COMPTON J. TUCKER
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
J. H. ELGIN, JR.
J. E. MCMURTREY III
Plant Genetics and Germplasm Institute
USDA/SEA
Beltsville, MD 20705

Temporal Spectral Measurements of Corn and Soybean Crops

The relationship of red and photographic infrared spectral radiances to corn and soybean biomass, percent cover, plant height, chlorosis, and leaf loss were determined.

INTRODUCTION

THIS IS THE SECOND REPORT on the remote sensing application(s) of hand-held radiometers to agricultural crop monitoring. The first paper (Tucker *et al.*, 1979) reported the general approach, operating procedure, radiance transformations, and specifically compared agronomic and spectral data.

We now evaluate for corn and soybeans the relationship(s) between temporally collected red and photographic infrared spectral radiances and biomass, plant height, percentage crop cover, percentage crop chlorosis (degree of plant yellowing), and percentage leaf loss as they change during the plant growth cycle.

KEY WORDS: **Agronomy; Biomass; Chlorosity; Corn plants; Crops; Infrared spectra; Leaves (botany); Plant growth; Radiance; Radiometers; Research; Soybean plants**
ABSTRACT: A ground-based, hand-held radiometer, configured to measure red and photographic infrared spectral radiances, was successfully used to collect *in situ* temporal spectral measurements of corn and soybean crops. Significant relationships were found between the radiance data and the biomass, plant height, percentage crop cover, percentage crop chlorosis, and percentage leaf loss. The results of this experiment show conclusively that hand-held radiometers can be used to collect spectral data that are highly correlated to several agronomic variables. These findings suggest approaches for agronomic research *per se*, and confirm the value of remote sensing of agricultural targets.
REFERENCE: Tucker, Compton J., Elgin, J. H., Jr., and McMurtrey, J. E., III, "Temporal Spectral Measurements of Corn and Soybean Crops," *Photogrammetric Engineering and Remote Sensing,* Journal of the American Society of Photogrammetry, ASP, Vol. 45, No. AP5, May, 1979

PREVIOUS WORK

Increase in biomass is inherent in the growth and development of crop plants. Since the early culture of crops man has known that a relationship exists between the variable biomass and the development of the crop canopy, and that increases in biomass are usually associated with increases in crop yields. Now, with the advent of space flight technology and data collection, the possibility of monitoring the development of the crop canopy and biomass increases by means of remote sensing is evident. Already, several investigators have reported relationships between remotely sensed data and vegetational density, percentage crop canopy cover, and/or biomass. Thomas *et al.* (1967) reported that reflectances from cotton fields were strongly affected by the amount of biomass and associated percentage canopy cover. Stanhill *et al.* (1972) investigated the effect of fertilizer treatment upon the 0.50-0.70 and 0.70-0.90 μm reflectance from wheat. They concluded that the reflectivity was affected but attributed the effects to differences in biomass and not to changes in the optical properties of the wheat

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 45, No. 5, May 1979, pp. 643-653.

canopy. Weigand *et al.* (1974) used Landsat MSS data and found significant correlations with leaf area index (LAI), plant population, percentage cover, and plant height. Bauer *et al.* (1977) reported high correlations between spectral measurements and winter wheat height and percentage cover.

Other workers have reported relationships between remotely sensed data and crop condition. Johnson (1965) located areas of low sugarcane vigor by using infrared photography. Gausman *et al.* (1975) successfully used Landsat MSS_5 data (0.60-0.70 μm) to identify chlorotic sorghum areas of 1.2 acres or larger. Field spectrometer data supported the Landsat results and demonstrated that the chlorotic sorghum had higher red reflectances than the nonchlorotic sorghum. Thomas and Oerther (1977) detected nitrogen stress on sugarcane by using infrared photography. Thomas and Gerberman (1977) detected reductions in cabbage yield caused by nitrogen and water stresses by measuring cabbage canopy reflectance.

Several researchers proposed methods for the use of Landsat data to follow crop development. Rouse *et al.* (1973) proposed a two-band approach for assessing biomass and following phenological development. Richardson and Wiegand (1977) proposed a look-up table approach for mapping vegetation cover and crop development by use of Landsat MSS bands 5 and 7. Kauth and Thomas (1976) developed a Landsat technique for characterizing the soil brightness and the green vegetation development for wheat and other crops. Numerous investigators used spectral data for estimating green biomass and/or monitoring the green leaf area or biomass through time. These publications were reviewed by Tucker (1979).

The published findings in this area of research have been largely based on data from Landsat, aerial photographic, or spectrometric techniques from large land areas. Our study relies solely upon red (0.65-0.70 μm) and photographic infrared (0.775-0.825 μm) spectral measurements taken under natural conditions with a two-channel, hand-held radiometer on small crop production areas under close experimental supervision.

Methods - Location

Study locations and data used

We selected two fields of well-drained silt loam soil located on the USDA Beltsville Agricultural Research Center for this study. One field (approximately 1.6 ha) was planted to Pioneer 3369A corn (*Zea mays* L.) on May 3, 1977 and one (approximately 0.4 ha) to Essex soybeans (*Glycine max* L.) on May 26, 1977. The corn was planted in rows 76 cm apart at a population of approximately 48,400 plants per hectare. The soybeans were in rows 36 cm apart at a population of approximately 280,000 plants per hectare. Prior to planting, the soil was limed, conventionally tilled, and fertilized according to recommended rates. Herbicides were applied at planting to control weeds. No additional tillage or weed control was required during the growing season.

For the purpose of better experimental control in sampling, small plot areas were designated within the larger fields. Four replicates of eight corn plots and nine soybean plots were identified for spectral monitoring and biomass harvest throughout the growing season. Each corn plot was 3 by 3 m, consisting of 3-m lengths of four corn rows; each row contained approximately 12 plants. Each soybean plot was 1.8 by 2.4 m, consisting of 2.4-m lengths of five soybean rows; each row contained approximately 25 plants.

One plot in the center of each replication was designated as a "standard plot" (reference point for other plots) from which spectral and agronomic data were collected weekly throughout the season. The remaining plots were used for biweekly biomass determinations.

Beginning on June 1, 1977 for the corn (when plants were approximately 30 cm high) and on June 30, 1977 for the soybeans (when plants were approximately 10 cm high) and continuing every two weeks thereafter, spectral and agronomic data from one of the biomass plots in each replication were taken to assure similarity with the standard plot, and the plot was harvested and the forage weighed for biomass determination. A sample of the wet biomass was taken, oven-dried, and the dry biomass calculated.

The agronomic data taken from the plots included crop growth stage (described by Hanway (1963) and Hanway and Thompson (1971)), average plant height in centimetres, estimated percentage crop cover, estimated percentage of canopy with chlorotic leaves (leaf chlorosis), and estimated percentage leaf loss from the canopy. The weekly agronomic data were taken by the same observer throughout the growing season.

Spectral data from the plots were taken, using a two-channel, hand-held digital radiometer slightly modified from that described by Pearson *et al.* (1976). Twenty-four red (0.65-0.70 μm) and 24 photographic infrared (0.775-0.825 μm) radiance measurements were made for each corn plot; 16 were made for each soybean plot. The radiometer was modified from that used by Pearson *et al.* by the removal of the digital interface and hand-held calculator.

Data were collected from a 1.5-m ladder for the corn plots and from the ground for the soybean plots. The radiometer was held approximately 3.5 m and approximately 1.5 m above the ground surface for the corn and soybean canopies, respectively. Data from each experimental plot were averaged and the mean values used thereafter in the analyses. Although we attempted to obtain spectral measurements on the plots at seven-day intervals, overcast conditions often precluded the seven-day sampling procedure. Actual measurements were usually made at six- to eight-day intervals; the mimimum interval was four and the maximum 12 days, depending on the weather. Data were collected between the hours of 10:30 and 15:00 EDT in direct sunlight under cloudless or partly cloudy skies. Haze conditions varied from very clear with low humidity to hazy with high humidity. The individual red and photographic infrared readings were transformed into the

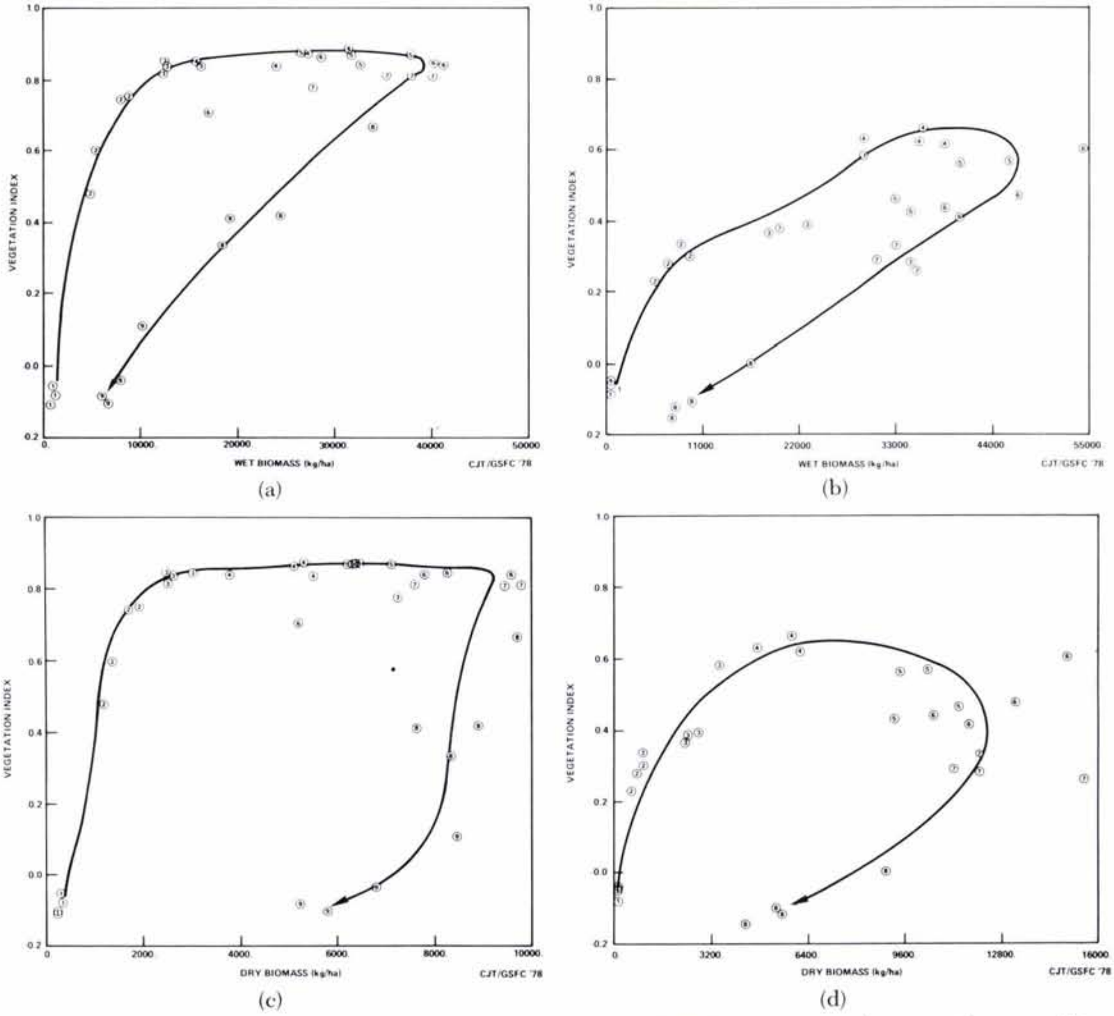


FIG. 1. The averaged VI ([ir−red]/[ir+red]) radiance values plotted against (a) soybean wet biomass, (b) corn wet biomass, (c) soybean dry biomass, and (d) corn dry biomass. All data are from small field plots measured biweekly. The numbers within each data point correspond to the sampling sequence. The solid line connects the data points with respect to time.

normalized difference vegetation index (VI) of (ir−red)/(ir+red) after Rouse *et al.* (1973)

Results and Discussion

A summary of the seasonal data is presented in Appendix A. The most significant aspects are discussed below.

The most apparent result of this experiment was the trend in the relationship between the VI radiance values and wet and dry biomass (Figure 1). Initial values for the VI and biomass were low for both corn and soybeans. Within about four weeks (sampling period 3) for soybeans and six weeks (sampling period 4) for corn, the VI values reached a maximum while the biomass continued to increase.

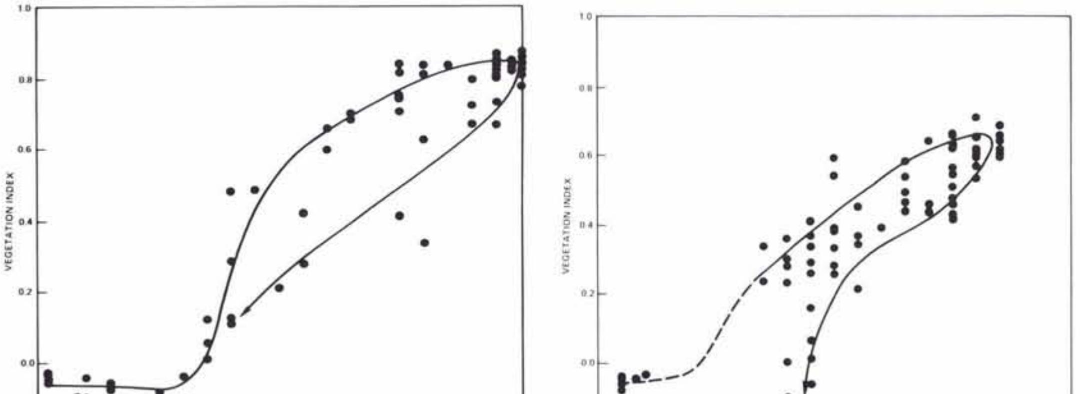
Around biomass sampling period 3, the soybean canopy had reached maximum crop cover. This is apparent by the asymptotic nature of the VI versus biomass curves (Figures 1a and 1c). Developmentally, Figure 1c shows that the soybean canopy reached maximum crop cover when the dry biomass was approximately 2,500 kg/ha. After this point, the crop cover remained constant and continued to produce the photosynthates that increased the aboveground dry biomass with time. This same relationship held until the soybeans reached senescence at sampling period 7, and VI values began to decrease (periods 7-9) along with an associated decrease in wet and dry biomass. The reduction in wet biomass resulted from plant maturation and associated loss of moisture due to senescence. The reduction in dry biomass resulted from losses of dry leaves and petioles from the senescent plants.

The temporal VI-biomass relationships were less evident for corn than for soybeans (Figures 1b and 1d), possibly because of the difficulty in accurately measuring corn from a small ladder. In corn, VI radiance values reached a maximum at sampling period 4; dry biomass reached a maximum at sampling periods 6-7. After the onset of senescence at about sampling period 7, the VI and dry biomass values both decreased. The dry biomass decreased primarily because of leaf loss and VI because of crop chlorosis (yellowing) and associated leaf loss (Fig. 1d). The reduction in chlorophyll density resulted in a decrease in the VI.

Wet biomass reached a maximum at sampling periods 5-6 and thereafter decreased rapidly, apparently from crop maturation and from the drying that was associated with senescence (Figure 1b). The tracking phenomenon of the VI versus biomass curves with time shows the close relationship of red and ir spectral measurements to plant growth and development.

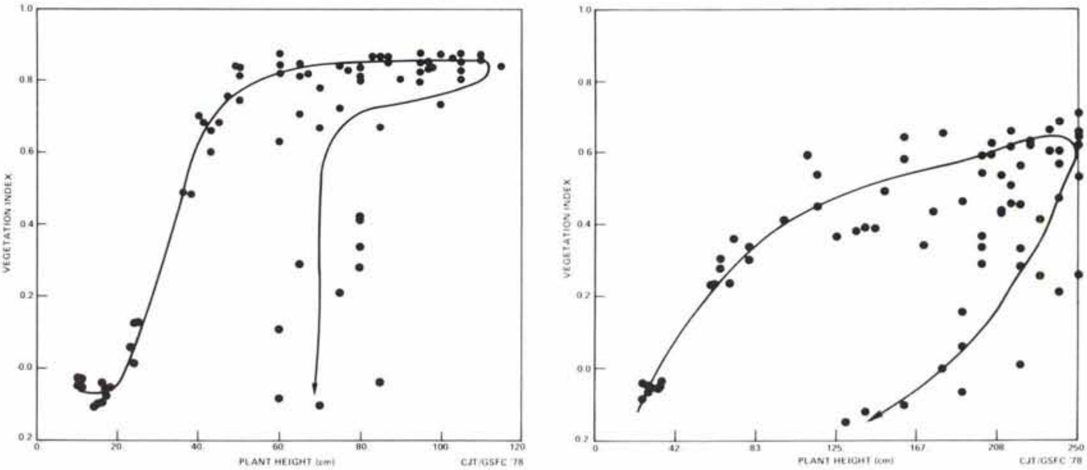
The VI plotted against percentage crop cover also exhibited a tracking phenomenon with time (Figure 2). This was more apparent for soybeans than for corn, but the patterns were generally similar.

The soybean plots became spectrally apparent (Figure 2a) when the crop cover reached about 30 to 35 percent. The same spectrally apparent point was difficult to de-



(a) (b)

Fig. 2. The averaged VI ([ir−red]/[ir+red]) radiance values plotted against (a) soybean estimated percentage crop cover and (b) corn estimated percentage crop cover. All data are from small field plots measured weekly. The solid line represents the progression of time.



(a) (b)

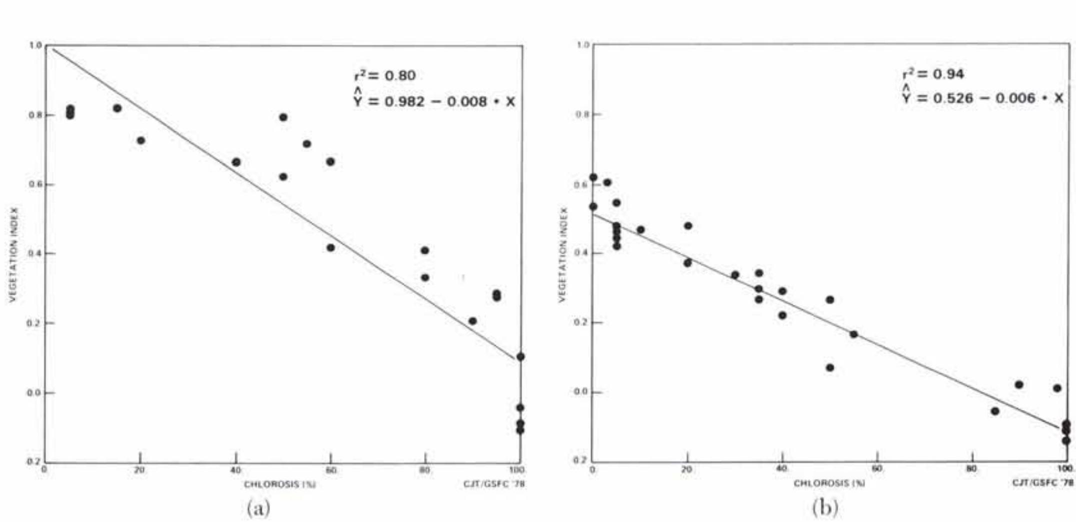
FIG. 3. The averaged VI ([ir−red]/[ir+red]) radiance values plotted against (a) soybean plant height and (b) corn plant height. All data are from small field plots measured at weekly intervals. The solid line represents the progression of time.

termine for corn, but was at approximately 20 to 25 percent (Figure 2b). From these points onward, the values increased until the respective crop canopies reached maximum crop cover. Maximum percentage crop cover corresponded to the maximum VI radiance values. When senescence began, the values for VI and crop cover decreased.

The relationship between the VI and plant height was somewhat similar for corn and soybeans (Figure 3). The curves increased to the respective maximum VI values, remaining at these values for a period of time until senescence began to occur, and then decreased as progressively more of the canopy entered the senescent state.

The soybean plant height stabilized at 60 to 80 cm as the plants matured (Figure 3a). The losses of leaves and petioles during senescence resulted in progressively lower VI values.

For corn, plant height gradually decreased due to European corn borer damage and weather-related breakage of the upper stalk



(a) (b)

FIG. 4. The averaged VI ([ir−red]/[ir+red]) radiance values plotted against estimated percentage of canopy chlorosis (yellowing) for (a) soybeans and (b) corn. All data are from small field plots measured at weekly intervals.

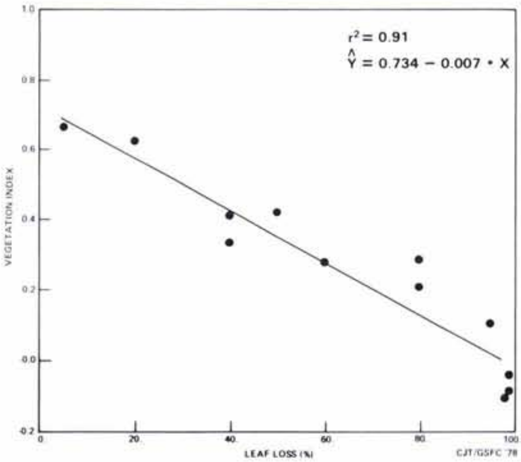


FIG. 5. The averaged VI ([ir−red]/[ir+red]) radiance values plotted against the estimated percentage of canopy leaf loss for soybeans. All data are from small field plots.

after the corn canopy entered the senescent period. The decreases in corn plant height with time, as with soybeans, were associated with decreasing VI values (Figure 3b).

Estimated percentage chlorosis and VI radiance values were negatively related (Figure 4). Chlorosis results from either unfavorable environmental conditions and/or from senescence. Most of the chlorosis in crops results from senescence. In either condition the physiological effect is the same—the chlorophyll concentration is reduced. This effect is visible as a "yellowing" of leaves.

In soybeans, estimated chlorosis was generally associated with estimated leaf loss. Leaf loss was preceded by a chlorotic condition. Leaf loss showed a negative linear relationship with VI (Figure 5). This was expected because loss of leaves results in loss of chlorophyll and canopy cover. Leaf loss did not occur when VI values were >0.65.

Linear correlation coefficients for the red, ir, and VI versus the agronomic variables were computed and are presented in Table 1. These correlations generally reflect similar relationships as shown for the VI versus the agronomic variables in Figures 1 to 5. Table 2 presents correlation coefficients among the agronomic variables. It is obvious that most of these variables are closely interrelated and are little more than different expressions of the same physiological phenomenon—crop growth and development.

Thus, our data have indicated that red and photographic infrared radiances are closely related to the basic physiological properties of corn and soybeans. By means of nondestructive red and ir spectral measurements, remotely sensed inferences can be recorded and their fundamental relationships to biomass production can be shown.

TABLE 1. CORRELATION COEFFICIENTS BETWEEN THE SAMPLED AGRONOMIC VARIABLES AND THREE RADIANCE VARIABLES. THE SAMPLE SIZE APPEARS IN PARENTHESIS.

A. Corn

	Agronomic Variable				
Radiance Variable	Percentage Crop Cover (n = 76)	Plant Height (n = 76)	Percentage Chlorosis (n = 26)	Wet Biomass (n = 32)	Dry Biomass (n = 32)
RED	−0.41**	−0.26*	0.73**	−0.39*	−0.18 ns
IR	0.67**	0.45**	−0.66**	0.61**	0.30 ns
VI	0.87**	0.61**	−0.97**	0.80**	0.39*

B. Soybeans

	Agronomic Variable					
Radiance Variable	Percentage Crop Cover (n = 84)	Plant Height (n = 84)	Percentage Chlorosis (n = 21)	Percentage Leaf Loss (n = 12)	Wet Biomass (n = 36)	Dry Biomass (n = 36)
RED	−0.81**	−0.71**	0.87**	0.64*	−0.61**	−0.55**
IR	0.57**	0.32**	−0.88**	−0.94**	0.37*	−0.15 ns
VI	0.95**	0.73**	−0.89**	−0.95**	0.70**	0.30 ns

* significant at the 0.05 level.
** significant at the 0.01 level.

TABLE 2. CORRELATION COEFFICIENTS BETWEEN THE SAMPLED AGRONOMIC VARIABLES.

A. Corn

	Agronomic Variable			
	Total Dry Biomass	Percentage Crop Cover	Plant Height	Percentage Chlorosis
Total Wet Biomass	0.79** (n = 36)	0.88** (n = 36)	0.92** (n = 36)	−0.92** (n = 17)
Total Dry Biomass		0.55** (n = 36)	0.85** (n = 36)	−0.71** (n = 17)
Percentage Crop Cover			0.83** (n = 88)	−0.84** (n = 38)
Plant Height				−0.75** (n = 38)

B. Soybeans

	Agronomic Variable				
	Total Dry Biomass	Percentage Crop Cover	Plant Height	Percentage Chlorosis	Percentage Leaf Loss
Total Wet Biomass	0.80** (n = 36)	0.82** (n = 36)	0.73** (n = 36)	−0.98** (n = 9)	−0.96** (n = 8)
Total Dry Biomass		0.52** (n = 36)	0.76** (n = 36)	−0.76** (n = 9)	−0.77** (n = 8)
Percentage Crop Cover			0.78** (n = 100)	−0.90** (n = 29)	−0.97** (n = 20)
Plant Height				−0.64** (n = 29)	−0.13 ns (n = 20)
Percentage Chlorosis					0.93** (n = 20)

* significant at the 0.05 level.
** significant at the 0.01 level.

CONCLUSIONS

(1) Red and photographic ir radiance measurements were correlated to corn and soybean total wet biomass, percentage crop cover, plant height, percentage chlorosis, and percentage leaf loss.

(2) Significant interrelationships were found between biomass, percentage crop cover, plant height, percentage chlorosis, and percentage leaf loss which resulted from their relationship(s) to the phenology of each crop.

(3) Monitoring the green leaf area or biomass temporally by red and photographic infrared radiance data allowed nondestructive remotely sensed inferences that were highly correlated to crop growth and development. This technique might be used in agronomic research per se (nondestructive measurement potential) and also for comparison between crop spectral data collected on the ground and data collected by satellite and aircraft.

ACKNOWLEDGMENTS

We thank the following people for help in the collection of data in the field: Jim Fan, Lee Miller, Shel Summer, Simon Chang, Steve Fields, Charlie Schnetzler, Lou Walter, George Jacobs, Lelo de Gasparus, Frank

Wood, Sigfried Auer, Susan Dankoff, Per Eckerborn, Jerry Christenson, Craig Tom, Bill Wigton, Ruth Whitman, Ned Fetcher, Emmett Chappelle, Connie Miller, and John Barker. We thank Freeman Smith for the loan of the instrument.

References

Bauer, M. E., L. F. Silva, R. M. Hoffer, and M. F. Baumgardner. 1977 . *Agricultural Scene Understanding*. LARS Contract Report 112677. 273 pp.

Gausman, H. W., A. H. Gerberman, and C. L. Wiegand. 1975. Use of ERTS-1 to Detect Chlorotic Grain Sorghum. *Photogram. Eng. and Remote Sensing*, 41(2):177-181.

Hanway, J. J. 1963. Growth Stages of Corn. *Agron. J.* 55:487-492.

Hanway, J. J., and H. E. Thompson. 1971. *How a Soybean Plant Develops.* Special Report 53, Iowa State University Cooperative Extension Service, Ames, Iowa, June 1971.

Johnson, P. L. 1965. *Investigation of Sugarcane Vigor with Aerial Photography in Puerto Rico.* Special Report 93, CRREL, Hanover, New Hampshire.

Kauth, R. J. and G. S. Thomas. 1976. The Tasselled Cap—A Graphic Description of the Spectral-Temporal Development on Agricultural Crops as Seen by Landsat. *Proc. Symp. of Machine Processing of Remote Sensing Data*, Ch. 1103-1, LARS, Purdue.

Pearson, R. L., L. D. Miller, and C. J. Tucker. 1976. Hand-held Spectral Radiometer to Measure Gramineous Biomass. *Appl. Optics* 15 (2): 416-418.

Richardson, A. J., and C. L. Wiegand. 1977. Distinguishing Vegetation from Soil Background Information. *Photogram. Eng. and Remote Sensing*. 43(12):1541-1552.

Rouse, J. W., R. H. Haas, J. A. Schell, and D. W. Deering. 1973. Monitoring Vegetation Systems in the Great Plains with ERTS. *Third ERTS Symposium*, NASA SP-351 I:309-317.

Stanhill, G., V. Kalkofi, M. Kuchs, and Y. Kager. 1972. The Effects of Fertilizer Application of Solar Reflectance from a Wheat Crop. *Israel J. Agr. Res.* 22:109-119.

Thomas, J. C., and A. H. Gerberman. 1977. Yield/Reflectance Relations in Cabbage. *Photogram. Eng. and Remote Sensing.* 43(10): 1257-1266.

Thomas, J. C., and G. F. Oerther. 1977. Estimation of Crop Conditions and Sugarcane Yields Using Aerial Photography. *Proc. Am. Society of Sugarcane Tech.* 6:93-99.

Thomas, J. C., C. L. Wiegand, and V. I. Myers. 1967. Reflectance of Cotton Leaves and its Relation to Yields. *Agron. J.* 59:551-554.

Tucker, C. J. 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. *Remote Sensing of Environ.* (in press).

Tucker, C. J., J. H. Elgin, J. E. McMurtrey, and C. J. Fan. 1979. Monitoring Corn and Soybean Crop Development by Hand-held Radiometer Spectral Data. *Remote Sensing of Environ.* (in press).

Wiegand, C. L., H. W. Gausman, J. A. Cuellar, A. H. Gerberman, and A. J. Richardson. 1974. Vegetation Density as Deduced from ERTS-1 MSS Response. *Proc. Third ERTS-1 Symposium*, Vol. I, Section A, pp. 93-116.

Appendix A
Agronomic and Spectral Data Collected from Corn and Soybean Plots at the Beltsville Agricultural Research Center in 1977.

Corn										
Plot[1] Type	Julian Date	Rep	Crop Growth Stage[2]	Plant Height (cm)	Est. Crop Cover (%)	Est. Chlorosis (%)	Total Wet Biomass (kg/ha)	Total Dry Biomass (kg/ha)	Red Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)	IR Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)
B	152	1	1	28	5	.	585.4	64.9	0.273	0.247
B	152	2	1	33	5	.	683.0	76.4	0.188	0.167
B	152	3	1	25	5	.	634.2	72.2	0.642	0.537
B	152	4	1	25	5	.	683.0	78.2	0.457	0.420
S	152	1	1	30	5	.	.	.	0.220	0.198
S	152	2	1	34	8	.	.	.	0.157	0.142
S	152	3	1	28	5	.	.	.	0.748	0.654
S	152	4	1	35	10	.	.	.	0.507	0.467
B	167	1	2	60	40	.	5708.1	565.2	0.152	0.247
B	167	2	2	65	40	.	7220.5	753.7	0.122	0.218
B	167	3	1	80	40	.	9659.9	980.5	0.163	0.306
B	167	4	1	80	35	.	8684.1	942.4	0.131	0.267
S	167	1	1	62	35	.	.	.	0.152	0.247
S	167	2	2	65	40	.	.	.	0.100	0.191
S	167	3	1	70	35	.	.	.	0.219	0.357

APPENDIX A—*Continued*

						Corn				
Plot[1] Type	Julian Date	Rep	Crop Growth Stage[2]	Plant Height (cm)	Est. Crop Cover (%)	Est. Chlorosis (%)	Total Wet Biomass (kg/ha)	Total Dry Biomass (kg/ha)	Red Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)	IR Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)
S	167	4	1	72	40	.	.	.	0.110	0.239
S	174	1	2	98	45	.	.	.	0.367	0.879
S	174	2	2	115	50	.	.	.	0.256	0.872
S	174	3	2	115	55	.	.	.	0.346	0.904
S	174	4	2	110	50	.	.	.	0.235	0.941
B	181	1	2	140	60	.	23076.3	2806.9	0.400	0.899
B	181	2	2	135	50	.	19856.4	2437.7	0.355	0.795
B	181	3	2	160	65	.	29516.3	3507.7	0.226	0.859
B	181	4	2	125	45	.	18685.5	2347.1	0.365	0.786
S	181	1	2	145	50	.	.	.	0.380	0.857
S	181	2	2	160	70	.	.	.	0.182	0.843
S	181	3	2	150	65	.	.	.	0.339	0.992
S	181	4	3	180	80	.	.	.	0.204	0.983
S	189	1	3	170	55	.	.	.	0.435	0.890
S	189	2	3	200	80	.	.	.	0.252	0.978
S	189	3	3	175	70	.	.	.	0.378	0.963
S	189	4	3	205	85	.	.	.	0.252	0.993
B	200	1	4	225	75	.	29516.3	4760.9	0.172	0.769
B	200	2	4	235	75	.	36200.1	5905.2	0.124	0.613
B	200	3	4	225	75	.	38688.2	6180.6	0.129	0.562
B	200	4	4	205	75	.	35809.8	6151.5	0.203	0.900
S	200	1	4	215	75	.	.	.	0.150	0.732
S	200	2	4	250	80	.	.	.	0.104	0.604
S	200	3	4	215	80	.	.	.	0.192	0.814
S	200	4	4	240	85	.	.	.	0.170	0.915
S	203	1	5	210	65	.	.	.	0.198	0.664
S	203	2	5	250	85	.	.	.	0.112	0.529
S	203	3	5	220	75	.	.	.	0.304	0.823
S	203	4	5	235	85	.	.	.	0.197	0.786
B	209	1	5	210	75	.	34834.1	9271.7	0.372	0.933
B	209	2	5	190	65	10	33028.9	11411.9	0.369	1.000
B	209	3	5	220	75	.	40395.8	9459.0	0.258	0.924
B	209	4	5	240	80	.	46055.1	10356.4	0.250	0.909
S	209	1	5	215	75	.	.	.	0.313	0.965
S	209	2	5	250	85	.	.	.	0.218	1.005
S	209	3	5	200	75	5	.	.	0.287	0.970
S	209	4	5	250	85	.	.	.	0.193	0.931
B	223	1	6	210	65	5	38639.5	10569.0	0.299	0.761
B	223	2	7	240	80	3	54348.9	14997.6	0.192	0.779
B	223	3	6	240	75	5	46884.5	13256.1	0.175	0.494
B	223	4	7	230	75	5	40298.2	11737.8	0.171	0.427
S	223	1	6	215	70	5	.	.	0.300	0.800
S	223	2	7	250	85	.	.	.	0.187	0.788
S	223	3	6	200	55	20	.	.	0.296	0.639
S	223	4	7	250	80	.	.	.	0.196	0.651
B	238	1	9	200	45	35	30931.1	11235.0	0.240	0.441
B	238	2	9	220	50	30	33175.3	12072.7	0.215	0.431
B	238	3	9	250	45	35	35517.1	15539.9	0.256	0.437
B	238	4	9	220	50	40	34834.1	12084.0	0.200	0.360
S	238	1	9	200	45	35	.	.	0.234	0.474
S	238	2	9	240	75	20	.	.	0.157	0.437
S	238	3	9	190	45	55	.	.	0.262	0.362
S	238	4	9	230	50	50	.	.	0.205	0.352
S	245	1	9	190	45	50	.	.	0.500	0.566
S	245	2	9	240	55	40	.	.	0.355	0.553
S	245	3	9	190	45	85	.	.	0.550	0.484
S	245	4	9	220	45	90	.	.	0.427	0.440
B	272	1	10	160	40	100	10001.4	5318.5	0.512	0.417
B	272	2	10	180	40	98	16685.2	8969.4	0.380	0.382
B	272	3	10	130	35	100	7757.2	4322.4	0.486	0.360
B	272	4	10	140	45	100	8147.5	5543.3	0.387	0.303

[1] B = plot harvested for biomass determination; S = standard plot.
[2] Numerical growth stage classification system for corn proposed by Hanway, 1963.

APPENDIX A—*Continued*

Soybeans											
Plot[1] Type	Julian Date	Rep	Crop Growth[2] Stage	Plant Height (cm)	Est. Crop Cover (%)	Est. Chlo-rosis (%)	Est. Leaf Loss (%)	Total Wet Biomass (kg/ha)	Total Dry Biomass (kg/ha)	Red Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)	IR Radiance ($\mu w \cdot cm^{-2} * 10^{-2}$)
S	175	1	V0	10	2	.	.	.	.	0.382	0.358
S	175	2	V0	11	2	.	.	.	.	0.381	0.355
S	175	3	V0	10	2	.	.	.	.	0.415	0.374
S	175	4	V0	11	2	.	.	.	.	0.384	0.342
B	181	1	V1	17	15	.	.	1254.4	308.6	1.042	0.882
B	181	2	V1	18	15	.	.	1045.4	259.1	1.011	0.901
B	181	3	V1	14	8	.	.	731.8	192.2	1.222	0.975
B	181	4	V1	15	10	.	.	731.8	194.4	1.192	0.966
S	181	1	V1	16	10	.	.	.	.	0.893	0.820
S	181	2	V1	17	15	.	.	.	.	1.017	0.897
S	181	3	V1	16	8	.	.	.	.	0.881	0.721
S	181	4	V1	15	10	.	.	.	.	0.831	0.678
S	189	1	V2	25	40	.	.	.	.	0.332	0.423
S	189	2	V2	28	45	.	.	.	.	0.541	0.692
S	189	3	V2	24	35	.	.	.	.	0.590	0.599
S	189	4	V2	23	35	.	.	.	.	0.840	0.936
B	199	1	V3	47	75	.	.	8885.6	1905.4	0.123	0.902
B	199	2	V3	43	60	.	.	5435.9	1335.8	0.209	0.848
B	199	3	V3	38	40	.	.	4808.7	1157.1	0.273	0.786
B	199	4	V3	50	75	.	.	8153 .8	1683.2	0.098	0.699
S	199	1	V3	41	65	.	.	.	.	0.099	0.540
S	199	2	V3	45	65	.	.	.	.	0.142	0.766
S	199	3	V3	36	45	.	.	.	.	0.266	0.779
S	199	4	V3	40	65	.	.	.	.	0.142	0.843
S	203	1	V3	50	80	.	.	.	.	0.114	1.301
S	203	2	V3	50	80	.	.	.	.	0.113	1.099
S	203	3	V3	43	60	.	.	.	.	0.212	1.025
S	203	4	V3	49	75	.	.	.	.	0.114	1.335
B	209	1	V3	65	95	.	.	12648.9	2480.2	0.110	1.338
B	209	2	V3	60	85	.	.	12753.4	2600.9	0.102	1.380
B	209	3	V3	60	95	.	.	12439.8	2503.4	0.120	1.198
B	209	4	V3	65	95	.	.	16098.6	3022.7	0.115	1.365
B	223	1	R5	103	100	.	.	28643.0	5110.7	0.087	1.197
B	223	2	R5	98	100	.	.	24147.9	5514.9	0.048	0.539
B	223	3	R5	75	75	.	.	16307.7	3779.0	0.101	1.176
B	223	4	R5	60	100	.	.	31674.5	5314.3	0.083	1.255
S	223	1	R5	97	98	.	.	.	.	0.048	0.531
S	223	2	R5	77	95	.	.	.	.	0.040	0.434
S	223	3	R5	67	75	.	.	.	.	0.057	0.578
S	223	4	R5	97	98	.	.	.	.	0.041	0.508
B	238	1	R7	85	100	.	.	31779.0	6234.3	0.089	1.278
B	238	2	R7	100	100	.	.	26761.3	6329.4	0.080	1.186
B	238	3	R7	105	100	.	.	27284.0	6370.4	0.083	1.233
B	238	4	R7	83	100	.	.	37842.1	7132.1	0.081	1.157
S	238	1	R7	110	100	.	.	.	.	0.086	1.225
S	238	2	R7	95	100	.	.	.	.	0.079	1.207
S	238	3	R7	87	95	.	.	.	.	0.079	1.131
S	238	4	R7	110	95	.	.	.	.	0.085	1.147
S	245	1	R8	110	100	.	.	.	.	0.080	1.061
S	245	2	R8	95	95	.	.	.	.	0.076	0.950
S	245	3	R8	87	95	.	.	.	.	0.075	0.944
S	245	4	R8	110	100	.	.	.	.	0.077	1.046
B	256	1	R8	115	100	.	.	41291.8	9582.5	0.090	1.045
B	256	2	R8	105	100	.	.	32719.9	7805.7	0.092	1.075
B	256	3	R8	65	75	.	.	17144.0	5195.1	0.142	0.831
B	256	4	R8	60	100	.	.	40246.5	8273.4	0.091	1.109
S	256	1	R8	105	100	.	.	.	.	0.091	1.039
S	256	2	R8	95	98	.	.	.	.	0.091	0.976
S	256	3	R8	80	95	.	.	.	.	0.084	0.947
S	256	4	R8	105	100	.	.	.	.	0.090	1.085
S	269	1	R8	105	95	15	.	.	.	0.090	0.929
S	269	2	R8	95	90	50	.	.	.	0.102	0.905
S	269	3	R8	80	90	50	.	.	.	0.091	0.821
S	269	4	R8	95	95	5	.	.	.	0.080	0.809
B	272	1	R8	80	100	5	.	40141.9	9457.1	0.107	1.027
B	272	2	R8	105	100	.	.	37946.7	9794.1	0.104	1.002
B	272	3	R8	70	100	.	.	27911.2	7246.5	0.105	0.869
B	272	4	R8	65	100	.	.	35437.8	7599.0	0.099	0.960

APPENDIX A—*Continued*

						Soybeans					
Plot[1] Type	Julian Date	Rep	Crop Growth[2] Stage	Plant Height (cm)	Est. Crop Cover (%)	Est. Chlorosis (%)	Est. Leaf Loss (%)	Total Wet Biomass (kg/ha)	Total Dry Biomass (kg/ha)	Red Radiance ($\mu w \cdot cm^{-2} \cdot 10^{-2}$)	IR Radiance ($\mu w \cdot cm^{-2} \cdot 10^{-2}$)
S	272	1	R8	100	95	20	.	.	.	0.137	0.890
S	272	2	R8	85	90	60	.	.	.	0.166	0.840
S	272	3	R8	75	90	55	.	.	.	0.131	0.820
S	272	4	R8	90	95	5	.	.	.	0.106	0.974
B	284	1	R9	70	95	40	5	34078.8	9707.3	0.174	0.859
B	284	2	R9	80	80	80	40	18502.9	8335.9	0.319	0.640
B	284	3	R9	80	75	80	40	19339.2	7628.8	0.266	0.646
B	284	4	R9	80	55	60	50	24566.0	8900.0	0.275	0.674
S	284	1	R9	80	55	95	60	.	.	0.299	0.531
S	284	2	R9	75	50	90	80	.	.	0.365	0.561
S	284	3	R9	65	40	95	80	.	.	0.309	0.565
S	284	4	R9	60	80	50	20	.	.	0.167	0.734
B	318	1	R11	85	30	100	99	7944.8	6785.6	0.287	0.265
B	318	2	R11	70	30	100	99	6690.3	5774.8	0.285	0.230
B	318	3	R11	60	25	100	99	6063.1	5202.8	0.296	0.247
B	318	4	R11	60	40	100	95	10244.6	8445.9	0.267	0.330

[1] B = plot harvested for biomass determination; S = standard plot.
[2] Growth stage classification for soybeans proposed by Hanway and Thompson, 1971.

(Received June 30, 1978; revised and accepted February 6, 1979)

ASP Needs Back Issues of Journal

Because of an unexpected demand, the supply of some back issues of *Photogrammetric Engineering and Remote Sensing* has been depleted. Consequently, until further notice, National Headquarters will pay to the Regions—or to individual members—$1.00 for each usable copy of the following issues sent to ASP Headquarters, 105 N. Virginia Ave., Falls Church, VA 22046:

Year	*Volume and Number*
March 1971	Vol. XXXVII, No. 3
February 1973	Vol. XXXIX, No. 2
September 1973	Vol. XXXIX, No. 9
November 1973	Vol. XXXIX, No. 11
February 1975	Vol. XLI, No. 2
March 1975	Vol. XLI, No. 3
May 1976	Vol. XLII, No. 5
February 1977	Vol. XLIII, No. 2
March 1977	Vol. XLIII, No. 3
April 1977	Vol. XLIII, No. 4
February 1978	Vol. XLIV, No. 2

Forthcoming Articles

Dr. M. Leonard Bryan, The Effect of Radar Azimuth Angle on Cultural Data.
Charles Dancak, Temperature Calibration of Fast Infrared Scanners.
Dr. K. Jeyapalan, Numerical Cadastral Survey.
Dr. Robert W. Johnson, Robert M. Glasgow, Dr. Iver W. Duedall, and *Dr. John R. Proni,* Monitoring the Temporal Dispersion of a Sewage Sludge Plume.
Terrence J. Keating and *Dennis R. Boston,* Digital Orthophoto Production Using Scanning Microdensitometers.
G. Konecny, Methods and Possibilities for Digital Differential Rectification.
Harry F. Lins, Jr., Some Legal Considerations in Remote Sensing.
Ken M. Morgan, Donald R. Morris-Jones, Gerhard B. Lee, and *Ralph W. Kiefer,* Cropping Management Using Color and Color Infrared Aerial Photographs.
John R. Schott, Temperature Measurement of Cooling Water Discharged from Power Plants.