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Measurement of Internal Temperature of Cotton Bolls

Evangelos D. Gonias* • Derrick M. Oosterhuis • Androniki C. Bibi

Department of Crop, Soil, and Environmental Sciences, University of Arkansas, 1366 Altheimer Drive, Fayetteville, AR 72704, USA

Corresponding author: * egonias@hotmail.com

ABSTRACT

Questions have arisen about the accuracy of the COTMAN accumulated heat units rule (i.e., 850 heat units after NAWF=5) to determine when to defoliate. It has been suggested that the actual temperatures of the developing bolls in the canopy may not be closely represented by ambient temperatures measured in a meteorological site. The objective of this field study was to measure the internal temperature of developing bolls and correlate it to ambient temperature. Internal boll temperatures were as much as 5°C warmer than ambient temperatures at midday and similar at night. There were no significant differences in boll temperature measurements recorded at different depths, 0.5 and 1.0 cm, in the boll, and there were no significant cultivar differences. A predictive equation was formulated to determine internal boll temperatures using ambient temperature data. Defoliation studies are required to determine the effect on yield and fiber quality when heat units are calculated based on ambient and internal boll temperatures.

Keywords: COTMAN, crop monitoring, *Gossypium hirsutum* L., heat units, infrared, thermocouple
Abbreviations: AT, ambient temperature; **BT**, boll temperature; **TC**, thermocouple; **IR**, infrared

INTRODUCTION

The heat unit (HU) concept is an integral part of the COTMAN crop monitoring program (Danforth and O'Leary 1998), i.e. for predicting the time after physiological cutout at nodes above white flower equal five (NAWF = 5) to insecticide termination and defoliation. However, some controversy and skepticism has arisen about the accuracy of the accumulated heat unit rule (i.e. 850 HU after NAWF = 5) to determine when to defoliate (Oosterhuis *et al*. 2008). This is because the accumulated heat units for timing defoliation (for optimum yields) have varied tremendously from year to year. It has been suggested that the actual temperatures of the developing bolls in the canopy may not be closely represented by ambient temperatures measured at a meteorological site.

Research on internal boll temperatures is limited and not associated with how those may affect decision making i.e. defoliation timing for optimum maturity of the last effective harvestable boll population at NAWF = 5. As reported by Anderson (1940), internal temperature of immature cotton bolls during the day, measured with a copper-constantan thermocouple inserted at the center of the cotton bolls, can be as much as 6-8°C higher than the ambient temperature. While at night the difference between ambient and internal boll temperature is not more than 1°C. Chu and Henneberry (1992) investigated the influence of ambient temperature, temperature at 30 cm below canopy top, vapor pressure deficit, solar radiation and wind velocity on internal boll temperature, measured by thermocouple thermometers. They concluded that temperature at 30 cm below canopy top, vapor pressure deficit, solar radiation and wind velocity only provided little additional precision in predicting internal boll temperature when used with the ambient temperature that alone accounted for 96.3% of the boll temperature variation. Internal boll temperatures should provide a more accurate indication of boll growth requirements for seed and fiber development and, therefore, for prediction of boll maturity. The objective of this study was to measure the internal temperature of developing cotton bolls and correlated it to ambient temperature. In addition, diurnal changes of boll temperature were evaluated. The knowledge from this study could help COTMAN crop monitoring predictions of boll maturity and also in studies of temperature effects on fruit metabolism.

MATERIALS AND METHODS

Two temperature measuring devices that can be used to measure boll temperature are the thermocouple (TC) and infrared (IR) thermometers. For the purpose of the study both types of equipment were tested. The equipment used in the study was a Raytek ST60 IR thermometer (Raytek Corporation, Santa Cruz, CA) and Extech 421502 TC thermometer (Extech Instruments Corporation, Waltham, MA), with a 0.6 mm diameter type K penetrating probe. Ambient temperature was recorded with a Kestrel 3000 handheld thermometer (Nielsen-Kellerman, Boothwyn, PA).

Measurements were conducted in 2004 and 2005 at the University of Arkansas Main Experimental Station, Fayetteville, AR. The cotton (*Gossypium hirsutum* L.) variety DP444 was used in both years of the study. Boll internal temperature measurements were taken between 1:00 pm and 3:00 pm in first-fruiting position bolls, five nodes from the top of the plant. The boll surface temperature was first taken with the IR thermometer and then the internal boll temperature was recorded with the TC thermometer. Ambient temperature was recorded after measurements were taken in 5 bolls. The IR thermometer was held 5 cm away of the cotton boll, while the TC thermometer probe was inserted 1 cm into the boll.

In 2005 a set of 6 commercial cultivars was used (ST5599BR, PM1218BR, DP555BR, FM960BR, ST5242BR, DP444BR). Measurements were taken with IR and TC thermometer on two different days in 15 bolls of each variety to investigate potential variety differences in internal boll temperatures.

In both years of the study diurnal changes in boll internal temperature were measured in tagged bolls every 2 hours starting at 7.00 am and finishing at 7.00 pm. The effect of the measurement depth in the boll was also investigated in both years. First the penetrating probe of the TC thermometer was placed 0.5 cm in depth and the temperature was recorded. Then the probe was inserted to 1 cm in depth and a second measurement was taken.

Statistical differences were detected using analysis of variance

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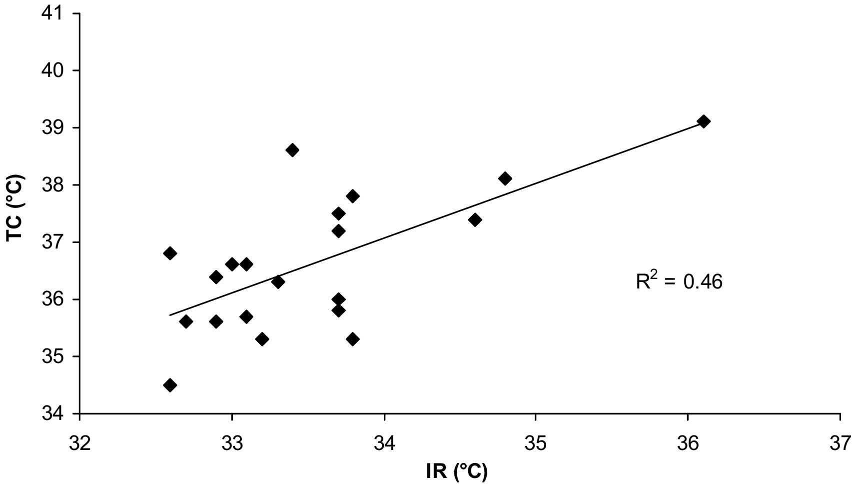

Fig. 1 Comparison of infrared (IR) to thermocouple (TC) thermometer. Measured at August 18, 2005. Ambient temperature was 33.4°C.

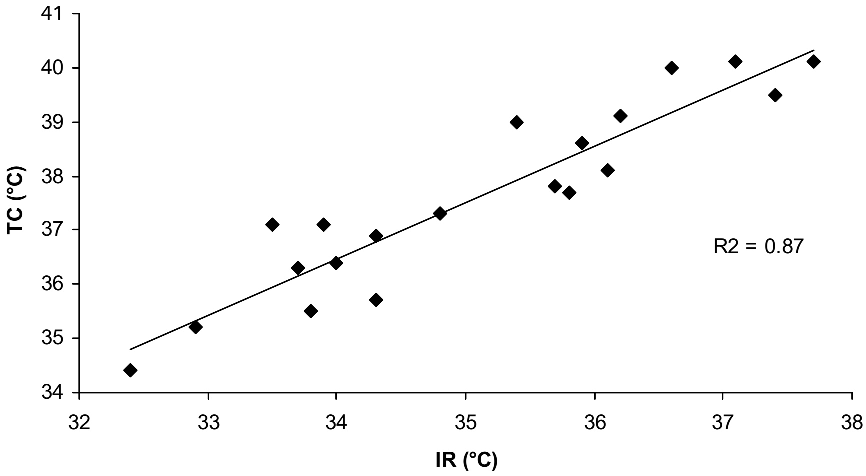

Fig. 2 Comparison of infrared (IR) to thermocouple (TC) thermometer. Measured at August 24, 2005. Ambient temperature was 32.6°C.

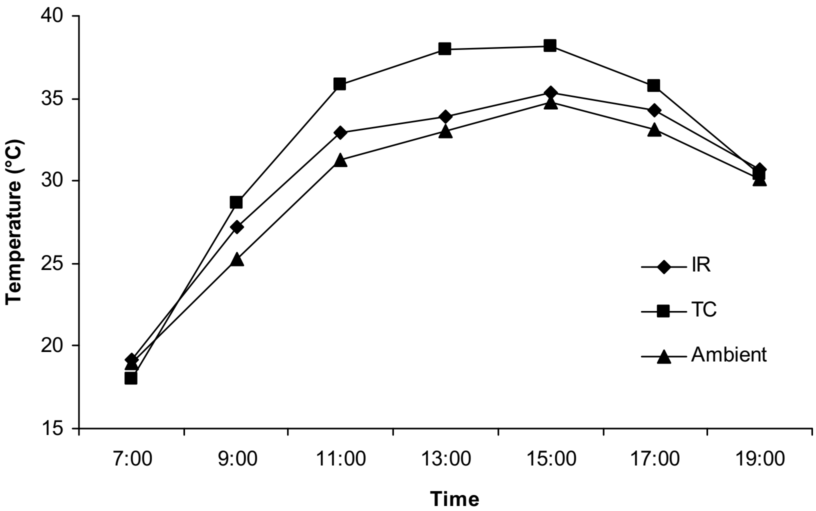

Fig. 3 Diurnal changes in ambient, boll surface (IR), and internal boll (TC) temperatures. Measured September 1, 2005.

(ANOVA). Data means were separated at probability values $\alpha \leq 0.05$. The statistical analysis was performed with JMP 6 software (SAS Institute Inc., Cary, NC).

RESULTS

Comparison of IR to TC thermometer

Although the IR thermometer provides an easy and fast measurement of cotton boll surface temperature, measurements made did not always correlate with internal boll temperature readings made by the TC thermometer (**Figs. 1, 2**). It appears that temperature readings of the IR thermometer, as in the case of **Fig. 1** are more variable (R^2=0.46) than readings made with the TC thermometer, possibly due to wind at the time of the measurement. Therefore, the TC thermometer is more appropriate to measure internal temperature of cotton bolls.

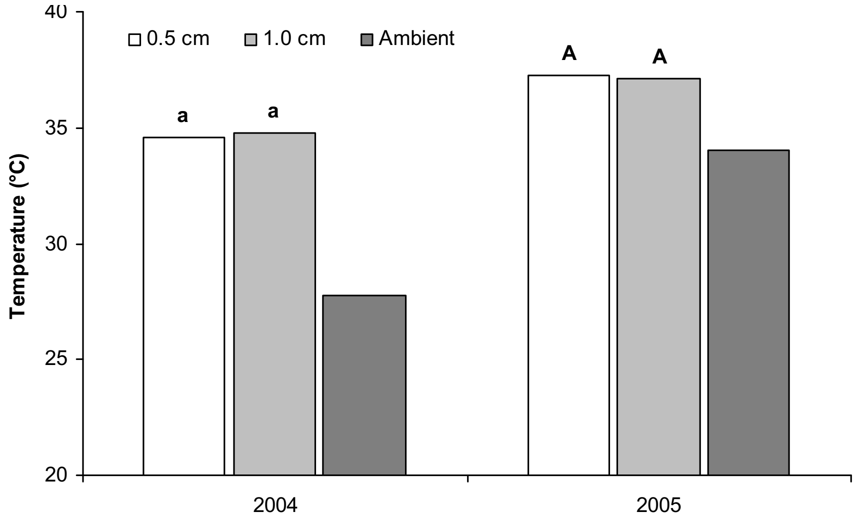

Fig. 4 Boll internal temperature at 0.5 and 1.0 cm in depth. Measured August 30, 2004 and August 21, 2005. Columns with the same letter within a year are not significantly (P=0.05) different.

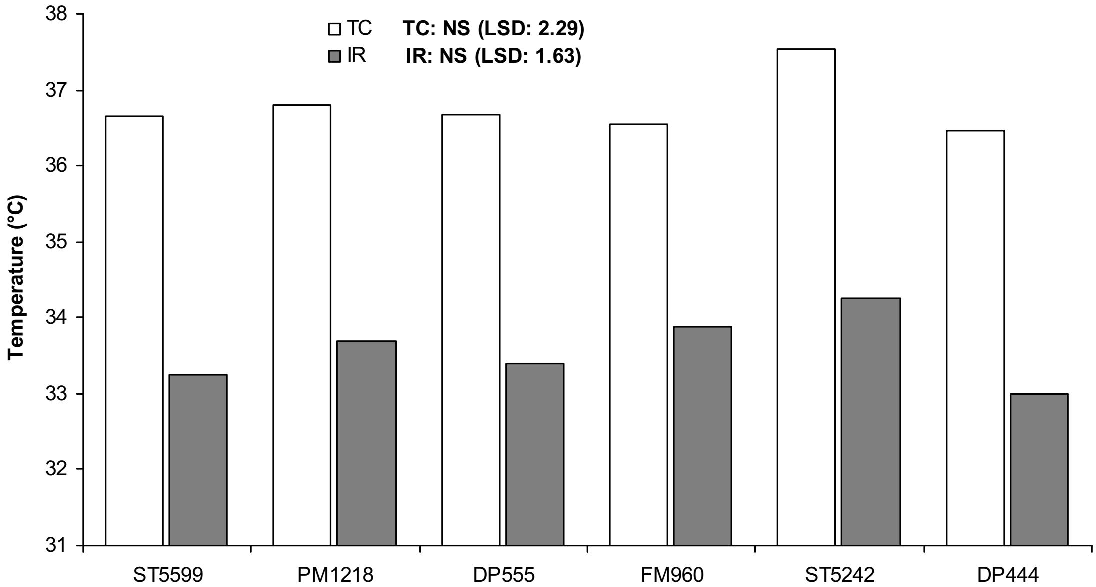

Fig. 5 Boll surface (IR) and boll internal (TC) temperature of six cultivars. Measured September 1, 2005. Ambient temperature was 32.9 °C.

Diurnal changes in boll temperature

Diurnal changes in the ambient temperature, boll surface temperature made by the IR thermometer, and internal boll temperature made by the TC thermometer are shown in **Fig. 3**. Internal boll temperatures were similar to the ambient early (7:00 am) and late (7:00 pm) in the day. However, boll temperature measured with the TC thermometer was as much as 5°C warmer than ambient temperature at midday. Whereas boll surface (IR) temperature did not differ more than 1°C to the ambient temperature.

Measurement depth

Boll temperature measurements made at 0.5 cm and 1.0 cm in depth with the TC thermometer were not significantly ($P \leq 0.05$) different in both years of the study (**Fig. 4**). At the time of measurement bolls were 7 and 3.1°C warmer than the ambient in 2004 and 2005, respectively.

Cultivar effect

The six cultivars used in this study did not show statistically significant differences ($P \leq 0.05$) in boll surface (IR) or boll internal (TC) temperatures on September 1, 2005 (**Fig. 5**). Similarly, no significant differences in boll temperatures were observed on August 21, 2005 (data not shown).

Predictive equation

The ambient temperature at the time of measurement (AT) and the average boll internal temperature (BT) for every day that measurements were taken were plotted in **Fig. 6**. From the graph the following equation was developed (R^2=0.81).

$$BT = 0.5298 \times AT + 19.387 \quad (1)$$

With the above equation internal boll temperature, for calculation of heat units, can be predicted by using air temperature data recorded by a weather station.

DISCUSSION

In this study instruments (thermocouple and infrared thermometers) for measuring cotton boll temperature were evaluated. Previously, thermocouple probes had been used for measuring internal temperature of cotton bolls (Anderson 1940; Chu and Henneberry 1992), flowers of alpine buttercup (*Ranunculus aboneus*) (Stanton and Galen 1989), and flowers of *Lotus corniculatus* (Jewell *et al*. 1994). In our studies, the TC thermometer provided a direct measurement boll internal temperature, but the IR thermometer provides an easier and faster method for estimating boll temperature. However, IR thermometer measurements (boll surface tem-

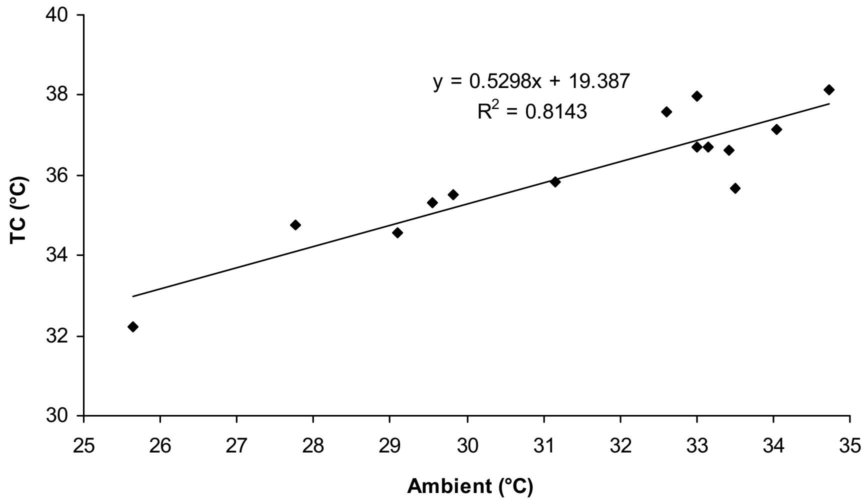

Fig. 6 Comparison of ambient to boll internal temperature.

perature) did not always correlate with values recorded by the thermocouple thermometer (**Figs. 1, 2**). Therefore, it was concluded that the TC thermometer is the more appropriate and accurate technique for measuring internal temperature of developing cotton bolls.

Although late and early in the day boll internal temperature was similar to ambient temperature, at midday cotton bolls were 5°C warmer compared to the ambient temperature over the crop. These diurnal changes of boll temperature were similar to previous reports by Anderson (1940), where internal temperature of cotton bolls was measured as much as 6-8°C higher than the ambient temperature during the day, while at night temperature differences were less than 1°C. Increased internal temperature, of several degrees above the ambient temperature, has been also shown in the flowers of an alpine buttercup (*Ranunculus aboneus*) (Stanton and Galen 1989). Similarly, dark-keeled flowers of *Lotus corniculatus* had internal temperature, measured by copper-constant and micro-thermocouple probes, higher than the ambient temperature (Jewell *et al.* 1994).

Boll internal temperature was not significantly affected by the measuring depth and cotton cultivars. Finally, ambient temperature recorded by a weather station can be used to estimate boll internal temperature using equation (1) developed in this project.

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