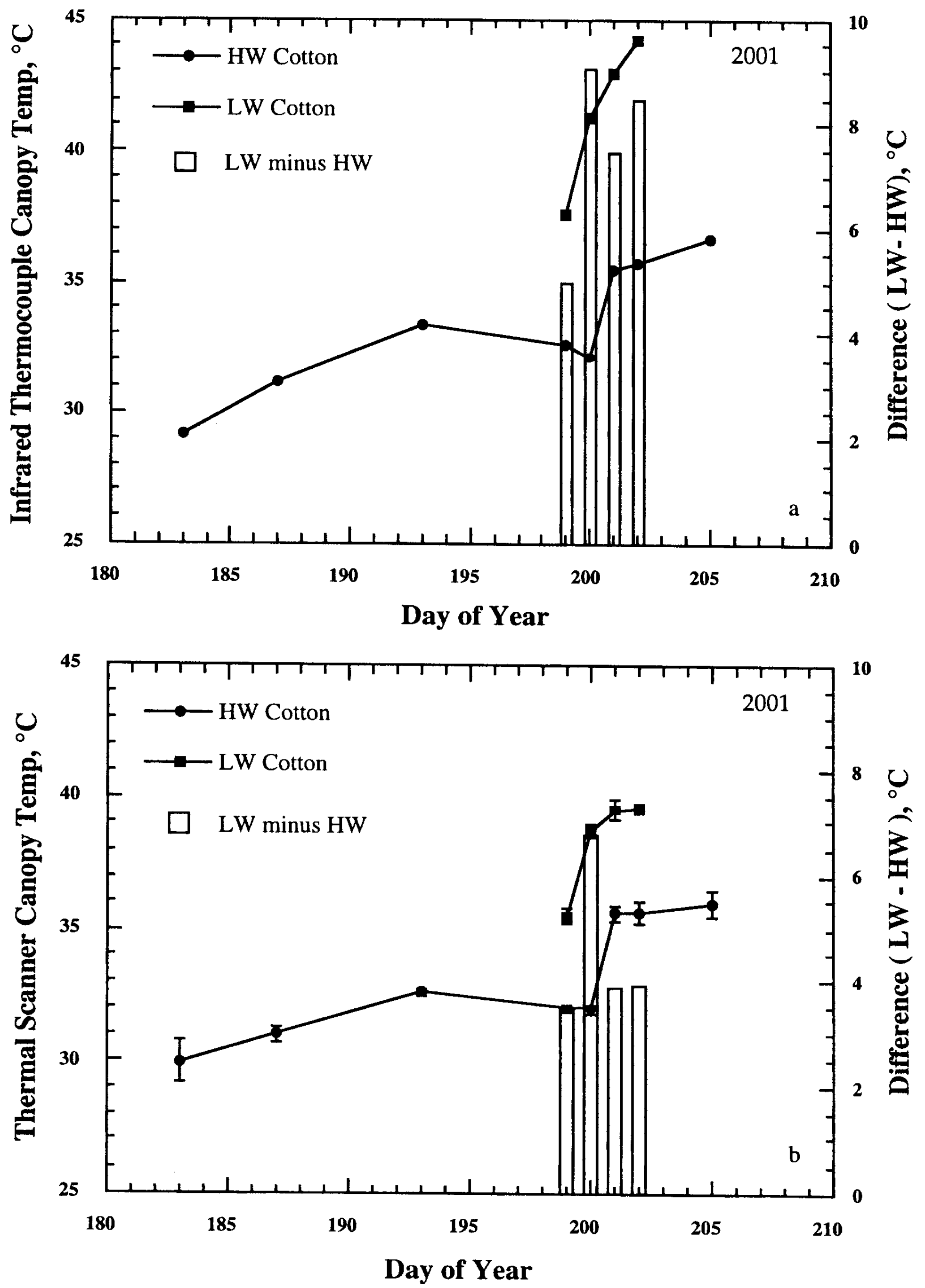

Figure 1. Comparison of canopy temperature measured with infrared thermocouple and thermal scanner sensors, 2001.

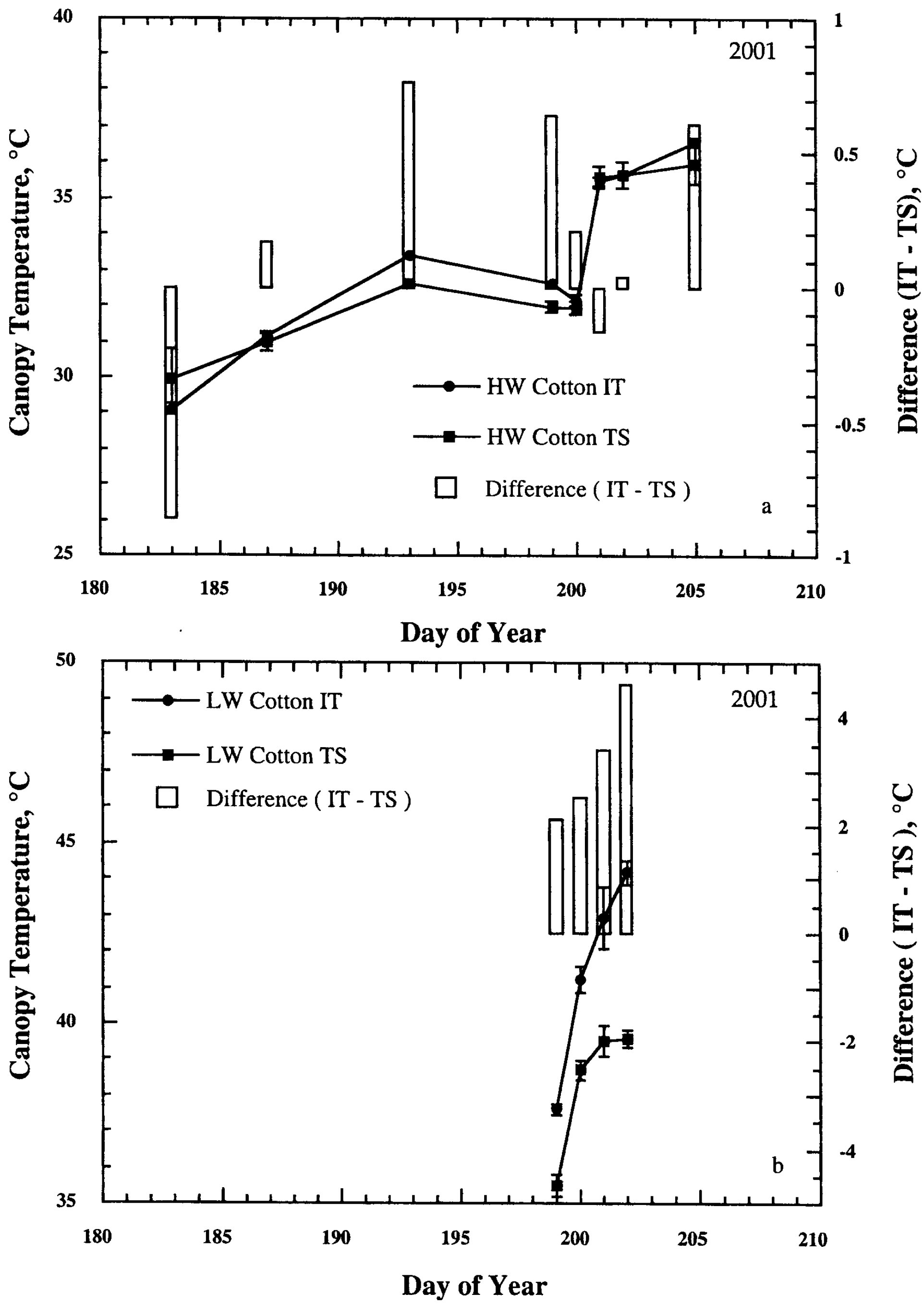

Figure 2. Comparison of canopy temperatures measured by infrared thermocouples and a thermal scanner within HW and LW water levels of cotton, 2001.

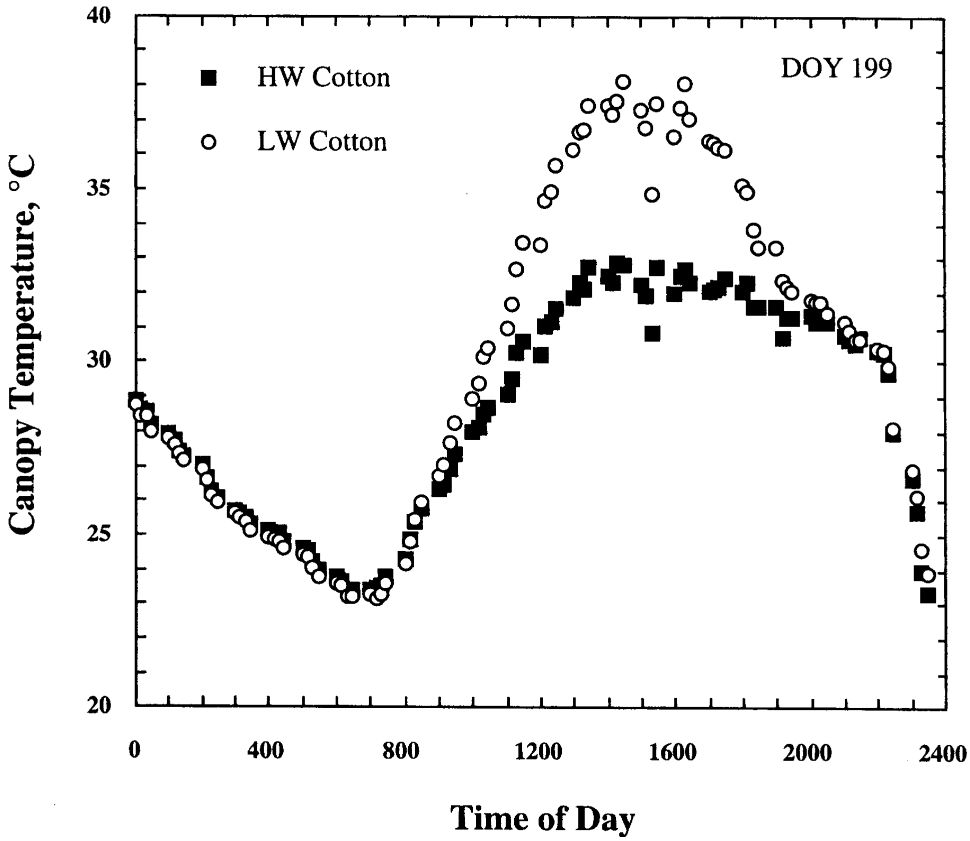

Figure 3. Canopy temperatures measured with infrared thermocouples indicate that different sensors in the HW and LW cotton were properly calibrated because night time temperatures were similar.

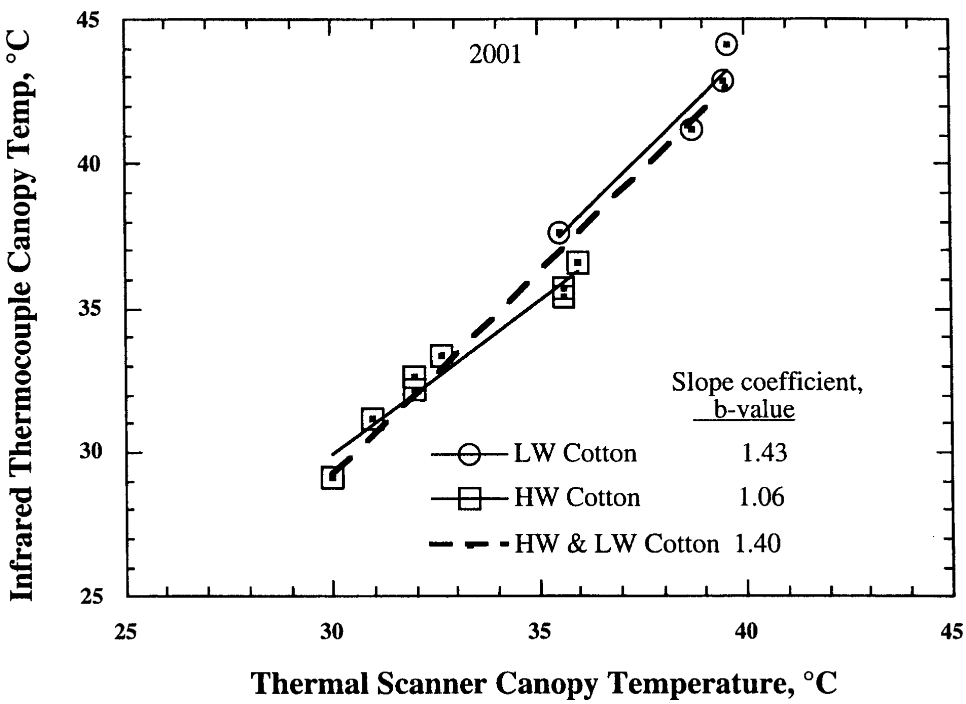

Figure 4. Relationship between canopy temperature measured with a thermal scanner and infrared thermocouples in HW and LW cotton, 2001.