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Soybean Canopy Reflectance as Influenced by Cultural Practices

by J.C. Kollenkark, C.S.T. Daughtry, and M.E. Bauer

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16. Abstract

Experiments were conducted at West Lafayette, Indiana in 1978 and 1979 to study the reflectance factor of soybean canopies as affected by differences in row width, population, planting date, cultivar, and soil type. Reflectance factor data were acquired throughout the growing season with a Landsat-band radiometer. Agronomic data included plant height, leaf area index, development stage, total fresh and dry biomass, percent soil cover, and grain yield. The results indicated that row width, planting date, and cultivar influence the percent soil cover, leaf area index, and biomass present, which were in turn related to the multispectral reflectance. Additionally, the reflectance data were quite sensitive to the onset of senescence. Soil color and moisture were found to be important factors influencing the reflectance in single Landsat bands, but the near infrared/red reflectance ratio and the greenness transformation were less sensitive than the single bands to the soil background present.

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Introduction

As world demand for food continues to expand, increased pressures are being placed on our agricultural systems to supply timely and accurate crop production information. In recent years considerable progress has been made toward the operational use of remote sensing technology to inventory crop acreages, assess crop stresses, and predict yields (Bauer et al., 1978). Understanding the relationship between the reflectance measured and the various cultural practices used in today's soybean production is one of the keys for further development and use of remote sensing as a tool for crop inventory.

Spectral reflectance values have been related to leaf area index, fresh and dry biomass, plant water content, chlorophyll content, percent soil cover and crop yield (Bauer, 1975; Bauer et al., 1978; Ahlrichs, 1978; Tucker et al., 1977). Colwell (1974) observed that at high soil cover levels, the reflectance factor in the red wavelength region was less sensitive to changes in percent soil cover as solar elevation decreased. The reflectance factor in the near infrared wavelength region is best for estimating leaf area index and biomass in dense canopy situations (Ahlrichs, 1978; Colwell, 1974). Holben et al. (1980) observed a high correlation of radiance in the red wavelength region to changes in percent soil cover in soybeans, but a poor correlation between crop cover and leaf area index because the leaf area index continued to increase beyond the point of 100 percent soil cover. Field data acquired by Tucker (1977) and laboratory work by Gausman et al. (1971) show that the change in the spectral response in the visible region levels off at low leaf area indicies (approximately 2.0), compared to the near infrared region where the spectral response levels off at much higher leaf area indicies (approximately 8.0).

The importance of the soil background, especially under low soil cover, to spectral reflectance has been recognized by many. Colwell (1974) examined two differently colored soils with similar soil covers (approximately 37 percent) and reported a spectral response nearly three times higher on the light-colored soil than on the dark-colored soil in the red wavelength region. Increasing soil moisture decreases the reflectance in all wavelengths (Stoner, 1979) and may increase or decrease the contrast between the soil and vegetative reflectance (Colwell, 1974; Tucker, 1977).

The appearance of crops are greatly influenced by many cultural and environmental factors which may be sources of variation or error in remotely-sensed observations of crops. In the search for maximum soybean yields, cultural practices including row spacing, population, and planting date are being modified. The trend has been to move from wide rows to narrower rows, to higher plant populations, and to earlier planting dates. All of these changes result in greater light interception early in the growing season and higher yields.

The objectives of this research were to study the reflectance characteristics of soybean canopies throughout the growing season as affected by several current cultural practices and to relate changes in reflectance factor to changes in agronomic characteristics of soybean canopies.

Materials and Methods

Experimental Conditions

Experiments were conducted on the Purdue Agronomy Farm northwest of West Lafayette, Indiana. The 1978 experiment was a randomized, complete block design which included three blocks, three cultivars (Amsoy 71, Wells, and Elf), three populations (111,000, 185,000, and 259,000 plants/ha), and three row widths (15, 45, and 90 cm) for a total of 81 plots. The plot size was 2.3 x 14.5 meters and all rows were in a north-south orientation. The plots were hand thinned to obtain the desired populations.

The 1979 soybean cultural practices experiment was a randomized, complete block design with two soil types (Chalmers silty clay loam, typic Argiaquoll, and Russell silt loam, typic Hapludalf), two blocks within each soil type, two row widths (25 and 75 cm), two cultivars (Amsoy 71, Williams), and three planting dates. Planting dates for the Chalmers silty clay loam were May 10, May 24, and June 15. Poor drainage on the Russell silt loam delayed the planting dates on it to May 24, June 15, and July 3. The plot size was 3.4 x 15 meters and all rows were planted in the north-south orientation.

Spectral Measurements

Radiance measurements, used to determine reflectance factor (RF), were acquired with a Landsat-band radiometer (Exotech Model 100) several times throughout the growing season each year (Table 1). Nicodemus et al. (1977) and Robinson and Biehl (1979) describe the conditions and procedures for obtaining the reflectance factor data which closely approximate the bidirectional reflectance factor (BRF). The Exotech Model 100 is a four-band radiometer with a 15 degree field of view that acquires data in the following wavelength regions: 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 µm. Data were taken only under near cloud-free conditions (especially in the vicinity of the sun) when the solar elevation angle was at least 45 degrees above the horizon.

The radiometer and motor driven camera were attached to a boom mounted on a pickup truck for quick and efficient data collection in the field (Figure 1). The instruments were elevated 3.4 meters above the soil surface in 1978 and 5.2 meters in 1979. Instruments were leveled for a nadir look angle and measurements were taken over two locations in each plot. Observations were taken on-row and off-row to obtain a

Table 1. Number of observations taken and the soil condition for all the dates of multispectral data collection over the soybean cultural practices experiments in 1978 and 1979.

1978			1979			
Date	No. of Plots (Chalmers)	Soil Condition	Date	No. of Plots (Chalmers)	No. of Plots (Russell)	Soil Condition
June 22	27	wet	Apr 29	10	-	-
July 5	81	wet	June 4	24	-	dry
July 6	81	moist	June 11	24	10	moist
July 11	81	dry	June 14	24	10	wet
July 20	54	dry	June 15	24	10	moist
July 28	81	dry	June 21	26	26	wet
August 4	54	moist	June 25	26	26	moist
August 8	27	dry	June 26	26	26	moist
August 13	27	wet	July 2	26	26	wet
August 21	81	dry	July 10	26	26	moist
August 31	81	dry	July 16	13	26	wet
Sept 19	54	dry	July 18	26	26	dry
Oct 17	54	dry	Aug 12	13	26	dry
			Sept 4	26	26	dry
			Sept 9	26	26	dry
			Sept 17	26	26	dry
			Sept 24	26	26	dry

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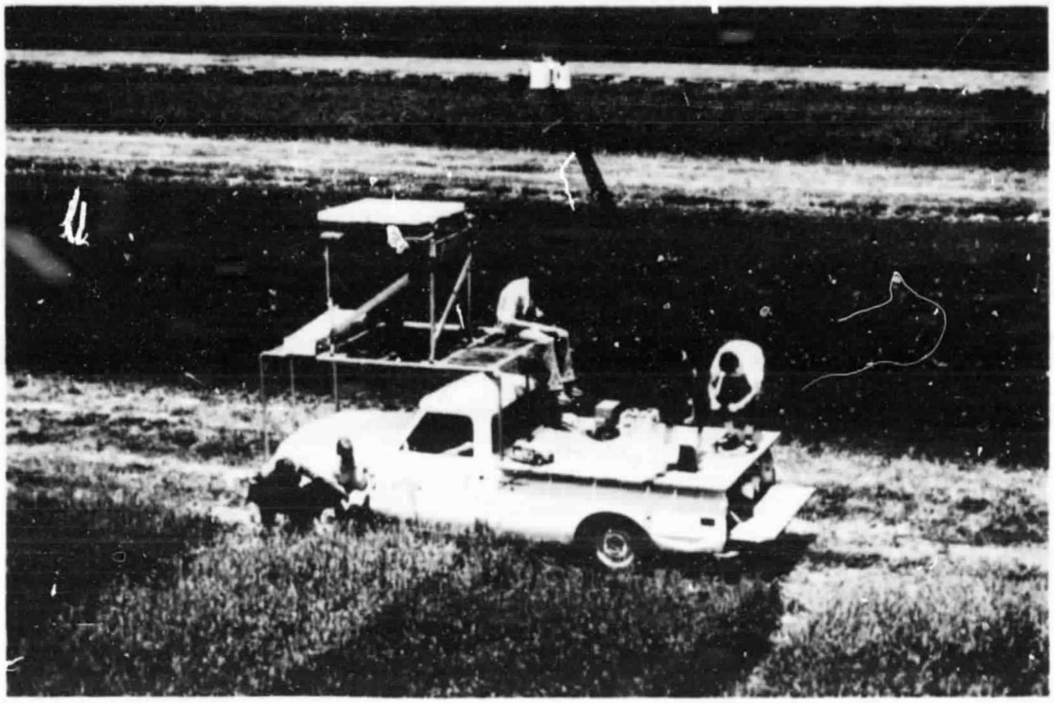

Figure 1. Field radiometer system including Exotech Model 100 radiometer, camera, and $BaSO_4$ calibration standard.

better estimate of the overall canopy response for the plot and to reduce any bias. Measurements in all four bands were recorded concurrently by a printing data logger. A vertical photograph was taken of each plot for later crop assessment and soil cover determination.

Agronomic Measurements

Agronomic measurements, which were collected coincidentally with the reflectance factor data in 1979 and weekly in 1978, included height, leaf area index, development stage, total fresh and dry biomass, and dry stem (including petioles), pod, and green leaf blade weights, and soil moisture. Percent soil cover was determined by placing a grid over the vertical photograph and counting the intersections occupied by green vegetation. Leaf area index (LAI) was calculated by multiplying the leaf area/dry leaf weight ratio of a random subsample of green leaves by the total dry green leaf weight and dividing by the soil area represented. Visual assessment of the soil moisture and crop condition were made during the spectral data collection. Crop condition assessment included evaluation of lodging, and hail, insect, and herbicide damage.

Data Analysis

The reflectance factor data were analyzed as band means and as transformations. The reflectance factor data were transformed into greenness as described by Kauth and Thomas (1976) for Landsat MSS data and modified for spectrometer data (Malila and Gleason, 1977). The greenness funtion used was as follows: Greenness = [(Band3 * 0.17289) + (Band4 * 0.59538)] - [(Band1 * 0.48935) + (Band2 * 0.61249)]. Band1 to Band4 refer to the reflectance factors in each band. A near infrared/red reflectance ratio, 0.8-1.1 μm/0.6-0.7 μm, was also considered in the analysis. Regression and correlation analyses were used to quantify the relationship between spectral values and agronomic characteristics. Analysis of variance and Duncan's Multiple Range Test were used to determine which of the experimental treatments accounted for the variability in spectral responses.

Results and Discussion

Relationships Between Reflectance Factor and Agronomic Variables.

Previous research has indicated that the reflectance of crop canopies is related to the amount of vegetation present and in particular to the amount of photosynthetically active vegetation present in the canopy (Aase and Siddaway, 1980; Bauer et al., 1979; Leamer et al., 1978). The senescing plant canopy causes an increased spectral response in the visible wavelength region due to a decrease in the pigment concentration and thus absorption. A decreased response in the near infrared region may be due to a deterioration of the cell constituents (Knipling, 1970). Ahlrichs (1978) and Leamer et al. (1978) observed substantial decreases in the correlation of canopy variables and reflectance factor as the canopy began to senesce or ripen. Figures 2 to 5 illustrate this effect as the red (0.6-0.7 μm; Figure 2), the near infrared (0.8-1.1 μm; Figure 3), the near infrared/red reflectance ratio (Figure 4), and the greenness transformation (Figure 5) are plotted against soil cover, both with (a) and without (b) the dates which included senescent plant material. Plots with senescing canopies still have a high soil cover, but have a reflectance factor value approaching that of a low soil cover plot. The remainder of the analyses of reflectance factor with canopy variables do not include dates with senescent vegetation.

Figures 2c, 3c, 4c, and 5c illustrate the effect of removing dates where the soil is moist to wet from the previous days' rain. Reflectance factor in both the visible and near infrared bands was greatly affected by changes in soil background, especially under low soil covers, whereas the near infrared/red and greenness functions were not greatly influenced by changes in soil moisture. The low reflectance values seen in the first two graphs of the red and near infrared bands (Figures 2b and 3b) are removed when the wet soil dates are taken out (Figures 2c and 3c). The relationship of canopy variables and reflectance factors are not clear if wet, moist, dry soils are treated together. Therefore, data from those dates with wet or moist soil were removed for those analyses involving the two single bands as they were strongly affected by the changes in soil moisture. Reflectance factors in both the visible and near infrared bands were greatly affected by changes in soil background, especially under low soil covers, whereas the near infrared/red and greenness functions were not greatly influenced by changes in soil moisture. The relationship of canopy variables and reflectance factors are not clear if wet, moist, and dry soils are treated together. Therefore, data from those dates with wet or moist soil were removed for those analyses involving the two single bands as they were strongly affected by the changes in soil moisture.

Soil color was a new factor introduced into the 1979 soybean cultural practices experiment. The effects of soil color background differences were quite similar to those observed with the wet versus dry soils. Figure 6 is a plot of the mean response of the band or transformation by the percent soil cover. The two single bands (Figures 6a and 6b) show significant differences in RF to soil type when equal soil cover percentages are compared. This was especially noted for lower soil covers. In both the red and near-infrared bands, the dark soil response was significantly lower until the canopy reached 80-90 percent cover. The effect of soil background on response was less in the near-infrared/red ratio and greenness plots (Figures 6c and 6d). The greenness transformation is essentially a difference of the near infrared and red bands, respectively. Since the reflectance factor response to soil background changes were similar in all bands, a normalizing effect occurs in both transformations.

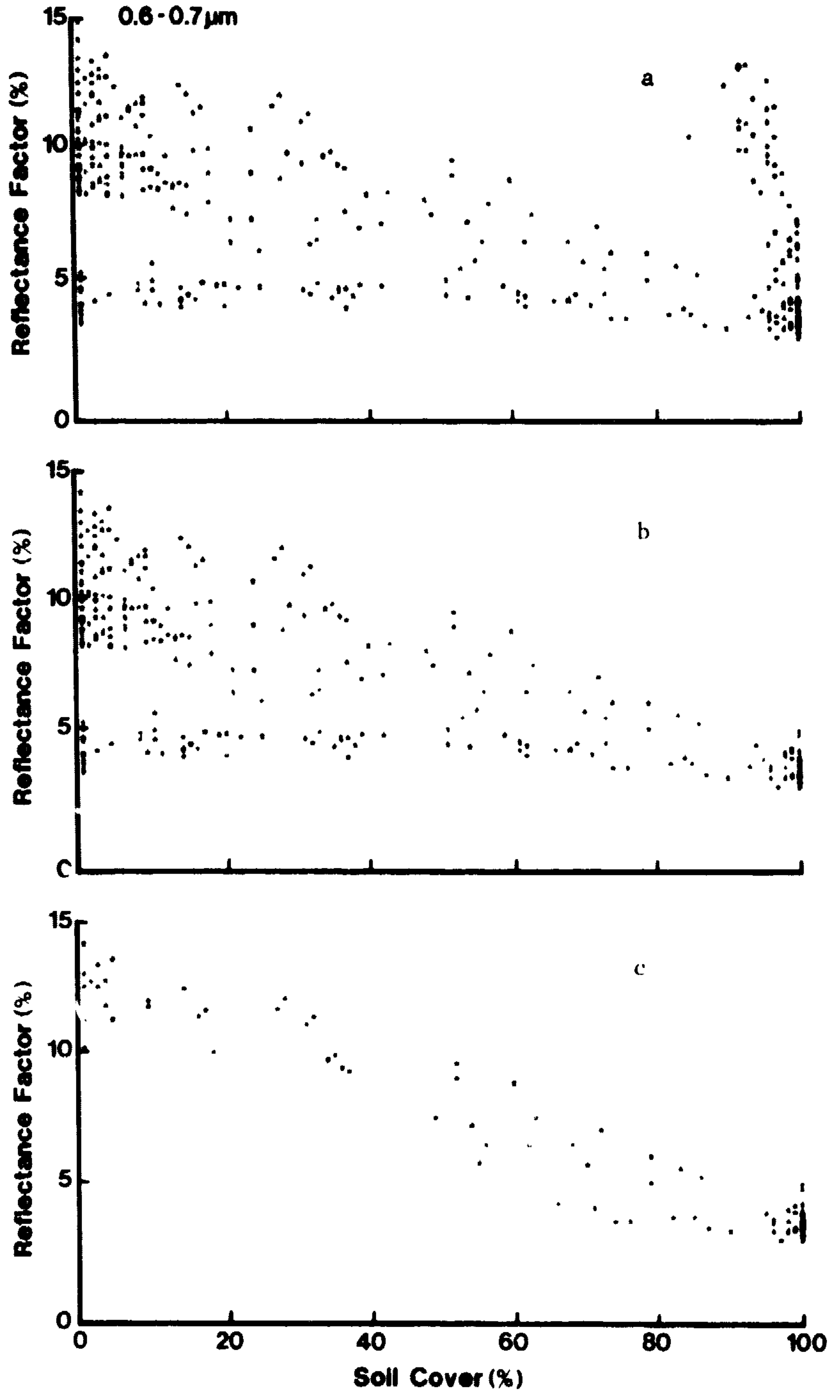

Figure 2 Relationship of RF in the red wavelength region (0.6-0.7 µm) to percent soil cover in 1979 (a) full data set (b) minus dates including senescing vegetation (c) minus dates including senescing vegetation and/or moist soil. (Chalmers silty clay loam)

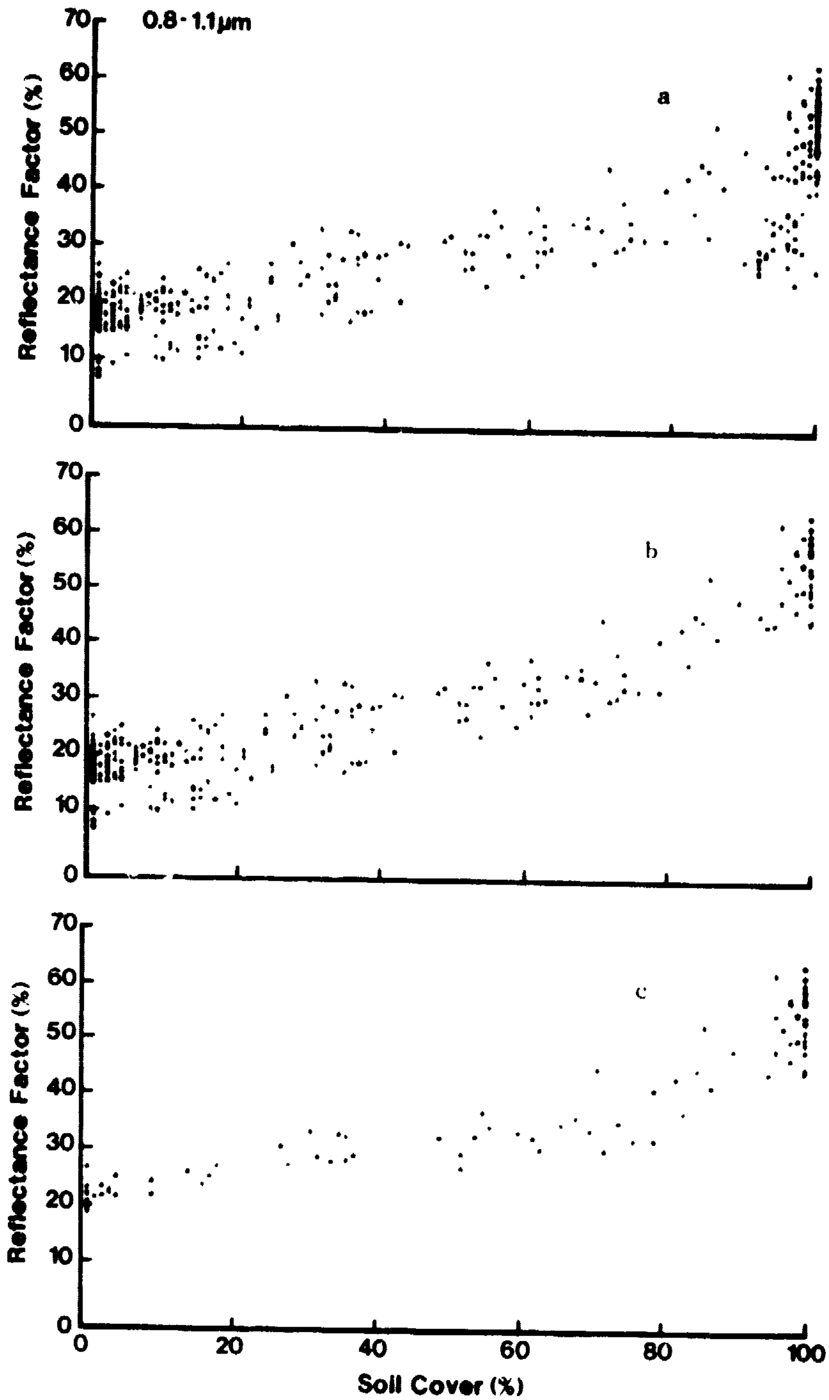

Figure 3. Relationship of RF in the near infrared wavelength region (0.8-1.1 μm) to percent soil cover in 1979. (a) full data set (b) minus dates including senescing vegetation (c) minus dates including senescing vegetation and/or moist soil. (Chalmers silty clay loam)

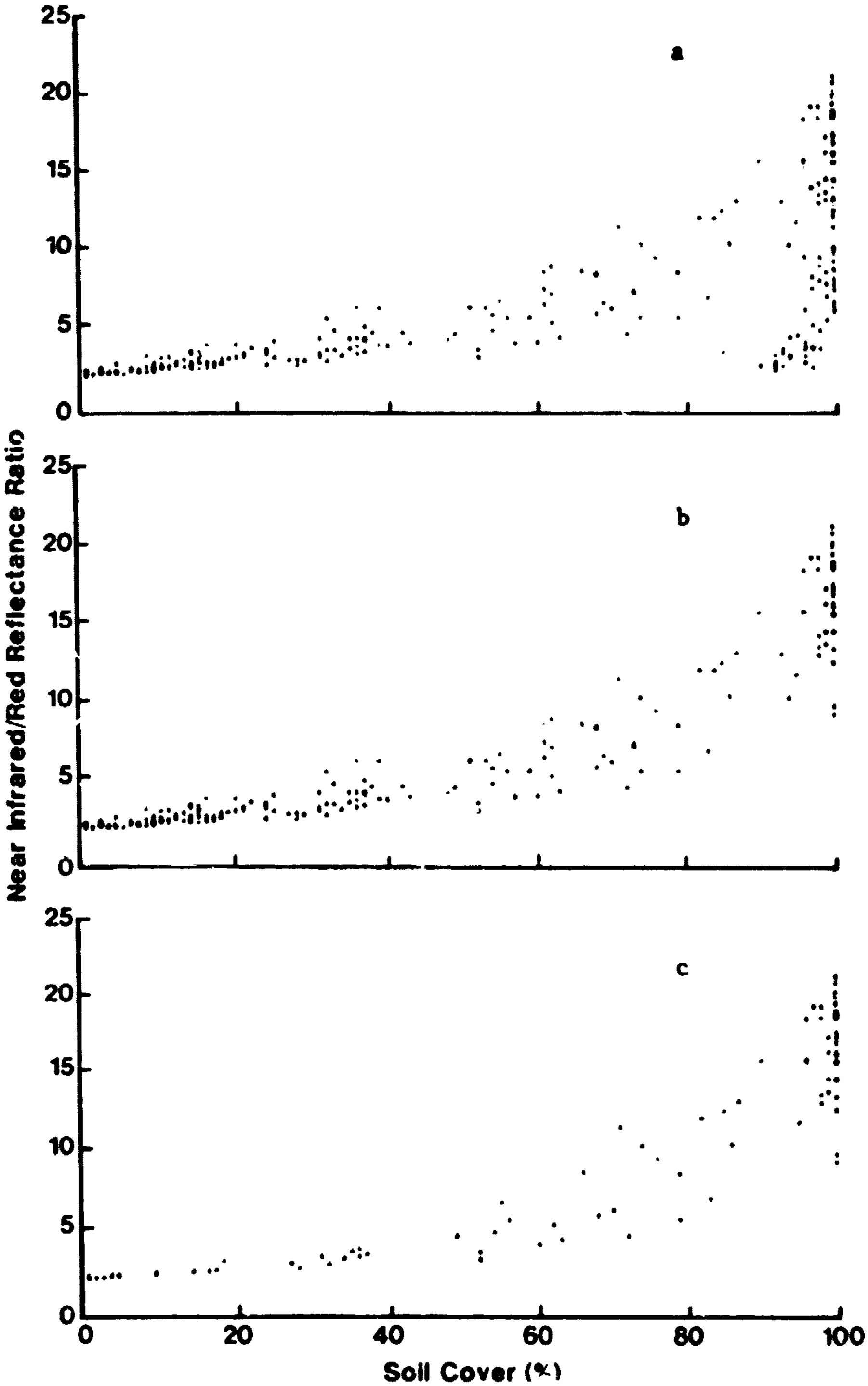

Figure 4. Relationship of the near infrared/red reflectance ratio to percent soil cover in 1979 (a) full data set (b) minus dates including senescing vegetation (c) minus dates including senescing vegetation and/or moist soil. (Chalmers silty clay loam)

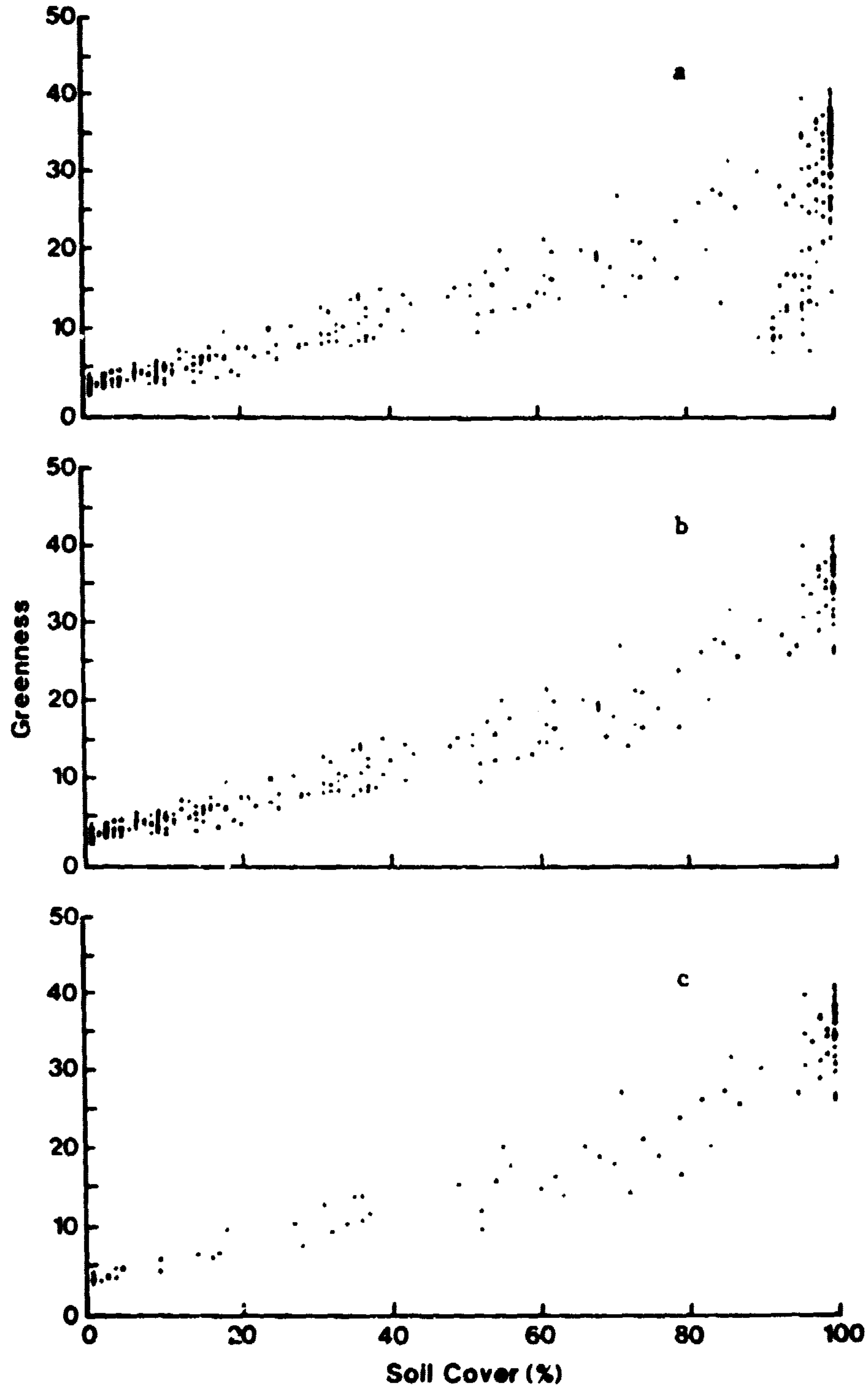

Figure 5. Relationship of the greenness transformation to percent soil cover in 1979 (a) full data set (b) minus dates including senescing vegetation (c) minus dates including senescing vegetation and/or moist soil. (Chalmers silty clay loam)

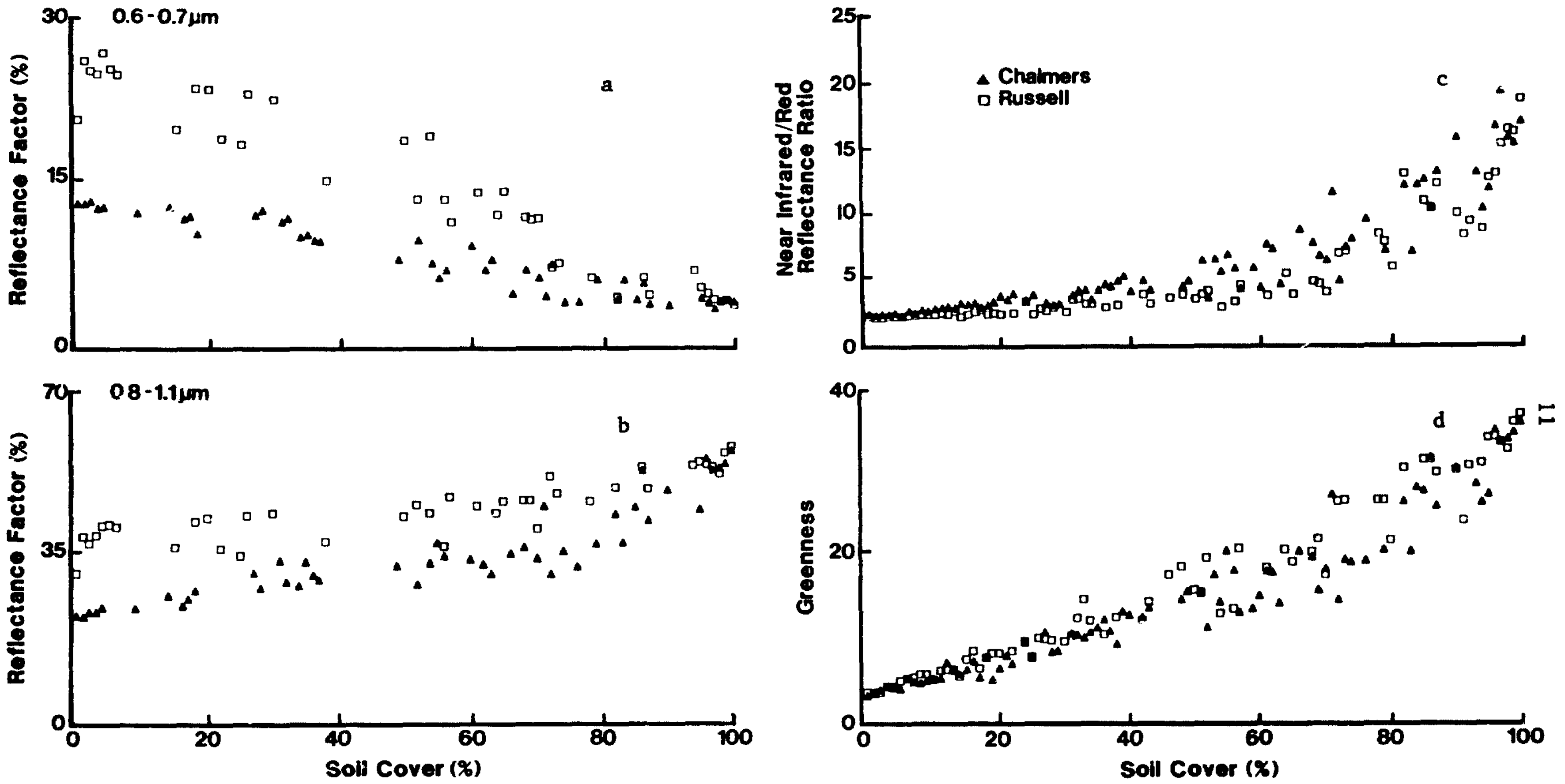

Figure 6. Effect of soil background on the relationship of percent soil cover to four different spectral variables (a) RF in red wavelength region (0.6-0.7 µm) (b) RF in near infrared wavelength region (0.8-1.1 µm) (c) near infrared/red reflectance ratio (d) greenness.

Table 2 shows the results of fitting a quadratic equation $y = b + bx + bx^2$ to the data where y is the agronomic variable, x is the spectral band or transformation, and b is the regression coefficient. Percent soil cover and leaf area index were highly correlated with the different bands and transformations. The near infrared/red and greenness transformations had stronger relationships to the canopy characteristics than either single band. More spectral information is contained in these transformations and more data, including moist soil data, can be utilized in the analysis. In 1978, the coefficient of determination values (R^2) for percent soil cover were 0.90, 0.93, 0.97, and 0.97 to the red and near infrared bands, and the near infrared/red and greenness transformations, respectively.

Figure 7 illustrates the relationship between four different agronomically important crop variables with greenness on the dark soil plots. A near linear relationship with little scatter is evident between the percent soil cover and the greenness function (Figure 7a). The function reaches an asymptote as the maximum value for soil cover is reached. The curvilinear shape for the other factors were the result of a non-linear relationship between soil cover and leaf area index and biomass. Complete canopy cover was reached before the maximum values were reached for leaf area index or biomass.

A fairly strong relationship between increases in greenness to increases in leaf area index is shown in Figure 7b. The moderately high amount of scatter at higher greenness levels was probably due to sampling errors. This could include irregular plant distribution and size within a plot, or poor estimates of plant populations from the counts taken in late June.

A question that may be asked is why are the coefficients of determination between greenness and fresh and dry biomass so much lower than those between greenness and soil cover or leaf area index? The upper periphery of a soybean canopy, the primary radiation reflecting portion of the canopy, is largely comprised of leaves. Percent soil cover and leaf area index are mainly functions of the green leaves throughout most of the growing season. The green leaf area index, as illustrated in Figure 8a, reaches a maximum value in late August, and then falls off. It is about this same time when maximum values of greenness are noted, that the dry leaf weight becomes a smaller proportion of the total dry weight (Figure 8b). Other components, including stems and pods that are not observed from the nadir view angle prior to the onset of senescence, have a faster growth rate late in the season and thus make up a larger portion of the total dry weight. Similar results were observed by Hanway and Thompson (1967). Therefore, later in the season after near-full canopies are obtained, the canopy may still be accumulating biomass that, perhaps, is not spectrally detectable.

Table 2. Coefficient of determination values (R^2) from fitting both the linear and quadratic values of four spectral variables for two soil types to explain the variation in percent soil cover, leaf area index, fresh biomass, and dry biomass in 1979.

Soil Type	Agronomic Variable	Spectral Variable: Red	NIR	NIR/Red	Greenness	Range of Data
Chalmers	Soil Cover	.94	.93	.95	.98	0-100 %
	Leaf Area Index	.65	.80	.85	.86	0-8.9
	Fresh Biomass	.61	.71	.81	.81	0-9120 (g/m^2)
	Dry Biomass	.53	.64	.73	.74	0-2489 (g/m^2)
Russell	Soil Cover	.98	.93	.92	.98	0-100 %
	Leaf Area Index	.73	.69	.83	.84	0-8.8
	Fresh Biomass	.59	.49	.71	.66	0-9633 (g/m^2)
	Dry Biomass	.47	.36	.57	.52	0-3027 (g/m^2)

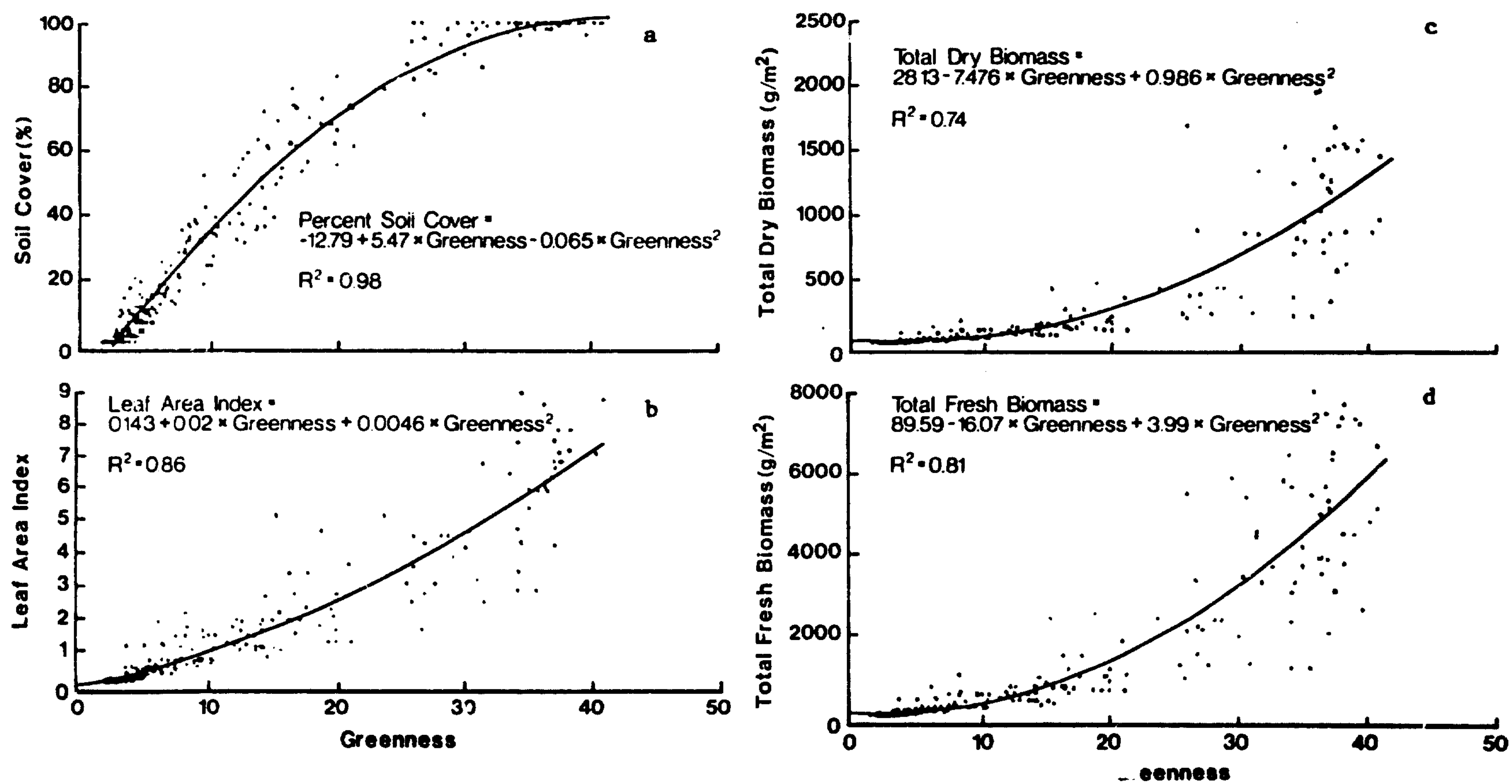

Figure 7. Plots of four agronomic variables versus greenness (a) percent soil cover (b) leaf area index (c) total dry biomass (d) total fresh biomass. (Chalmers silty clay loam)

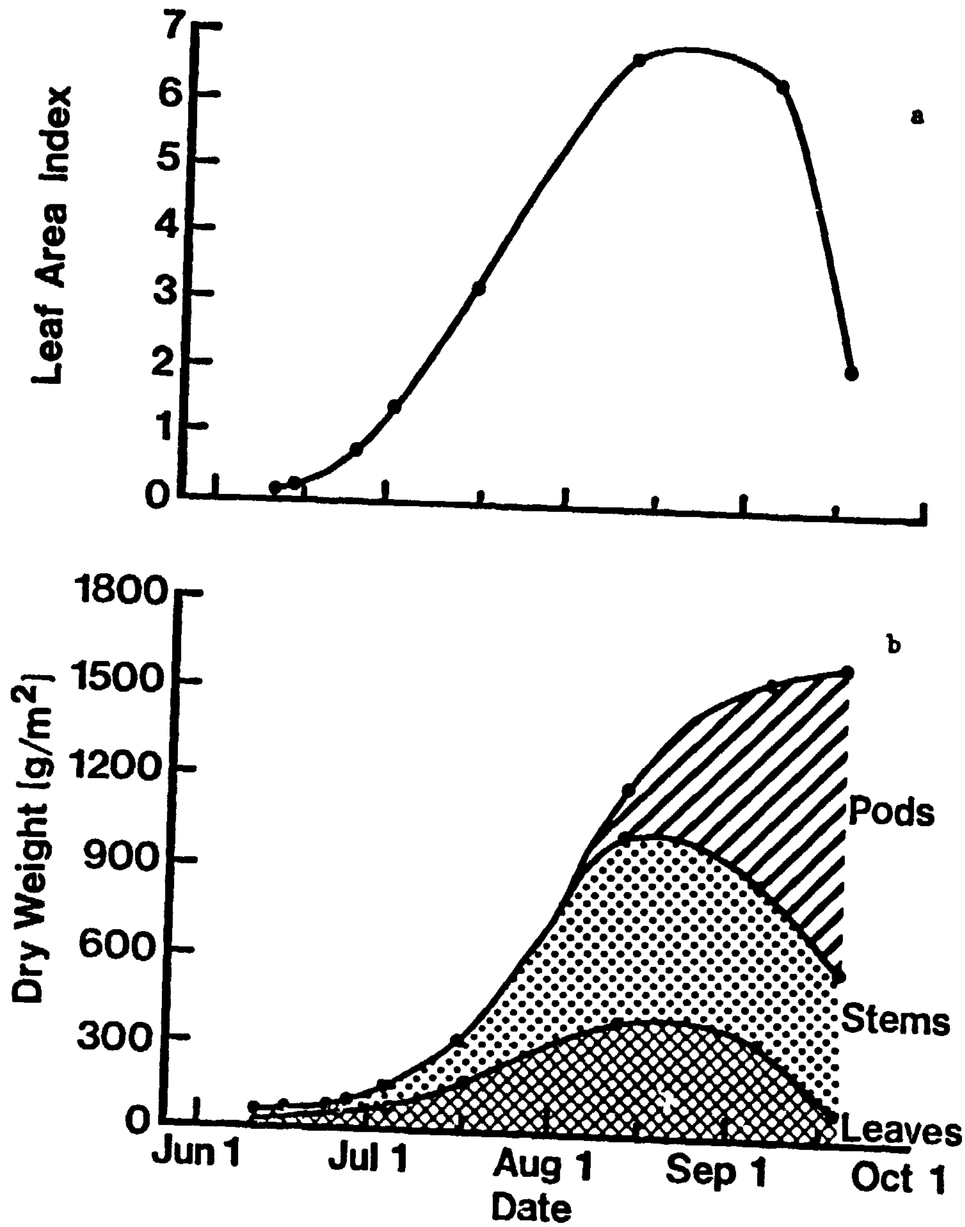

Figure 8. Seasonal changes in (a) leaf area index and (b) soybean canopy components for the May 24 planting date on Chalmers silty clay loam.

Effects of Cultural Practices on Reflectance Factor.

In the 1978 experiment, row width and cultivar were the primary factors affecting the measured spectral response (Figures 9 and 10 and Tables 3 and 4). Row width significantly affected the measured soil cover and reflectance through the first part of the season when canopies were filling in at different rates (Figure 9). The photographs in Figure 11 illustrate the differences in soil cover for the three row widths on two dates in the 1978 season. The canopies with the two narrow row widths developed quite similarly, but the canopy with the 90 cm row width developed slowly. Very little difference was seen after August 20, when all three canopies reached nearly 100 percent cover.

Differences in spectral response among cultivars early in the season were attributed to differences in soil cover. Elf, a compact and determinate semi-dwarf, filled in faster than the other two taller indeterminate cultivars. By September 1, differences were due to the three cultivars senescing at different times and rates (Figure 10). Figure 12 contains photographs of the three cultivars in the 45 cm wide row spacing at three times during the growing season. Elf (maturity group III) had considerably more green leaf area later in the season than Amsoy 71 or Wells (maturity group II). Leamer et al. (1978) also showed spectral differences in wheat cultivars having different maturity dates. Plant population in the 1978 experiment did not show any significant effect on either soil cover or reflectance measurements.

In the 1979 experiments, row width and cultivar showed trends similar to those seen in the 1978 experiment. Again, the response seemed related to the amount of photosynthetically active (green) vegetation present. The effect of row width on percent soil cover and reflectance are shown in Figure 13 and Table 5. The differences were greatest in the first part of the season. Amsoy 71 (maturity group II) and Williams (maturity group III), had similar soil covers and spectral responses except for late in the season when differences in plant senescense occurred, with Amsoy 71 showing signs of senescence first. Amsoy 71 was also the taller of the two indeterminate cultivars and was somewhat more susceptible to lodging.

The effect due to the three planting dates was a result of differing amounts of green vegetation present and thus the measured reflectance factor and transformations. Figure 14 and Table 6 show examples of the seasonal changes in soil cover and spectral response of soybeans in the 75 cm wide rows on the light-colored soil as a function of planting date. Early planting dates had higher percent soil covers early in the season and therefore a dramatic effect on the four spectral variables was noted. The largest differences due to planting date were usually observed in the spectral functions involving the red wavelength band. The maximum soil cover and infrared spectral response to green vegetation was observed for all planting dates at approximately the time the plants were at development stage R5 (beginning seed).

Included in the appendix are several tables that show the percentage of the total variation accounted for by each treatment from

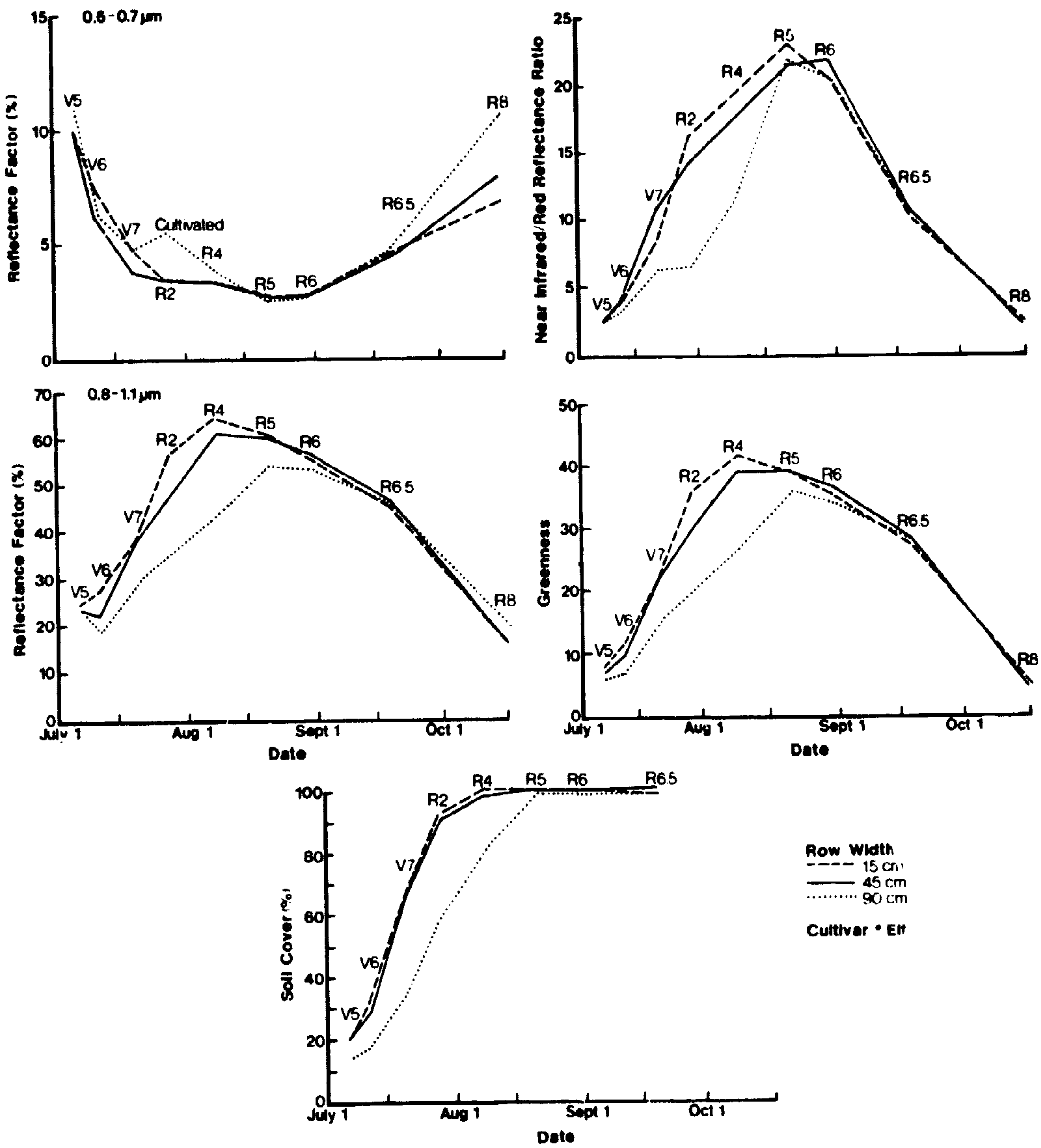

Figure 9. Seasonal changes in four spectral variables and percent soil cover for three row widths in 1978 for the cultivar Elf. Development stages (Fehr and Caviness, 1977) are indicated for each observation date.

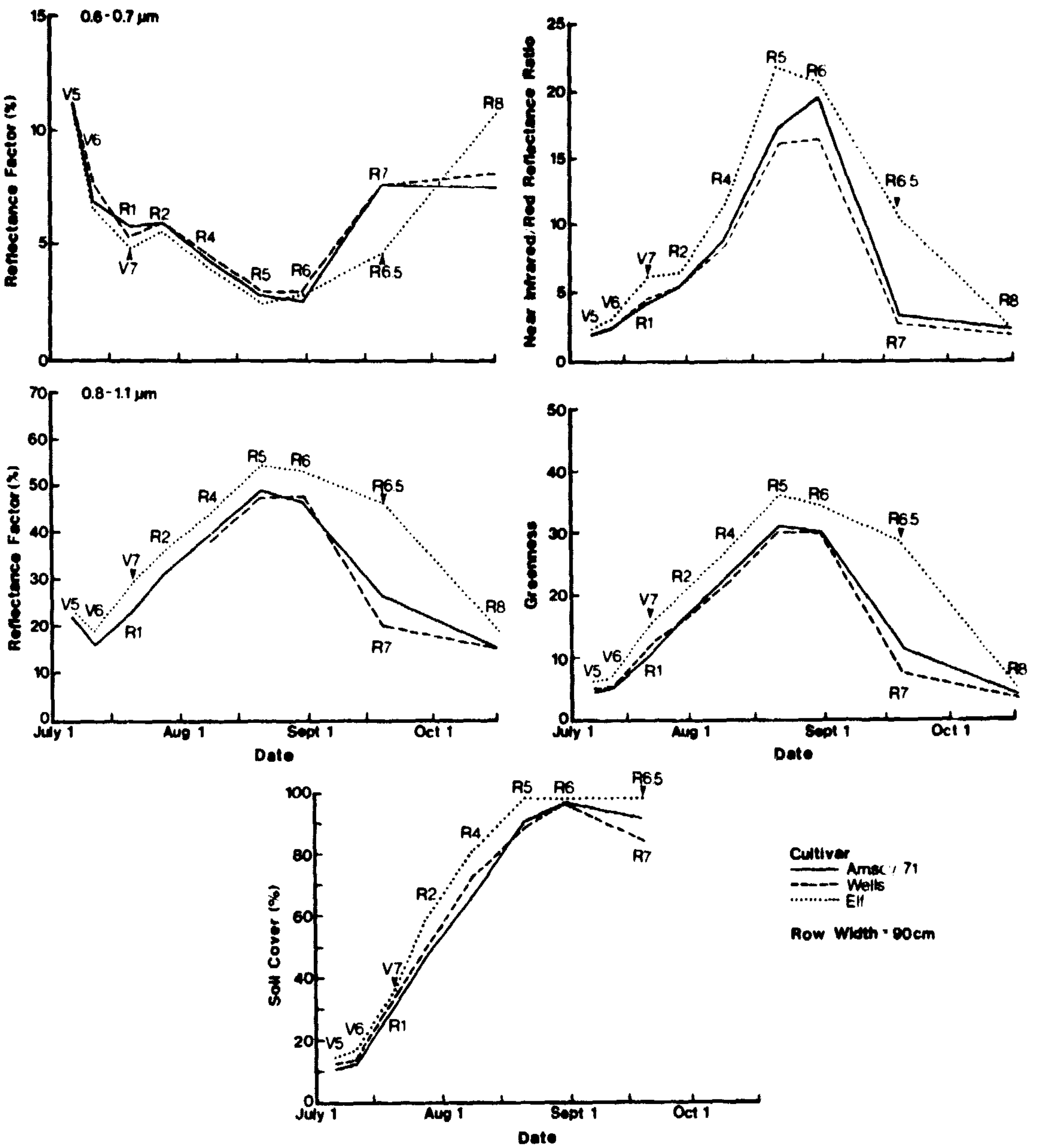

Figure 10. Seasonal changes in four spectral variables and percent soil cover for three cultivars in 1978 on 90 cm wide rows. Development stages (Fehr and Caviness, 1977) are identified for each observation date. Arrows indicate development stages that are unique for that cultivar.

Table 3. Mean values of percent soil cover and four spectral variables for three row widths on selected dates in 1978. Means are taken across block and population.

Acquisition Date	Row Width, cm	Percent Soil Cover	Red	NIR	NIR/Red	Greenness
July 6	15	19.4a *	9.8 b	24.1a	2.5a	7.2a
	45	19.8a	10.0ab	23.4a	2.4a	6.7a
	90	14.0 b	10.8a	23.8a	2.2a	6.2a
July 11	15	31.4a	7.5a	27.3a	3.7a	11.6a
	45	28.6a	6.1 b	22.0 b	3.7a	9.3a
	90	16.1 b	6.5 b	18.9 c	2.9a	6.8b
July 20	15	66.6a	4.7a	38.9a	8.6ab	22.4a
	45	68.6a	3.7 b	38.4a	10.7a	22.9a
	90	34.4 b	4.8a	28.7 b	6.0 b	15.3 b
July 28	15	91.5a	3.5 b	56.3a	16.3a	35.7a
	45	90.0a	3.4 b	47.9 b	14.3 b	30.1 b
	90	58.0 b	5.5a	35.9 c	6.6 c	19.6 c
August 8	15	100.0	3.4	64.4	19.0	41.5
	45	99.0	3.4	60.9	17.8	39.1
	90	80.7	3.8	43.7	11.6	26.8
August 21	15	100.0a	2.7a	60.7a	23.1a	39.4a
	45	100.0a	2.8a	60.5a	21.7a	39.2a
	90	98.3 b	2.5a	54.9 b	22.1a	35.6 b
August 31	15	99.8a	2.8a	56.0ab	20.7a	36.1ab
	45	100.0a	2.7a	56.9a	21.9a	36.8a
	90	98.6 b	2.6a	53.0 b	20.6a	34.1 b
Sept. 19	15	98.7a	4.5a	45.6a	10.3a	27.2a
	45	100.0a	4.3a	47.1a	11.0a	28.6a
	90	98.8a	4.5a	47.1a	10.6a	28.3a
Oct. 17	15	6.8 b	15.6a	2.4a		4.8a
	45	8.0 b	15.3a	1.9b		3.8a
	90	10.7a	20.3a	2.0ab		5.4a

*Means followed by the same letter within each date are not significantly different at the 5% level by Duncan's Multiple Range Test.

Table 4. **Mean values of percent soil cover and four spectral variables for three cultivars on selected dates in 1978. Means are taken across block and population.**

Acquisition Date	Cultivar	Percent Soil Cover	Red	NIR	NIR/Red	Greenness
July 6	Amsoy 71	10.6a *	11.1a	21.8 b	2.0 b	4.5 b
	Wells	11.6a	11.2a	21.9 b	2.0 b	4.6 b
	Elf	14.0a	10.8a	23.8a	2.2a	6.2a
July 11	Amsoy 71	11.4 b	6.8ab	16.5 b	2.4 b	4.9 b
	Wells	13.4ab	7.4a	16.5 b	2.4 b	4.7 b
	Elf	16.1a	6.5 b	18.9a	2.9a	6.8a
July 20	Amsoy 71	29.5 c	5.6a	22.6a	4.1 b	10.3 b
	Wells	34.0 b	5.2 b	23.6a	4.5b	11.3ab
	Elf	34.4a	4.8 c	28.7a	6.0a	15.3a
July 28	Amsoy 71	47.3 b	5.9a	31.6 b	5.4 b	16.2 b
	Wells	50.2 b	5.9a	31.6 b	5.4 b	16.2 b
	Elf	58.0a	5.5 b	35.9a	6.6a	19.6a
August 8	Amsoy 71	64.3	4.3	38.8	9.0	22.9
	Wells	72.0	4.5	37.6	8.3	21.8
	Elf	80.7	3.8	43.7	11.6	26.8
August 21	Amsoy 71	89.7 b	2.8a	48.7 b	17.4 b	30.9 b
	Wells	89.1 b	3.0a	47.6 b	16.1 b	30.1 b
	Elf	98.1a	2.5 b	54.9a	22.1a	35.6a
August 31	Amsoy 71	96.4a	2.5 b	47.0 b	19.5a	30.0 b
	Wells	96.2a	2.9a	47.8 b	16.6 b	30.2 b
	Elf	98.5a	2.6ab	53.0a	20.6a	34.1a
Sept. 19	Amsoy 71	92.0 b	7.5a	26.5 b	3.5 b	11.5 b
	Wells	84.5 c	7.4a	20.4 c	2.8 b	7.4 c
	Elf	98.8a	4.5 b	47.1a	10.6a	28.3a
Oct. 17	Amsoy 71		7.5a	15.3 b	2.2a	4.4a
	Wells		8.1a	15.6ab	2.0a	3.3a
	Elf		10.7a	20.3a	2.0a	5.4a

*Means followed by the same letter within each date are not significantly different at the 5% level by Duncan's Multiple Range Test.

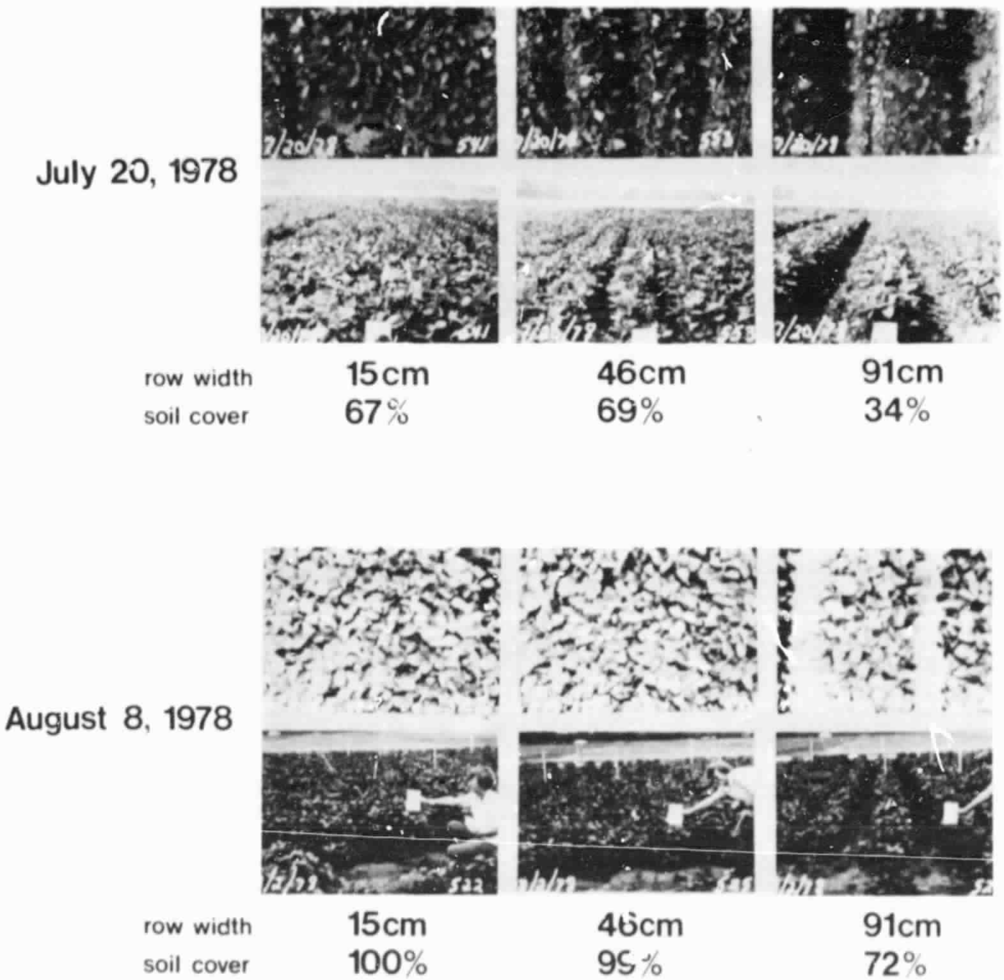

Figure 11. Changes in soil cover over three row widths on two dates.

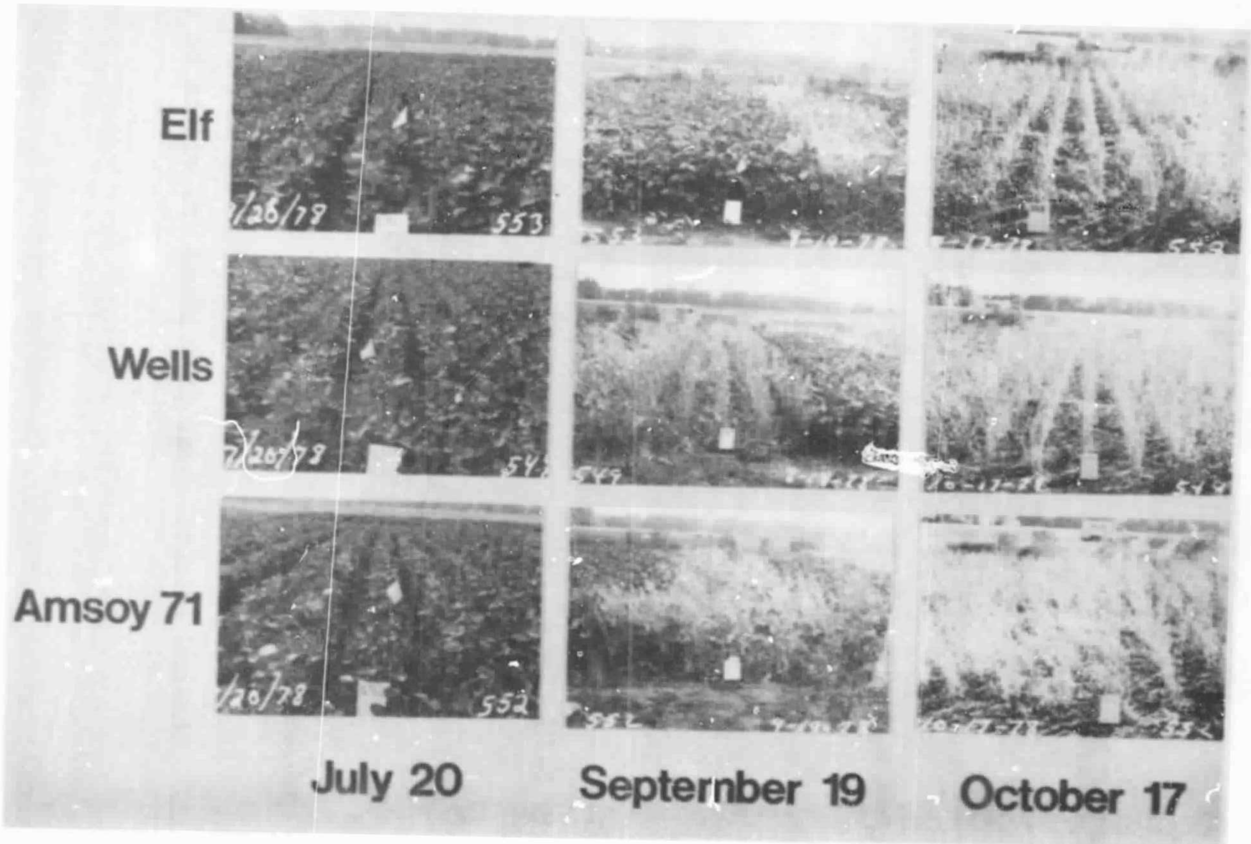

Figure 12. Visual differences among three cultivars through the 1978 growing season.

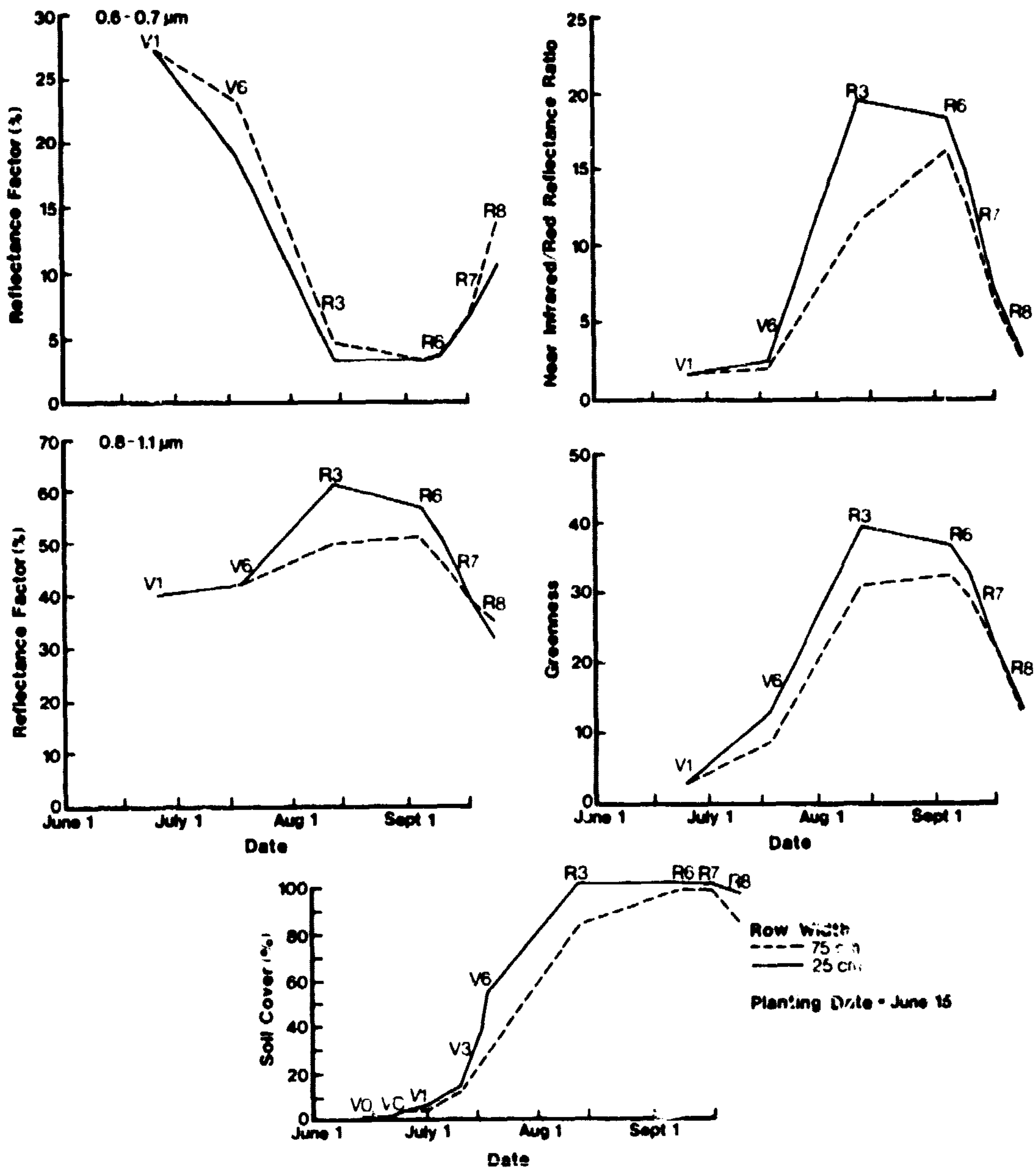

Figure 13. Seasonal changes in four spectral variables and percent soil cover for two row widths in 1979 for the June 15 planting date. Development stages are indicated for each observation date (Russell silt loam).

Table 5. Mean values of percent soil cover and four spectral variables for two row widths on selected dates in 1979. Means are taken across block and cultivar.

Acquisition Date	Row Width, cm	Percent Soil Cover	Red	NIR	NIR/Red	Greenness
June 26	25	2.0a*	26.5a	38.8a	1.5a	2.6a
	45	1.8a	24.3 b	35.7 b	1.5a	2.5a
July 18	25	52.0a	18.7 b	42.7a	2.3a	12.8a
	45	23.0 b	23.0a	42.3 b	1.8 b	7.8 b
August 12	25	100.0a	3.1a	61.0a	19.5a	39.2a
	45	83.3 b	4.4a	50.0 b	11.6 b	30.4 b
Sept. 4	25	100.0a	3.0a	56.6a	18.6a	36.3a
	45	95.3a	3.3a	51.1a	16.0a	32.3a
Sept. 9	25	100.0a	3.5a	51.5a	15.0a	32.3a
	45	96.8a	3.8a	47.2a	13.1a	29.0a
Sept. 17	25	99.5a	6.1a	39.7a	7.4a	21.7a
	45	96.5a	6.3a	39.3a	6.7a	21.3a
Sept. 24	25	95.3a	10.2b	31.2a	3.3a	12.5a
	45	82.0a	13.6a	34.1a	2.6a	11.5a

*Means followed by the same letter within each date are not significantly different at the 5% level by Duncan's Multiple Range Test.

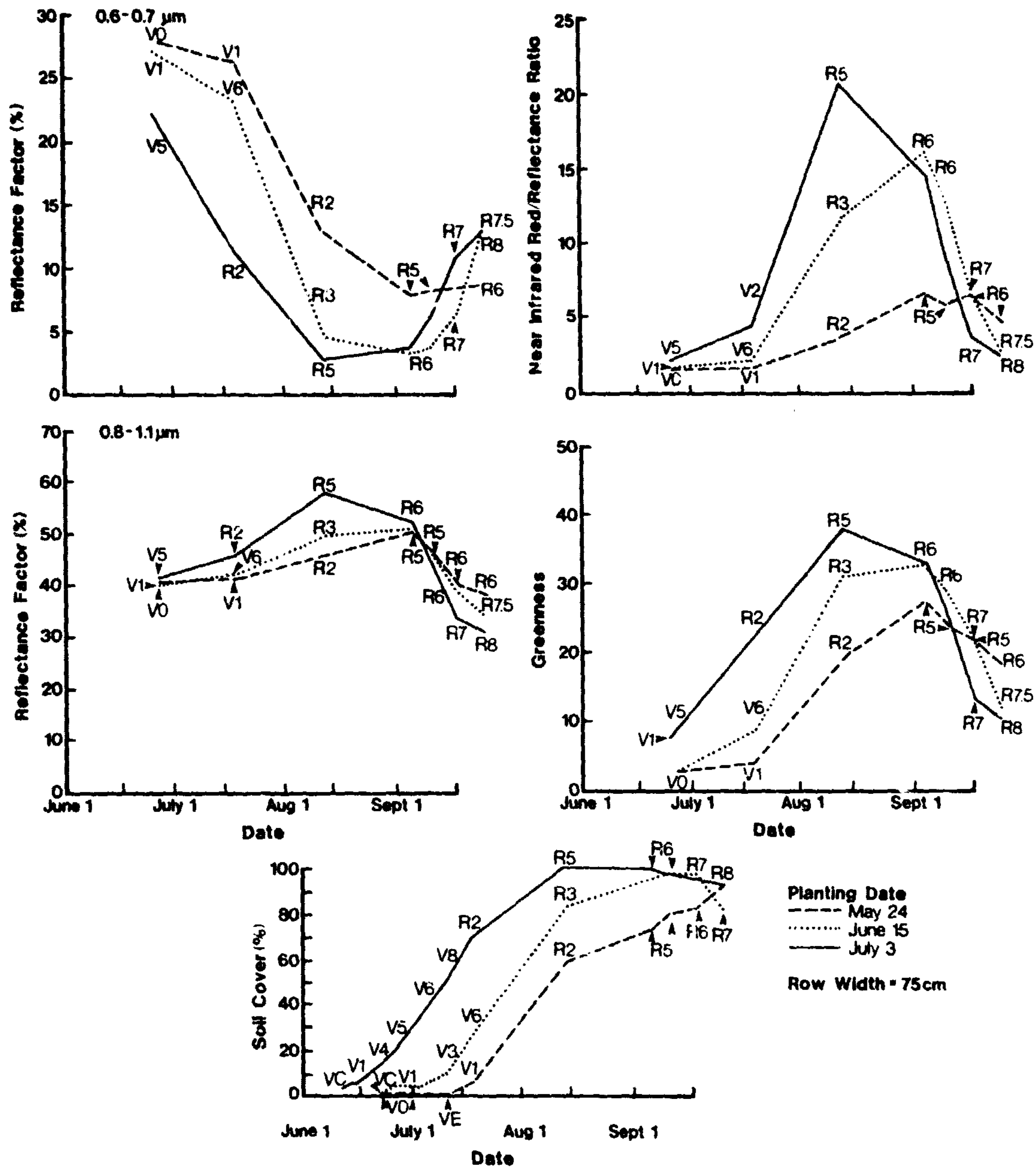

Figure 14. Seasonal changes in four spectral variables and percent soil cover for three planting dates in 1979 for 75 cm wide rows. Development stages (Fehr and Caviness, 1977) are indicated for each observation date. Arrows indicate development stages that are unique for that planting date (Russell silt loam).

Table 6. Mean values of percent soil cover and four spectral variables for three planting dates on seleeted dates in 1979. Means are taken across block and cultivar.

Acquisition Date	Planting Date	Percent Soil Cover	Red	NIR	NIR/Red	Greenness
June 26	May 24	19.3a *	19.9 b	35.2a	1.9a	7.0a
	June 15	1.8 b	24.3a	35.7a	1.5 b	2.5 b
	July 3	0.0 b	19.9 b	29.7 b	1.5 b	2.5 b
July 18	May 24	68.5	11.2	45.8	4.1	21.4
	June 15	23.0	23.0	42.3	1.8	8.0
	July 3	4.5	26.1	40.6	1.6	4.1
Aug. 12	May 24	99.3a	2.8 c	58.0a	20.8a	37.4a
	June 15	83.3 b	4.4 b	50.0 b	11.6 b	30.4 b
	July 3	58.8 c	12.8a	45.3 c	3.6 c	19.5 c
Sept. 4	May 24	99.3a	3.7 b	51.7a	14.6a	32.4a
	June 15	83.3 b	4.4 b	51.1a	16.0a	32.3a
	July 3	73.8 b	7.8a	50.0a	6.6 b	27.3 b
Sept. 9	May 24	97.8a	5.7 b	44.9a	9.2 b	25.7 b
	June 15	96.8a	3.8 b	47.2a	13.1a	29.0a
	July 3	89.8 b	8.2a	46.6a	5.9 c	24.6 b
Sept. 17	May 24	94.5a	11.1a	33.7 b	3.4 b	13.4 b
	June 15	96.5a	6.3 b	39.3a	6.7a	21.3a
	July 3	83.3 b	6.4 b	40.0a	6.4a	21.5a
Sept. 24	May 24	91.5a	13.4a	31.1 c	2.4 b	9.9 b
	June 15	82.0a	13.6a	34.1 b	2.6 b	11.5b
	July 3	82.0a	8.8b	37.0a	4.6a	18.0a

*Means followed by the some letter within each date are not significantly different at the 5% level by Duncan's Multiple Range Test.

the analysis of variance (ANOVA) for both percent soil cover and the various spectral variables. These data confirm the effect of row width and planting date on both the soil cover and the reflective response and illustrate the importance of cultivar as a late season effect due to differences in maturity dates.

Conclusions

The results of these experiments indicate that several cultural practices cause differences in percent soil cover, leaf area index, and biomass which in turn are manifested in the spectral reflectance characteristics of soybean canopies. Soil color and moisture were found to be important factors to consider when measuring reflectance in single bands within the visible and infrared wavelength regions. Spectral response was found to be very sensitive to plant senescense. For predicting agronomically important crop canopy variables with reflectance data, dates which include senscing plant vegetation should be deleted from the analysis. The near infrared/red reflectance ratio and the greenness transformation were useful in predicting percent soil cover and leaf area index, and were found to be less sensitive than single bands to the soil background present.

Understanding both the agronomic and spectral changes in the soybean crop canopy is a key to further development and use of remote sensing technology. This study has evaluated several cultural practices in soybeans that affect the percent soil cover, leaf area index, and biomass and which in turn are closely related to the canopy reflectance. This information will be useful in future applications on a large scale for crop identification and for estimation of agronomic variables related to crop growth, development, and yield.

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APPENDIX

Table A-1. Percent of variation (R^2) for the variable greenness associated with planting date, cultivar, row width, and their interactions in 1979. (Russell silt loam)

Treatment Effect	Observation Date: June 25	June 26	July 10	August 12	Sept. 4	Sept. 9	Sept. 17	Sept. 24
Planting Date	76.4	74.6	87.0	52.6	9.8	12.3	59.4	77.1
Cultivar					12.6	20.9	15.6	5.5
Row Width	7.9	7.7	5.4	31.2	39.0	24.9	4.4	3.5
PC				2.7	2.5	4.9	1.6	2.7
PR	11.9	13.9	6.8	11.1	11.1	4.2	4.8	2.3
CR					2.2	1.0		
PCR						1.7	2.2	
Model +	97.2	96.5	99.4	98.2	77.8	69.9	88.0	91.8

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

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Table A-2. Percent of variation (R^2) for the variable percent soil cover associated with planting date, cultivar, row width, and their interactions in 1979. (Russell silt loam)

Treatment Effect	Observation Date							
	June 25	June 26	July 10	August 12	Sept. 4	Sept. 9	Sept. 17	Sept. 24
Planting Date	82.2	67.8	87.2	37.3	29.8	26.9	14.6	5.9
Cultivar					2.5	3.4	7.9	11.2
Row Width	4.7	8.8	4.9	35.9	26.7	30.2	29.6	32.7
PC					1.0			2.9
PR	9.1	17.3	7.3	24.0	29.8	26.9	21.7	3.6
CR				1.1	2.5	3.4	6.6	6.2
PCR					1.0			
Model +	96.6	94.3	99.5	99.5	93.3	90.7	80.9	63.1

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-3. Percent of variation (R^2) for the variable greenness associated with planting date, cultivar, row width, and their interactions in 1979. (Chalmers silty clay loam)

Treatment Effect	June 4	June 11	June 15	June 25	June 26	July 18	Aug 12	Sept 4	Sept 9	Sept 17	Sept 24
	Observation Date										
Planting Date	75.0	63.4	64.3	63.2	66.0	53.5	16.1	17.8	8.8	44.7	54.7
Cultivar		2.1	2.1	2.7	2.0	3.7	1.1	15.0	3.7	11.0	18.3
Row Width	1.8	14.7	15.6	13.2	15.6	29.5	42.9	42.9	4.5	1.2	
PC	3.8	3.1	1.7	2.2		4.0	2.9	26.7	26.6	18.8	14.1
PR	3.8	10.2	8.9	5.3	5.2	3.1	26.9	6.5	2.0		2.7
CR	1.1	1.1	3.3	1.1	1.1	1.1			2.1		
PCR	1.4	1.3	1.7		1.3		4.6	3.4	14.1	1.5	
Model +	87.7	95.8	97.5	88.5	92.0	95.6	94.4	74.7	57.2	79.4	90.4

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-4. **Percent of variation (R^2) for the variable percent soil cover associated with planting date, cultivar, row width, and their interactions in 1979. (Chalmers silty clay loam)**

Treatment Effect	June 4	June 11	June 15	June 25	June 26	July 18	Aug 12	Sept 4	Sept 9	Sept 17	Sept 24
	Observation Date										
Planting Date	51.7	65.3	54.4	64.0	57.3	52.5	30.0	7.8	5.5	14.0	14.4
Cultivar	7.0	4.8	2.7		1.7				15.0	2.8	19.4
Row Width	2.2	11.3	17.8	14.0	24.6	34.4	24.7	14.0	4.4	7.6	3.6
PC	16.6	2.5	2.0			1.4	5.5	13.4	10.8	37.2	26.8
PR	3.7	5.8	16.1	8.5	12.6	2.9	24.3	7.8	4.4	1.8	4.6
CR	1.7	1.0							2.2		1.6
PCR	3.3	1.7	1.5	1.8		3.3	8.4	13.4	3.4	7.5	5.1
Model +	86.2	92.6	95.4	88.9	97.1	94.8	93.5	56.4	45.7	70.8	70.8

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-5. Percent of variation (R^2) for the variable percent soil cover associated with row width, cultivar, population, and their interactions in 1978.

Treatment Effect	Observation Date: July 6	July 11	July 20	July 28	August 21	August 31	Sept. 19
Row Width	17.9	63.5	43.8	66.0	43.3	23.9	10.3
Cultivar	12.3	4.1	14.5	10.5	7.8	6.0	55.0
Population		2.7	6.0	3.0	2.6	6.1	1.3
RC	9.2	4.6	8.6	3.0	13.2	2.9	8.2
RP	2.8	1.5	2.8	1.6	3.0	7.0	1.1
CP	2.3	1.1	3.4	1.9		1.2	1.1
RCP	15.5	2.7	9.6	3.1		5.0	4.6
Model +	60.2	80.0	88.6	88.1	70.9	52.1	81.6

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-6. Percent of variation (R2) in reflectance of the 0.6-0.7 um wavelength band associated with row width, cultivar, population, and their interactions in 1978.

Treatment Effect	July 6	July 11	July 20	July 28	August 21	August 31	Sept. 19	Oct. 17
	Observation Date							
Row Width	7.3	39.9	27.4	71.5				2.5
Cultivar	9.9	10.8	14.2	3.9	9.0	14.3	77.7	1.2
Population	4.5	5.0	9.0	3.1	1.6	1.0		2.0
RC	2.6	4.2	6.3	1.0	7.7	1.0		10.3
RP	4.5	1.8	1.1		3.1			10.5
CP	1.9	2.5	3.5		4.7	2.1	1.4	4.5
RCP	5.4	3.3	11.2	1.8	2.7	5.1	2.1	6.6
Model +	36.1	67.4	72.7	82.5	29.7	24.2	82.5	37.5

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-7. Percent of variation (R^2) in reflectance of the 0.8-1.1 um wavelength band associated with row width, cultivar, population, and their interactions in 1978.

Treatment Effect	July 6	July 11	July 20	July 28	August 21	August 31	Sept. 19	Oct. 17
	Observation Date							
Row Width	9.6	65.3	36.8	41.5	51.2	12.4		1.8
Cultivar	12.3	7.6	19.0	24.8	20.8	32.8	91.3	10.1
Population	2.1	1.7	2.8	1.9	1.3			
RC	9.1	1.7	6.1	6.6	2.6			10.0
RP	4.3					2.5		8.3
CP	7.5	1.2	5.0			5.1		
RCP	7.8	3.2	6.9	3.6	2.3	3.5	1.1	10.8
Model +	52.6	81.2	77.1	79.6	79.6	57.9	95.4	41.1

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-8. **Percent of variation (R^2) for the variable near infrared/red ratio associated with row width, cultivar, population, and their interactions in 1978.**

Treatment Effect	Observation Date							
	July 6	July 11	July 20	July 28	August 21	August 31	Sept. 19	Oct. 17
Row Width	13.6	12.3	27.2	55.8	17.9	2.6		1.8
Cultivar	15.3	17.6	21.4	15.8	16.1	21.7	96.4	6.1
Population	3.6	5.5	6.1	2.1	2.4	1.7		3.5
RC	4.7	4.5	8.2	5.7	7.8	1.1		3.2
RP	3.3	2.2			3.1			6.3
CP		2.6	2.4		2.2	3.3		3.8
RCP	7.6	5.4	6.8	2.4	2.4	4.8		21.6
Model +	48.4	50.0	72.7	82.8	51.7	36.1	98.2	46.3

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-9. Percent of variation (R^2) for the variable greenness associated with row width, cultivar, population, and their interactions in 1978.

Treatment Effect	Observation Date: July 6	July 11	July 20	July 28	August 21	August 31	Sept 19	Oct. 17
Row Width	13.8	32.2	33.2	46.5	50.7	13.3		1.0
Cultivar	18.2	15.7	20.2	22.3	22.4	35.6	94.5	17.0
Population	3.8	4.7	3.9	2.2	1.6	1.1		1.8
RC	5.5	3.5	6.5	5.6	3.0			5.3
RP	2.7	1.7				2.4		
CP	1.1	2.7	4.6			4.9		1.7
RCP	8.0	5.3	7.6	3.2	2.1	3.8		19.9
Model +	53.1	65.6	76.6	80.9	81.1	61.9	97.3	47.2

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-10. Percent of variation (R^2) in reflectance of the 0.6–0.7 um wavelength associated with planting date, cultivar, row width, and their interactions in 1979. (Chalmers silty clay loam)

Treatment Effect	Observation Date: June 4	June 11	June 15	June 25	June 26	July 18	Aug 12	Sept 4	Sept 9	Sept 17	Sept 24
Planting Date	36.5	15.2	15.1	58.5	54.9	66.4	26.9	42.6	47.4	51.8	45.2
Cultivar	10.0	9.4	7.5	2.1	2.0		1.2		4.4	4.4	12.9
Row Width	4.4	14.5	17.3	15.3	23.5	12.0	1.1				3.7
PC	13.5	19.2	13.9	1.3			11.9	16.3	19.5	15.4	12.5
PR	4.9	8.4	18.6	7.4	9.8	7.5	2.8				
CR		1.3	2.0					2.7	1.2	2.0	4.4
PCR	2.5	7.2	7.8	2.3	3.1	2.1	25.0	1.9	3.2		
Model +	72.0	75.2	82.3	87.5	93.9	89.0	47.4	64.9	76.2	74.5	79.0

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-11. Percent of variation (R^2) in reflectance of the 0.8-1.1 um wavelength band associated with planting date, cultivar, row width, and their interactions in 1979. (Chalmers silty clay loam)

Treatment Effect	June 4	June 11	June 15	June 25	June 26	July 18	Aug 12	Sept 4	Sept 9	Sept 17	Sept 24
	Observation Date										
Planting Date	43.2	60.9	79.8	61.2	66.9	40.2	14.4	13.6	6.1	38.2	53.3
Cultivar	5.8			3.1	1.9	7.5	1.6	16.4	3.4	15.8	18.8
Row Width	1.4	5.8	7.2	11.5	10.1	33.0	43.9	5.8		1.9	
PC	4.8	1.0		2.6		7.0	2.6	26.9	24.5	20.6	13.5
PR		4.6	2.2	3.7	3.0	6.7	27.4	7.5	2.6	1.3	4.1
CR			1.9	1.5	2.0	1.7			1.8		
PCR	3.3	5.1	1.4				4.3	4.2	17.8	3.2	
Model +	59.4	77.7	93.2	84.0	85.2	96.6	94.1	75.0	56.2	81.1	90.5

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-12. Percent of variation (R^2) for the variable near infrared/red ratio associated with planting date, cultivar, row width, and their interactions in 1979. (Chalmers silty clay loam)

Treatment Effect	Observation Date										
	June 4	June 11	June 15	June 25	June 26	July 18	Aug 12	Sept 4	Sept 9	Sept 17	Sept 24
Planting Date	59.9	50.2	48.5	51.3	52.4	63.6	36.2	43.2	34.5	64.9	52.9
Cultivar	5.5	5.0	4.8	4.0	3.2	2.4		4.5	2.3	7.1	19.0
Row Width	1.1	17.0	18.7	17.5	22.4	18.8	20.0				
PC	13.6	8.0	5.0	3.5	1.6	2.2	7.0	20.7	22.6	6.4	19.5
PR	7.0	11.5	12.7	10.6	11.7	6.4	11.7	2.2		2.1	1.9
CR	1.5	2.2	4.7	2.4	2.1			3.2	3.4	1.7	
PCR	1.7	2.4	3.3	1.3	1.3	1.9	2.7	2.0	4.3	1.4	
Model+	94.2	96.3	97.8	90.6	94.8	95.4	77.7	76.6	67.3	84.4	94.2

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-13. Percent of variation (R^2) in reflectance of the 0.6-0.7 um wavelength associated with planting date, cultivar, row width, and their interactions in 1979. (Russell silt loam)

Treatment Effect	Observation Date							
	June 25	June 26	July 10	August 12	Sept. 4	Sept. 9	Sept. 17	Sept. 24
Planting Date	77.3	78.3	82.9	53.0	28.0	16.4	50.0	49.6
Cultivar					1.4	9.8	18.7	16.9
Row Width	6.9	1.8	6.5	18.5	21.5	26.7	7.8	15.6
PC			1.0	1.2		5.6	8.3	3.4
PR	12.3	16.0	3.4	24.9	36.0	24.1	3.5	1.8
CR					1.6	3.8	1.5	1.0
PCR							2.9	
Model +	97.7	98.5	94.0	98.3	90.0	87.2	93.2	88.7

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-14. Percent of variation (R^2) in reflectance of the 0.8-1.1 um wavelength band associated with planting date, cultivar, row width and their interactions in 1979. (Russell silt loam)

Treatment Effect	Observation Date: June 25	June 26	July 10	August 12	Sept. 4	Sept. 9	Sept. 17	Sept. 24
Planting Date	29.6	81.4	80.9	44.2	1.4	9.2	57.5	75.0
Cultivar	8.1			3.1	17.9	21.5	11.4	
Row Width	7.0	7.4	2.8	37.9	33.3	14.6	1.5	2.0
PC				3.8	6.3	4.9	5.3	7.2
PR	2.6	2.4	11.0	8.1	2.2		6.7	4.2
CR	2.1				1.6			
PCR	3.8	3.3			2.6	2.4	1.2	
Model+	53.4	95.0	95.5	97.7	65.3	53.4	83.8	88.8

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.

Table A-15. Percent of variation (R^2) for the variable near infrared/red ratio associated with planting date, cultivar, row width, and their interactions in 1979. (Russell silt loam)

Treatment Effect	Observation Date: June 26	June 26	July 10	August 12	Sept. 4	Sept. 9	Sept. 17	Sept. 24
Planting Date	59.6	60.9	60.8	70.1	18.5	16.9	49.2	67.0
Cultivar					3.6	12.7	10.2	5.8
Row Width	10.7	10.4	13.2	17.3	32.0	27.8	11.4	10.2
PC	1.0			1.0	5.1	8.6	4.0	2.0
PR	19.0	20.7	24.4	8.5	28.9	22.1	14.2	10.0
CR					3.0	1.3		
PCR	1.4						1.3	
Model +	93.0	92.5	98.6	97.9	91.3	89.7	90.3	95.0

+ Model includes variation due to treatments. Total variation is due to blocks, treatments, and experimental error. Percentages less than 1.0 are omitted for clearity but are included in model.