FINAL PROJECT REPORT
WTFRC Project Number: TR-06-606

Project Title: Irrigation Automation Using Infrared Temperature Sensors

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Other funding Sources

Agency Name: **None**
Amount awarded:
Notes:

Total Project Funding: $40,000

Budget History:

Item	**Year 1:**		
Salaries	19,716		
Benefits	6,703		
Wages	2,987		
Benefits	344		
Equipment	7,250		
Supplies	1,000		
Travel	2,000		
Miscellaneous			
Total	40,000		

Objectives

The objectives of this research was to investigate an automatic irrigation scheduling system with a feedback and control loop using infrared temperature sensors on apple trees. At the same time we investigated the possibilities of using canopy temperature as sensed by the same sensor to automatically control irrigation for cooling. This preliminary study is taking place at the Washington State University Irrigated Agriculture Research and Extension Center in Prosser, WA on a small research block of Fuji apple trees. This first year will be spent purchasing equipment, setting up the experiment, testing hardware configurations and sensor positioning, writing software, testing correlations with the FST sensor and otherwise getting preliminary results. This experiment is planned such that it will lead into two additional years of tests in a commercial orchard on apple trees where the fully automatic experiment will be implemented to get comparative data over several seasons.

The specific objectives and the progress that has been made towards completing those objectives are as follows:

1. Purchase necessary equipment and tools
2. Hire technician level II
3. Install equipment in the field
4. Complete short-term experiment to correlate canopy temperature with fruit surface tree temperature sensor
5. Write automatic control algorithms and data logging software
6. Test hardware configurations
7. Test IR sensor view angles, mounting height, and mounting configurations
8. Test software and automatic control algorithms using mock-up data
9. Collect and analyze preliminary data for defining/refining time and temperature thresholds
10. Look for opportunities to expand usefulness to automatic cooling

Significant Findings

- Infrared temperature sensors can be used to determine stress in fruit trees.
- The parameters necessary for automatic irrigation scheduling using the time-temperature-threshold (TTT) method of irrigation scheduling were determined.
- In order to get accurate canopy temperature measurements either two sensors must be used to look at both sides and averaged, or a sensor placed looking straight down on a tree must be used. If the sensors are oriented this way, row orientation is not critical.
- Canopy temperature correlates very well with temperatures from a fruit surface temperature (FST) sensor. This shows promise for using canopy temperature data to automate evaporative cooling.

Results and Discussion

Sensor Orientation

Temperature differences from sensors pointed downwards at approximately 45 degree angles looked at both the north and south (Figure 1) sides of a tree, and both the east and west (Figure 2) sides of a tree. Because the difference was significantly different from zero either two sensors must be used to look at both sides of a tree and averaged, or a sensor must be placed such that it looks straight down on the top of the tree.

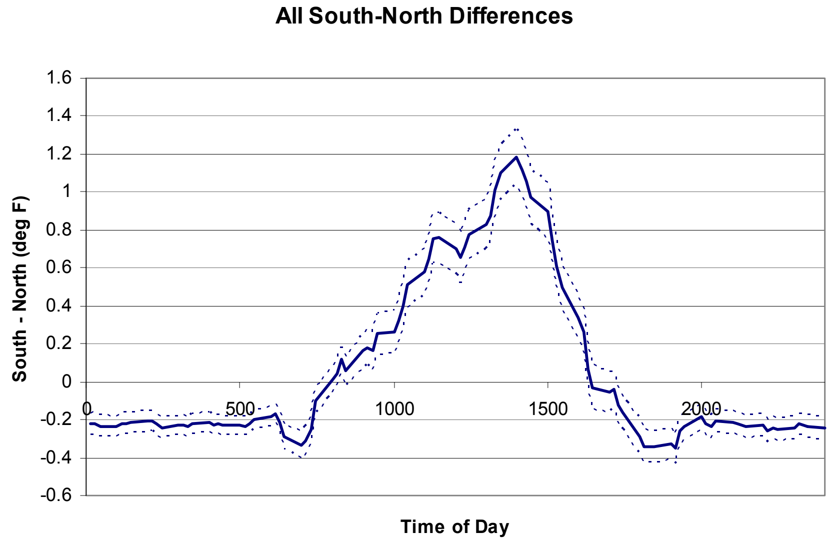

Figure 1. The mean temperature difference between the south and north (south - north) sides of the tree at different times of day. The dotted lines are the 95% confidence interval on the mean.

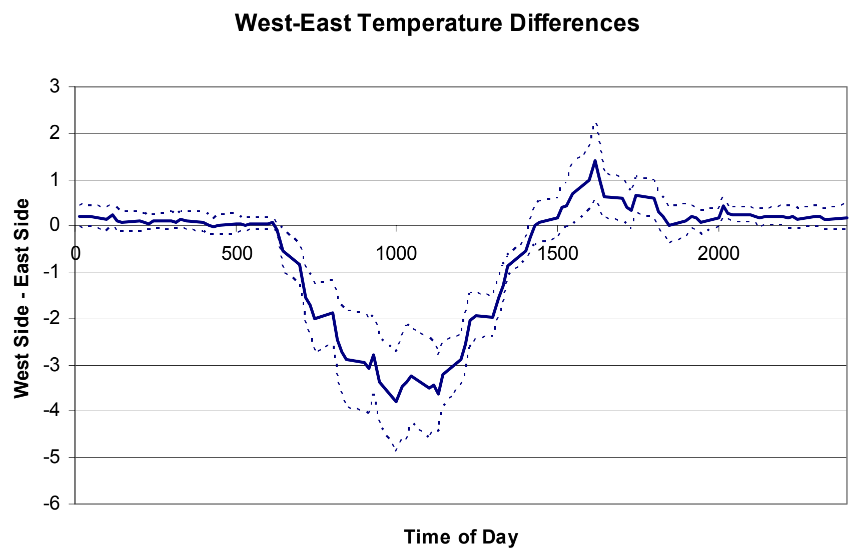

Figure 2. The mean temperature difference between the west and east (west - east) sides of the tree at different times of day. The dotted lines are the 95% confidence interval on the mean.

A fruit surface temperature (FST) sensor was installed in the field with the canopy temperature sensors. These were averaged and plotted over the course of a day (figure 3) and also plotted against each other (figure 4) to look at the correlation between the two.

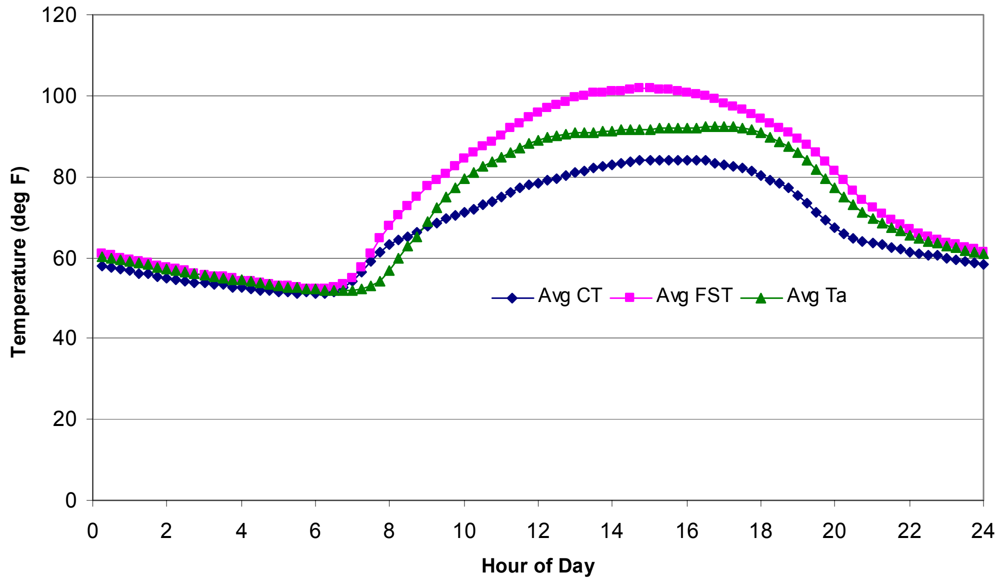

Figure 3. Average canopy temperature (CT), air temperature (Ta) and readings from the fruit surface temperature (FST) over the course of a day. Many days during the hot parts of the summer were averaged.

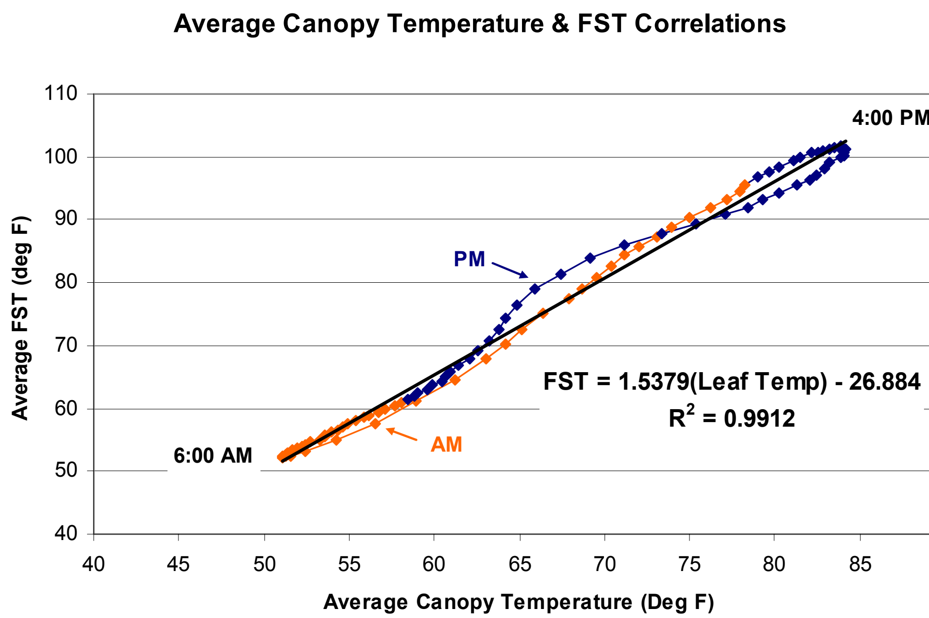

Figure 4. Correlation of canopy temperature with the fruit surface temperature (FST) sensor.

Many days during the hot parts of the summer were averaged.

Hysteresis is evident from both figures 3 and 4. This has to do with the differences in a canopy temperature sensor's ability to see both sunlit, and shaded canopy and fruit and the greater thermal mass of the FST compared with relatively small thermal mass of leaves. Fruit surface temperature can be predicted from canopy temperature using the equation:

$$FST = 1.538 \times T_l - 26.89$$

Where *FST* is the fruit surface temperature, T_l is the canopy or leaf temperature and all measurements are in deg F.

The correlations between FST and canopy temperature were examined over time to see if they changed as the weather cooled down (Figure 5). The correlation between the two remained fairly constant over time.

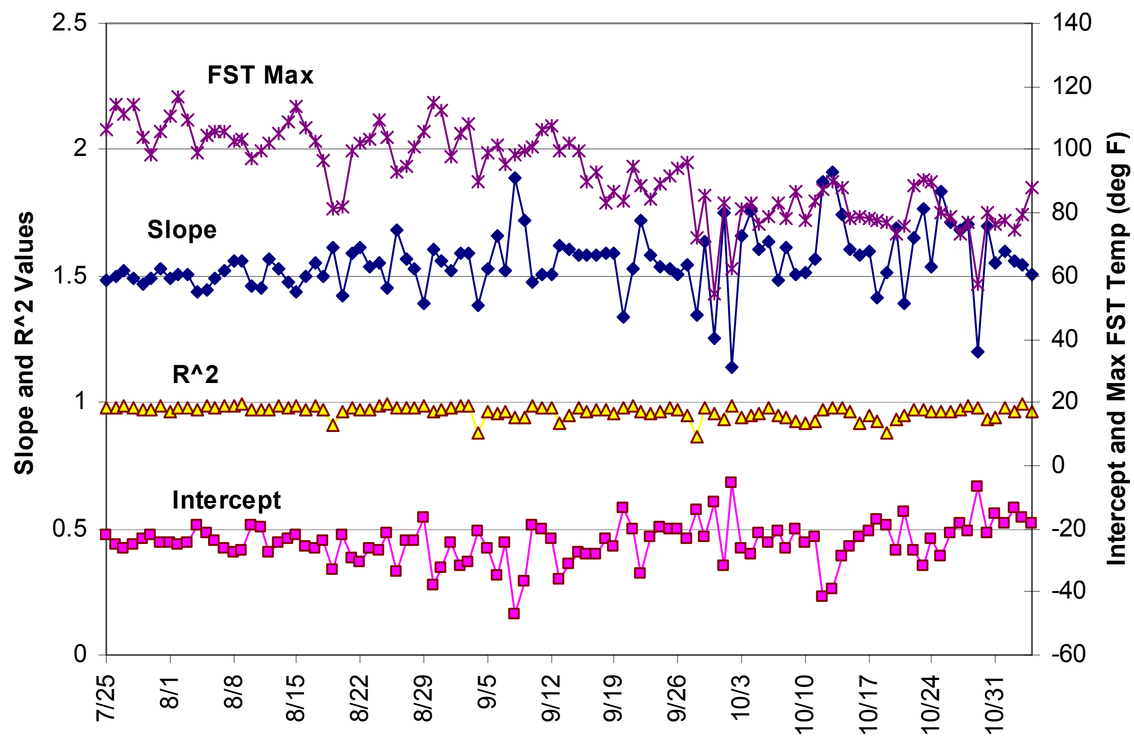

Figure 5. Daily correlations between canopy temperature and the fruit surface temperature (FST) sensor are plotted over time along with the maximum fruit surface temperature reading.

It was also important to determine whether canopy temperature could detect tree stress. To do this the water was turned off to half of the trees and the other half were fully irrigated. Leaf water potential readings were taken (2 readings from each tree) at eight different times throughout the season. Figure 6 shows that there were differences in these readings and Table 1 shows that these differences were significant at the 0.05 level on all occasions except the readings taken on 8/21/07. This date had one outlying point that caused the variance to be very high and weakened the test for significant differences. These significant differences coincided with clearly measured canopy temperature differences on those days (Figure 7). This demonstrates that canopy temperature can show tree water stress.

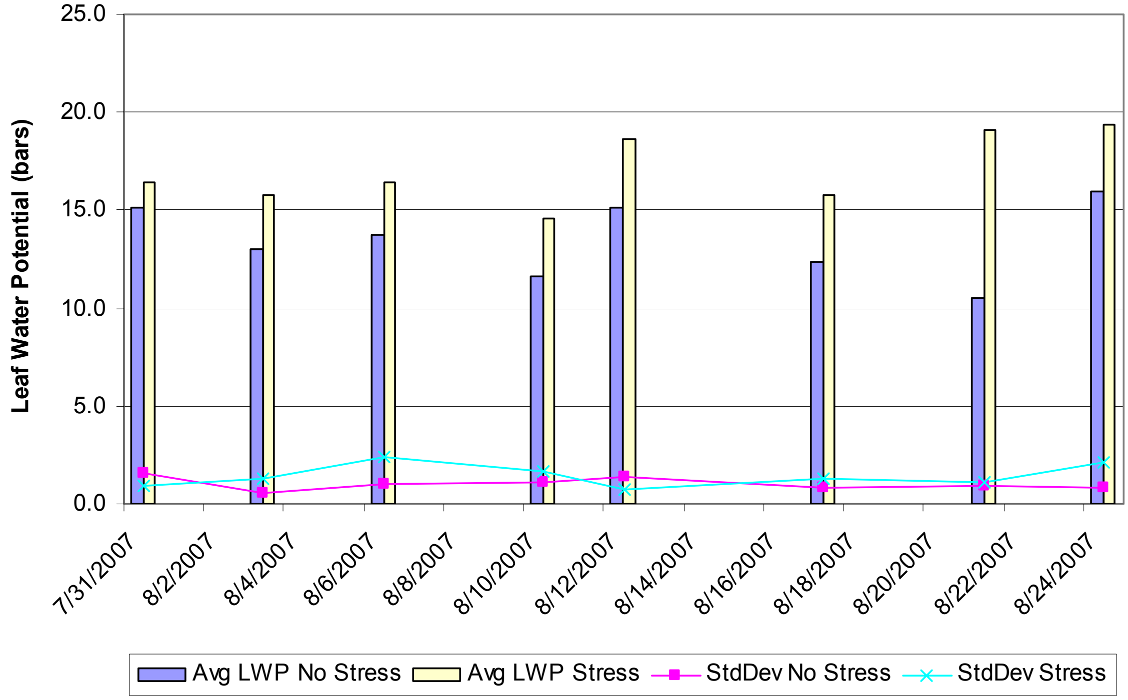

Figure 6. Comparison of the average leaf water potential (LWP) reading (in bars) from water stressed trees and trees that did not have water stress. The standard deviations of these readings are also plotted. Values given in Table 1.

Table 1. The average leaf water potential (LWP) readings (in bars) from water stressed and non-stressed trees. Variances for these parameters are given for comparison along with the probability that the differences were significantly different from zero.

Date	Avg LWP No Stress	Avg LWP Stress	Variance No Stress	Variance Stress	P(T<-t)
7/31/07	15.2	16.5	3.74	1.10	0.01807
8/3/07	13.0	15.7	0.57	2.13	0.00002
8/6/07	13.8	16.4	3.55	7.40	0.00062
8/10/07	11.6	14.5	1.52	3.54	0.00025
8/12/07	15.1	18.6	4.82	1.11	0.00015
8/17/07	12.4	15.7	1.15	2.01	0.00002
8/21/07	10.5	19.1	1.33	375.25	0.08166
8/24/07	16.0	19.4	0.98	5.42	0.00045

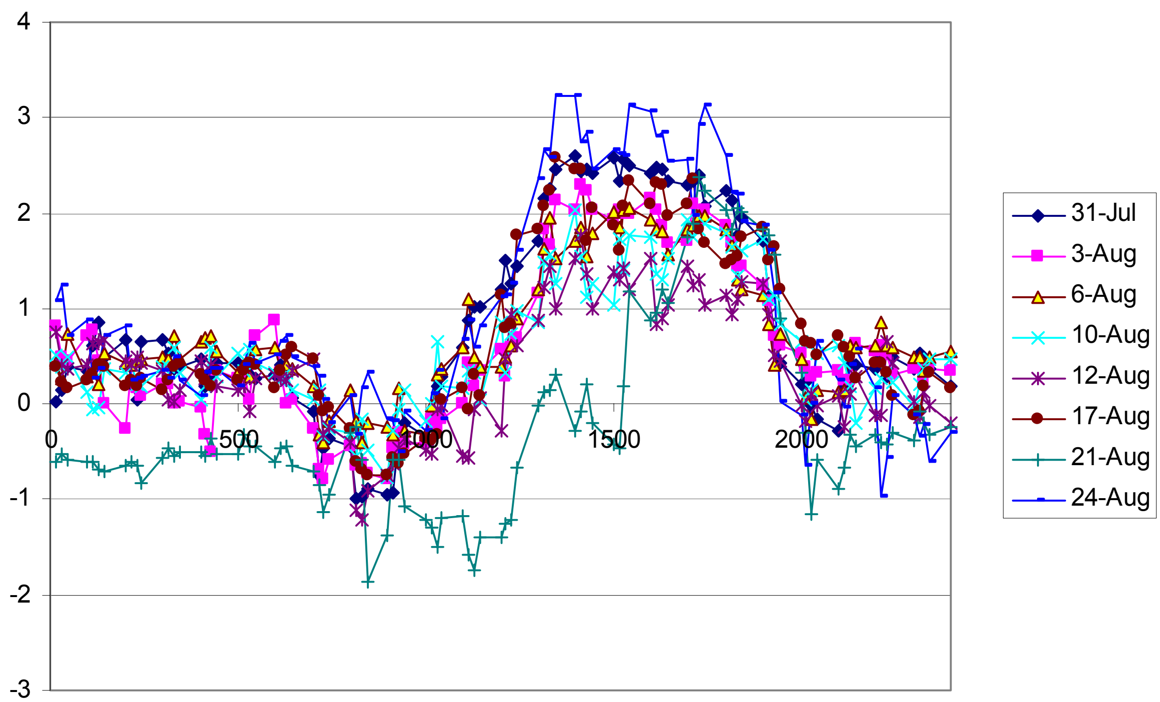

Figure 7. On the days that the leaf water potential readings were taken the average canopy temperature difference is also given (in deg F).

In order to determine the temperature and time thresholds for automating irrigation scheduling using the time temperature threshold (TTT) method of irrigation scheduling apple tree leaves were collected, sealed and sent overnight in a refrigerated envelope to the lab in Lubbock Texas where the original research on the TTT method was done. The leaves were frozen in liquid nitrogen and enzyme assays are being performed on these leaves. The theoretical temperature threshold given was 50 deg F. Although this seems low the time threshold needed to schedule irrigations at that temperature threshold was determined (Table 2). Other time thresholds are also given for other temperature thresholds.

Table 2. Time thresholds for different temperature threshold values. Times given in minutes and hours.

Temp Threshold (deg F)	Time Threshold (min)	Time Threshold (hrs)
50	1035	17.25
59	720	12.00
64	540	9.00
66	480	8.00
68	435	7.25
70	315	5.25
72	225	3.75