

Effect of Dew on Canopy Reflectance and Temperature

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The diurnal behavior of canopy reflectance and emittance was characterized for six spring wheat cultivars using two ground-based radiometers that had spectral bandpass characteristics similar to the multispectral scanner and thematic mapper radiometers on Landsats 4 and 5. Nadir measurements of spectral reflectance and emittance were made over well-watered canopies with and without dew to determine its effect on each wavelength interval. The diurnal patterns of reflectances from canopies without dew were symmetric with respect to solar noon. However, when dew was present on canopies, morning reflectances in wavelengths shorter than $0.7 \mu\text{m}$ and longer than $1.15 \mu\text{m}$ were significantly different than those observed during the afternoon under similar solar zenith angles. Quantitative measurements of dew density in each cultivar established that moderately high dew levels increased reflectance in visible wavelengths by 40–60%, and decreased reflectance in wavelengths between 1.15 and $2.35 \mu\text{m}$ by 25–60%. No effect of dew was noted in the near-IR region of the spectrum between 0.7 and $1.1 \mu\text{m}$ or the thermal IR (10.4 – $12.5 \mu\text{m}$).

Introduction

The use of remotely sensed spectral observations for the management of renewable resources is an area which has received considerable attention over the last decade. Substantial research efforts have focused on establishing calibrations of radiometric sensors (Slater, 1984), identifying and compensating for the effects of the atmosphere on data quality (Dave, 1980), and unraveling the complex relationship which exists between the bi-directional reflectance properties of plant canopies and meaningful agronomic properties (Daughtry et al., 1980; Tucker et al., 1980; Pinter et al., 1981; 1983). Yet the effects of meteorological events such as precipitation and dew* on the quality of multispectral data remain largely unknown and for the most part ignored.

This is ironic because these phenomena frequently persist throughout the mid-morning overpass times of current resource monitoring satellites and also because dew-related events are usually enhanced by the same calm, cloud-free conditions which analysts consider optimum for data acquisition.

Dew is usually deposited as tiny spheroid droplets on waxy cuticles of plant leaves. This results in a high degree of specular reflection. As a consequence, the reflectance from plants with dew on them differs from that of a canopy covered with a continuous layer of water of an equivalent thickness. Given the unusual

*The meteorological definition of dew refers to the condensation of atmospheric moisture onto a surface (Monteith, 1957; Burrage, 1972; Rosenberg et al., 1983).

More commonly, the "dew" observed in agricultural systems is derived from distillation of soil water into the boundary layer from whence it subsequently condenses onto plants. Although not dew in the strictest sense of the term, I will collectively refer to any moisture present on plant surfaces in droplet form as dew regardless of its origin. Differences in the size and spatial distribution of these droplets may occur, but the relative effect on scene reflectivity is likely to be similar for dew, distillation, gutation, rainfall, and perhaps even sprinkle irrigation.

bidirectional reflectance properties of water in droplet form, empirical studies can provide a quick look at the overall effect of dew on canopy reflectance without resorting to extensive assumptions required in modelling efforts.

One such study was conducted earlier using a ground-based radiometer and intensive multitemporal sampling techniques on wheat grown in Phoenix (Pinter and Jackson, 1981). The reflectances of wheat canopies with dew were compared with canopies where shelters prevented nighttime dew formation. The amount of dew present on the canopies was significantly correlated with a decrease in a vegetation index calculated as the ratio of near-IR to red reflectances (0.8–1.1 and 0.6–0.7 μm , respectively). Although the total amount of dew (kg m^{-2} ground area) present on the canopies was influenced by phenological stage and green leaf area, the functional relationship between dew density (kg m^{-3} canopy volume) and reflectance was independent of these parameters.

The spatial and temporal heterogeneity of dew contribute to the complexity of interpreting reflectance data from plant communities. This is because adjacent fields may have varying propensities for dew formation as a result of different soil water contents. Sequential scenes of the same region may have different amounts of dew as synoptic weather patterns change. Such considerations mandate a better understanding of dew and its effect on reflectance. This knowledge is required to avoid classification errors and correctly assess vegetation parameters such as biomass and leaf area. If reliably monitored via a noncontact remote sensing technique, dew density and duration could be used to predict the onset of

dew-related diseases. Obviously, it is also important that we thoroughly understand the effects of dew on reflectance so that future data acquisitions can be timed appropriately.

The objectives of the present study were to evaluate the overall effects of dew on diurnal patterns of reflectance and emittance of well-watered wheat and to quantify the relationship between dew density and spectral information in the visible, near-IR, mid-IR, and thermal wavelength intervals currently proposed for agricultural resource management.

Experimental

The field site

Six cultivars[†] of spring wheat (*Triticum aestivum* L.) were planted in mid-December 1982 at Phoenix, AZ (33°26'N, 112°01'W). Seed was sown in north-south oriented rows that were spaced at 0.18-m intervals. Each cultivar was grown in a separate 12 × 25 m flood irrigation basin. The soil was classified as an Avondale loam [a fine, loamy, mixed (calcareous), hyperthermic, Antropic Torrifluent].

Plants were maintained under nonlimiting water and nutrient conditions. Growth was characterized from five twice-weekly destructive samples which were centered around the 9 March 1983 dew experiment. Green biomass (dry weight) was estimated from 12 plants selected at random from each cultivar on each sampling date. Green leaf area index (GLAI) was measured using an optically integrating

[†]The cultivars (Ciano 79, Genaro 81, Pavon 76, Seri 82, Siete Cerros 66, and Yecora 70) were obtained from Drs. David Saunders and Joel Ransom of Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in Ciudad Obregon, Sonora, Mexico.

leaf area meter on a subsample of three median-sized plants chosen from the biomass sample. Plant populations and grain yields (on a dry weight basis) were determined for each cultivar at final harvest in June 1983.

Spectral measurements

An Exotech Model 100-A and Barnes Modular Multiband Radiometer Model 12-1000[‡] were used for spectral observations (Table 1). Radiometers were equipped with 15° field-of-view apertures and deployed in a nadir orientation so that the same vegetation areas were viewed by each. The Exotech had spectral bandpass filters similar to the two visible and two near-infrared (IR) channels of the Landsat multispectral scanner (MSS). The spectral characteristics of the Barnes Modular Multiband Radiometer (MMR, Robinson et al., 1979) were simi-

lar to those of the Landsat thematic mapper (TM). In addition to the three visible, one near-IR, two mid-IR, and one thermal channels of the TM, the MMR also has a second near-IR waveband (1.15–1.30 μm) which does not have an equivalent on the TM. During measurements the Exotech was hand-held above the canopy; the MMR was suspended slightly above the shoulder level of the operator on a backpack carrying system. This imparted portability to a radiometer which, because of its heavier weight, is normally mounted on a boom for ground-based operations. With the backpack system, an operator could quickly take numerous spectral measurements over adjacent field plots. Observations with both radiometers were taken from boardwalks which extended across the plots in an east to west direction. Sensor height was about 1.3 m above the top of the canopy, and thus the field of view encompassed an area about 0.35 m in diameter.

Analog signals from both radiometers were logged on Polycorder[‡] data collection devices which also recorded the time

[‡]Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U. S. Department of Agriculture.

TABLE 1 Spectral Band Specifications of the Exotech Model 100A and Barnes Modular Multiband Radiometers (MMR)^a

RADIOMETER BAND		LANDSAT BAND	WAVELENGTH INTERVAL (μm)	DETECTOR TYPE	RANGE
Exotech	1	MSS4	0.5–0.6	silicon	green
	2	MSS5	0.6–0.7	silicon	red
	3	MSS6	0.7–0.8	silicon	near-IR
	4	MSS7	0.8–1.1	silicon	near-IR
Barnes	MMR1	TM1	0.45–0.52	silicon	blue
	MMR2	TM2	0.52–0.60	silicon	green
	MMR3	TM3	0.63–0.69	silicon	red
	MMR4	TM4	0.76–0.90	silicon	near-IR
	MMR5	no equiv.	1.15–1.30	PbS	mid-IR
	MMR6	TM5	1.55–1.75	PbS	mid-IR
	MMR7	TM7	2.08–2.35	PbS	mid-IR
	MMR8	TM6	10.4–12.5	LiTaO ₃	thermal

^aBoth radiometers were equipped with 15° field-of-view apertures.

of each set of measurements for later sun angle calculations. Raw voltages were converted to target radiances by subtracting radiometer dark level voltages, dividing by gain settings and multiplying by the radiometer calibration factors. No calibrations were available for the MMR; subsequent calculations were performed on voltage equivalent radiances. Reflectances were calculated as the ratio of radiances measured over each vegetation target to irradiances inferred from observations of a calibrated 0.6×0.6 m, painted BaSO_4 reflectance panel that was horizontally positioned in the field. Irradiance data were obtained at the start, midpoint, and finish of each measurement sequence and a time-based linear interpolation was then used to estimate irradiance at the time when individual targets were measured.

Correction factors were applied to the BaSO_4 data to compensate for the non-Lambertian behavior of the panel (Kimes and Kirchner, 1982; Robinson and Biehl, 1979). Additional factors were applied to MMR bands 5, 6, and 7 to correct the PbS detectors for temperature sensitivity (Jackson and Robinson, 1985). MMR thermal data (band 8) were reduced according to procedures outlined by Jackson et al. (1983).

Spectral measurements were made over four 1×3 m target areas within each cultivar. Dew was permitted to dissipate naturally on two of the target areas within each cultivar. The process was accelerated on the remaining targets by gently wiping the canopy with absorbent cotton towelling at 0800 h and again at 0900 h. Six spectral observations taken within each target area were pooled yielding 12 observations of natural dew covered vegetation and 12 of dewless vegetation per

cultivar at each time period. Data collection began at 0745 h (MST) and continued at 30–45-min intervals throughout the day. Each data set required approximately 8–10 min to complete: 19 such data sets were obtained using the Exotech radiometer; 16 with the MMR.

Dew density

The amount of dew present on the canopy was estimated from samples collected at 1-h intervals from 0730 to 1230 h (MST). This was accomplished by cutting a bundle of adjacent stems at ground level with a razor blade and gently transferring the vegetation to a tared plastic bag so that a minimum amount of dew was lost in the process. The bag was then sealed and weighed to determine the combined wet weight of the vegetation and dew. The plants were blotted with cotton towelling for 3 min and then weighted to determine the total amount of dew and tissue water lost during processing. To account for the tissue water loss component, I subtracted the water lost from the 1130 h sample when there was no dew visible on the plants. The samples were then oven dried at 70°C for 48 h. These data were converted to dew density (kg m^{-3} canopy volume) first by dividing the weight of the water lost as dew by the ratio of the dry biomass of the sample to the dry biomass per m^2 of the plot and then dividing that quotient by the field height of the canopy.

Weather and sun conditions

Atmospheric weather conditions were favorable for moderately heavy morning dew accumulations for several days prior to and during the 9 March 1983 experi-

ment. Nighttime skies were clear, precipitable water in the upper atmosphere was low and wind conditions were mostly calm during the predawn period: Ideal conditions for maximum radiative cooling and condensation of moisture onto the canopy. Surface soils in all plots remained wet throughout the day and plant water status was near optimum; a result of three rain-falls totalling 6.25 cm the previous week and 10 cm of irrigation on 22–23 February. An air temperature of 12.7°C was recorded at a height of 150 cm during the first set of measurements at 0745 h; a maximum of 27.0°C was measured at 1615 h. Relative humidities at those times were 81 and 26%; dew point temperatures were 9.5 and 5.9°C, respectively.

Conditions were also very good for obtaining high quality reflectance measurements. Cloud-free skies with low to moderate haze levels prevailed throughout the day. Winds were generally light and from the east with occasional calm periods. On 9 March 1983, sunrise occurred at 0652 h, solar noon at 1239 h, and sunset at 1825 h (MST). Solar zenith angles varied from approximately 78° during the first set of measurements to 38° at midday and 75° during the last set of Exotech readings. Solar azimuth angles varied from 104 to 249° during measurements. The spectral distribution of irradiance as inferred from

radiometric measurement of the calibrated BaSO₄ reference panel with the Exotech radiometer (Fig. 1 in Pinter et al., 1985) revealed a symmetrical pattern about solar noon.

Agronomic parameters

Each wheat cultivar was approaching complete canopy cover and 38–47 cm in height by 9 March (Table 2). Minor differences were noted in phenological stages of growth; all, however, were separated by less than 1 week of development. Green biomass levels and green leaf areas were similar for all varieties. Final grain yields at harvest approached yield potentials (CIMMYT, 1982). The architectural structure of the canopies varied considerably among cultivars, ranging from the most planophile, Yecora, to the most erectophile, Ciano. Canopy architecture is discussed in more detail in Pinter et al. (1985).

Dew conditions

Early morning dew accumulation was moderately high on all cultivars (Fig. 1). Sensitive weighing lysimeters positioned within 3 cultivars showed no changes which could be attributed to true dew fall from the atmosphere. Instead, dew appeared to result from distillation of soil moisture which was then condensed onto

TABLE 2 Agronomic Characteristics of Wheat Cultivars on 9 March 1983 and Final Grain Yield at Harvest

PLOT	CULTIVAR	GROWTH STAGE		FIELD HEIGHT (cm)	GREEN LAI	DRY GREEN BIOMASS (tha ⁻¹)	GRAIN YIELD (tha ⁻¹)
		ZADOKS	FEEKES				
1B	Yecora	32	7	46	4.5	2.57	7.12
2B	Siete Cerros	31	6	46	4.7	2.38	7.12
3B	Ciano	23	2	44	4.5	2.48	6.96
4B	Pavon	32	7	46	4.4	2.56	6.89
5B	Genaro	26	3	38	4.2	2.57	7.49
6B	Seri	32	7	47	3.5	2.87	7.10

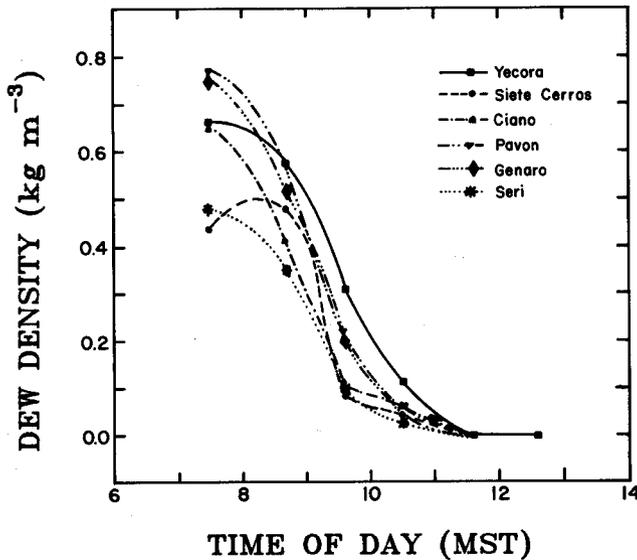


FIGURE 1. Dew densities measured on each cultivar of wheat on 9 March 1983.

the canopy. Dew amounts shown in Fig. 1 are expressed as density values (water weight per unit canopy volume) as opposed to dew depth because earlier work (Pinter and Jackson, 1981) had shown that reflectances were better correlated with dew density when canopies of different heights were being compared. For reference purposes, I observed that a moderately high dew density of 0.5 kg m^{-3} was sufficient to thoroughly wet cloth trousers after walking just several meters through the canopy.

The differences in dew density among canopies did not appear related to the architecture of the different cultivars. Seri, the cultivar which had the lowest average dew density during the morning, was located on the easternmost border of the field where the light east winds may have dissipated the moisture more rapidly. Measurements showed that dew decreased regularly until approximately 1100 h. At that time visual inspection revealed no dew remained on any of the canopies. The trend lines shown in Fig. 1

were calculated using a sliding polynomial curve fitting technique similar to that proposed by DuChateau et al. (1972). This technique provided an objective method whereby dew densities at specific times could be interpolated for comparison with spectral data acquired at irregular intervals.

Results and Discussion

All six cultivars were similar in green leaf area index, green biomass, and single leaf reflectance characteristics (Pinter et al., 1985); yet cultivar related differences in canopy architecture caused major differences in reflectance among them at different times throughout the day. Examples of visible, near-IR, and mid-IR reflectances measured with the MMR on 9 March 1983 are shown in Fig. 2 for two separate areas within Yecora and Ciano canopies which had dew present during the morning. Notice that the greatest diurnal variation in reflectance with time of day was found for Ciano, the

most erectophile canopy. Reflectance changes for the most planophile cultivar Yecora, appeared minimal. Replicate sets of six measurements within the two separate areas of each cultivar confirmed consistent diurnal patterns even though the actual reflectances were slightly offset from one another. Data observed for the other cultivars were intermediate in nature. Diurnal variability in reflectance was more evident for visible light where the contrast between reflectance of soil and vegetation was the highest. To a lesser extent, it could also be seen in the mid-IR wavelengths. The daily patterns of reflectance observed in the near-IR did not appear as dependent on canopy architecture or time of day.

A conspicuous feature of the data in Fig. 2 was that morning reflectances were unlike those observed during the afternoon. This lack of symmetry with respect to solar noon was evident in all wavebands except the near-IR between 0.7 and 1.1 μm . The hysteresis can be visualized more clearly when the reflectances are plotted as a function of solar zenith angle (Fig. 3). Morning reflectances in MMR 3 were much higher than those observed in the afternoon under similar solar zenith angles. This same pattern was repeated for each of the other visible channels (Exotech bands 1 and 2 and MMR bands 1 and 2). On the other hand, reflectances in MMR 4 (near-IR) show very little hysteresis between morning and afternoon data. This was also true of Exotech bands 3 and 4. The longer near-IR waveband of MMR 5 (1.15–1.30 μm , not shown) behaved similarly to the reflectances in the mid-IR portion of the spectrum. These are typified by MMR 7 of Fig. 3, where morning reflectances were much lower than those observed in the afternoon.

Several researchers have pointed out that asymmetric patterns of reflectance can potentially arise from a diverse number of physical and biological properties (Fuchs et al., 1972; Duggin, 1977; Jackson et al., 1979; Kimes et al., 1980; 1983; Pinter et al., 1983). Many of these suggested causes can be eliminated as the source of hysteresis in reflectance observed here. In the present experiment, for example, the north-south orientation of wheat rows minimized the effects of changing solar azimuth angles on reflectance, resulting in similar patterns of sun and shade for comparable solar zenith angles before and after solar noon. Optimum plant water status precluded any major diurnal changes in physiological processes. No stress-induced wilting or rolling of the leaves was seen nor was the wind strong enough to alter canopy architecture during the sequence of measurements. Heliotropic leaf movements, while important in cotton, alfalfa, sunflower, and other dicots were not a conspicuous behavior of the small grains involved in the present study.

Although diurnal changes in the spectral composition of incoming light could alter the reflectance properties of a canopy sufficiently to account for the observed hysteresis, differences between morning and afternoon irradiances in each wavelength (equivalent voltages for the MMR^s) at comparable zenith angles were minimal. Furthermore, skies were clear,

^sThe temperature dependent nature of the channels with PbS detectors (MMR band 5, 6, and 7) must be compensated for correctly when MMR data are used to establish irradiant fluxes (Jackson and Robinson, 1985). Transforming target radiance data into reflectances tends to minimize the temperature sensitivity problem of these channels provided that the temperature changes of the instrument remain relatively small and change monotonically between sequential measurements over the BaSO₄ reflectance panel.

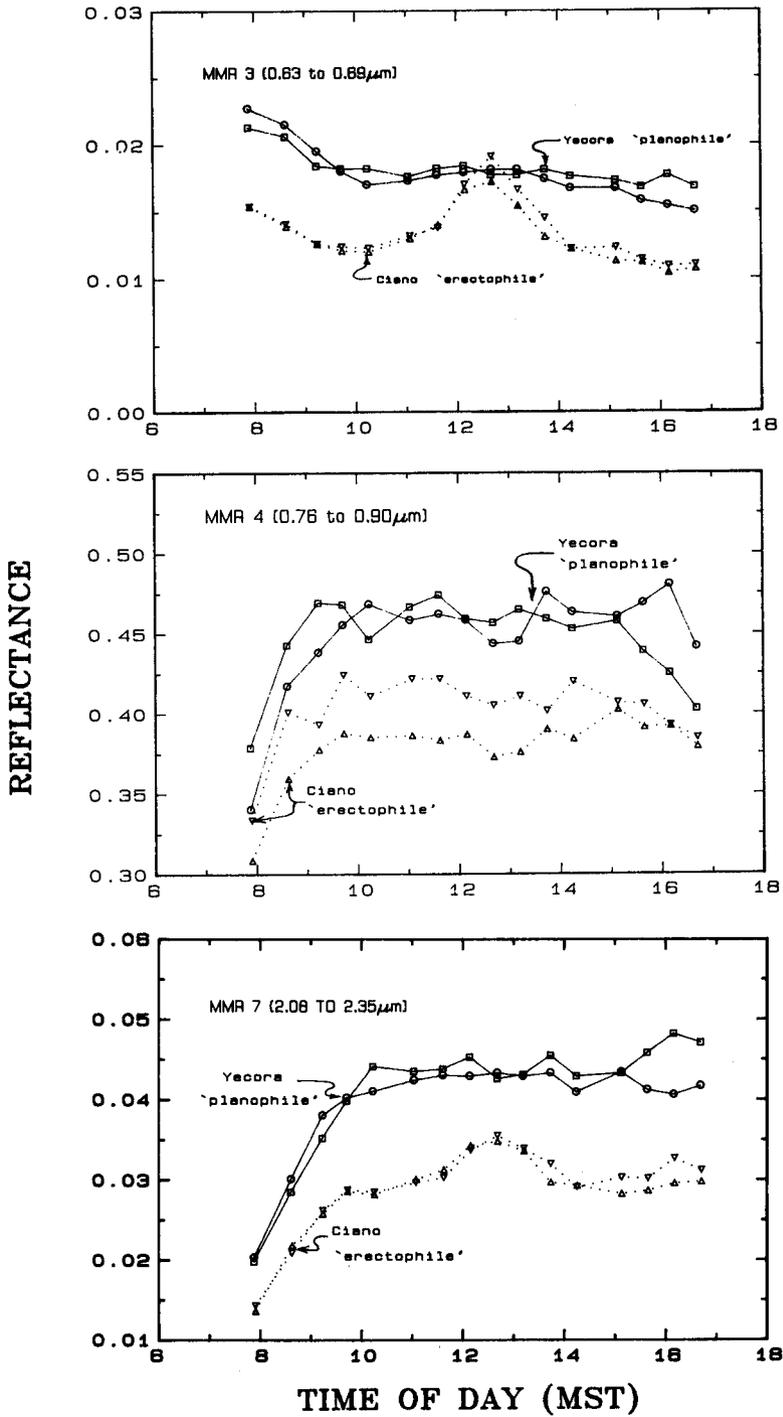


FIGURE 2. Diurnal patterns of reflectance in selected wavelength intervals for a planophile (Yecora; solid line) and an erectophile wheat cultivar (Ciano; dotted line) with dew present during the morning.

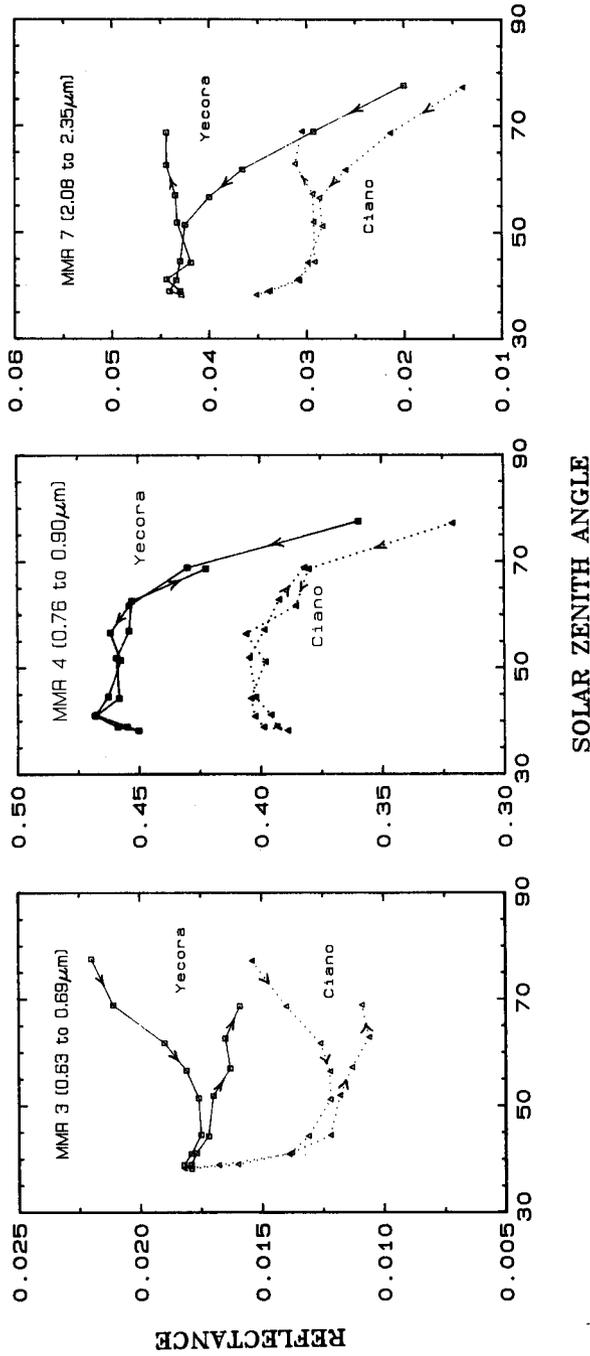


FIGURE 3. Measured reflectances in the red, near-IR, and mid-IR wavebands in Yecora and Ciano wheat as a function of solar zenith angle. Dew was present on these targets during the morning. Arrows indicate the progression of measurements from morning to afternoon.

and the ratio of diffuse to global solar radiation was symmetric about solar noon. The data were not biased by a systematic change in the sun-observer-sensor-target geometry because reflectances were consistently measured with the observer to the north of the targets.

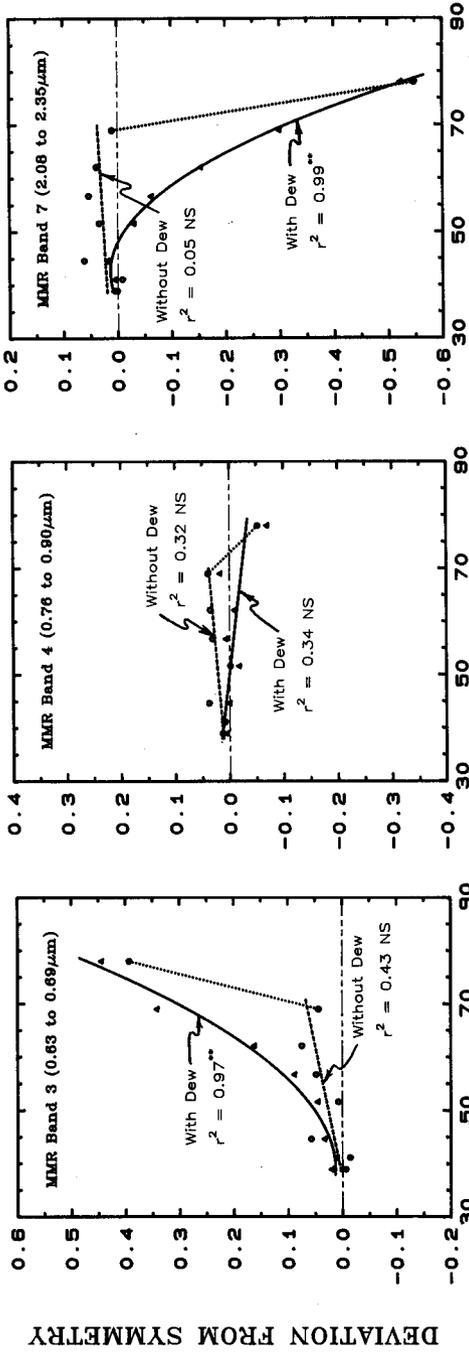
Dew remains as the most evident and visible difference between the canopies during morning and afternoon observations. It is also a logical source of reflectance asymmetry. Indeed, if the data of Fig. 3 are examined more closely, one finds that the hysteresis is minimal at solar zeniths of 50° and less. This corresponds to a time after 1000 h when much of the dew had already dissipated from the canopies. And earlier, Pinter and Jackson (1981) had been able to reverse the diurnal asymmetry of reflectance in wheat by spraying canopies with a fine water mist to achieve simulated dew conditions in the afternoon when the plants would otherwise be dry.

In order to relate changes in canopy reflectance and dew, morning reflectances were compared with those observed for the same measurement sites during the afternoon at similar solar zenith angles. Thus each target served as its own "control" and the results became less sensitive to the unique spectral characteristics of each cultivar. First, solar zenith angles were calculated for each set of reflectance measurements taken during the day (Threlkeld, 1962). Then the afternoon reflectance data were linearly interpolated to obtain the predicted reflectances for solar zenith angles corresponding to those occurring during morning measurements. The differences between observed morning and predicted afternoon reflectances were expressed as a fractional deviation from the afternoon

reflectance. A deviation of -0.35 , for example, is interpreted as a morning reflectance which is 35% less than afternoon reflectances.

The amount of hysteresis occurring at each solar zenith angle depended upon the wavelength interval and whether or not the canopies were covered with dew. Figure 4 shows this relation for MMR bandwidths which are representative of the three types of responses I observed. The canopies with natural dew are represented by triangular symbols and solid lines while those which were relatively free of dew (after 0800 h) are shown by circular symbols and dashed lines. Each data point is the average hysteresis value observed for six cultivars. Values near zero in the dewless canopies indicate that morning reflectances were similar to those observed in the afternoon. Least-squares regression of deviations on solar zenith established that their reflectances were symmetric about solar noon (i.e., the slopes were not significantly different from zero). By comparison, regression analysis of data from canopies with natural dew revealed significant deviations from symmetry in all but the near-IR portion of the spectrum between 0.7 and $1.1 \mu\text{m}$. Morning reflectances in the visible wavebands were 40–60% higher than afternoon observations; mid-IR reflectances were 25–60% lower.

Further evidence that dew caused asymmetry in reflectance of certain bands can be seen by examining the change in reflectance at the time of dew removal. The solid circular symbols at 78° solar zenith represent reflectances measured over the "dewless" targets just prior to dew removal. Before 0800 h, reflectances of those areas were markedly asymmetric compared with afternoon observations yet



SOLAR ZENITH ANGLE

FIGURE 4. Fractional deviation of morning reflectance compared with interpolated afternoon data at similar solar zenith angles. Each datum is the average for six cultivars. Triangular symbols and solid lines are for targets with natural morning dew. Open circles and dashed lines represent data for targets from which the dew was wiped at 0800 h and again at 0900 h (MST). Coefficients of determination (r^2) and levels of significance (NS = slope not different from zero at $p \geq 0.95$; * = significant at $p \geq 0.95$; ** = significant at $p \geq 0.99$) are based on either first or second order polynomial regression.

very similar to the targets which had natural dew. After 0800 h, however, the reflectances in all wavebands except those between 0.7 and 1.1 μm showed an abrupt step function change which was coincident with the removal of dew. This is shown by the dotted line in fig. 4. From that time on hysteresis was not evident in the reflectances of the dewless canopies.

Correlations between dew and changes in spectral reflectance

The time interpolated density of dew (Fig. 1) was plotted against the fractional deviation (hysteresis) in reflectance observed for each cultivar during all morning measurement periods. Results show a significant positive correlation between dew density and change in reflectance for all five visible wavebands (Fig. 5 and 6). Moderately high dew densities of 0.6–0.8 kg m^{-3} (approximately 0.3–0.4 mm depth) increased early morning reflectances of wheat canopies by 40 to more than 60%. Reflectances in MMR 3 appear to be slightly more sensitive to the presence of dew on the canopy than those measured with the wider red waveband equivalent found on the Exotech and MSS radiometers. In the near-IR region of the spectrum less than 1.1 μm the correlations between dew and changes in reflectance measured with the Exotech were not significant. I observed a slight decline in reflectance in MMR band 4 with increasing amounts of dew. Although this relationship was significant at $p \geq 0.95$, the large scatter of data about the trend line would eliminate this band from any practical utility in dew detection. The near-IR waveband spanning 1.15–1.30 μm (MMR 5, with no equivalent on the Landsat TM) showed a moderate inverse

correlation with dew, decreasing as much as 20–30% when dew was present on the canopy. A strong inverse relation was found between dew and changes in mid-IR waveband reflectances. In MMR bands 6 and 7, where water absorption properties were not offset by specular reflectance components in the nadir direction, dew reduced overall scene reflectance by as much as 60%.

Ratios of reflectances in different wavelength intervals, mirrored the additive effects of their component bands, and were better correlated with dew density than changes observed in single bands (Fig. 7). This was probably a result of reflectances in each band responding similarly to variation induced by target, irradiance, and measurement error between time periods so that the ratio of bands became more sensitive to the effect of dew. The ratio of Exotech bands 4 and 2 showed a 20–30% decrease as a result of morning dew concentrations. The ratio of MMR bands 7 and 3 revealed the most dramatic response with increasing dew because MMR 3 has a very strong positive correlation with dew while MMR 7 has a negative correlation. The use of such an index for assessing the amount of dew present on a canopy is obvious. The same index should have considerable potential for assessing relative differences in plant water content provided that concomitant changes in projected canopy biomass and/or stress-related changes in canopy architecture do not mask the effect.

Effect of dew on canopy temperatures

Canopy temperatures were measured with the thermal-IR channel of the MMR (Fig. 8). The thermal behavior of all cultivars was very similar whether or not

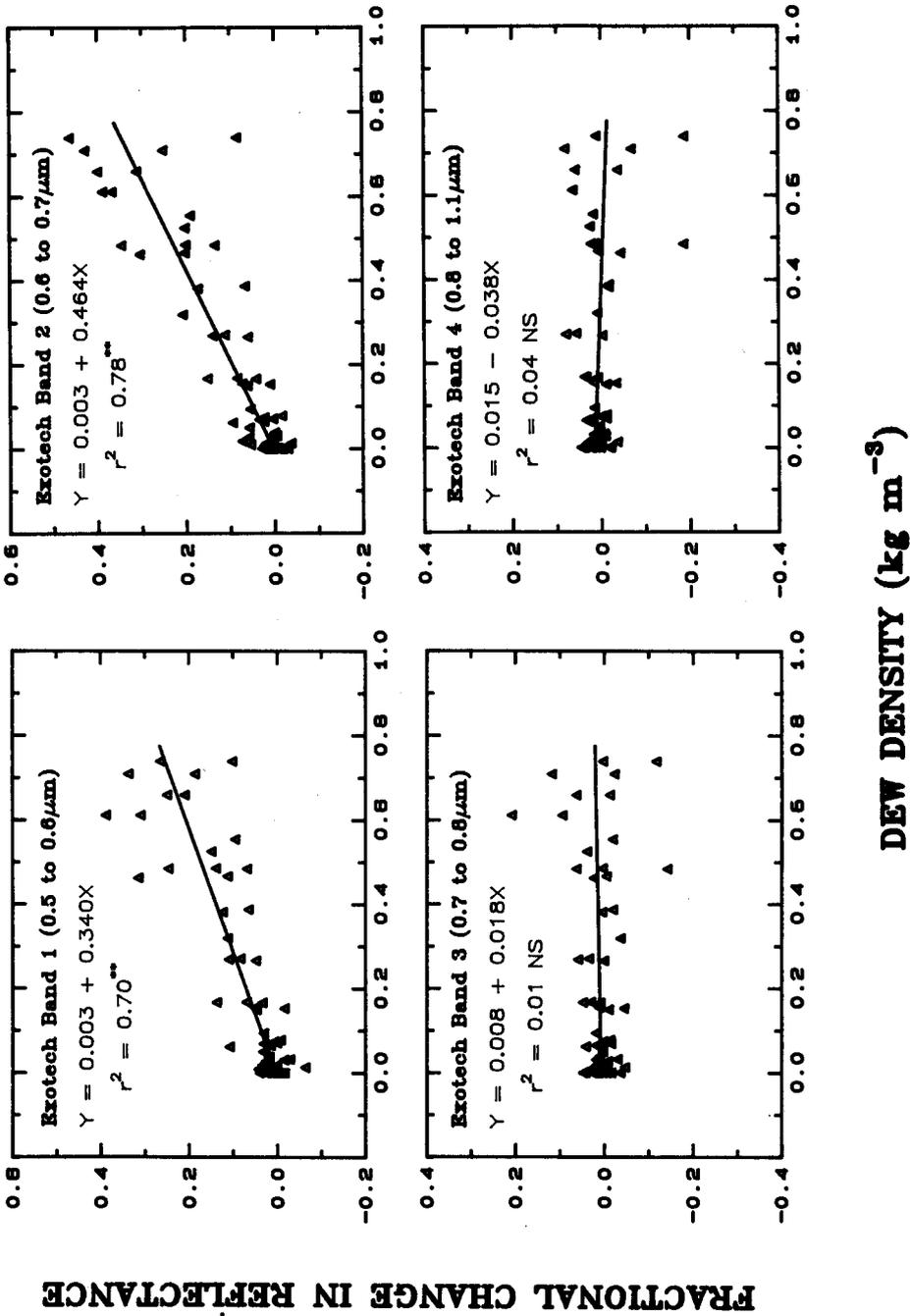


FIGURE 5. The fractional change in Exotech reflectances as a function of measured dew density of each wheat cultivar. Levels of significance are the same as those defined for Fig. 4.

FRACTIONAL CHANGE IN REFLECTANCE

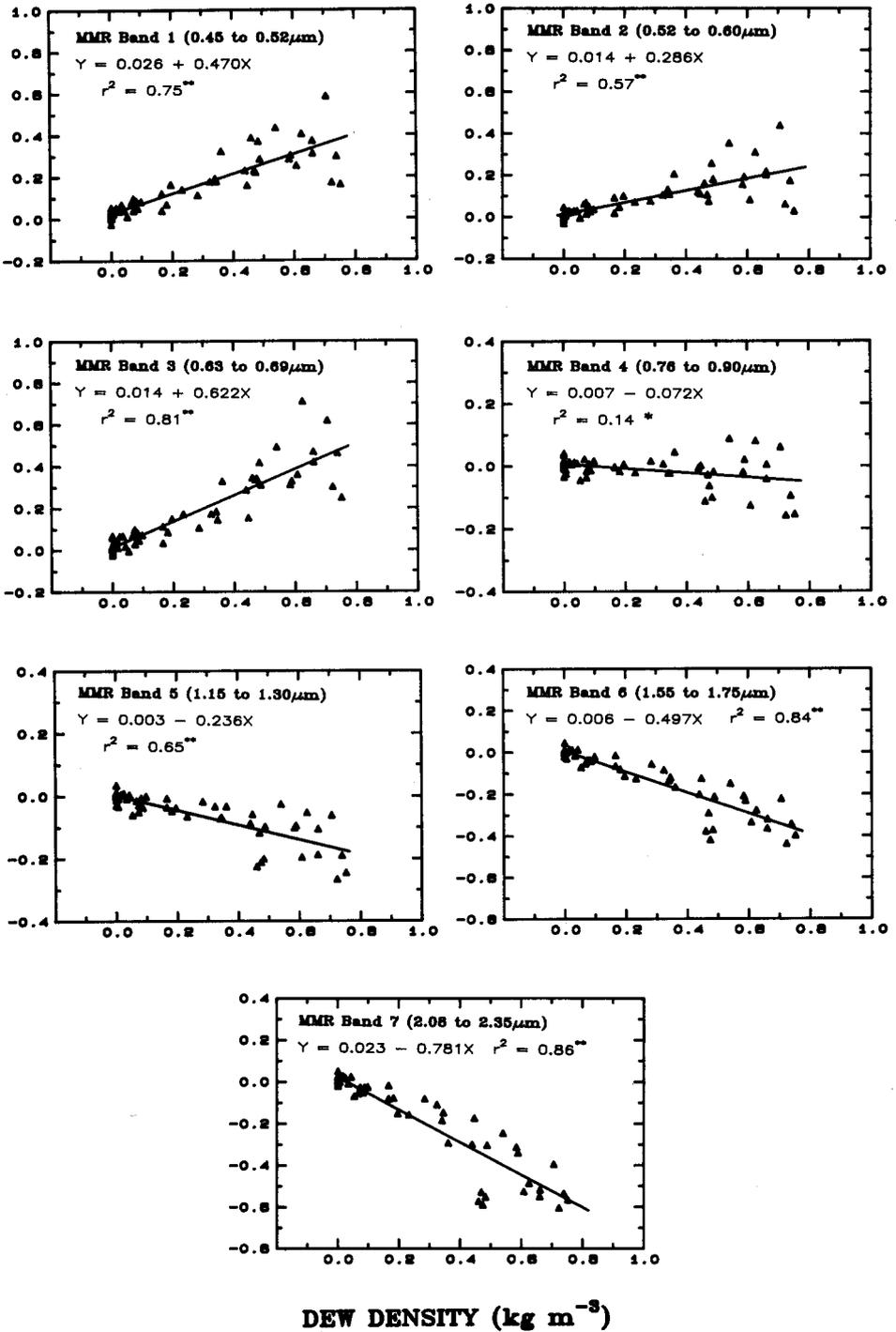


FIGURE 6. The fractional change in MMR reflectances as a function of measured dew density of each wheat cultivar. Levels of significance are the same as those defined for Fig. 4.

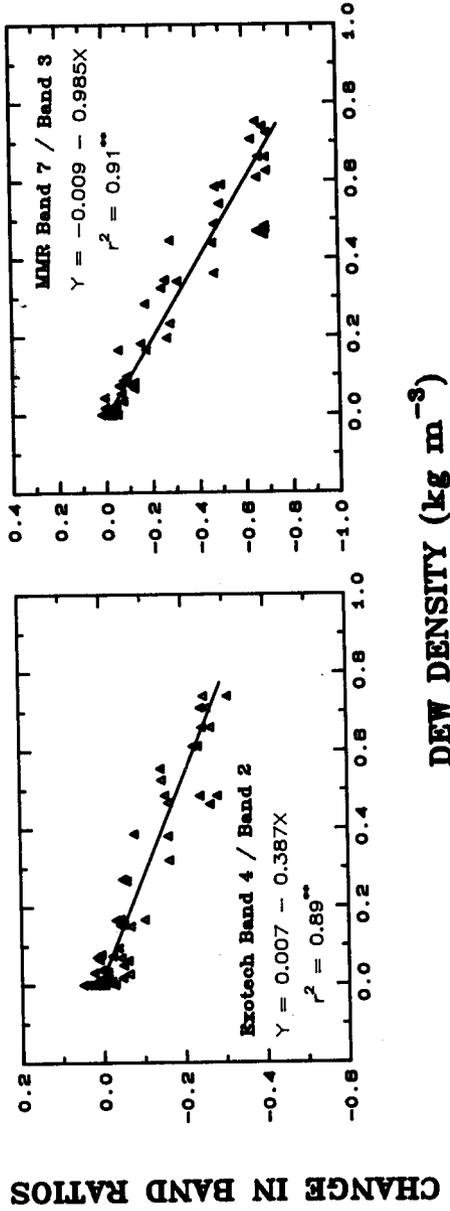


FIGURE 7. The fractional change in ratio type indices derived from two bands of each radiometer as a function of measured dew density of each wheat cultivar. Levels of significance are the same as those defined for Fig. 4.

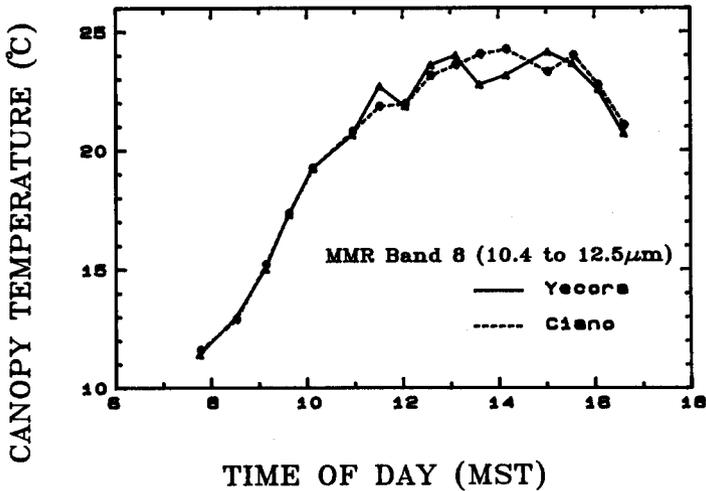


FIGURE 8. Radiant canopy temperatures measured with the MMR on 9 March 1983. Data are for canopies with morning dew and were uncorrected for target emissivity.

dew was present (only Yecora and Ciano targets with morning dew are shown in Fig. 8). Temperatures of 11.5°C were observed at the onset of the measurement sequence. Temperatures increased rapidly during the morning, reaching a plateau of 23–24°C during midday. Fluctuating windspeed and cultivar specific differences in leaf diffusion resistance parameters (U.S. Water Conservation Laboratory, unpublished data) probably contributed to the 1–2°C variability observed during midday. The diurnal asymmetry in temperatures arises from storage of sensible heat in the canopy and soil. It precludes an analysis of dew-induced changes in temperature similar to that used in the reflective solar portion of the spectrum. However, Fig. 9 reveals no systematic difference between temperatures of targets with natural morning dew and those without dew after 0800 h. In fact, maximum differences were observed after 1100 h when the canopy was relatively dry. Results indicate that dew does not

cause a measurable change in the radiant temperatures of well-watered wheat transpiring at near-potential rates, even though the radiation balance at the surface of the canopy is changed and despite the fact that mechanisms of latent heat exchange are probably also altered.

Summary and Implications

Multitemporal data collected using ground-based radiometers established the effects of dew on wheat canopy reflectance and emittance in 12 waveband intervals currently available for agricultural resource management purposes. In the visible and mid-IR regions, morning reflectances of canopies with dew were significantly different from reflectances observed during the afternoon at similar solar zenith angles. This pattern of diurnal asymmetry was used to show that moderately high dew conditions increased reflectance in the visible portion of the spectrum from 40–60% and decreased re-

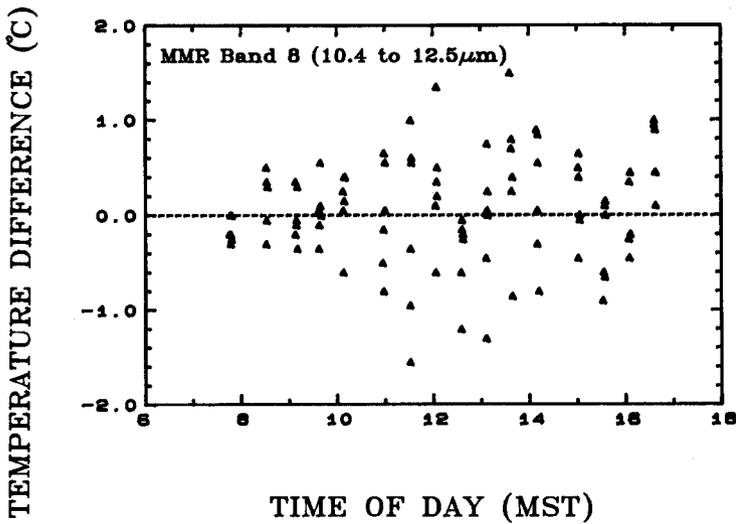


FIGURE 9. Observed differences in canopy temperatures between targets with different dew conditions on 9 March 1983. Data for six cultivars of wheat are shown. A positive value indicates that the "dewless" target (after 0800 h) was warmer than the target with natural dew. By 1100 h the dew had dissipated from both treatments.

flectance in the mid-IR by approximately the same amount. The reflectance of light in the near-IR portion of the spectrum between 0.7 and 1.1 μm was not affected by moderately high levels of dew. The thermal emittance properties of canopies with dew were similar to dewless canopies in this experiment where soil moisture was adequate and plants were transpiring at near potential rates.

Such observations have serious implications for vegetation assessment and land use classification schemes which make use of the visible or mid-IR regions of the electromagnetic spectrum. The effects of dew could mask actual reflectance differences existing between soil types, cultivars, growth stages, stress levels, or other factors affecting productivity. A survey of the distribution and persistence of dew in important agricultural regions would be of value in establishing the magnitude of the problem. It is now clear

from this study, however, that interpretations of early morning data acquisitions should take the potential complications introduced by dew into account. Finally, diurnal changes in reflectance could be used to monitor the amount and duration of canopy wetness for input into models that deal with the epidemiology of dew-related plant diseases.

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