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Variations of Crop Canopy Spectral Reflectance Measurements Under Changing Sky Conditions

Relative differences between spectral reflectances collected under cloudy and sunny conditions above the same location of a crop canopy at approximately the same time are relatively constant for both red and far-red spectral regions.

Abstract: *The possibility of using reflectance data collected under both cloudy and sunny conditions is studied. Extreme values of red and far-red reflectances measured directly over bare soil and crop canopies during intermittently cloudy conditions can differ by more than 100 percent and 60 percent, respectively. Eliminating the irradiance variations by using only data collected under sunny conditions reduced such variation to within 1 percent for bare soil and to within 8 percent and 20 percent for crop canopy red and far-red reflectances, respectively. In general, the reflectances measured under cloudy conditions with relatively constant irradiance values are constant and approximately 10 percent larger than the ones measured at similar sun angles during sunny conditions. This result is independent of the species and the spectral regions under study.*

Introduction

Remote sensing from ground platforms has been used in agriculture to quantify information regarding crop canopy characteristics (Jackson *et al.*, 1980). It has been found that good estimates of crop canopy parameters by spectral techniques depend upon the variability introduced in spectral reflectance data by vegetation factors (Waller *et al.*, 1981). Accuracy of the estimates is often decreased by the presence of non-vegetative factors affecting spectral reflectances (Crist, 1984). It is then important for deriving true relationships between crop spectral reflectances and a given canopy parameter to either maintain the reflectance measuring conditions as constant as possible or to develop methods that will account for the changing conditions (Richardson, 1981; Goel *et al.*, 1984).

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Photogrammetric Engineering and Remote Sensing,
Vol. 51, No. 6, June 1985, pp. 689-695.
0099-1112/85/5006-0689$02.25/0

Variations in both quantity and quality of solar irradiation change crop canopy spectral reflectances (Fuchs *et al.*, 1972; Dave, 1980). Understanding the effects of changing sky conditions on canopy reflectances is thus important for accurate estimations of crop canopy parameters by ground based remote sensing (Colwell, 1974). Methods allowing the selection of periods of sunny conditions during intermittently cloudy days were developed by Duggin (1980) and Richardson (1981). Data collected under cloudy conditions were found useful for distinguishing between soil and vegetation (Thomas *et al.*, 1977). However, Robinson and Biehl (1979) concluded that the presence of clouds changes the intensity of the irradiance too rapidly and unpredictably to measure useful reflectance values.

The objectives of this paper are to identify the differences that occur between spectral reflectance data collected under sunny conditions from those collected under cloudy conditions, and to examine the possibility of using both types of data for estimating crop canopy reflectances.

Methods

The effects of changing irradiance conditions on spectral reflectances were analyzed for sunflower (*Helianthus annuus* L. cv. Sigco 449), rapeseed (*Brassica campestris* L. var. Candle), barley (*Hordeum vulgare* L. var. Massey-Breeder No 2), bare soil, and alfalfa (*Medicago sativa* L. cv. Saranac) with data collected on 20 July, 26 July, 29 July, 6 August, and 22 August, respectively. Crops were seeded in 10-m by 8-m plots on a fertilized Rubicon sandy soil.

Radiometric data were collected every 2 seconds with a spectroradiometer which consecutively measured, at selected central wavelengths, (790, 740, 675, and 648 nm) the reflected radiances and incident irradiances. Wavelength band selection was based upon spectral properties of green plants (Knipling, 1970; Tucker and Maxwell, 1976). The interference filters used were characterized by a narrow spectral half bandwidth of 10 nm (Brach *et al.*, 1983).

Four conical reflected radiances and four hemispherical incident irradiances recorded every 16 seconds provided four hemispherical-conical reflectances after ratioing the former with the latter for each wavelength (Nicodemus *et al.*, 1977). Both the irradiance and radiance data were collected with the same sensor and spectral filter, thereby eliminating potential differences between two detecting systems.

Effects of changing background, canopy architecture, crop physiology, and viewing angles of the sensor were eliminated by maintaining the spectroradiometer stationary above the same crop location. The influence of solar elevation and azimuth angles was attenuated by grouping the data in periods of 300 seconds, while variability introduced by wind was minimized by using the median instead of the mean as an estimator of the reflectance of a canopy location sampled during a short period of time (Lord *et al.*, 1983). Once the influence of these factors was reduced as much as possible, changes in sky conditions were assumed to be responsible for most of the variability observed in spectral reflectance measurements.

Two different constant irradiance conditions were analyzed and compared. Sky conditions were defined as sunny when shadows were visible on the ground. These conditions referred to an irradiance regime of approximately 25 percent diffuse and 75 percent direct; sky was either cloudless or partially cloudy, but the sun and its vicinity were always cloudless. Cloudy conditions were assumed when the sun was completely hidden by clouds with no shadow visible on the ground. A diffuse regime of relatively constant irradiance characterized this condition. In order to qualify a period as constant in sky condition, spectral irradiance values collected every 16 seconds for each wavelength had to remain within 5 percent of the mean for at least four consecutive sets of measurements.

The statistical analysis of the reflectance data set was performed with a factorial model of analysis of variance (Snedecor and Cochran, 1957).

Results and Discussion

Reflectance values collected above the same canopy location vary when the irradiance conditions change. Figure 1 presents this result for bare soil. Dotted lines represent the deviation of the irradiance measurements from the mean irradiance. In order to reduce the influence of wind variations, deviation from the median are calculated for spectral reflectances (Lord *et al.*, 1983). For a period of 5 minutes with changing irradiance conditions, extreme values of red and far-red reflectances can differ by more than 100 percent and 60 percent, respectively (Figure 1B). These differences are less than 1 percent during constant irradiance conditions (Figure 1A). The strong variability introduced in reflectance data by the changing conditions is confirmed by the high standard deviations found for either the irradiance or reflectance data. It may be noted that the irradiance standard deviations do not significantly differ between red and far-red wavelengths because the irradiance attenuation by clouds is relatively similar for these two spectral regions (Kondratyev, 1969).

Differences in extreme values of reflectances measured over alfalfa exceed 60 percent during periods of changing irradiance conditions (Figure 2B) while they are within 8 percent during periods of uniform conditions (Figures 2A and 2C). The influence of wind on these measurements can be assumed to be negligible because the reflectance measurements collected in periods of constant irradiance and under similar wind conditions 20 min-

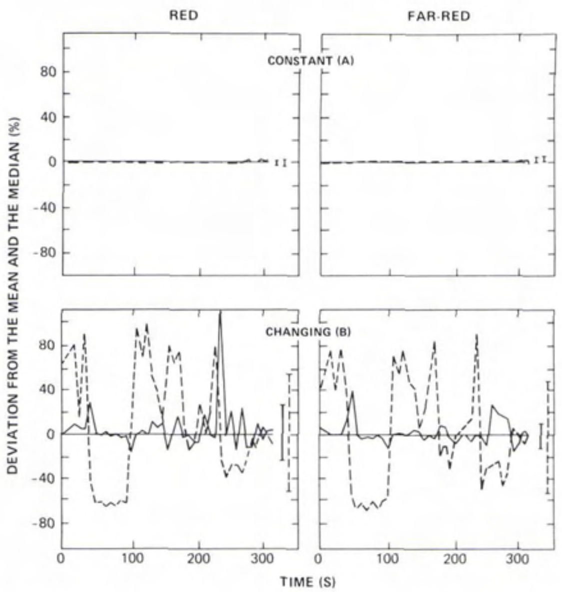

FIG. 1. Deviations of the irradiance (----) from its mean and deviation of the reflectance (———) from its median for bare soil during periods of constant (A) and changing (B) irradiances at solar elevation angles of 57° and 64°, respectively. Bars denote the standard deviations.

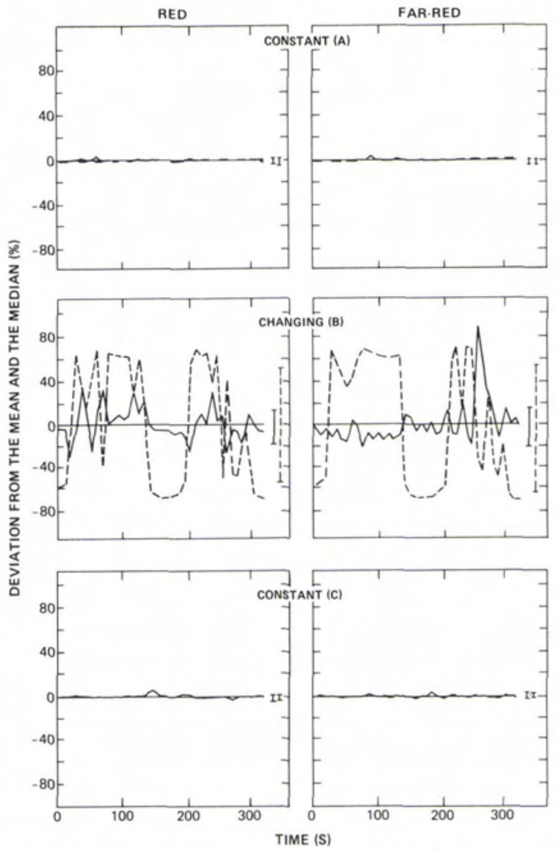

FIG. 2. Same as Figure 1 but for alfalfa at 10 percent flowering during periods of constant (A), changing (B), and constant (C) irradiances at solar elevation angles of 59° and 60° before and after noon, respectively.

utes before (Figure 2A) and after (Figure 2C) a period of variable sky conditions do not show large variations. High reflectance and irradiance standard deviations calculated for data from the variable period (Figure 2B) also confirm that higher variations in reflectance data shown for this period are principally due to the continuous variations in the sky conditions. For a canopy composed of plants with less rigid stems, the presence of wind variations introduces more variability (Lord *et al.*, 1983). Figure 3 shows for a barley canopy higher deviations from the median and higher standard deviations for the period including both sunny and cloudy conditions. Extreme values of red and far-red reflectances collected at each 8 seconds during a period of 5 minutes differ by about 75 percent and 35 percent, respectively (Figure 3B). These differences do not exceed 25 percent and 20 percent, respectively, during 5 minutes of sunny conditions (Figure 3A). For a specific spectral reflectance value, the error due to sky conditions may then exceed the error of 10 percent found by Duggin (1980) for the reflectance factor collected over wheat canopies.

When the irradiance conditions change within a period of 5 minutes, the largest reflectance deviations from the median usually occur when two successive irradiance values display the largest absolute differences. This corresponds to the time when clouds either begin or stop covering the sun. These transition times for the insolation conditions may be easily identified with our method, because irradiance values are collected every 4 seconds. Measurement of plant canopy spectral reflectances during these transition periods must then be avoided, because they are subject to large errors (Milton, 1981). The errors result from changes in angular properties of the incident radiation between times of measurement of the two components of the spectral reflectance; that is, the irradiance and the reflected radiation. Between transition times, both sunshine and cloudy conditions of uniform irradiances show relatively constant spectral reflectance values.

To compare spectral reflectances collected under cloudy and sunny conditions, we identify numerous periods which include both cloudy and sunny subperiods of constant irradiances. A subset of data from a subperiod of uniform irradiance conditions is selected only when the differences between irradiance values remain within 5 percent for a minimum of 64 seconds. Its median and the median for the nearest subperiod characterized by the other uniform irradiance conditions are calculated and compared only if the middle of both subperiods are not

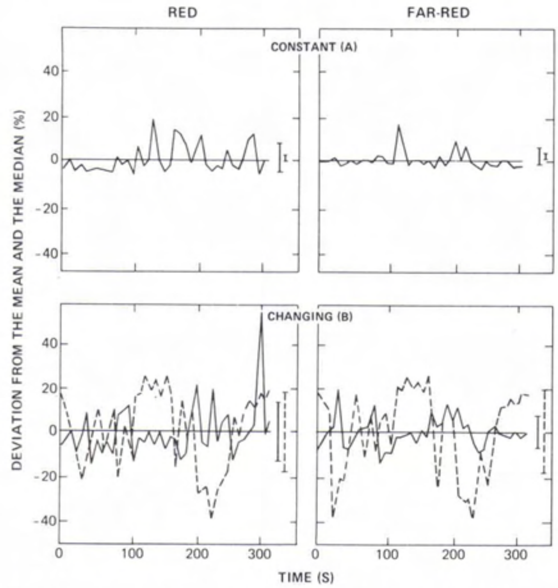

FIG. 3. Same as Figure 1 but for barley at hard dough during periods of constant (A) and changing (B) irradiances at solar elevation angles of 63° and 65°, respectively.

separated by more than 30 minutes in time. This is done rapidly enough to assume similar sun angles.

Figure 4 indicates that the far-red reflectances measured above a given location of a crop canopy usually increase during cloudy conditions, whereas this enhancement is present only for barley in the red region. This increase is probably caused by the smaller specular reflection under a regime of completely diffuse irradiance. This, in turn, increases the proportion of the total reflected energy reaching the detector located at nadir. The analysis of variance of reflectance data collected by wavelength over a whole day shows that the differences between the spectral reflectances collected under both irradiance conditions are significant. Daily variations in sun angle also introduce significant variability in the spectral reflectance data, but the percentage of the total variability explained by "sky conditions" is very high for a factor having 12 to 28 times less degrees of freedom than "sun angle" (Table 1). This result confirms the importance of taking into account the irradiance conditions when spectral reflectance measurements are collected.

The degrees of freedom of "sun angle" in Table 1 are partitioned into two groups in order to see if a

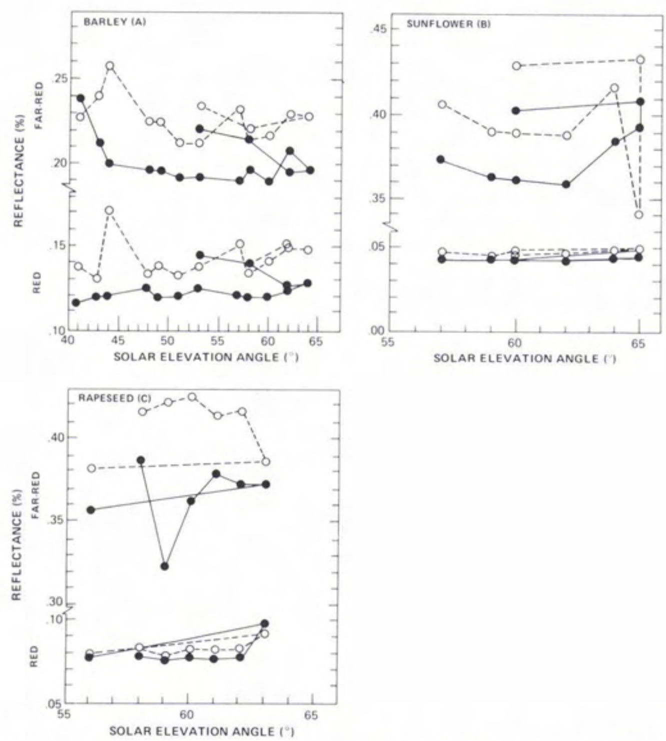

FIG. 4. Red (675 nm) and far-red (790 nm) reflectances collected over barley at hard dough, sunflower at flowering, and rapeseed at onset of flowering under both cloudy (----) and sunny (———) conditions.

TABLE 1. PERCENTAGE OF THE TOTAL VARIABILITY EXPLAINED BY "SKY CONDITIONS" AND "SUN ANGLE" FACTORS, THIS LAST ONE BEING DECOMPOSED IN "SUNNY" AND "CLOUDY" FACTORS. ALL THE FACTORS ARE SIGNIFICANT AT THE α LEVEL 0.05, EXCEPT FOR THOSE WITH AN ASTERISK.

Crop (growth stage)	Main Factor	df	Central Wavelength (nm) 790	740	675	648
Sunflower (flowering)	sky conditions	1	26.1	33.7	38.7	44.6
	sunny	6	35.9	39.6	48.7	43.0
	sun angle	12	73.9	66.3	61.3	55.4
	cloudy	6	38.0	26.7	12.6	12.4
Rapeseed (onset of flowering)	sky conditions	1	75.0	68.0	8.2	8.6*
	sunny	6	16.2	17.2	58.7	78.7
	sun angle	12	25.0	32.0	91.8	91.4
	cloudy	6	8.8	14.8	33.1	12.7
Barley (hard dough)	sky conditions	1	44.9	41.5	41.8	28.1
	sunny	14	42.6	29.8	40.9	43.3
	sun angle	28	55.1	58.5	58.2	71.9
	cloudy	14	12.5*	28.7	17.3	28.6

* Non-significant at α level 0.05.

significant amount of variability is still introduced in spectral reflectances collected under cloudy conditions. This analysis is performed because the presence of clouds means completely diffuse characteristics of the incident radiation and, consequently, a possible decrease in the importance of the daily variations in sun angle on spectral reflectance measurements collected under such sky conditions. The first group includes the data collected under sunny conditions, while the second one includes those collected under cloudy conditions (Table 1). The application of an F-test on these data indicates significant differences at the 1 percent level for both conditions and for all wavelengths. These differences probably occur because the presence of clouds does not completely eliminate the directionality of the incident radiation; more incident energy is still provided by the portion of the sky which is located near the sun (Kondratyev, 1969). However, the percentage of the variability explained by the data collected under sunny conditions is always higher than the one collected under cloudy conditions (Table 1).

In order to find a method to adjust the spectral reflectance measurements collected under both sky conditions, differences observed between the spectral reflectances collected under cloudy conditions and those collected under sunny conditions are given in Table 2. These results show that the far-red reflectances collected under cloudy conditions often increase by about 10 percent compared to those collected under sunny conditions. With the exception of rapeseed, the red reflectance differences between the same two conditions of constant irradiance also remain near 10 percent.

The absence of differences for red reflectances collected over rapeseed is probably due to its minimal vertical structure compared to the other two crops. The structure of the canopy and the strong absorption of red radiation by green leaves would explain this absence of influence for the red region compared to the far-red one, because the amount of energy which could be reflected is always low (Knipling, 1970).

Within a given species, and particularly for barley, some specific ratios differ from the approximate 1.10 value normally calculated. Some of those deviations are caused by the presence of only one outlier which cannot be weighed by the other reflectance values. This is often caused by a relatively short sampling period for this specific period. For example, the ratio for barley at solar elevation angle of 41° and for 790 nm increases from 0.95 to 1.07 when one reflectance measurement collected under constant cloudy conditions is eliminated due to a non-negligible increase of the irradiance values for this specific measurement. This change in the irradiance value might be due to irradiance variations within the sampling frequency of 8 seconds.

Deviations from the 1.10 ratio are not all explained by the presence of outliers. For example,

TABLE 2. RATIOS OF THE REFLECTANCES COLLECTED UNDER CLOUDY AND SUNNY CONDITIONS AT SIMILAR SUN ANGLES FOR DIFFERENT TIMES OF DAY AND FOR DIFFERENT SPECIES.

		Wavelength (nm)			
		790	740	675	648
Sunflower (flowering)	60	1.04	1.04	1.09	1.09
	65	1.06	1.05	1.02	1.03
	65	0.87	1.08	1.05	1.04
	64	1.09	1.09	1.09	1.10
	62	1.08	1.08	1.06	1.13
	59	1.07	1.03	1.07	1.06
	57	1.09	1.09	1.07	1.07
	mean ± S.D.	1.04 ± 0.08	1.07 ± 0.02	1.06 ± 0.02	1.07 ± 0.02
Rapeseed (onset of flowering)	58	1.08	1.08	0.98	0.99
	59	1.31	1.02	0.95	1.02
	60	1.17	1.11	0.94	0.97
	61	1.09	1.09	0.96	1.05
	62	1.12	1.10	0.98	0.99
	63	1.03	1.03	1.08	0.92
	56	1.07	1.04	1.02	1.03
	mean ± S.D.	1.13 ± 0.08	1.07 ± 0.03	0.99 ± 0.05	0.99 ± 0.04
Barley (hard dough)	41	0.95	1.04	1.19	1.03
	43	1.13	1.40	1.09	1.12
	44	1.30	1.57	1.43	1.05
	48	1.15	1.13	1.06	1.01
	49	1.15	1.14	1.17	1.12
	51	1.11	1.09	1.10	1.08
	53	1.11	1.14	1.10	1.05
	57	1.23	1.20	1.25	1.20
	58	1.09	1.15	1.12	1.25
	60	1.15	1.12	1.18	1.13
	61	1.10	1.16	1.21	1.21
	64	1.16	1.16	1.16	1.14
	62	1.17	1.17	1.22	1.23
	58	1.03	1.02	0.99	1.00
	53	1.07	0.96	1.01	1.04
	mean ± S.D.	1.13 ± 0.07	1.16 ± 0.13	1.15 ± 0.09	1.11 ± 0.07

the elimination of outliers on the basis of a constant irradiance reduces the ratio of reflectances for barley at a solar elevation angle of 43° and for 740 nm from 1.40 to 1.31, a value which is still too high. But wind variations also introduce variability in this specific case, as indicated by the relatively large fluctuations in the reflected radiation values while the irradiance values vary only slightly (Figure 3A). It appears that the relative difference between reflectances collected under sunny and cloudy conditions is similar for three different species characterized by large canopy structural differences, because the 1.10 ratio or a close value is found for more than 80 percent of the results listed in Table 2.

CONCLUSIONS

Based on the results presented in this paper, the following conclusions can be made:

- Changing atmospheric conditions introduce significant amounts of variability in crop canopy spectral reflectance data, the absolute difference between two consecutive reflectance measurements reaching a maximum at the time when clouds either begin or stop covering the sun;
- daily variations in sun angle caused significant variations in spectral reflectance data collected under both sunny and cloudy conditions of constant irradiance; and
- the spectral reflectance data collected under cloudy conditions are greater than those collected under the same experimental condition but sunny; more importantly, the relative difference between these two measurements is reasonably constant.

This last result suggests that it should be possible to adjust on some relative scale all the reflectance data collected under different conditions of uniform irradiation. The estimation of a given crop canopy parameter would then be more accurate, because more data would be available.

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(Received 20 July 1984; accepted 19 December 1984; revised 11 March 1985)