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Experimental Relations between Airborne and Ground Measured Wheat Canopy Temperatures

For canopies that covered at least 85 percent of the soil surface, airborne measurements differed from ground measurements of plant temperature by less than 2°C.

Abstract: *Experiments using ground based measurements of canopy temperatures have shown that plant temperatures are good indicators of plant water stress, and thus are useful for assessing water requirements and predicting yields. An intensive 23-day airborne- and ground-measurement program was conducted in Phoenix, Arizona in 1977 to compare airborne acquired wheat canopy temperatures with simultaneous ground measurements. For canopies that covered at least 85 percent of the soil surface, airborne measurements differed from ground measurements of plant temperature by less than 2°C. Regardless of the amount of plant cover, the airborne measurements were virtually identical to ground-nadir measurements, and thus represent a combination of plant temperature and soil background temperature.*

Introduction

A remote sensing technique recently proposed for assessing crop water stress is the stress degree day concept, which was developed by Idso *et al.* (1977) and Jackson *et al.* (1977). This technique uses the difference between crop canopy temperature and ambient air temperature taken about 1 to 1.5 hr after local solar noon. The summation of the daily values is directly related to crop water needs and crop yields.

The feasibility of using an airborne thermal scanner to assess crop moisture stress has been demonstrated previously (Millard *et al.*, 1978). Although this was not the first airborne demonstration of the relation be-

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tween canopy temperatures and crop moisture stress (Myers *et al.*, 1966; Wiegand *et al.*, 1968; Bartholic *et al.*, 1972; Nixon *et al.*, 1973; Moore *et al.*, 1975; Heilman *et al.*, 1976) it was the first to investigate the use of airborne thermal imagery to implement the stress degree day concept and the first to quantitatively relate airborne-acquired canopy temperatures to wheat water potential (Ehrler *et al.*, 1978), a primary measurement of plant water stress.

This paper describes the results of an experiment designed to further explore the relationship between airborne- and ground-acquired canopy temperatures. In order to assess plant water stress, plant canopy temperatures must be measured. This is a relatively simple matter using an infrared radiometer held at an angle of about 30° from the horizontal, but a nadir viewing airborne scanner measures an integrated signal consisting of soil and plant temperatures. The amount of soil background interference is dependent upon canopy cover. Our experiment was carried out during the spring of 1977, and consisted of an intensive 23-day program of airborne and ground measurements over 12 differentially irrigated plots of wheat in Phoenix, Arizona. Our objective was to measure the influence of soil temperatures on airborne-acquired canopy temperatures as a function of percent canopy cover.

Experimental

A spring wheat (***Triticum durum*** Desf. var. Produra) was planted in an Avondale loam soil in December, 1976. After planting, the field was divided into 12, 36 by 15 m plots. Each plot was irrigated at various times during the growing season so as to produce a range of soil moisture and plant water stress conditions. Each irrigation consisted of approximately 10 cm of water. Canopies in five of these plots were considered representative of various percent covers and were chosen for analysis in this paper. These plots represented the range of induced plant stress. Presentation of data from the remaining plots would have been redundant. The irrigation schedule for the plots discussed here is shown in Table 1.

TABLE 1. WHEAT IRRIGATION SCHEDULE

	Wheat Plots				
Irrigation Dates	1	2	3	4	5
December 7	X	X	X	X	X
January 27				X	
February 15	X	X		X	
March 12					
March 17	X				
March 24		X			X
April 1					
April 6	X				
April 12					
April 15					

Plant canopy temperatures were measured on the ground with Barnes* PRT-5 Radiation Thermometers, operating in the 10.5 to 12.5 μm bandpass region. The temperature measurement technique consisted in orienting a 20° field-of-view (FOV) radiometer to view the wheat in a nadir direction (normal to the target), and aiming a 2° FOV radiometer to view the wheat at an angle of about 30° from the horizontal. Measurements were obtained at six locations along two reference lines extending into each field for the 20° FOV and at four locations from the east and west edges of the field looking inward with the 2° FOV radiometer. Each set of measurements was averaged. The measurements were made twice a day: 30 minutes before sunrise and about 1.5 hours after local solar noon. Only the afternoon data were utilized in this paper.

Airborne measurements at 300-m altitude were made at the same time as the afternoon ground measurements with a Texas Instruments Model RS-25 Infrared Line Scanner. This scanner measures in the 10.5 to 12.5 μm bandpass region and has a 0.46-m instantaneous field of view. It contains two black body calibration sources with platinum resistance temperature readouts. The scanner data were recorded on a Sangamo Saber III 14-channel tape recorder and processed to produce digital temperature maps and pseudo-colored images. An average of pixel-by-pixel temperatures around each reference line was used for comparison with ground data. Atmospheric temperatures and dew point measurements were acquired at 75-m altitude intervals to correct scanner data for atmospheric effects. These corrections were about 1°C to 1.5°C.

Three photo interpreters independently evaluated the fraction of each plot covered by the green canopy from nadir-acquired color infrared aerial photographs of the test site taken on 24 March, 5 April, and 13 April 1977. They determined that plots 1 through

* Trade names and company names are included for the benefit of the reader and imply no endorsement or preferential treatment of the product listed by either NASA or USDA.

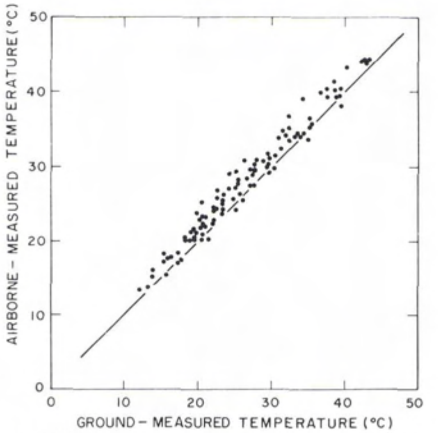

FIG. 1. Airborne vs. ground-measured field temperatures from a nadir-oriented infrared radiometer.

TABLE 2. VALUES OF THE COEFFICIENT OF DETERMINATION ($r^2_{y \cdot x}$) AND STANDARD ERROR OF ESTIMATE ($s_{y \cdot x}$) FOR FIVE PLOTS WITH VARIOUS CANOPY COVERS

	Canopy Cover (%)				
	50	65	75	90	95
$r^2_{y \cdot x}$	0.99	0.93	0.98	0.95	0.98
$s_{y \cdot x}$	6.2	4.2	2.9	1.2	1.0

5 had average percent ground covers over the three week period of 93, 90, 50, 73, and 63 percent, respectively. These percentages were rounded to the closest five percent level for presentation of results. The standard errors of the mean of the green canopy cover estimates were 1.7, 2.4, 2.9, 4.1, and 2.4, respectively, for the five plots.

RESULTS

Figure 1 shows the relationship between airborne-measured field temperatures and those obtained on the ground with an infrared radiometer in the nadir direction. A regression analysis of these data gave a slope of 0.997, an intercept of 1.5°C, a coefficient of determination ($r^2_{y \cdot x}$) of 0.98, and a standard error of 1.2°C. This analysis indicated that the airborne measurements can indeed be used to determine field temperatures over the range of 10°C to 45°C.

Although the relationship in Figure 1 is quite good, the question remains as to whether these data represent true wheat canopy temperatures. Because the airborne line scanner sees both plants and soil if the plant canopy is not complete, the resulting temperature measurements are not representative of true plant temperatures. We want to know at what point the canopy sufficiently covers the soil to insure that the soil temperature has a negligible effect on the measurement. Figure 2 shows the airborne-measured field temperatures, plotted against ground-based temperature measurements that were taken at an angle of about 30° from horizontal. At this angle the radiometer sees only vegetation and therefore measures only the blackbody canopy temperature. The five sets of data points were taken from separate plots whose plant cover ranged from 50 to 95 percent. At the sparsest canopy cover (50 percent) the data points fall considerably above the 1:1 dashed line, but as the canopy cover in-

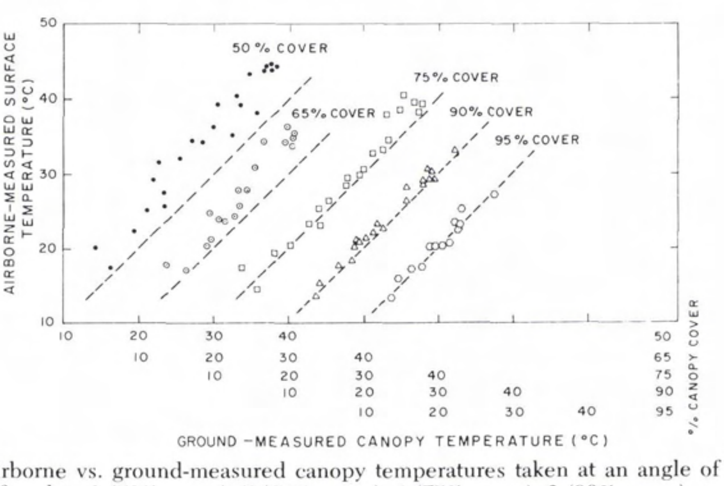

FIG. 2. Airborne vs. ground-measured canopy temperatures taken at an angle of 30° from horizontal for plots 3 (50% cover), 5 (65% cover), 4 (75% cover), 2 (90% cover), and 1 (95% cover).

creases the data more nearly approach the unity relationship. Our results showed that, when the canopy cover was at least 85 percent, the airborne measurements differed from true plant temperatures by less than 2°C. Values of the coefficient of determination ($r^2_{y \cdot x}$) and standard error of estimate ($s_{y \cdot x}$) are given in Table 2 for the five plots described above. Both of these parameters were calculated using the 1:1 dashed lines in Figure 1 to obtain the estimated (or expected) values of y (airborne-measured field temperature), as described by Spiegel (1961).

A plot of the standard error of estimate from Table 2 as a function of percent canopy cover is shown in Figure 3. The inverse relationship from 50 to 90 percent canopy cover, followed by a leveling off at about 1°C from 90 to 100 percent, is quite striking. The minimum error of 1°C is a composite of errors derived from both airborne and ground-based temperature measurements. If we know the magnitude of error in temperature measurement that can be tolerated in a data analysis, we can determine the minimum canopy cover necessary to achieve the desired result from Figure 3. Conversely, if we know what percent of the area is covered by green plant material, we are able to determine what the error will be in determining canopy temperature.

These results emphasize the need for the development of a technique that uses airborne-acquired data to estimate plant canopy temperatures under conditions of incomplete canopy cover.

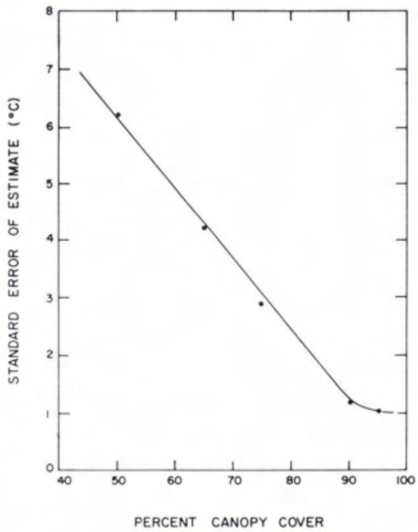

FIG. 3. Standard error of estimate values from Table 2 as a function of percent canopy cover.

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