COTTON CANOPY TEMPERATURE AS A MEANS OF IDENTIFYING CROP STRESS AND ITS RELATIONSHIP WITH PHOTOSYNTHESIS AND YIELD

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Abstract

Cotton (*Gossypium hirsutum*) was grown at the Texas A&M University Research farm in Burleson County, TX under a sub-surface drip irrigation system during 2012 and 2013. The objective of the study was to demonstrate the usefulness of canopy temperature data to help identify crop stress in managing decision making in cotton production and its relationship with photosynthetic rates and final yield. Canopy temperatures were measured constantly throughout the growing season using infrared thermometers (IRTs). Photosynthetic-related measurements were taken with a LI-COR 6400 between 10:00am to 2:00pm in three different crop developmental stages and related to canopy temperature and final crop yield. For the specific environmental conditions during this study, we found strong linear relationships between canopy temperature and photosynthetic activity as well as canopy temperature and final yield across years, especially for plots subjected to some water availability limitation during the season (dryland conditions).

Introduction

Cotton crops all over the US Cotton Belt and other parts of the world are constantly under some type of environmental stress. Most plants growing under natural conditions, are more often than not, unable to express their full genetic potential (Boyer, 1982). Among abiotic stresses, high temperature stress is perhaps the most common, constant, and difficult to deal with. High temperatures such as 30/20 °C day/night have been implicated in causing fruit shedding in cotton (Reddy et al., 1991). While some fruit shedding is normally expected during the plant reproductive stage, excessive loss of such structures due to stress will negatively affect final crop yield. Technology has evolved very rapidly in the past few decades, enabling it to be applied in agriculture in a relatively cost-effective fashion. With the improvements in data acquisition equipment and widespread use of the Internet, farmers are now able to monitor various parameters of their crops in real time, without the need of physically being in the field. Infrared thermometers (IRT's) are used to monitor plant canopy temperature; sensors are relatively inexpensive and could provide valuable information about the efficiency of different irrigation regimes while also providing a possible stress index value.

Materials and Methods

The study was conducted at the Texas A&M University experimental farm in Burleson County, near College Station, Texas during the 2012 and 2013 cotton growing seasons. A single variety (Phytogen 499 WRF) was planted under a sub-surface drip irrigation system on 04/10/12 and 04/09/13, for 2012 and 2013, respectively. Experimental plots were arranged in a randomized complete block design with an irrigation split, namely dryland and irrigated (80% evapotranspiration replacement), with four replications. A total of 32 plots (four rows by 32') were established and the center pair harvested with a modified 2-row John Deere 9910 spindle harvester on 09/04/12 and 09/10/13, for 2012 and 2013, respectively. Additionally, one Smartcrop™ (Smartfield, Inc., Lubbock, TX) infrared thermometer (IRT sensor) was installed per plot to monitor crop canopy temperature. One SmartWeather™ (Smartfield, Inc., Lubbock, TX) station was also installed in the field, adjacent to the experimental field in order to capture and record relevant weather information. Furthermore, photosynthetic-related data was collected using a LI-COR 6400 (LI-COR, Inc., Lincoln, NE) in three distinct plant stages; early bloom (EB), full bloom (FB), and open boll (OB). Data was collected for the 3rd uppermost fully expanded leaf in three different plants for each plot between the hours of 10:00am and 02:00pm.

Results and Discussion

The total amount of rainfall for the experimental site during 2012 was 41.1 inches, while 2013 rainfall total was 38.59 inches, both years totals being fairly close to the 13-year average (Fig. 1). In 2012, roughly half (19.8 inches) of the total precipitation fell within the growing season (from 04/10/12 through 09/04/12), while in 2013 the total rainfall within the season was 7 inches lower (12.8 inches).

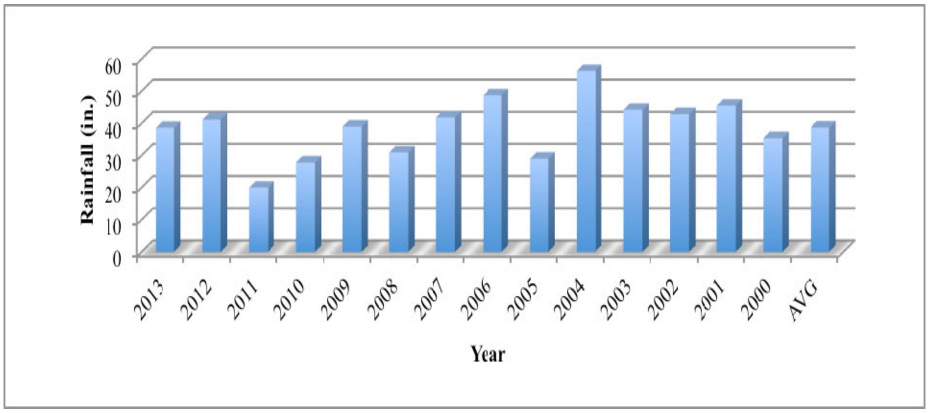

Figure 1. Historical 13-year rainfall totals for the experimental site, including 2012 and 2013. The 13-year average is shown on the far-right side.

As shown on Fig. 2, the majority of total daily rainfall for 2012 was around 0.1 to 0.4 inches, rainfall events were very well distributed along the season, and coupled with a few more intense events, were able to maintain soil moisture. For this particular season, rainfall was not considered to be a strong limiting factor for cotton growth and development. Rainfall during the growing season for the following year (2013) totaled at 12.8 inches. Contrasted with 2012, 2013 rainfall was marked by a greater frequency and volume within the first half of the period studied, however, like previously mentioned, 7 inches lower within the whole growing season. Statistical analysis of water potential measurements failed to demonstrate any significant differences, at the 5% level of probability, among plots within the same irrigation regime (e.g. between plots grown under dryland conditions) for either year studied.

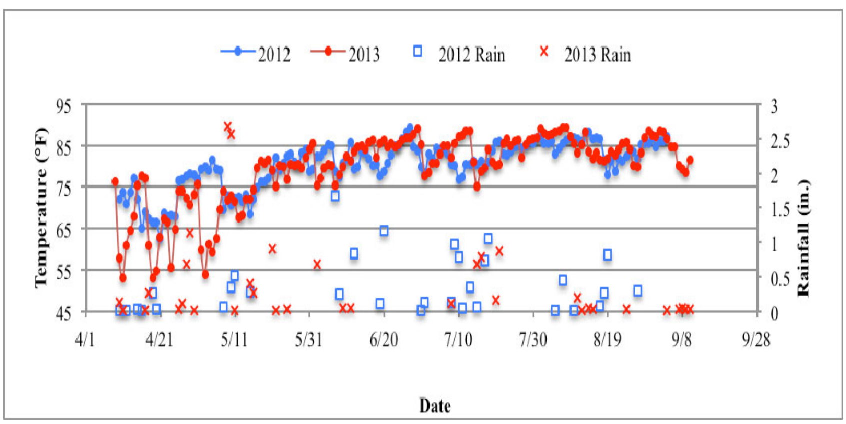

Figure 2. Graph shows average ambient temperature as well as rainfall totals and its distribution within the growing season for both years of the study (2012 and 2013).

Figures 3 and 4 shows regression of canopy temperature and photosynthetic activity. Data for 2012 and 2013 are combined for dryland and irrigated conditions in figures 4 and 5, respectively. Photosynthetic activity was measured with a LiCOR 6400 between the hours of 10:00am and 2:00pm in three different stages (early bloom, full bloom, and at harvest). The canopy temperature data is shown as the average value registered between 10:00am and 2:00pm, on the same dates when photosynthetic activity was measured. The coefficient of determination (R^2) for dryland plots is fairly high at 0.71. The red arrow shown indicates plant maturity (from early bloom to harvest) and also a trend, meaning: Photosynthetic activity was higher at the early bloom stage, and decreased as the crop aged. Higher photosynthetic activity was registered early in the reproductive phase (EB), while lower values were found at the harvest stage (OB). Canopy temperature followed the opposite trend. Lower values were found at the early bloom stage, and canopy temperature increased as the season progressed, such that highest values were found at the open boll stage. The same trend was visible when irrigated plots data was combined (2012 + 2013), however, it is important to note that the coefficient of determination (R^2) is 0.59, roughly 10% lower than that of the dryland plots. Photosynthetic activity range seems to be similar for both dryland and irrigated plots; however, canopy temperature of irrigated plants was, in general, always lower than their dryland counterparts.

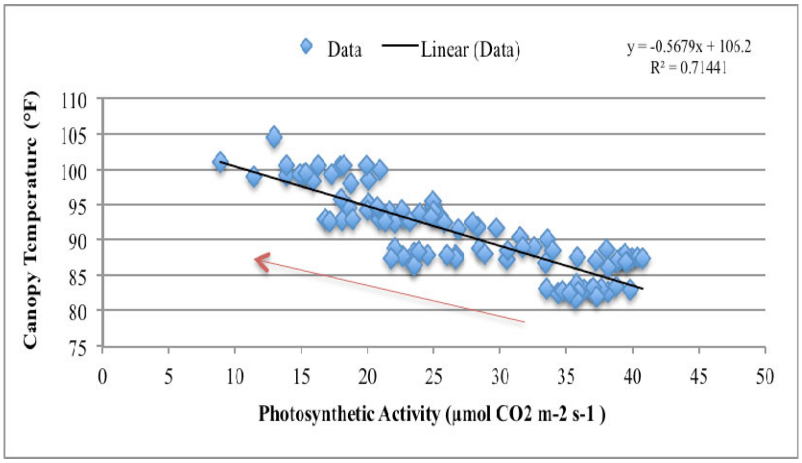

Figure 3. Regression of canopy temperature and photosynthetic activity for dryland plots. Data for canopy temperature is an average from 10:00am to 2:00pm in specific days to match photosynthetic data collection. 2012 and 2013 dryland plots data are combined. Red arrow indicates maturity (crop aging).

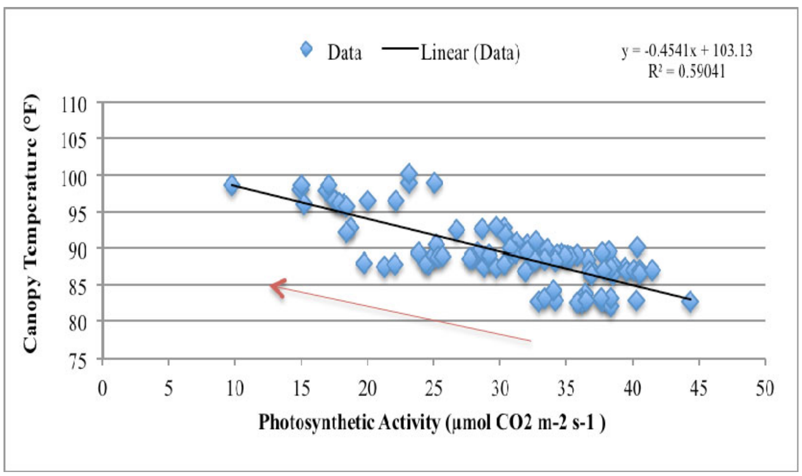

Figure 4. Regression of canopy temperature and photosynthetic activity for irrigated plots. Data for canopy temperature is an average from 10:00am to 2:00pm in specific days to match photosynthetic data collection. 2012 and 2013 irrigated plots data are combined. Red arrow indicates maturity (crop aging).

The IRT data shown on figure 5 was collected at the early bloom stage and combined across years according to their respective irrigation scheme (i.e. dryland and irrigated). Graph shows a clear yield separation between 2012 and 2013. It is also interesting to note that in 2012, yields were higher and canopy temperatures had a smaller range. In 2013 yields were lower and canopy temperature range was greater. Irrigated plots yielded more than dryland plots, especially in 2013, where a more effective differential irrigation (i.e. dryland vs. irrigated) could be applied. Similar to what happened in figures 4 and 5, the R^2 value is higher for dryland than for irrigated plots. This may indicate that canopy temperature is a better predictor of photosynthetic activity and yield when the crop is under some drought stress.

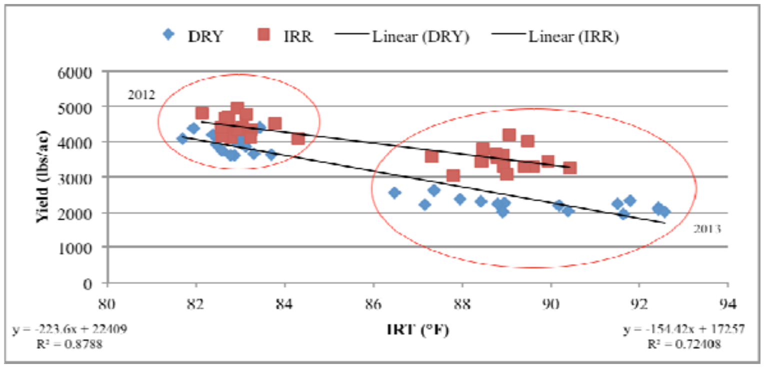

Figure 5. Regressions of yield and canopy temperature. Graph shows combined data for 2012 and 2013. Linear equations and R^2 are displayed on the bottom of the graph for dryland and irrigated plots, left and right, respectively.

Pearson's correlation coefficient shows a negative correlation between canopy temperature and photosynthetic activity (IRT/Photo) and final crop yield and canopy temperature (Yield/IRT), meaning that changes in those variables follow a trend, such that as canopy temperature increases, photosynthetic activity decreases (Table 1). Also, yield tends to increase as canopy temperature decreases. Correlations did not yield consistent results across years, perhaps due to differences in environmental conditions (rainfall) during the growing season. When we look at IRT/Photo, the combined data (ALL I+D) shows a highly significant correlation between the two variables, for both years of the study. Yield/IRT was only significant in 2012 when data collected at the OB stage was combined (dryland + irrigated). For 2013, Yield/IRT were significantly correlated early in the reproductive phase (EB) when data was combined (I+D), and for dryland (D) plots. Like in 2012, Yield/IRT was also significant in 2013 at the OB stage with irrigated and dryland plots data combined (I+D). Additionally, both variables were significantly correlated when data collected throughout the season was combined.

Table 1. Correlation coefficients between some of the parameters measured. For this study, we would like to draw your attention to the IRT/Photo (canopy temperature/photosynthetic activity) and Yield/IRT (final yield/canopy temperature) columns. EB (early bloom); FB (full bloom); OB (open boll); ALL (all three stages combined); I (irrigated); D (dryland); I+D (irrigated + dryland combined); r (Pearson's Correlation Coefficient); * Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.0001$

Year	Stage	Irrigation	n	IRT/Photo r	Yield/Photo r	Yield/IRT r	Fluoro/Photo r	Fluoro/IRT r	Fluoro/Yield r
2012	EB	I+D	32	-0.0988	0.1901	-0.1293	-0.0683	-0.3854*	0.3495*
2012	EB	D	16	0.1422	0.3291	-0.3465	-0.1663	-0.6221*	-0.0814
2012	EB	I	16	-0.2793	0.1039	-0.3476	-0.0456	-0.2452	0.681**
2012	FB	I+D	32	0.158	0.1305	-0.0494	0.0744	-0.1413	-0.029
2012	FB	D	16	0.1964	0.0787	0.0026	0.1225	-0.2745	0.1234
2012	FB	I	16	0.1414	-0.0845	-0.197	0.1412	-0.0187	0.3131
2012	OB	I+D	32	-0.2401	0.263	-0.5897**	-0.2648	0.6966***	-0.6202**
2012	OB	D	16	-0.2264	-0.0071	-0.3134	-0.0685	0.2517	-0.3696
2012	OB	I	16	0.1601	0.1187	-0.1972	0.0966	0.4154	0.0341
2012	ALL	I+D	96	-0.8921***	0.0606	-0.0593	0.183	-0.4127***	-0.1589
2013	EB	I+D	32	-0.1148	0.1291	-0.3771*	0.0776	0.1529	-0.0449
2013	EB	D	16	-0.1698	-0.2912	-0.6778**	0.1292	0.2698	-0.1212
2013	EB	I	16	0.1737	-0.2665	0.0063	0.0947	0.0065	0.2131
2013	FB	I+D	32	-0.2217	0.4044*	-0.2493	0.1461	-0.2372	0.633***
2013	FB	D	16	-0.5581*	-0.1365	-0.1132	-0.0105	-0.2635	0.3435
2013	FB	I	16	0.1001	0.1202	-0.3718	-0.1106	-0.0914	0.5826*
2013	OB	I+D	32	-0.8014***	0.8073***	-0.8712***	-0.6411***	0.6509***	-0.7479***
2013	OB	D	16	0.0114	-0.3532	-0.0602	0.0155	-0.3569	-0.1511
2013	OB	I	16	-0.054	0.2364	-0.0957	-0.0171	0.2356	-0.3403
2013	ALL	I+D	96	-0.482***	0.4517***	-0.4556***	-0.1613	0.187	-0.115

Despite the differences in environmental conditions across years, canopy temperature as measured by IRT's seem to have a strong linear relationship with both photosynthetic activity and final yield, especially when the crop was grown under dryland conditions. However, before any conclusions can be made regarding these relationships, we believe further investigation in a more controlled environment (i.e. greenhouse) is appropriate. Furthermore, due to its potential, long-term monitoring of canopy temperature for specific varieties/locations could prove to be beneficial. Generating such database could possibly provide valuable insight into the different varieties ability to cope with high temperature stress under contrasting environmental conditions.

Acknowledgements

The authors would like to gratefully acknowledge the financial and/or technical support from AgroFresh, Smartfield, Cotton Incorporated, Texas State Support Committee, and the Department of Soil and Crop Sciences at Texas A&M University. Technical support from Jonathan Moreno, Landon Crotwell, Jordan Maldonado, Steven Garcia, Henrique Carvalho, Hunter Teel, and Zachary Zemanek is also appreciated.

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