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May 1980

Technical Report

Effects of Management Practices on Reflectance of Spring Wheat Canopies

by C.S.T. Daughtry, M.E. Bauer, D.W. Crecelius, and M.M. Hixson

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16 Abstract

Analyses of multispectral measurements from satellites offer the potential to monitor and inventory crop production. The crop canopy is a dynamic entity influenced by many cultural and environmental factors. To quantify and understand several of the potential sources of variation in spectral measurements of crops, an experiment was conducted at the Williston, North Dakota, Agricultural Experiment Station in 1977. The effects of available soil moisture, planting date, nitrogen fertilization, and cultivar on reflectance of spring wheat (Triticum aestivum L.) canopies were investigated. Spectral measurements were acquired on eight dates throughout the growing season, along with measurements of crop maturity stage, leaf area index, biomass, plant height, percent soil cover, and soil moisture. Planting date and available soil moisture were the primary agronomic factors which affected reflectance of spring wheat canopies from tillering to maturity. Comparisons of treatments indicated that during the seedling and tillering stages planting date was associated with 36 and 85% of variation in red and near infrared reflectances, respectively. As the wheat headed and matured, less of the variation in reflectance was associated with planting date and more with available soil moisture. By mid July soil moisture accounted for 73 and 69% of the variation in reflectance in red and near infrared bands, respectively. Differences in spectral reflectance among treatments were attributed to changes in leaf area index (LAI), biomass and percent soil cover. Cultivar and N fertilization rate were associated with very little of the variation in the reflectance of these canopies.

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EFFECTS OF MANAGEMENT PRACTICES ON REFLECTANCE OF SPRING WHEAT CANOPIES[1]

C.S.T. Daughtry, M.E. Bauer, D.W. Crecelius, and M.M. Hixson[2]

ABSTRACT

Analyses of multispectral measurements from satellites offer the potential to monitor and inventory crop production. The crop canopy is a dynamic entity influenced by many cultural and environmental factors. In order to quantify and understand these potential sources of variation in spectral measurements of crops, an experiment was conducted at the Williston, North Dakota, Agricultural Experiment Station in 1977. The effects of soil moisture, planting date, nitrogen fertilization, and cultivar on reflectance of spring wheat (Triticum aestivum L.) canopies were investigated. Spectral measurements were acquired on eight dates throughout the growing season with a radiometer (Exotech 100 A) in four wavelength bands (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μm) at 3.5 m above the plots. On each date that spectral data were acquired, concomitant measurements of crop maturity stage, leaf area index, biomass, plant height, percent soil cover, and soil moisture were made.

In this experiment, planting date and available soil moisture were the primary agronomic factors which affected reflectance of spring wheat canopies from tillering to maturity. Comparions (R^2) of treatments indicated that during the seedling and tillering stages planting date was associated with 36 and 85 percent of variation in red (0.6-0.7 μm) and near infrared (0.8-1.1 μm) reflectances, respectively. As the wheat headed and matured, less of the variation in reflectance was associated with planting date and more with available soil moisture. By mid July soil moisture accounted for 73 and 69 percent of the variation in reflectance in red and near infrared bands, respectively. Differences in spectral reflectance among treatments were attributed to changes in leaf area index (LAI), biomass and percent soil cover. Cultivar and N fertilization rate were associated with very little of the variation in reflectance of these canopies. Agronomic practices which result in differences in LAI, biomass, and percent soil cover potentially can be monitored by remote sensing and may be useful in estimating crop production.

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[2] Research agronomists, former graduate assistant, and research statistician.

INTRODUCTION

The reflectance properties of single plant leaves have been identified and studied in laboratories for more than a decade. Relationships of physical and biological characteristics, such as leaf morphology, chlorophyll concentration, and leaf water content, to reflectance of leaves have been well established. Several comprehensive reviews of various aspects of this research have been published (2,4,5,7,12).

Although knowing the reflectance characteristics of single leaves is basic to understanding the reflectivity of crop canopies, significant differences exist between spectra of single leaves and crop canopies. Canopies are more than simple collections of leaves. Complex interactions which are not factors when spectra of single leaves are measured must be considered in remote sensing of canopies grown under field conditions. Some important agronomic parameters influencing reflectance of crop canopies are leaf area index, percent soil cover, biomass, leaf geometry, leaf color and soil color (2,3,7). Because the crop canopies are dynamic entities, they are influenced by many management practices and environmental factors, including cultivar seeding rate, fertilization, soil moisture and disease (1,2,3,9,14).

Crop identification and crop area estimation promise to be two of the major applications of remote sensing. In the recently completed Large Area Crop Inventory Experiment (LACIE), this technology was pushed to near operational use for wheat (10). Remote sensing also offers considerable potential for acquiring information about crop conditions and yields (2,14). If multispectral remote sensing is to be used successfully to identify and inventory crops, it is important to quantify and understnad the sources of variation in spectral measurements of crops. Some of the variation may be associated with important agronomic factors, which it may be desirable to monitor or inventory (e.g., dryland vs. irrigated wheat). On the other hand, it is also important to know the magnitude of variation associated with a factor, such as cultivar, which one probably would not be interested in monitoring.

The objectives of this experiment were (1) to determine the relationship of canopy characteristics to the reflectance of spring wheat and (2) to determine the effect of several agronomic treatments, which represented the farming practices of the northern U.S. Great Plains, on the multispectral reflectance of spring wheat during different development stages.

MATERIALS AND METHODS

Data were collected at the North Dakota State Agricultural Experiment Station at Williston (43.32°N, 103.42°W) during the summer of 1977. The station is located in the gently rolling uplands above the Missouri River Valley and is representative of dryland farms of the region. Because of limited precipitation (36 cm per year) the majority of the land is planted to crops every other year and is left fallow in intermediate years to accumulate subsoil moisture.

The spring wheat (Triticum aestivum L.) experiment was a split plot design. Within each available soil moisture condition (whole plot), there were two blocks replications of a factorial experiment with cultivar, nitrogen fertilization, and planting date as treatments:

Soil Moisture: Low (wheat crop in 1976)
High (fallow in 1976)

Planting Date: Early (9 May 1977)
Late (23 May 1977)

Cultivar: Semi-dwarf (Olaf)
Standard (Waldron)

Nitrogen Fertilization: None
44 kg N/ha

The plots were 3.5 m wide and 15.3 m long with 18 cm wide, north-south rows. The soil was a Williams loam fine-loamy, mixed typic argiborolls which has a dark brown (10 YR 3/2) surface color when moist and very light (10 YR 4/3) color when dry. Although moisture in the top 20 cm of soil of the whole plots were similar at planting, the profile of fallow soil contained 20 percent (3 cm) more water in the 20 to 60 cm zone than the profile of soil on which wheat was grown in the previous year.

Spectral measurements were made with an Exotech 100 radiometer in four wavelength bands, 0.5-0.6, 0.6-0.7, 0.7-0.8, and 0.8-1.1 μm, corresponding to the four spectral bands of the Landsat MSS. Measurements in all bands were taken concurrently and recorded by a printing data logger. Duplicate observations were acquired over each plot and were averaged for these analyses. A boom mounted on a van supported the radiometer vertically at 3.5 m above the canopies and 3.5 m away from the van. At this elevation with 15° field of view the sensor viewed a 0.9 m diameter ground area. The reflectances of all plots were measured on eight dates during the growing season when the sun angle was greater than 45° above the horizon. On selected dates reflectances were measured four to eight time per day at approximately hourly intervals. Only data acquired during a two hour interval centered on solar noon were used in these analyses.

A 1.2 m square panel painted with highly reflecting barium sulfate was used as a reference surface for determination of the bidirectional reflectance factor (11). This reflectance standard provided a field calibration reference with stable, known reflectance properties. A dark level response of the instrument was also obtained by holding an opaque, light-tight apparatus against the instrument's optical ports to measure the internal system noise or deviation from zero. The response of the reference panel was measured approximately every 15 minutes during the data collection period and the dark level every 30 minutes. These values were then used in the following equation to calibrate readings taken over the plots:

$$\mathrm{BRF}\ (\lambda) = \frac{\mathrm{Ds}(\lambda) - \mathrm{ds}\ (\lambda)}{\mathrm{Dr}(\lambda) - \mathrm{dr}\ (\lambda)} \cdot \mathrm{Rr}\ (\lambda)$$

Where, BRF (λ) = bidirectional reflectance factor (%) at a specific wavelength interval (λ)

$\mathrm{Ds}(\lambda)$ = response of instrument to scene (plot),

$\mathrm{ds}(\lambda)$ = dark level response of instrument taken closest to time to scene,

$\mathrm{Dr}(\lambda)$ = response of instrument to painted barium sulfate reference standard,

$\mathrm{dr}(\lambda)$ = dark level response of instrument taken closest in time to reference standard measurement, and

$\mathrm{Rr}(\lambda)$ = reflectance of painted barium sulfate reference standard (measurement in laboratory by comparison with pressed barium sulfate).

Spectral data were acquired over the north end of these plots and agronimic data were collected from the southern two-thirds of each plot. This kept the plants viewed by the sensor untrampled and intact throughout the growing season. Measurements of crop maturity stage (8), percent soil cover, plant height, leaf area index, biomass, soil moisture, and comments on crop condition were acquired each day that reflectance data were acquired. Crop biomass in each plot was estimated by harvesting plants in 1.0 m length of row (0.178 m^2). Each sample was placed in a plastic bag; weighed (fresh biomass); separated into stems, heads, green, yellow, and brown leaf blades (leaf sheaths were included with stems); dried at 60°C and reweighed. The leaf area of a random subsample of green leaf blades from each plot was measured (Lambda Instrument Co., Model LI-3000) and the leaf area: leaf dry weight ratio was estimated. Leaf area index was calculated using this leaf area: leaf weight ratio and total dry weight of green leaf blades from plants in 1.0 m length of row. Grain yields were estimated from a 7.4 m^2 area harvested from the center of each plot with a small self-propelled combine. Vertical color photographs taken from 6 m were used to estimate percent soil cover in each plot.

Daily meteorological data useful for describing the growing season were acquired at a National Weather Service cooperative station located on the experiment station. On each day that spectral data were collected additional meteorological measurements including air temperature, barometric pressure, relative humidity, wind speed and direction, and total irradiance were recorded continuously on strip charts. These data were used primarily to document atmospheric conditions on days when spectral data were acquired.

The reflectance data were analyzed as band means and as transformations. The reflectance data were transformed using a principal component analysis into "greenness" and "brightness" variables as described by Kauth and Thomas (6) for Landsat MSS data and modified for spectrometer data. Correlation analyses were used to quantify the relationship between spectral values and agronomic characteristics. Analysis of variance was used to determine which of the experimental treatments accounted for the variability in spectral responses.

RESULTS AND DISCUSSION

Relation of Canopy Characteristics to Reflectance

The amount of vegetation present is one of the principal factors affecting the reflectance of crop canopies. Figure 1 illustrates the relationship between an agronomically important canopy characteristic, leaf area index (LAI), and reflectance in selected wavelength bands. This figure includes data from all treatments when green leaves were present (from seedling through heading). A portion of the scatter in the data is associated with various agronomic treatments, as well as measurement errors in the independent and dependent variables.

As LAI increased, red (0.6-0.7 μm) reflectance decreased and near infrared (0.8-1.1 μm) reflectance increased (Figure 1). These relationship of LAI and reflectance are slightly nonlinear, particularly in the red band. Studies of other canopies have indicated asymptotic responses of reflectance at leaf area indices greater than 3 or 4 (3.14).

Correlations of reflectance measurements in Landsat radiometer bands with several agronomic characteristics of spring wheat canopies are shown in Table 1. Fresh biomass, dry biomass, and plant water content correlated most highly with reflectance in the visible wavelengths and with the greenness transformation. Leaf area index and percent soil cover correlated highly with red and near infrared reflectance and the greenness transformation. Previous research has indicated that the amount of photosynthetically active (green) vegetation was highly correlated with reflectance of crop canopies (1,3,9). The decreased correlations of canopy variables and reflectance as the wheat began to ripen and senesce substantiated these observations (Table 1).

Plant growth and development were significantly influenced by the level of available soil moisture (Table 2) and these changes in canopy characteristics were manifested in their reflectances (Figures 2 and 3). For example, canopies of wheat planted early on fallow soil (high soil moisture) had significantly greater biomass, LAI, percent soil cover, infrared reflectance and lower red reflectance than canopies of other treatment combinations (Table 2).

Precipitation on the day prior to the day when spectral data were acquired tended to decrease both red and infrared reflectances. Approximately 10 to 12 mm of rain, which darkened the soil, fell prior to the acquisition of spectral measurements on 23 June and 7 July and probably contributed to the abrupt decreases in reflectance on these dates. These decreases are most evident for those canopies of late planted wheat (Figure 2 and 3) which had the lowest soil cover percentages (Table 2). Thompson (13) noted similar decreases in scene radiances following precipitation and was able to delineate precipitation patterns and drought severity using Landsat MSS imagery.

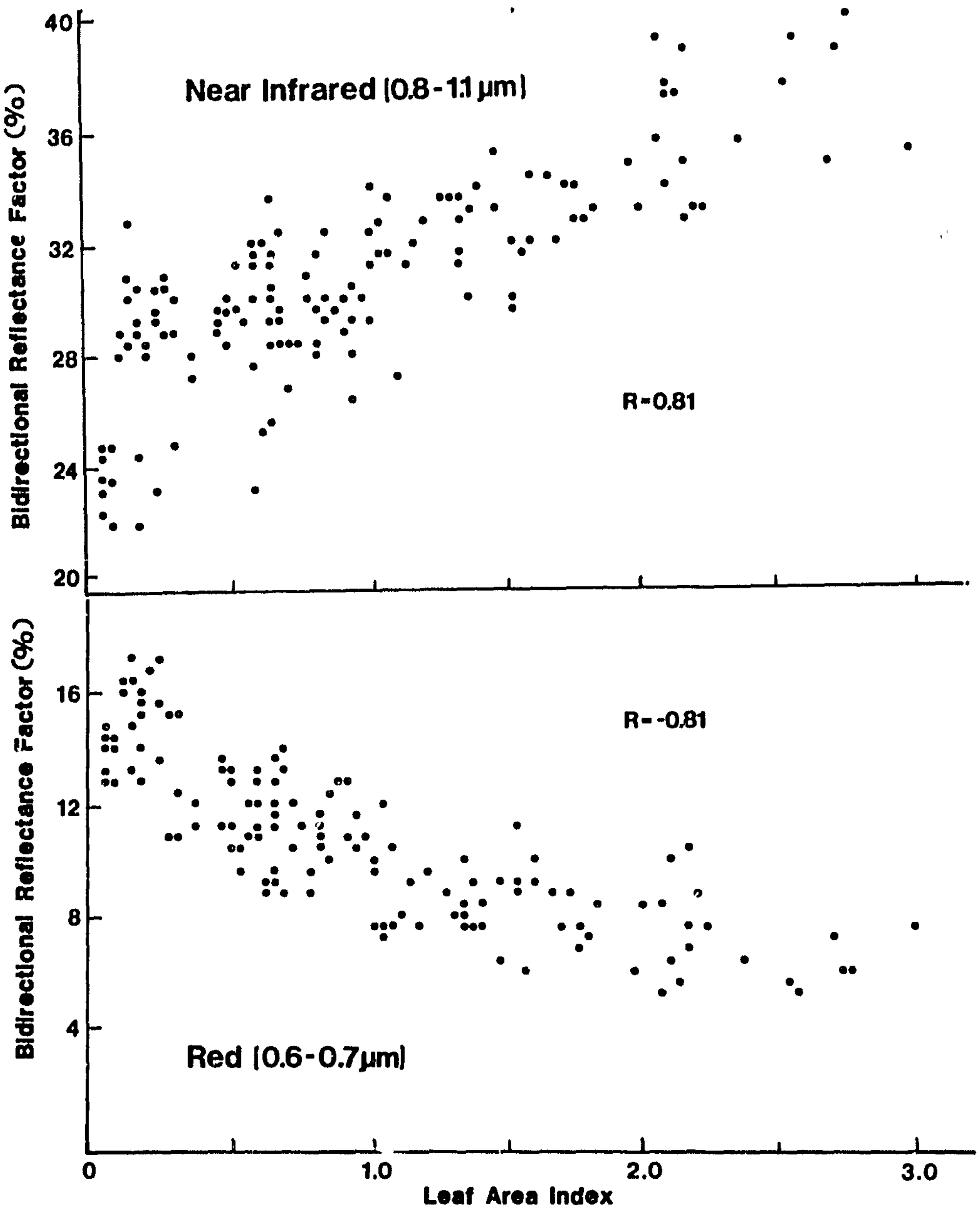

Figure 1. Relationships of red (0.6-0.7 µm) and near infrared (0.8-1.1 µm) reflectance and leaf area index of spring wheat canopies.

Table 1. Correlations of bidirectional reflectance factor with selected agronomic characteristics of spring wheat canopies for three time intervals.

Wavelength Band, µm	Plant Height	Percent Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass	Plant Water Content[†]
			Seedling to Harvest Maturity			
0.5-0.6	-0.40	-0.77	-0.74	-0.74	-0.54	-0.76
0.6-0.7	-0.23	-0.69	-0.79	-0.67	-0.36	-0.75
0.7-0.8	0.20	0.14	0.52	0.13	0.22	0.32
0.8-1.1	0.02	0.45	0.81	0.45	0.03	0.64
Greenness	0.17	0.67	0.88	0.65	0.25	.81
Sample size =	256	224	165	224	224	224
			Seedling to Soft Dough			
0.5-0.6	-0.63	-0.83	-0.79	-0.80	-0.65	-0.84
0.6-0.7	-0.55	-0.80	-0.81	-0.74	-0.57	-0.80
0.7-0.8	0.03	0.30	0.52	0.23	0.03	0.32
0.8-1.1	0.37	0.66	0.81	0.61	0.39	0.70
Greenness	0.51	0.80	0.88	0.75	0.53	0.82
Sample size =	153	153	153	153	153	153
			Seedling to Flowering			
0.5-0.6	-0.76	-0.89	-0.86	-0.85	-0.76	-0.86
0.6-0.7	-0.73	-0.88	-0.86	-0.82	-0.73	-0.84
0.7-0.8	0.37	0.51	0.56	0.46	0.34	0.49
0.8-1.1	0.65	0.80	0.83	0.76	0.64	0.79
Greenness	0.75	0.91	0.91	0.85	0.74	0.88
Sample size =	101	101	101	101	101	101

[†] Plant water content = Fresh Biomass - Dry Biomass

Table 2. Mean agronomic characteristics of spring wheat canopies as influenced by two available soil moisture levels and two planting dates.

Measurement Date	Soil Moisture Level	Planting Date	Maturity Stage	Plant Height	Soil Cover	Leaf Area Index	Fresh Biomass	Dry Biomass
				cm	%		g/m^2	g/m^2
June 1	High	Early	Tillering	14 a	7 a	0.2 a	72 a	8 a
		Late	Seedling	9 c	2 c	0.1 a	34 c	2 b
	Low	Early	Tillering	13 b	6 b	0.3 a	59 b	7 a
		Late	Seedling	9 c	2 c	0.2 a	35 c	3 b
June 18	High	Early	Tillering	29 c	46 a	1.7 a	770 a	105 a
		Late	Tillering	23 b	23 b	0.7 b	336 b	30 b
	Low	Early	Tillering	24 b	21 b	0.8 b	408 b	50 b
		Late	Tillering	23 b	20 b	0.7 b	315 b	29 b
July 3	High	Early	Heading	47 a	56 a	1.8 b	1460 a	328 a
		Late	Jointing	30 c	54 ab	2.4 a	1102 b	226 b
	Low	Early	Heading	40 b	43 b	0.9 c	711 c	186 bc
		Late	Jointing	29 c	51 c	1.4 b	660 c	150 c
July 14	High	Early	Watery	65 a	58 a	1.3 b	1533 b	620 a
		Late	Heading	58 b	60 a	2.1 a	1713 a	480 b
	Low	Early	Watery	46 c	42 c	0.5 d	723 c	285 c
		Late	Heading	46 c	49 b	0.9 c	715 c	215 d
July 20	High	Early	Milk	67 a	51 a	0.7 b	1526 a	603 a
		Late	Milk	68 a	51 a	1.2 a	1456 a	477 b
	Low	Early	Milk	45 b	38 c	0.2 c	788 b	307 c
		Late	Milk	48 b	44 b	0.5 b	695 b	224 c
August 5	High	Early	Hard Dough	65 a	46 a	0	794 b	468 b
		Lage	Soft Dough	66 a	46 a	0.1	1124 a	554 a
	Low	Early	Hard Dough	45 b	30 c	0	439 c	237 c
		Late	Soft Dough	46 b	35 b	0	564 c	259 c

Means followed by the same letter within each date are not significantly different at P=0.05 level by Duncan's Multiple Range test.

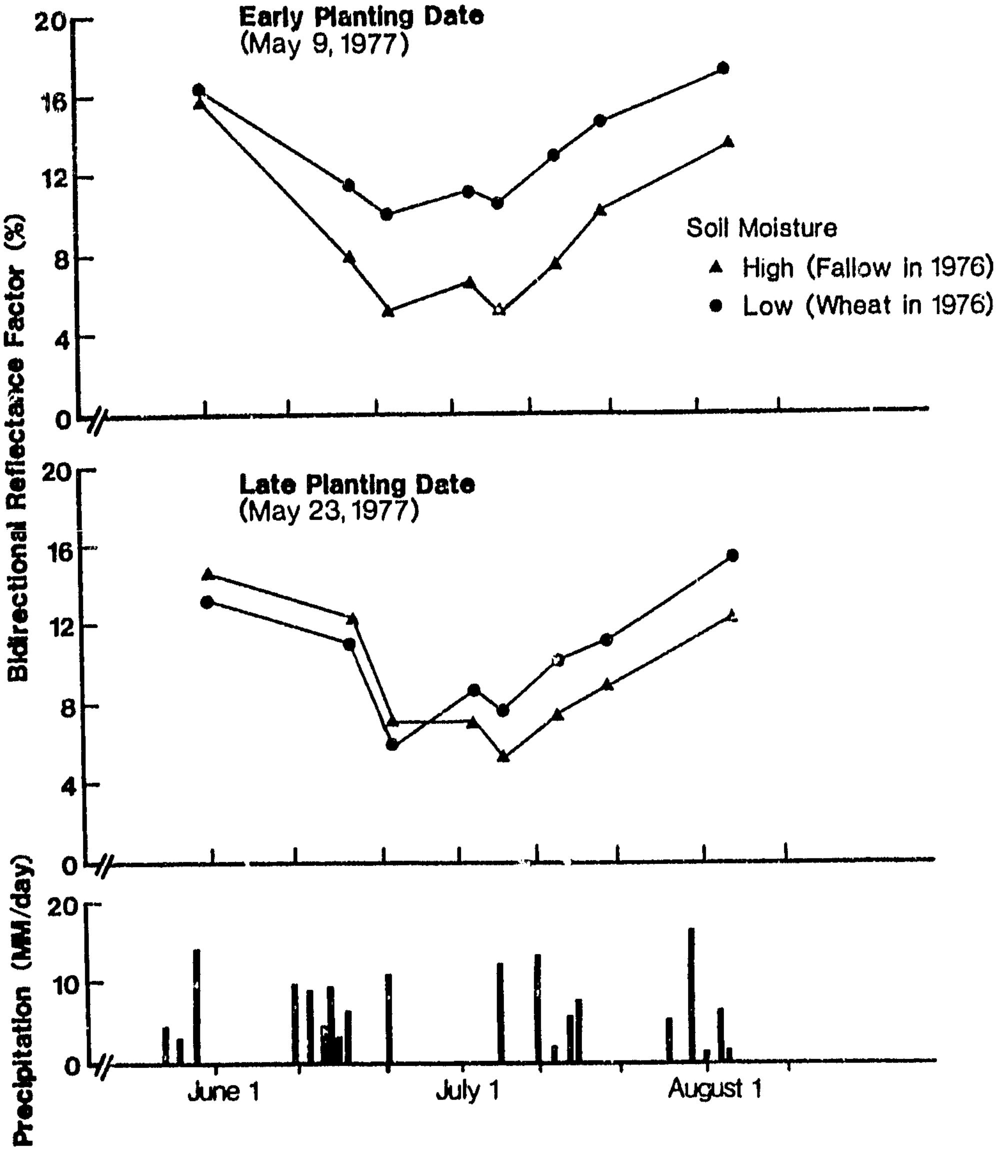

Figure 2. Temporal changes in red (0.6-0.7 μm) bidirectional reflectance factor of spring wheat canopies at two levels of available soil moisture and two planting dates. The standard errors of the mean on each date are smaller than the symbols used on these graphs. Occurrence and amount of precipitation are also indicated.

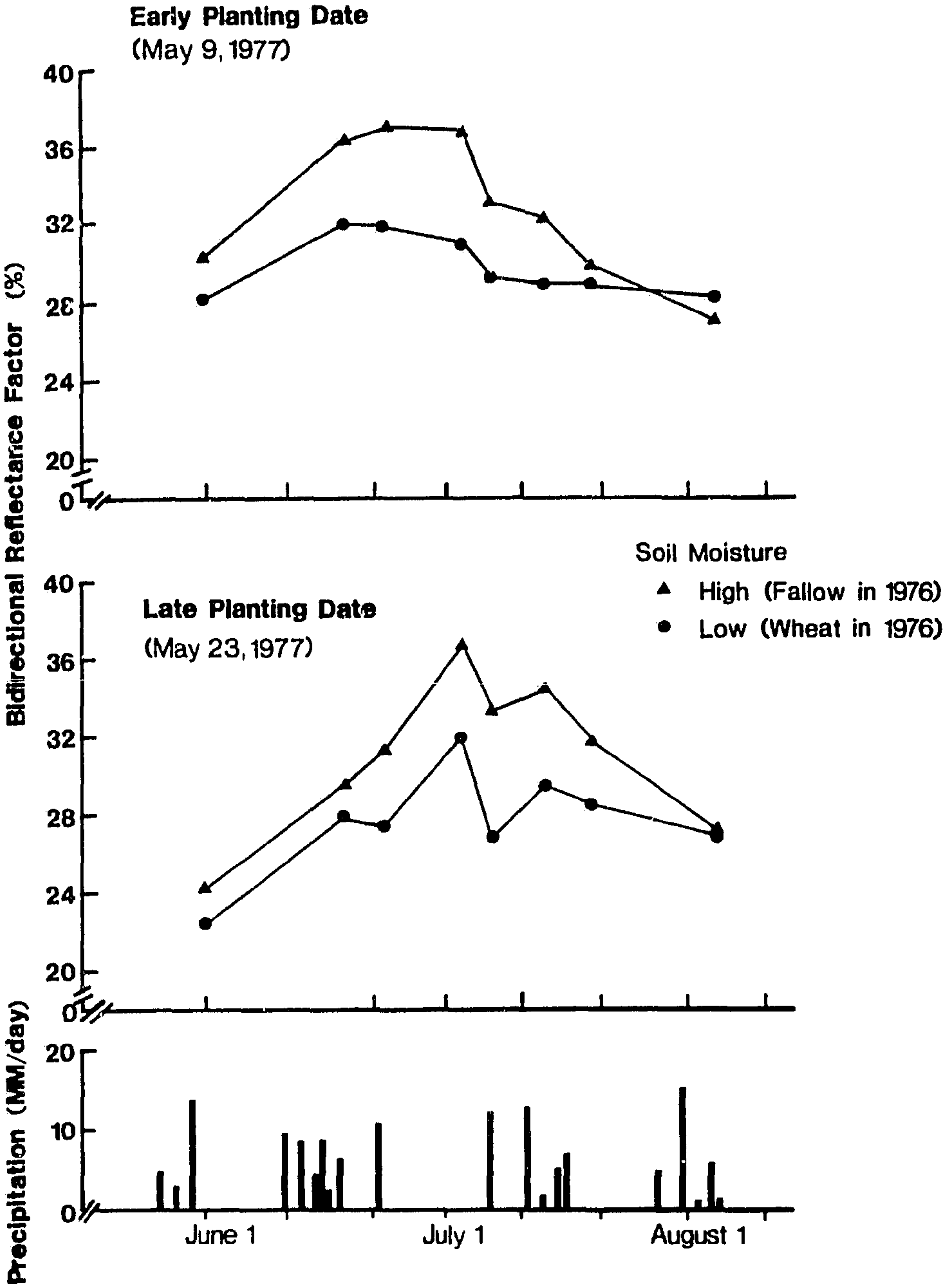

Figure 3. Temporal changes in near infrared (0.8-1.1 μm) bidirectional reflectance factor of spring wheat canopies at two levels of available soil moisture and two planting dates. The standard errors of the means on each date are smaller than the symbols used on these graphs. Occurrence and amount of precipitation are also indicated.

Relation of Agronomic Treatments to Reflectance

The high correlations of red (0.6-0.7 μm) and near infrared (0.8-1.1 μm) reflectance to green leaf area index and percent soil cover (Table 1) potentially can provide the basis to inventory indirectly certain cultural and management practices which could be useful in assessing crop production. For example if the ratios of near infrared to red (IR/red) reflectances of these wheat canopies at heading are plotted against grain yields, two distinct groupings of data are observed (Figure 4). Those wheat canopies with high IR/red reflectance also had high grain yields. Wheat grown on fallow soil (high soil moisture) produced 1748 and 1488 kg/ha of grain for early and late planting dates, respectively, compared to 648 and 724 kg/ha of grain for early and later-planted wheat, respectively, with low soil moisture.

Although no statistical test for the main effect of soil moisture level (whole plot in a nested design) was available, significant interactions of other factors with soil moisture provided indications of its significance. A method of ascertaining the overall importance of the experimental treatments was to consider the percentage of total variability from analysis of variance (ANOVA) accounted for by each treatment in several wavelength bands and transformation (Tables 3, 4 and 5). This approach permitted an evaluation of the effect of available soil moisture on reflectance of these canopies.

On 1 June, planting date was the primary factor affecting spectral response (Table 3, 4 and 5). With a 14-day difference between the early and late planting dates there were significant differences in the agronomic, as well as spectral characteristics of the wheat canopies (Table 2). The wheat planted at the later planting date 23 May was at the seedling stage, while the early planted wheat (9 May) was beginning to tiller. The differences in spectral response may be partially attributed to the significant differences in percent soil cover, leaf area index, and biomass, but since all wheat canopies covered less than 10 percent of the soil, differences in soil surface roughness are probably the major contributors to the differences in spectral response. Spectral data were acquired after the soil of the early planted wheat had been smoothed and crusted by several rains, while the soil of the late planted wheat was still rough from planting.

By early July differences in vegetative growth and spectral response due to planting date were reduced as the late planted wheat was nearly the same size as the early planted wheat (Table 2). At this time, heading to flowering stages of maturity, soil moisture availability was the major factor affecting the growth and development and spectral response of the wheat canopies.

Although there were significant differences in July due to planting date, cultivar and nitrogen fertilization, they were small compared to those associated with available soil moisture. The primary difference in these two cultivars was the 'Waldron' reached its full height 2 to 3 days before 'Olaf'. Both cultivars developed similar leaf area and biomass. However, we would expect that cultivars of wheat or any other crop which differ greatly

Table 3. Percent of variation (R^2) in reflectance of 0.6-0.7 μm wavelength band associated with soil moisture (M), cultivar(C), nitrogen fertilization(N), planting date (P) and their interactions.

Treatment Effect	Date							
	June 1	June 18	June 23	July 3	July7	July 14	July 20	August 5
Moisture	2.3	7.0	15.5	53.3	72.8	62.9	51.9	67.6
Cultivar			1.1			2.4	1.5	1.1
Nitrogen		3.2	9.0	1.9	2.6	3.8	1.3	1.1
Planting	36.5	24.1	4.5	4.1	6.7	9.3	26.6	13.4
MC								
MN		2.6	2.1					
CN	1.9			1.6				
MP	10.4	34.7	45.3	10.9	9.6	6.8	4.7	
CP			3.3					
NP				1.2				
MCN		1.2						
MCP			1.0	1.3				2.0
MNP	1.0	3.4						
CNP								
MCNP				1.9		1.0		
model†	55.7	78.4	82.8	83.6	94.4	88.6	88.0	89.0

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

Table 4. Percent of variation (R^2) in 0.8-1.1 µm wavelength band reflectance associated with soil moisture (M), cultivar (C), nitrogen fertilization (N), planting date (P), and their interactions.

Treatment Effect	Date							
	June 1	June 18	June 23	July 3	July 7	July 14	July 20	August 5
Moisture	9.3	20.0	28.2	59.8	69.1	62.3	35.5	6.3
Cultivar			10.2	10.0	4.1	2.9	4.4	
Nitrogen			1.4	3.7	2.7	6.7	4.4	
Planting	85.3	58.9	34.8		3.8	5.5	6.2	2.1
MC					2.9	1.6	1.6	
MN		2.6		2.2				1.4
CN							3.8	8.9
MP		4.1			5.9	2.5	10.8	7.1
CP							3.7	
NP							1.9	
MCN								2.4
MCP				2.0			2.2	2.3
MNP		1.2					1.4	7.5
CNP			2.3					
MCNP				4.2	1.3	2.3		
model[†]	96.3	89.6	79.9	84.2	91.9	87.2	76.7	41.6

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

Table 5. Percent of variation (R^2) in the greenness transformation of reflectance associated with soil moisture (M), cultivar (C), nitrogen fertilization (N), planting date (P) and their interactions.

Treatment Effect	Date							
	June 1	June 18	June 23	July 3	July 7	July 14	July 20	August 5
Moisture	8.1	16.6	41.1	64.2	86.6	72.2	62.8	72.8
Cultivar			8.9	2.9	2.0	2.7	2.8	3.2
Nitrogen			6.1	3.2	3.1	5.5	3.1	3.0
Planting	41.5	46.1	12.4	1.7		7.8	21.0	12.2
MC					1.4			
MN		2.8	1.8	1.7				
CM	1.5							
MP	9.5	15.5	16.0	4.3				
CP								
NP	1.1							
MCN	2.9							
MCP				1.7				
MNP	3.0	2.3						
CNP			1.6					
MCNP	2.4		1.7	5.8		1.6		
model[†]	71.8	86.6	90.8	86.1	95.2	92.7	93.4	94.9

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

in maturity and/or growth characteristics would also differ spectrally as shown by Leamer et al. (9). The addition of nitrogen fertilizer had only minor effects on the growth of wheat and accounted for very little of the variation in reflectance of these wheat canopies in 1977 when precipitation for June and July was below normal.

On July 20, moisture level was the most important factor accounting for differences in spectral response (Tables 3,4, and 5). Effects due to cultivar and fertilization were not significant except in the greenness t transformation (Table 5).

On August 5, as the canopies were ripening, soil moisture level and planting date continued to be the primary factors influencing the spectral response especially in the 0.6-0.7 μm band (Table 3) and greenness transformation (Table 5). Since the canopies had similar maturity stages, the difference in spectral response were attributed to the differences in percent soil cover and biomass (Table 2).

In summary, planting date and soil moisture status were the primary agronomic factors affecting the reflectance of spring wheat canopies from tillering to maturity in a semi-arid environment. Changes in canopy reflectance due to planting date and soil moisture were attributed to differences in maturity stage, leaf area index, biomass, and percent soil cover. Relatively high correlations between these canopy characteristics and reflectance were found. Cultivar and N fertilization had little effect on either the agronomic or spectral reflectance characteristics of these spring wheat canopies. Agronomic practices which result in differences in LAI, biomass, and/or percent soil cover can be monitored by remote sensing and may be useful in estimating crop production for large geographic areas.

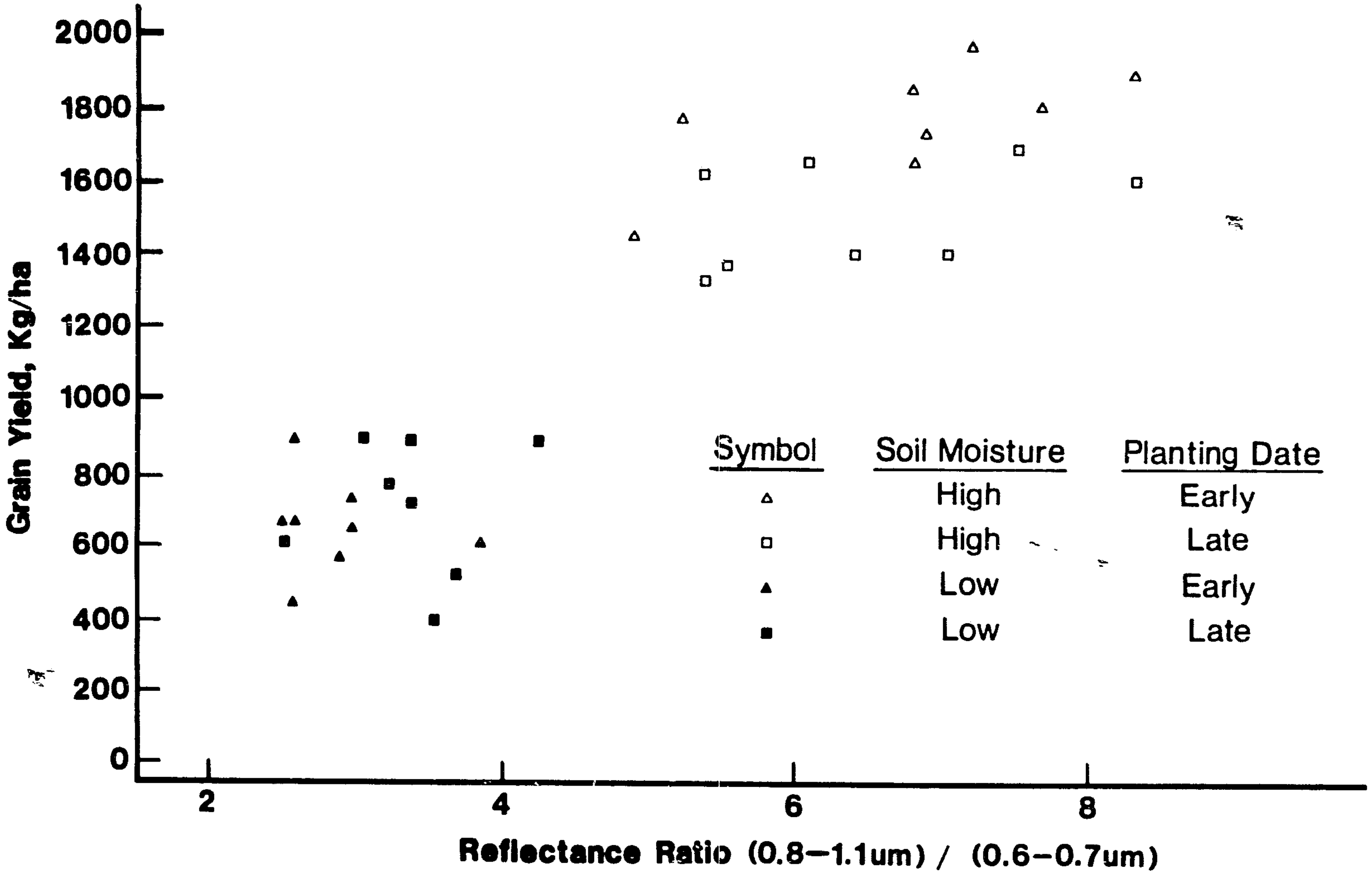

Figure 4. Relationship of grain yield with ratio of near infrared (0.8-1.1 μm) to red (0.6-0.7 μm) reflectance at heading on July 7, 1977.

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