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Diurnal Changes in Reflectance Factor Due to Sun-Row Direction Interactions

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DIURNAL CHANGES IN REFLECTANCE FACTOR DUE TO SUN-POW DIRECTION INTERACTIONS

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16. Abstract

To investigate the changes in the spectral reflectance factor related to row direction, sun direction, soil background, and crop development stage, Purdue/LARS collected two years of data of row crop canopies of soybeans grown in planter boxes and placed on a turntable. The results demonstrate that the direction of rows in a soybean canopy can affect the reflectance factor of the canopy by as much as 230%. The results for the red spectral region tend to support the validity of canopy reflectance models; results for the infrared spectral region do not.

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DIURNAL CHANGES IN REFLECTANCE FACTOR DUE TO SUN-ROW DIRECTION INTERACTIONS

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Summary

To investigate the changes in the spectral reflectance factor related to row direction, sun direction, soil background, and crop development stage, Purdue/LARS collected two years of data of row crop canopies of soybeans grown in planter boxes and placed on a turntable. The results demonstrate that the direction of rows in a soybean canopy can affect the reflectance factor of the canopy by as much as 230%. The results for the red spectral region tend to support the validity of canopy reflectance models; results for the infrared spectral region do not.

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1. INTRODUCTION

Row direction is an important factor influencing the radiance, and therefore the reflectance factor, of a row crop canopy. The range of row directions of fields of a particular crop is an important source of variation in satellite radiance measurements, adding uncertainty to crop identification and yield prediction. To investigate the changes in the spectral reflectance factor related to row direction, sun direction, soil background, and crop development stage, Purdue/LARS collected data of row crop canopies of soybeans (Glycine max), during two years.

2. LITERATURE

Numerous models have been proposed to explain and predict the measured reflectance factor of plant canopies as a function of plant geometry, sun angle, and view angle (1,2,3). The models by Suits and Smith deal with a canopy with no horizontal spatial variations (rows, for example).

Richardson et al. modeled the reflectance of a row crop with distinct horizontal spatial variations, as a function of plant, soil, and shadow components(3). A model suggested by Jackson et al. assumes an incomplete canopy of rectangular-shaped rows(4). The fractions of sunlit and shaded soil and vegetation viewed are calculated as a function of view angle for a particular canopy condition, described by plant cover, height/width ratio, row spacing and direction, time of day, day of year, latitude, and size of the radiometer resolution element.

Studies of the effect of sun zenith angle on reflectance generally have supported the predictions of the Suit's canopy reflectance model that the reflectance factor should increase as the solar elevation increases(5,6). Colwell attributes this to changes in the amount of shadow within the canopy(5). Field data have shown minor to significant increases in the infrared response with decreasing sun elevations (4,6,7).

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3. MATERIALS AND METHODS

During the first year of data collections, spectral measurements were taken every 15 minutes throughout the day over 9 plots of soybeans of differing row direction when they were at 64, 78, and 94 percent soil cover. Row directions in degrees from north were 90 (east), 105, 120, 135, 150, 165, 180, 210, and 240.

The second year, 1980, soybeans were grown in planter boxes and placed on a turntable, 3.6 meters in diameter, in the following manner: the larger soybeans (57 cm tall) were placed 70 and 60 cm apart to provide a 60 and 80 percent soil cover, respectively. The younger soybeans (17 cm tall) were placed 45 cm apart to provide 39 percent soil cover. The row direction was varied (180 degrees in 5 degree increments) as was the background between the rows (soil, black and white painted boards).

Radiance measurements, used to determine reflectance factor, were taken with a Landsat band radiometer (Exotech model 100) from 5.2 meters above the soil in 1979 and 8.8 meters in 1980. The radiometer has a 15 degree field of view and acquires data in the following wavelength regions: 0.5-0.6, 0.6-0.7; 0.7-0.8, 0.8-1.1 um.

4. RESULTS

The results, Figure 1, represent the reflectance factor of the soybean row crop for 60 percent background cover, two wavelength bands, red 0.6-0.7 um and infrared 0.8-1.1 um, the three backgrounds, soil and black and white painted boards, and azimuth angle from the solar azimuth direction. The results show that the reflectance factor of the canopy increased in both wavelength bands and for all row azimuth angles as the reflectance factor of the background material increased. For example, at zero degrees row direction in the red band, the R increased from about 3% for the black background, to 8% for the soil background, to more than 25% for the white background. For both the soil and the white backgrounds the R in both wavelength regions decreased for row directions away from zero. For example, at 90 degrees R is 5% and 8% in the red region and

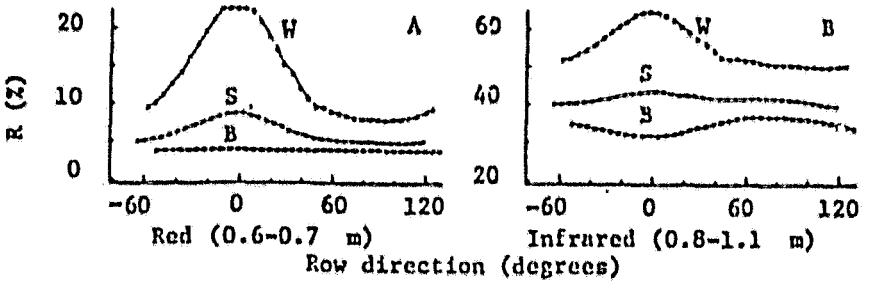

Fig. 1. Soybean canopy reflectance factor with row direction for white (W), soil (S), and black (B) backgrounds. Zero degrees row direction is the sun azimuth direction.

40% and 50% in the infrared region for the soil and white background, respectively. These values are significantly less than those corresponding to zero row direction. While the R of the black background changed little with row direction for the red region, in the infrared region it increased with row directions away from zero, unlike the row direction characteristics of the R of the soil and white backgrounds.

The results, Figure 2, show that the R varies with percent ground cover and row direction as well as with type of background and wavelength region. For the white background in both wavelength regions, Figures 2A and 2D, the curves of R are nested with the curve representing 40% background cover above, at all row directions, the 60% curve which in turn is above the 80% curve. For example, in the red region at zero row direction, the reflectance factors of the 40, 60 and 80 percent curves are 45, 23, and 15 percent. For the black background in both wavelength regions, Figures 2C and 2F, the curves of R are again nested but the progression is reversed compared to that of the white background; the highest reflecting canopy has 80% background cover; the lowest, 40%. For the soil background the progression of curves representing the various proportions of covered background depends upon wavelength band and row direction. In the red region the progression from highest reflecting to lowest reflecting is 40, 60, 80 percent cover at zero degrees row direction and 40, 80, 60 percent at 90 degrees. In the infrared the progression is 60, 80, and 40 percent at zero row direction and 80, 60 and 40 percent at 90 degrees.

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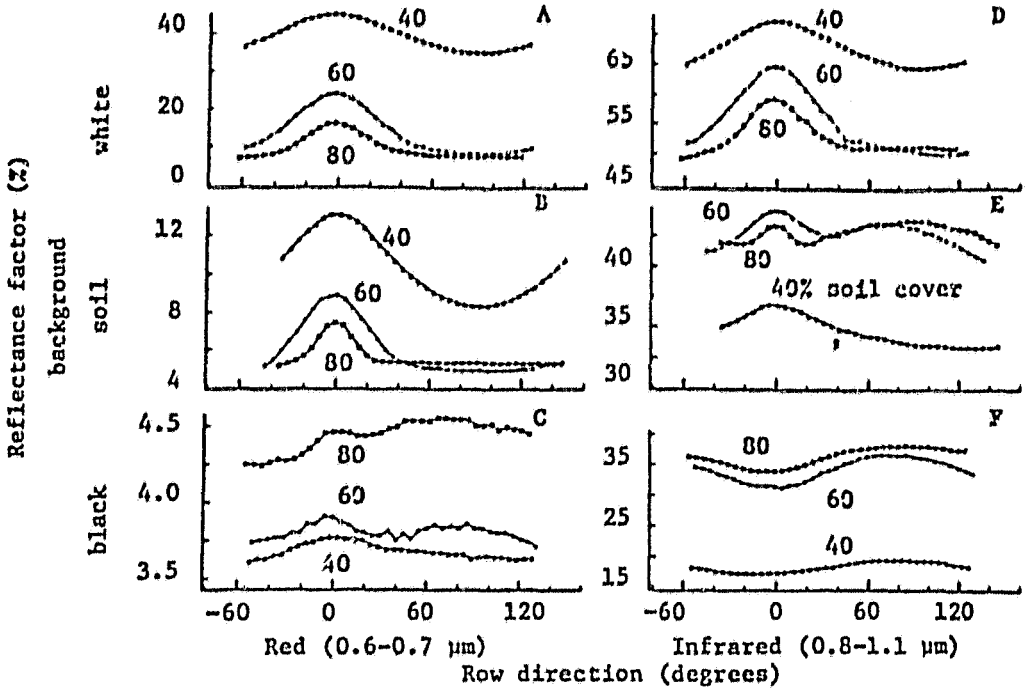

Fig. 2. Soybean canopy reflectance factor with row direction and background covers of 40, 60 and 80%. Zero row direction is the sun azimuth direction. Sun zenith angle is between 24 and 36 degrees.

The results, Figure 2A and 2B, show that for the red region and for soil and white backgrounds 60 and 80 percent covered by foliage there is a row direction beyond which the R changes little. For example, in Figure 2B the reflectance factor of the canopy with 80% cover does not change significantly for row directions more distant from zero than about 25 degrees. The angle is about 50 degrees for the 60 percent cover curve.

The results, Figure 3, show that for the canopy with 60% background cover, the R varies with sun zenith angle and row direction as well as with type of background and wavelength region. For the black background in both wavelength regions, Figures 3C and 3F, the reflectance factor increases at all row directions as the zenith angle of the sun increases. For example, in Figure 3C, the R of rows 60 degrees to the sun azimuth increases from 3.6% for period T1 (sun zenith angle) to 5.0% for period

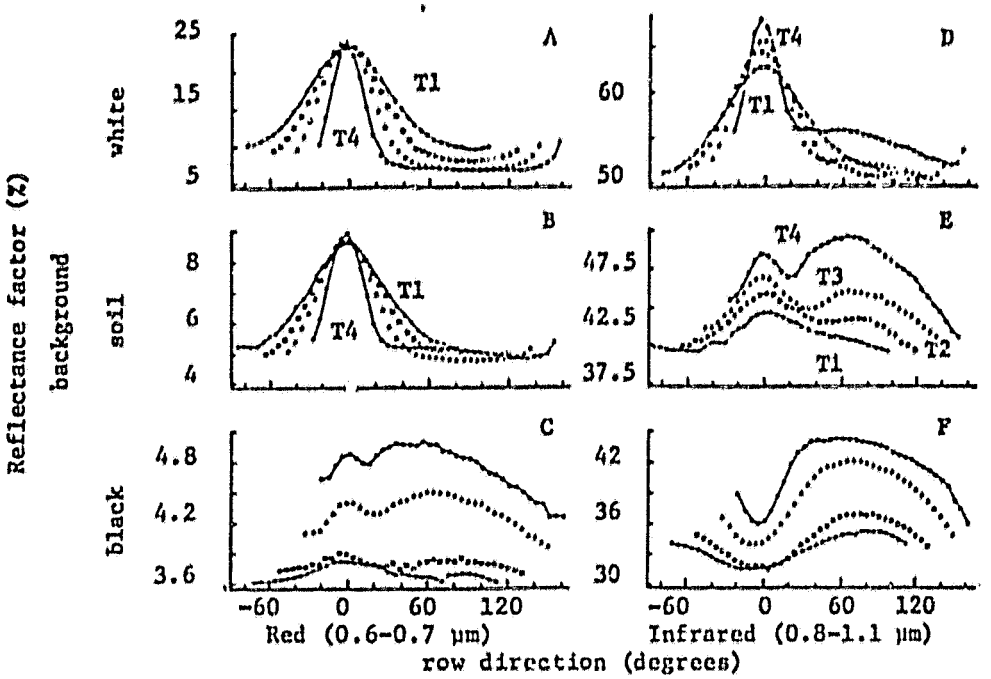

Fig. 3. Soybean canopy reflectance factor with row direction. Zero row direction is the sun azimuth direction. Time periods from solor noon and average sun zenith angles are: T1, -30m to 1h 05, 22°; T2, 1h 05 to 2h 03, 28°; T3, 2h 03 to 2h 23, 34°; T4, 2h 23 to 2h 35, 39°. Canopy had a background cover of 60 percent.

T4 (sun zenith angle of 38). In the red region, Figure 3C, each curve has two local maxima, one at zero row direction and another between 60 and 90 degrees. In the infrared, Figure 3F, the curves have global minima at zero degrees and global maxima between 60 and 90 degrees. Unlike Figures 3C, 3F, and 3F, all curves of Figures 3A, 3B, and 3D have global maxima at zero degrees row direction. As shown in Figures 3A and 3B, the R of the canopy oriented with zero degrees row direction did not change in the red region for the white and soil backgrounds. The R of the canopies with white and soil backgrounds did increase, Figures 3D and 3E, in the infrared at zero degrees row direction with increasing sun zenith angle.

The magnitude of the slope of the curves, Figures 3A, 3B, and 3D, is greatest near zero row directions and for period T4, late in the day at large sun zenith angles. For example, while the R at zero row direction

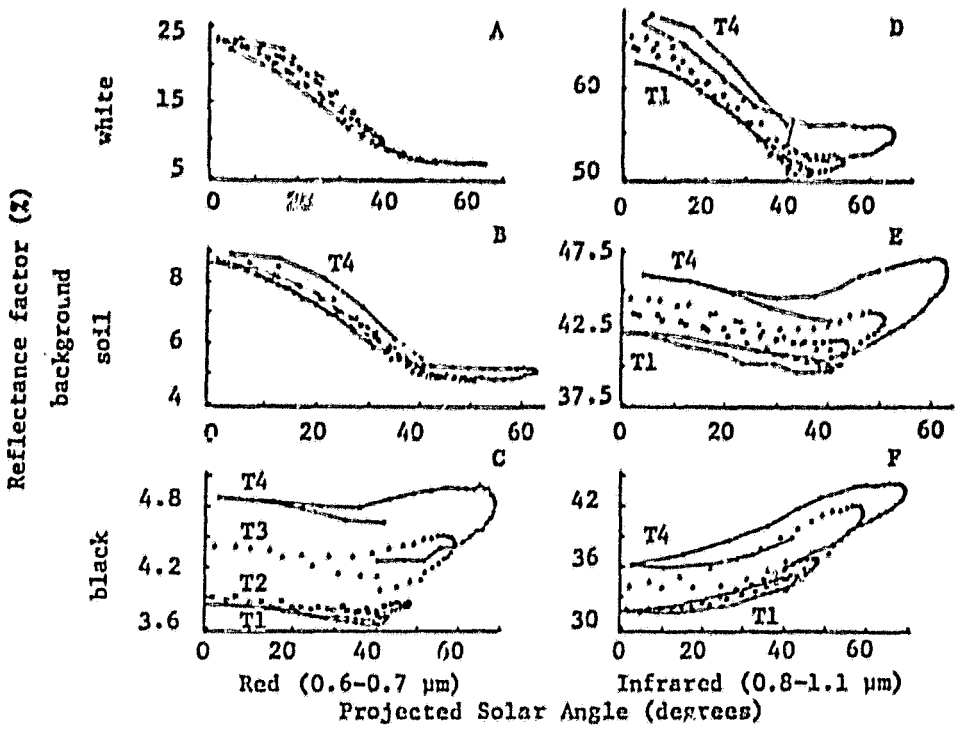

Fig. 4. Soybean canopy reflectance factor with projected solar angle. Time periods are as in Figure 3. Canopy had a 60 percent background cover.

for the white background, Figure 3A, is the same for all curves, about 24%, the R at 20 degrees row direction is significantly greater for period T1 (R = 20 percent) than T4 (R = 10 percent). The curves, Figures 3A, 3B, and 3D, tend to appear, for row directions near zero, more like a church spire late in the day (large zenith angles) rather than near solar noon.

The results, Figure 4, show that R is a function of one variable, projected solar angle, as well as background and wavelength. For the soil and white backgrounds measured in the red spectral region, Figures 4A and 4B, the projected solar angle explains most of the R variation in the two variables, row direction and sun zenith angle. The R values in both figures do not change substantially for data with projected solar angles larger than a critical angle, approximately 45 degrees. The reflectance factor of the black background measured in the red wavelength

region as well as the R of all backgrounds measured in the infrared region varied with both sun zenith angle and projected solar angle, unlike the R plotted in Figures 4A and 4B. The curve T4 in Figure 4C has two values of R for any specific projected solar angle; most curves in the figures for the infrared region show the same characteristic.

5. DISCUSSION

The results, Figures 1-4, demonstrate that the direction of rows in a soybean canopy can significantly affect the reflectance factor of the canopy. A measure of the effect upon R of changes in row direction, the quantity $100\% \ (R_{MAX} - R_{MIN})/R_{MIN}$, is as large as 230% for the highly reflective white background measured in the red spectral region, Figure 4A, and tends to be smaller for less reflective backgrounds and for the infrared spectral region.

The results for the red spectral region, a chlorophyl absorption band where little light is multiply scattered in the canopy, support the validity of canopy reflectance models which include the effects of rows. The models predict and the results for the white and soil backgrounds, Figures 1A and 1B, show that the canopy reflectance factor is largest when the background is fully illuminated (0 degrees row direction) and decreases (away from zero degrees row direction) proportion of sunlit background decreases. The results, Figures 4A and 4B, support these canopy reflectance models which predict that the R, Figures 3A and 3B, is symmetric about both the zero and 90 degree row directions. The models predict and the results support that the family of curves in row direction and solar zenith angle, Figures 3A and 3B, become one curve when plotted with projected solar angle, Figures 4A and 4B. The models predict and the results support the concept of a critical angle, Figures 4A and 4B, beyond which no portion of the canopy background is illuminated directly by sunlight directed down the rows and beyond which the canopy reflectance factor is constant. The results for the black background, Figures 3C and 4C, do not support the canopy reflectance models because the R for zero row direction increases with increasing sun zenith angle; the models predict R at zero row direction will remain constant or decrease as sun zenith angle increases.

The results for the infrared spectral region, Figure 3D, 3E, and 3F, a band with minimal light absorption by plant pigments and significant light scattering by plant foliage, as well as the results for the black background measured in the red spectral region, Figure 3C, tend not to support the validity of these canopy reflectance models. The results show but the models do not predict that the canopy R generally increases with increasing solar zenith angle. The increase in R is especially pronounced for large solar zenith angles and 60-90 degree row directions. Examination of photographs taken concurrently with the spectra indicates that when the sun zenith angle was large, leaves along the edges of rows were oriented to reflect a significant amount of flux to the radiometer. While the pubescent leaves of the soybean canopy did not appear as prominent specular reflectors, individual soybean leaves tend to preferentially scatter both visible and infrared light in the general direction of specularity(8). More importantly, analysis of data presented by Breece and Holmes suggests the hemispherical reflectance of leaves increases when they are illuminated at increasingly off-normal angles(8). Compared to the reflective characteristics of a canopy with perfectly diffuse, lambertian, leaves, both of these leaf phenomena would tend to increase the light flux at large solar zenith angles which is directed from the canopy to the radiometer.

A minor factor to be considered when examining the increase of the canopy reflectance factor for large solar zenith angles and 60-90 degree row directions is the proportion of shaded background illuminated by sunflecks. This proportion is largest for row directions near 90 degrees where sunlight must traverse the least amount of foliage to illuminate the background. Analysis of photographs indicated sunflecks on the background were a minor factor in the canopy reflectance.

6. ACKNOWLEDGEMENT

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