# SPATIAL CANOPY TEMPERATURE MEASUREMENTS USING CENTER PIVOT MOUNTED IRTS

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## ABSTRACT

Crop canopy temperature is useful as an indicator of plant water stress and possibly a good measurement to use as an irrigation schedule initiator. To help determine the feasibility of using canopy temperature to control irrigation events, 26 infrared thermometers (IRTs) were mounted along the main structure of a 3-tower, 137-m center pivot irrigation machine. The center pivot provided a platform to conduct spatial canopy temperature measurements over a 6-ha field that contained 12 different soil mapping units. The IRTs were mounted in pairs, for thirteen, 9.1-m segments along the center pivot. During the 1999 corn growing season, data were acquired on eight separate days during the grain fill period of an irrigation and nitrogen fertilizer rate experiment that consisted of 396 plots arranged in randomized blocks within the 12 soil mapping units. The IRT data were collected during a single pass of the center pivot, at mid-day during mostly sunny conditions. Data were collected and stored using a data logger and a PC mounted on the center pivot. Individual canopy temperature values were stored and later corrected using calibration values for each IRT. Data were then adjusted for temporal data slew caused by time-of-day effects. Measurement techniques, data adjustment algorithms, and sample data are reported. The quadratic relationship of adjusted canopy temperature and irrigation rate, for a day when the non-irrigated plots were under stress, indicates that approximately 65 to 95% of the variation across the 12 mapping units could be explained. For data acquired two days after a 41-mm rain, the relationship explained approximately 30 to 80% of the variation across the soil mapping units. Hence, there is a possibility of determining the relative soil water status using multiple, inexpensive IRTs.

**Keywords:** Infrared thermometer, canopy temperature, irrigation scheduling, drought stress

## INTRODUCTION

The southeastern USA Coastal Plain contains highly variable soils (including numerous shallow depressions of varying sizes), and also has highly variable rainfall. Even though the average annual rainfall is > 1000 mm, much of the summer rain occurs during thunderstorms and is highly variable from month to month and year to year. In the past 15 years at Florence, SC, the May rainfall has ranged from 14 to 122 mm, the June rainfall from 34 to 203 mm, and the July rainfall from 35 to 201 mm. These values were consistent with Sheridan et al.'s (1979) report of a 50% probability of a 22-day drought during the growing season.

The combination of limited rainfall, sandy soils, and high ambient temperatures can lead to severe plant water stress. One way to avoid plant water stress is to apply irrigation water; however, when and how much to irrigate are sometimes difficult to determine. Irrigation scheduling is not only important for timing, but also for water use efficiency. Of the many methods available for determining irrigation needs, soil-based measurements (soil water potential, soil water content, etc.), crop-based measurements (canopy temperature, leaf rolling index), and crop and/or evapotranspiration models (which have a varying array of inputs) are commonly used in this region.

This paper will focus on the use of crop canopy temperature as an early indicator of irrigation needs. The variation in canopy temperature increases with drought stress and was suggested by Aston and Van Bavel (1972) as an early indicator of need for irrigation. The challenge is to acquire the canopy temperature data at a spatial scale to show this variation. In a field study in 1993, Sadler et al. (1995) showed a 20 $^{o}$C change in canopy temperature in just a 50-m distance along one corn row. Another challenge is to acquire the data in a timely manner and have the results available for real-time irrigation decision-making. One approach to solve these problems, used by Upchurch et al. (1998), was to mount infrared thermometers (IRTs) on the center pivot itself.

Our purpose for this study was to collect spatially dense canopy temperature data of a corn crop using a 3-tower center pivot as a transporter for multiple infrared thermometers. An added advantage to this system was the ability to collect these data during an agronomic experiment with different irrigation rates that was situated on a field with 12 different soil map units. This provided the possibility of sensing plant water stress and showing how well-watered treatments relieved these drought symptoms across variable soils.

## MATERIALS AND METHODS

Twenty six IRTs were mounted along a 3-tower, 137-m center pivot irrigation system that had been modified for site-specific application of water and nutrients. The center pivot was divided into 13 segments, each 9.1 m in length. Details of the center pivot modifications can be found in Camp et al. (1998) and Omary et al. (1997). Two IRTs were placed near the opposite ends in each of the 13 segments, with each IRT pointed toward the center of the segment. The IRTs were mounted on adjustable masts and booms, and for this study, the IRTs were placed approximately 3 m forward of the center pivot main structure and approximately 1.5 m above the crop. The IRTs were aimed approximately 45$^{o}$ downward and 45$^{o}$ inward toward the crop rows. This positioning resulted in a canopy temperature ‘footprint’ centered approximately 2.5 m from each side of the 9.1-m segment. The goal was to acquire a canopy temperature at the center of each 6-row planter pass to avoid any plot edge effects. The IRTs used were Exergen Irt/c .3X with a 3:1 field of view and type K thermocouple leads (Exergen Corp., Newton, MA[1]). These IRTs had a published accuracy of +/- 2% and cost approximately $210 US in 1996.

The IRT data were collected using a CR21X datalogger (Campbell Scientific Inc., Logan, UT) mounted on the last tower of the center pivot. Data signal multiplexors were mounted at the two inner towers to decrease the amount of thermocouple cable needed. Data were collected on 15-sec intervals, which provided a canopy temperature ‘snapshot’ at approximately every 0.45$^{o}$ of center pivot movement. After each set of canopy temperatures was collected, the data were downloaded, via a short haul modem, to a 386-Mhz PC module integrated into a PLC (programmable logic controller; GE Fanuc model 90-30, Charlottesville, VA), which was mounted on the center pivot truss and used to control the application of water and nutrients. As each ‘snapshot’ of canopy temperature data was collected, the PC software interrogated the center pivot control system (C:A:M:S$^{TM}$ ) (Valmont Industries, Inc., Valley, NE) to obtain the angular position of the center pivot. This information was stored in a file along with a time stamp for later determination of the ground position for each of the canopy temperature values.

The data presented here were collected during the 1999 corn growing season on an area used to conduct an irrigation x N-fertilizer x soil map unit experiment. There were four irrigation treatments and two N-fertilizer treatments placed on 12 soil map units. Irrigation treatments were 0, 50, 100, and 150% of a base rate determined by soil water potential values (measured by tensiometers) and meteorological conditions. The two N-fertilizer treatments were the recommended rainfed and irrigated values (135 and 225 kg/ha). Descriptions of the soil map units and other details of this agronomic experiment can be found in Camp et al. (2000, this conference proceedings). The experimental plot sizes were approximately 9 m by 9 m. The plot treatments were organized into randomized complete blocks where there was sufficient area within the soil map unit boundaries; where there was not enough area, randomized incomplete blocks were used. On the larger soil map areas, multiple randomized complete blocks were used. The plot diagram for this experiment, including the soils map, is shown in Fig. 1.

Crop canopy temperature data were collected during the peak solar radiation periods for days that had a high probability (based on weather forecasts) of having clear skies. Eight days during the grain-fill period were chosen to acquire canopy temperature data. Of these eight, only two days had any significant cloud cover, and only for brief (~5-15 minutes) periods of time.

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

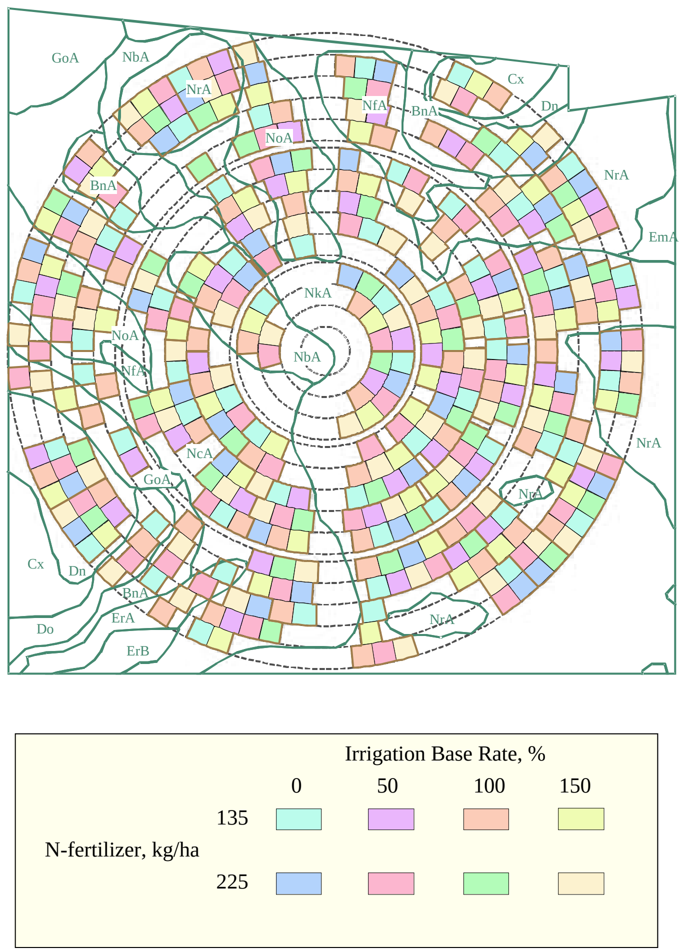


**Figure 1. Diagram of the 1999 corn plot layout for an irrigation x N-fertilizer x soil map unit experiment. Soil map unit outlines and codes are indicated on the diagram.**

Data were collected for the complete center pivot travel circle, which required approximately 3.5 hours. The ground position of each canopy temperature data point was determined by synchronizing the IRT data with the center pivot positional data and calculating the geometric offset from the center pivot structure. Before performing any analysis of the data, the raw temperature values were corrected for calibration offsets and adjusted for temporal slew. The field data values were corrected using individual calibration regression values determined in a laboratory setting prior to the IRTs being used. After that, the temperature values were adjusted to account for temporal slew (caused by over 3 hours of runtime). This adjustment was calculated as:

$$Tadj = (Tcal - Tpred) + Avg(Tcal),$$

where

$Tadj$ = adjusted canopy temperature value, $^{o}$C,

*Tcal* = canopy temperature value (after calibration applied), $^{o}$C,
*Tpred* = predicted canopy temperature value, $^{o}$C,
*Avg(Tcal)* = overall average of all canopy temperature values for this run, $^{o}$C.

The regression equation values (for calculating *Tpred*) were found by modeling the *Tcal* values against time and were determined using SAS Proc REG (SAS Institute, Cary, NC).

The adjusted canopy temperature values were assigned attributes based upon their ground position. The soil map unit, irrigation and N-fertilizer treatments, and plot number for each data point were determined using ARC/Info GIS software (ESRI, Redlands, CA). Also, ARC/Info was used to determine whether the data point was within the center 6.1 m of the plot (this was considered a control zone and avoided edge effects). Once those attributes were assigned to the data points, the dataset was statistically analyzed to determine relationships between crop canopy temperature and soil map units and irrigation rates.

## RESULTS

To illustrate the type of data and analysis available, the results from two representative days are shown. The first day was 23 July 1999, for which the non-irrigated treatments were probably under considerable water and heat stress. Eight days had passed since a rainfall event and the ambient temperature was 38.5 to 41 $^{o}$C. The second day was 26 July 1999, which was two days after a 41-mm rainfall event and had ambient temperatures of 33 to 37 $^{o}$C, which should indicate lower crop stress than the 23 July date.

Figures 2 and 3 show the adjusted canopy temperature values mapped using the Surfer graphical software (Golden Software, Golden, CO). The outlines of the soil map units and the experiment plot areas are superimposed on the data. Note, especially on 23 July, that the canopy temperature changes across the plot borders. The canopy temperature changed as much as 8 – 10 $^{o}$C in just a couple of meters. It is obvious, from the 26 July data, that the rain on 24 July reduced the canopy temperature variability across the plot areas. The warmer streak (orange to red symbols), evident on Fig. 3, which extends from the top of the figure to the bottom is a 7-m wide field road that is used to travel to the center pivot base.

One way to test the effectiveness of this method of IRT scans was to study the effect of the different irrigation base rates (IBR) on the canopy temperature. Figure 4 presents statistical output for one of the soil map units (GoA) for the two days of IRT data. Shown are the data points, a line connecting the means, and bars indicating one standard deviation from the mean. The fitted quadratic equations are shown on the graph. One can see the effect of the rainfall as the quadratic equation curves are drastically different.

Outputs from several more soil map units are shown in Figs. 5 and 6. The lines are graphical representations of the quadratic equation output from regression analysis of adjusted canopy temperature versus irrigation base rate. Five representative soil map units are shown by the color lines, and the black, dashed line shows the regression results from all the data. Note the large differences between the two days at the 0% base rate (no irrigation), but the small differences between the two days at the 100 and 150% irrigation base rates. Also

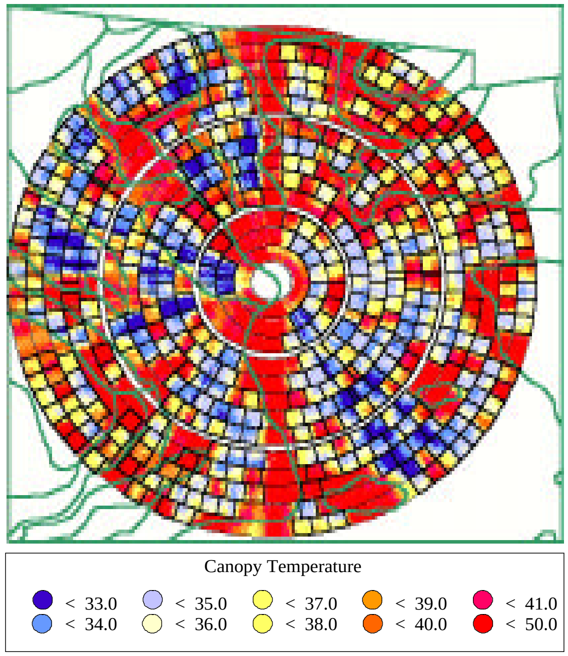


**Figure 2. Class post map of adjusted canopy temperature values for a warm, dry day (23 July 1999). Soil map unit and plot outlines are superimposed on the map.**

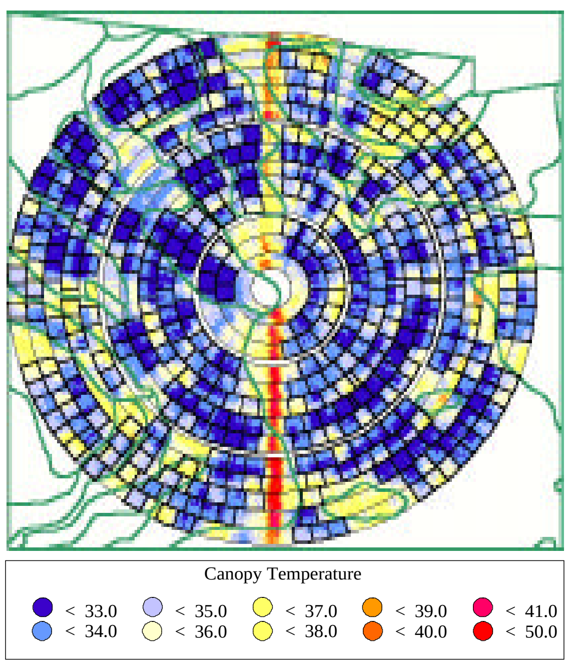


**Figure 3. Class post map of adjusted canopy temperature values 26 July 1999, two days after a 41-mm rain. Soil map unit and plot outlines are superimposed on the map.**

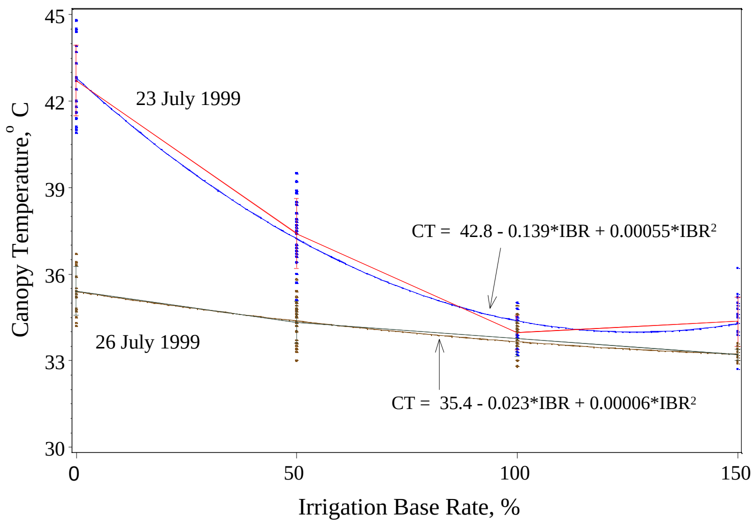


**Figure 4. Fitted quadratic curves (blue and orange lines), for canopy temperature versus irrigation base rate, for the GoA soil map unit with individual data points (dot symbols). Vertical bars indicate one standard deviation and the red and green lines join the mean values.**

notice, on the 23 July date, the different trends of the soil map units. The GoA data starts high but has the steepest decent, whereas the BnA data does not descend as far. A possible explanation could be that the BnA data are from two different areas of the field, and in fact did show different temperature patterns on the classed post map (Fig. 2). NkA and NoA are both Norfolk fine loamy sand soils. NoA has a deeper surface horizon, and thus expectedly shows a lower canopy temperature than the NkA soil, presumably caused by better water holding capacity.

Tables 1 and 2 show the regression output (adjusted canopy temperature versus irrigation base rate) for all soil map units on both days. The equation is:

$$CT = a0 + a1 * IBR + a2 * IBR^2,$$

where
$CT$ = canopy temperature, °C,
$IBR$ = irrigation base rate, %,
$a0$, $a1$, $a2$ are quadratic equation regression parameters.

The tables list the equation parameters as well as the $R^2$ values as computed in the regression analysis. On the warmer, drier day (23 July), $R^2$ values of 66 to 94% were obtained. After the rain (data of 26 July), 29 to 82% of the variation was explained, which is consistent with the generally lower variance displayed after the rain.

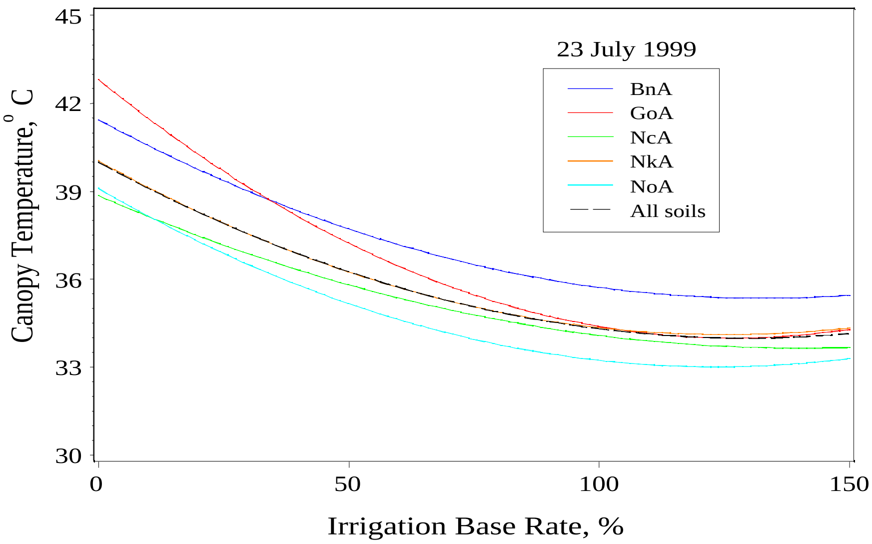


**Figure 5. Fitted quadratic curves of canopy temperature versus irrigation base rate for 23 July 1999. Data shown are for five representative soil map units (color lines) and a composite of all soil map units (black, dashed line).**

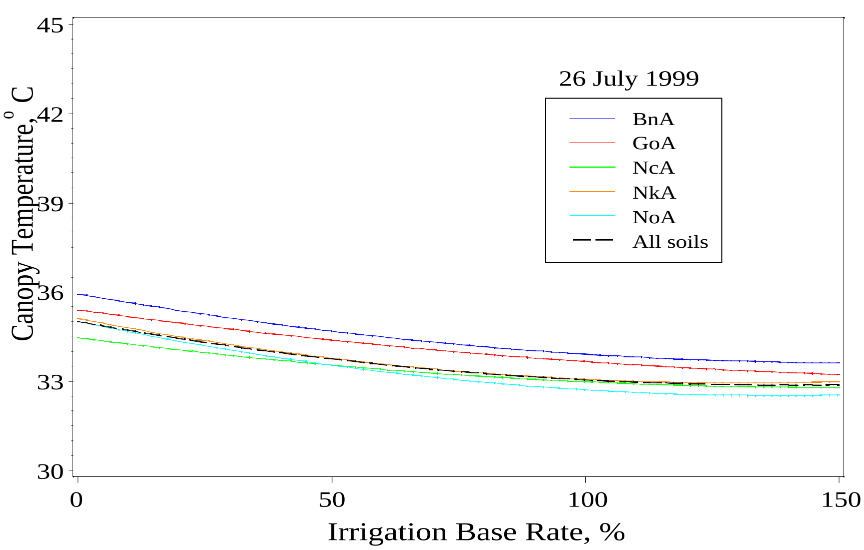


**Figure 6. Fitted quadratic curves of canopy temperature versus irrigation base rate for 26 July 1999. Data shown are for five representative soil map units (color lines) and a composite of all soil map units (black, dashed line).**

**Table 1. Quadratic regression equation parameters of canopy temperature versus irrigation base rate for all twelve soil map units on 23 July 1999.**

| Soil map unit | *a* 0 | *a* 1 | *a* 2 | $R^2$ |
|---|---|---|---|---|
| BnA | 41.4 | -0.0919 | 0.000346 | 0.66 |
| Cx | 40.8 | -0.1060 | 0.000496 | 0.88 |
| Dn | 41.8 | -0.0892 | 0.000304 | 0.86 |
| Do | 43.1 | -0.1259 | 0.000533 | 0.94 |
| ErA | 41.9 | -0.0657 | 0.000163 | 0.87 |
| GoA | 42.8 | -0.1392 | 0.000549 | 0.90 |
| NbA | 40.7 | -0.1470 | 0.000635 | 0.86 |
| NcA | 38.8 | -0.0742 | 0.000264 | 0.78 |
| NfA | 40.6 | -0.0764 | 0.000261 | 0.80 |
| NkA | 40.0 | -0.0947 | 0.000378 | 0.74 |
| NoA | 39.1 | -0.0986 | 0.000399 | 0.78 |
| NrA | 40.7 | -0.0924 | 0.000333 | 0.76 |

**Table 2. Quadratic regression equation parameters of canopy temperature versus irrigation base rate for all twelve soil map units on 26 July 1999.**

| Soil map unit | *a* 0 | *a* 1 | *a* 2 | $R^2$ |
|---|---|---|---|---|
| BnA | 35.9 | -0.0300 | 0.000097 | 0.29 |
| Cx | 33.6 | 0.0252 | -0.000184 | 0.38 |
| Dn | 36.0 | -0.0353 | 0.000124 | 0.72 |
| Do | 36.3 | -0.0424 | 0.000191 | 0.73 |
| ErA | 36.8 | -0.0472 | 0.000181 | 0.82 |
| GoA | 35.4 | -0.0233 | 0.000059 | 0.62 |
| NbA | 34.2 | -0.0391 | 0.000167 | 0.69 |
| NcA | 34.5 | -0.0223 | 0.000074 | 0.39 |
| NfA | 35.7 | -0.0375 | 0.000127 | 0.45 |
| NkA | 35.1 | -0.0332 | 0.000127 | 0.51 |
| NoA | 35.0 | -0.0360 | 0.000130 | 0.68 |
| NrA | 35.3 | -0.0341 | 0.000118 | 0.57 |

## SUMMARY

From the results of this study, we have shown the ability to measure crop canopy temperature on a relatively fine scale (several meters) using inexpensive IRTs mounted on an existing device (center pivot). With the advances in dataloggers and computer equipment, it is easy to collect the data and take action on the results in a short period. There could be many uses for this type of canopy temperature data, and we list a few possibilities.

One category of uses is as a post-irrigation check mechanism, such as determining the uniformity of irrigation applications, especially when using precision application equipment. Variations in canopy temperature could indicate the lack of application uniformity or could indicate problems in the water delivery system. Major water application problems should be obvious, as our plot areas with no irrigation were very easy to detect.

Another category is irrigation scheduling, for which IRT data could be used as the basis for event or amount planning. The canopy temperature data may be used by itself or most likely used in concert with soil-based measurements and models or forecasts. The possibilities exist for canopy temperature to actually trigger irrigation events in real-time. By mounting the IRTs ahead of the irrigation machine (careful to avoid water spray), it would be possible to change irrigation amounts based upon the current crop canopy temperature.

There could be many uses for this type of technology. The costs are relatively low, especially when the transport device already exists. As the field of precision application of water grows, this type of data acquisition may be required to control or regulate the use of water.

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