Title:

Determining Density of Maize Canopy:

III. Temporal Considerations[1]

by

E. R. Stoner

M. F. Baumgardner

P. E. Anuta

and

J. E. Cipra[2]

[1]Journal Paper No. 4931, Purdue University Agricultural Experiment Station, Contributed by the Laboratory for Applications of Remote Sensing and Department of Agronomy, West Lafayette, Indiana 47907. Supported by: NASA Grant NGL 15-005-112.

[2]Peace Corps, Brazil; Associate Professor, Agronomy Department; Associate Manager for Data Reformatting, LARS: and Research Agronomist.

ABSTRACT

Multispectral scanner data were collected in two flights over ground cover plots near the Purdue University Agronomy Farm's Weather Station at an altitude of 305 m. Energy in eleven reflective wavelength bands from 0.46 to 2.6 μm was recorded by the scanner. A set of eight ground reflectance panels was in close proximity to the ground cover plots and was used to normalize the scanner data obtained on different dates. The ground reflectance panels were used to relate laboratory reflectance measurements to scanner response. Separate prediction equations were obtained for both flight dates for all eleven reflective wavelength bands of the multispectral scanner. In this way, scanner response was normalized to ground panel reflectance. By normalizing the scanner data, ratios of scanner data could be related to leaf area index over time.

Normalized scanner data were used to plot relative reflectance versus wavelength for the ground cover plots. Spectral response curves resulted which were similar to those for bare soil and green vegetation as determined by laboratory measurements. The spectral response of different ground cover plots represented a "mixing" of the spectral response curves for the bare soil and green

vegetation components of the scene.

The spectral response curves from the normalized scanner data indicated that reflectance in the 0.72 to 1.3 µm wavelength range increased as leaf area index increased. A decrease in reflectance was observed in the 0.65 µm chlorophyll absorption band as leaf area index increased. This confirmed the validity of using the ratio of the response from a near infrared wavelength band to that of the red wavelength band in relating multispectral scanner data to leaf area index in maize.

Additional Key Words: ground cover, leaf area index, remote sensing.

INTRODUCTION

Many potential applications of remote sensing depend on the ability to view repeatedly a target of interest and characterize the spectral properties of that target over time. Determination of canopy density is certainly an area in which this ability is needed.

Comparisons of multispectral scanner data between flight dates have always been difficult because of the many variables involved. Weather and atmospheric conditions, scene illumination intensity as a function of wavelength, time of day, and angle of illumination can always be counted on to complicate comparisons between multispectral scanner flights.

Not only are there natural phenomena to content with, but there are also many problems involving the scanner system itself. Data values for the same ground target have been observed to change from one side of a flightline to the other and from the beginning of a flightline to the end. Changes in scanner response over time within the same flightline may occur due to drift in zero level reference as well as gain changes in the system. Gain changes are often made in one channel and not in another, thus it becomes difficult to make any comparisons between channels over time.

Airborne multispectral scanner data allow for examination of the spectral differences between various canopy densities (Kristof and Baumgardner, 1970, personal communication). Ratios of scanner data response can be related to the ground based measurement of leaf area index (Stoner, 1972, Multispectral determination of vegetative cover in corn crop canopies, M.S. Thesis, Purdue University, W. Lafayette, Indiana). It is desirable to be able to compare results from more than one flight date. In this way the theorized relationships between ratios of scanner data values and leaf area index can be tested.

Variations in scanner system response between flight dates prevented direct comparison of scanner data over time. Internal calibration standards within the multispectral scanner and reference to ground reflectance panels permit normalization of scanner response between flight dates (Silvestro, 1969; Hasell and Larsen, 1968).

Future efforts in remote sensing from orbital altitudes such as are proposed for the Earth Resources Technology Satellite (ERTS) and SKYLAB will be concerned with general views of agricultural crops. With the extremely high altitude and coarse resolution from space platforms, it is likely that discrimination of healthy green agricultural crops will be primarily on the basis of differences in vegetative cover, and not on individual plant spectral properties alone.

MATERIALS AND METHODS

Plot design and location were described by Stoner (1972, Multispectral determination of vegetative cover in corn crop canopies, M.S. Thesis, Purdue University, W. Lafayette, Indiana). A group of 12 ground cover plots were overflown at an altitude of 305 m on July 12 and July 21, 1971 by the University of Michigan multispectral scanner. A set of eight standard reflectance panels was located in proximity to the plots near the Purdue University Agronomy Farm's Weather Station. These reflectance panels were used to relate scanner response to reflectance, in an attempt to normalize the scanner data. Wavelength bands and corresponding channels of the University of Michigan multispectral scanner are given in Table 1.

The procedures used to normalize scanner data involved use of internal calibration sources within the multispectral scanner as well as reference to ground reflectance panels. A full description of the procedure will not be attempted here but can be referred to elsewhere (E. R. Stoner, 1972. Multispectral determination of vegetative cover in corn crop canopies, M.S. Thesis, Purdue University, West Lafayette, Indiana; P. E. Anuta and W. R. Simmons, 1972. Calibration of aircraft scanner data using ground reflectance panels. Laboratory for Applications of Remote Sensing (LARS) Information Note 030672, Purdue University, West Lafayette, Indiana).

Internal calibration of the scanner data was accomplished by a standard procedure at the Laboratory for Applications of Remote Sensing. (T. L. Phillips, 1969. Calibration of scanner data for operation processing programs at LARS. LARS Information Note 071069. Purdue University, West Lafayette, Indiana) in which reference is made to a dark level standard and a constant light source within the scanner. These calibration sources are recorded for every scan line of data for each channel in the reflective wavelength region, and can be used to eliminate low frequency bias level drift and amplification changes from the system.

Reflectance calibration was attempted with the use of a set of five gray level panels having reflectances of 4%, 8%, 16%, 32%, and 64% and three color panels--red, green, and blue. These panels served as a form of external calibration providing a ground to aircraft link capable of removing the effect of atmospheric scattering (Silvestro, 1969). Use of the panels allows estimation of gain correction factors for approximation of actual scene reflectance in each wavelenth band of the multispectral scanner. Hasell and Larsen (1968) describe the use of these eight reflectance panels in calibrating the output of the University of Michigan multispectral scanner.

Calibration to ground reflectance panels permits normalization of scanner data to scene reflectance when the area of interest is in environmental proximity to the reflectance panels. Environmental proximity in this case means an area of the same illumination, the same sun angle, the same aircraft altitude, and the same atmospheric conditions as the area from which scanner data are collected for ground reflectance panels.

The ground reflectance panel coordinates were determined in the flightline of interest and the LARSYS processing system (LARS, 1970) was used to obtain internally calibrated mean scanner data values for the panels for both flight dates. The scanner data values for the ground reflectance panels were later used in relating scanner response to actual scene reflectance.

It is assumed that the ground reflectance panels behave as perfectly diffuse or Lambertian reflectors of incident illumination; that is, they exhibit a uniform spatial distribution of radiance, independent of the geometry of illumination. Another assumption which had to be made was that laboratory DK-2 spectroreflectometer measurements of percent reflectance could be related to percent reflectance in a field situation. No field spectroradiometer was available to measure actual directional reflectance of the panels in the field so the DK-2 spectroreflectometer was used to characterize the reflectance of the eight panels.

Differences exist between the DK-2 spectroreflectometer and field or airborne spectroreflectometers in the way in which they measure percent reflectance. In the DK-2 spectroreflectometer, illumination is normal to the sample, and total reflectance is measured in an integrating sphere. Percent reflectance is determined as the ratio of energy reflected from the sample compared to a standard reflectance material (usually MgO). In the field or airborne situation, illumination is more or less hemispherical and radiance is measured from a single detector location, approximately normal to the panel. At the present time no information is available as to the magnitude of differences between laboratory and field reflectance measurements, and the assumption was made in this study that the differences between the two would not be too great.

DK-2 spectroreflectometer data for the red, green, and blue color panels are given in Figure 1. The DK-2 spectroreflectometer measurements indicate that the gray reflectance panels have a relatively constant percent reflectance over the wavelength range from 0.35 to 2.0 μm (Figure 2), whereas the color panels peak sharply in certain wavelengths. The percent reflectance values for each panel corresponding to the wavelength bands of the multispectral scanner were determined.

Percent reflectance versus scanner data values of the reflectance panels were plotted for all eleven wavelength bands for both flight dates. Prediction equations relating scanner response to reflectance were determined separately for all eleven channels for both flight dates. These equations could be used to determine the relative reflectance, normalized to ground reflectance panels, for ground targets in environmental proximity to the panels. Relative reflectance values were determined for the Russell silt loam ground cover plots from these equations.

The same ratio techniques described by Stoner (1972, Multispectral determination of vegetative cover in corn crop canopies, M.S. Thesis, Purdue University, W. Lafayette Indiana) were applied to the normalized reflectance data. The ratios of normalized reflectance in channels 8/7 and 9/7 were related to leaf area index. Stepwise multiple regression analysis was run on the data to determine the relationship of ratios of normalized reflectance to LAI for the ground cover plots.

RESULTS AND DISCUSSION

In order to understand the spectral response from corn canopies it is first helpful to get some idea of the individual spectral response of corn leaves and the soil background. DK-2 spectral reflectance curves for corn leaves with 80% moisture content, and two soils in saturated and air dry conditions were obtained (Figure 3). The spectral response curves for Chalmers silty clay loam, a dark surface soil, and Fincastle silt loam, a light surface soil, are shown. Fincastle silt loam is the somewhat poorly drained member of the catena of which Russell silt loam is the well drained member. The spectral curves for the Russell soil should be very similar to those illustrated for the Fincastle soil since they have the same surface color and texture and about the same organic matter content. The moisture content of the soil can greatly affect the spectral response of the soil. The surface soil condition in a field situation would probably be closer to the spectral response of the soil. The surface soil condition in a field situation would probably be closer to the spectral response illustrated for the air dry soil than that for the saturated soil (Hoffer and Johannsen, 1969).

The curves of scanner data values versus wavelength for three of the Russell plots on the July 12 flight date were plotted (Figure 4). The plots represent three greatly different ground cover conditions. The scanner data values used are the uncalibrated scanner response values from the July 12 multispectral scanner mission over the Agronomy Farm. The wavelength scale is incremented in micrometers on the bottom of the graph, with the corresponding mid-points of the channel wavelength bands being displayed at the top of the graph. It can be seen that there is no relationship between adjacent channels and that the shape of the spectral response curves can in no way be related to any familiar response curves for green vegetation or bare soil.

Normalized spectral response curves for three different ground cover situations were plotted for two scanner flight dates (Figures 5 and 6). The normalized response curves of Figure 5 are of the same three ground cover plots shown in Figure 4. The same original data were used for plotting these curves. The only difference is that the scanner data values in the latter have been normalized to relative reflectance, using the ground reflectance panels. The curves in Figure 5 resemble the DK-2 spectral response curves for green vegetation and bare soil. They have the

the familiar peaks in the green and near infrared wavelengths for green vegetation and the relatively smoothly increasing curve for bare soil (Figure 3). The plot with the higher leaf area index has a higher response in the 0.72 to 1.3 μm wavelength region and a lower response in the 0.65 μm chlorophyll absorption region than does the plot with a lesser LAI. The reflectance values for a dense canopy are within the range of values estimated by Knipling (1970). The response curve in Figure 5 for Russell plot 1, with an LAI of 0.01 (essentially bare soil) resembles quite closely the response curve in Figure 3 for air dry Pincastle soil.

In the plots of normalized spectral response curves (Figures 5 and 6) it is observed that the plots with high percent ground cover have a lower response in channels 10 and 11 than plots with lesser ground cover. This is probably a result of the spectral response of vegetation from the medium ground cover plots being "mixed" with the spectral response of the bare soil. This "mixing" of spectral components is in agreement with the theory of Miller (1969).

The normalized response curve for Russell plot 8 (Figure 6) shows much higher response throughout the 0.46 to 2.6 μm wavelength range than for Russell plot 1 (Figure 5), even though the ground cover was slightly higher on

Russell plot 8. Upon further investigation it was theorized that the great differences in spectral response between these two plots were not accountable only to ground cover differences. Examination of the Hi-Ranger photography taken over these two plots on July 13 and July 21 showed that the soil background appeared much lighter on the July 21 photography of Russell plot 8. Weather records from the Agronomy Farm Weather Station indicated that a long dry period preceded the July 21 flight while a rather substantial rain fell the day before the July 12 flight. It is likely then, that the great differences observed in the spectral response of the low ground cover plots on the two flight dates were accountable more to moisture differences than to differences in ground cover.

The ratios of normalized reflectance in channels 8/7 and 9/7 were calculated for the two flight dates. These ratios were then plotted against leaf area index (Figures 7 and 8). Stepwise multiple regression indicated a linear relationship between LAI and both ratios. Using the ratio of 9/7 for normalized data, 96.4% of the variation in LAI could be explained by the regression equation $\hat{Y} = -0.7245 + 0.2735X$. For the ratio of 8/7 for normalized data, 94.1% of the variation in LAI could be explained by the regression equation, $\hat{Y} = -0.5117 + 0.2971X$.

A considerable improvement occurred in the use of the ratio of normalized data in channels 8/7 to predict LAI over the use of uncalibrated scanner data values in these channels. The procedure of normalizing the reflectance of the plots to the ground reflectance panels apparently was successful in eliminating variations in scanner response between flight dates.

SUMMARY AND CONCLUSIONS

Multispectral scanner response can be related to the reflectance of ground reflectance panels in deriving prediction equations for relative reflectance from scanner data values. This normalization of scanner data to ground reflectance panels allows for extension over time of ratio techniques for predicting leaf area index. Regression equations can be evolved relating leaf area index to the ratios of scanner data values from channels 8 and 9 to scanner data values from channel 7.

Spectral response curves for maize canopies can be determine from the derived prediction equations relating panel reflectance to scanner response. The spectral response curves for different ground cover plots from normalized scanner data show that the various ground cover response curves represent a "mixing" of the spectral response from the green vegetation and bare soil components.

The normalized spectral response curves for the ground cover plots indicate an increase in reflectance in the 0.72 to 1.3 μm near infrared wavelength region with increasing leaf area index. A decrease in reflectance was observed for the 0.65 μm chlorophyll absorption band with increasing leaf area index.

Moisture differences apparently had a strong effect on the spectral response of the corn canopies on the two flight dates. Soil moisture differences greatly affect the spectral response from low ground cover plots.

The use of ground reflectance panels aids in deriving normalized reflectance values for maize canopies. One difficulty is the lack of a reflectance panel whose reflectance in the visible wavelength region is as low as that of a dense maize canopy. For this reason, extrapolation of data below the known reflectance value of the 4% reflectance panel is necessary. This may introduce error in estimating the normalized reflectance of dense maize canopies in the visible wavelength region.

The practical implications of using ratio techniques for analysis of ground cover are certain to become apparent in future efforts in remote sensing. The orbital perspective of the Earth Resources Technology Satellite (ERTS) and SKYLAB will provide a general view of agricultural crops. With the extremely high altitude and coarse resolution from space platforms such as these, it is likely that differences in vegetative cover will provide the strongest means of discriminating between various healthy green agricultural crops. Ratio techniques utilizing information from the near infrared and chlorophyll absorption regions should prove useful in analyzing relative canopy density.

LITERATURE CITED

1. Hasell, P. G. Jr., and L. M. Larsen. 1968. Calibration of an airborne multispectral optical sensor. Technical Report ECOM-00013-137, Willow Run Laboratories, Institute of Science and Technology, Univ. of Michigan, Ann Arbor, MI. 87 pp.
2. Hoffer, R. M., and C. J. Johannsen. 1969. Ecological principles in spectral signature analysis. In Remote Sensing in Ecology, Univ. of Georgia Press, P. Johnson (ed.), Athens, GA. pp. 1-16.
3. Knipling, E. B. 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. Remote Sensing of Environment. 1:155-160.
4. Laboratory for Agricultural Remote Sensing (LARS). 1970. Remote Multispectral Sensing in Agriculture. Vol. IV (Annual Report). Purdue Univ. Agr. Exp. Sta. Res. Bull. 873. pp. 80-86.
5. Miller, L. D. 1969. Measurement of resource environments with airborne thermal mappers - where do we stand? Proceedings of the Purdue Centenial Year Sumposium on Information Processing. Purdue Univ. pp. 746-763.

6. Silvestro, F. B. 1969. Multispectral photographic determination of reflectance. Photogrammetric Engineering. 35:259-262.

TABLE AND FIGURE CAPTIONS

Table 1. The eleven reflective channels and corresponding wavelength bands for the University of Michigan multispectral scanner.

Figure 1. DK-2 spectral reflectance for red, green, and blue LARS color panels.

Figure 2. DK-2 spectral reflectance for five LARS gray scale panels.

Figure 3. DK-2 spectral reflectance of maize leaves and of two soils in air dry and saturated conditions.

Figure 4. Uncalibrated scanner response curves for three Russell plots, July 12.

Figure 5. Normalized spectral response curves for three Russell plots, July 12.

Figure 6. Normalized spectral response curves for three Russell plots, July 21.

Figure 7. Leaf area index versus the ratio of normalized reflectance in channels 9/7 for two flight dates.

Figure 8. Leaf area index versus the ratio of normalized reflectance in channels 8/7 for two flight dates.

Table 1. The 11 reflective channels and corresponding wavelength bands for the University of Michigan multispectral scanner.

Channel	Limits of Spectral Bands (μm) Lower	Upper	Wavelength Region
1	0.46	0.49	visible
2	0.48	0.51	visible
3	0.50	0.54	visible
4	0.52	0.57	visible
5	0.54	0.60	visible
6	0.58	0.65	visible
7	0.61	0.70	visible
8	0.72	0.92	near infrared
9	1.00	1.40	near infrared
10	1.50	1.80	near infrared
11	2.00	2.60	near infrared

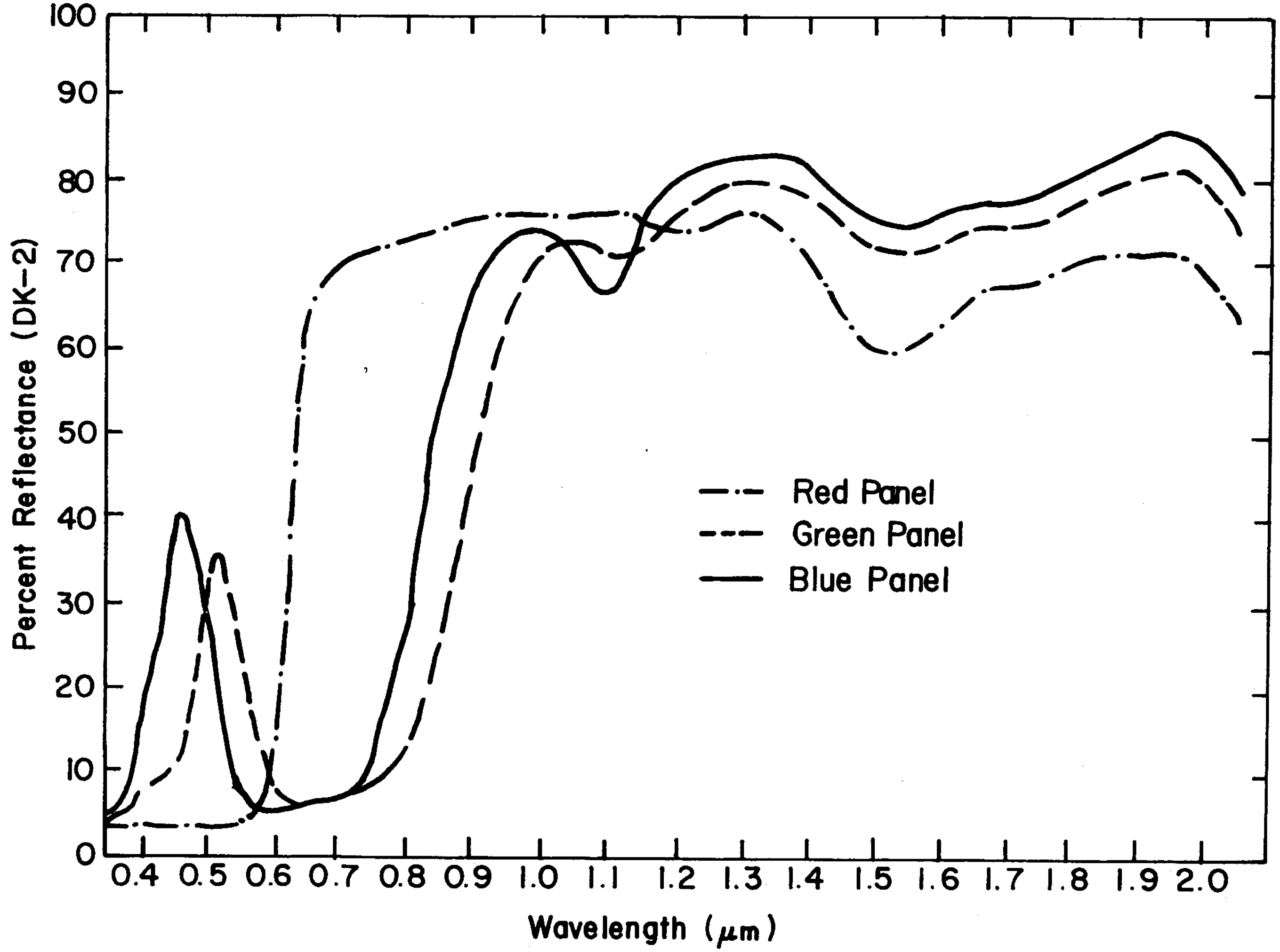

Figure 1. DK-2 spectral reflectance for red, green, and blue LARS color panels.

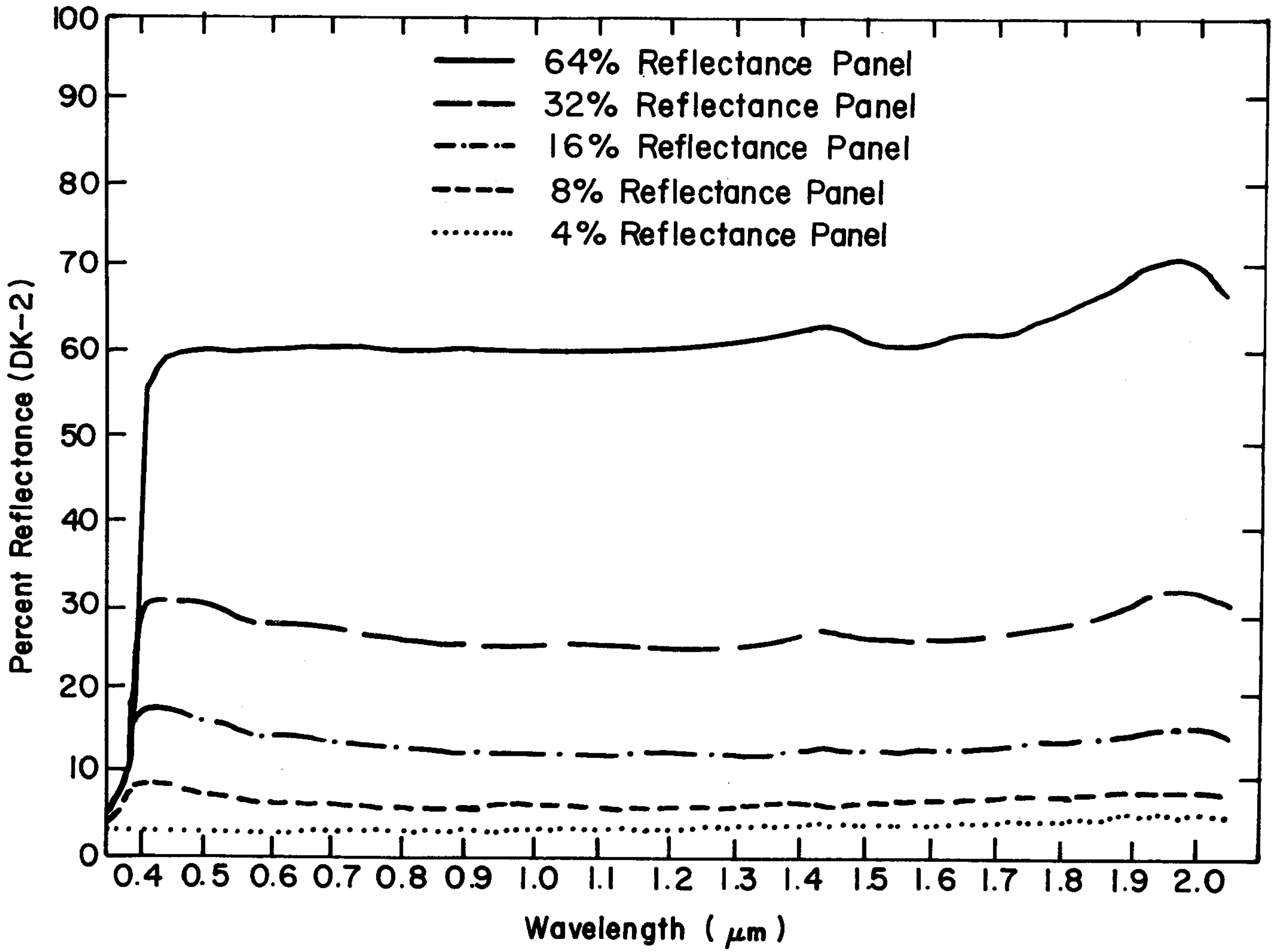

Figure 2. DK-2 spectral reflectance for five LARS gray scale panels.

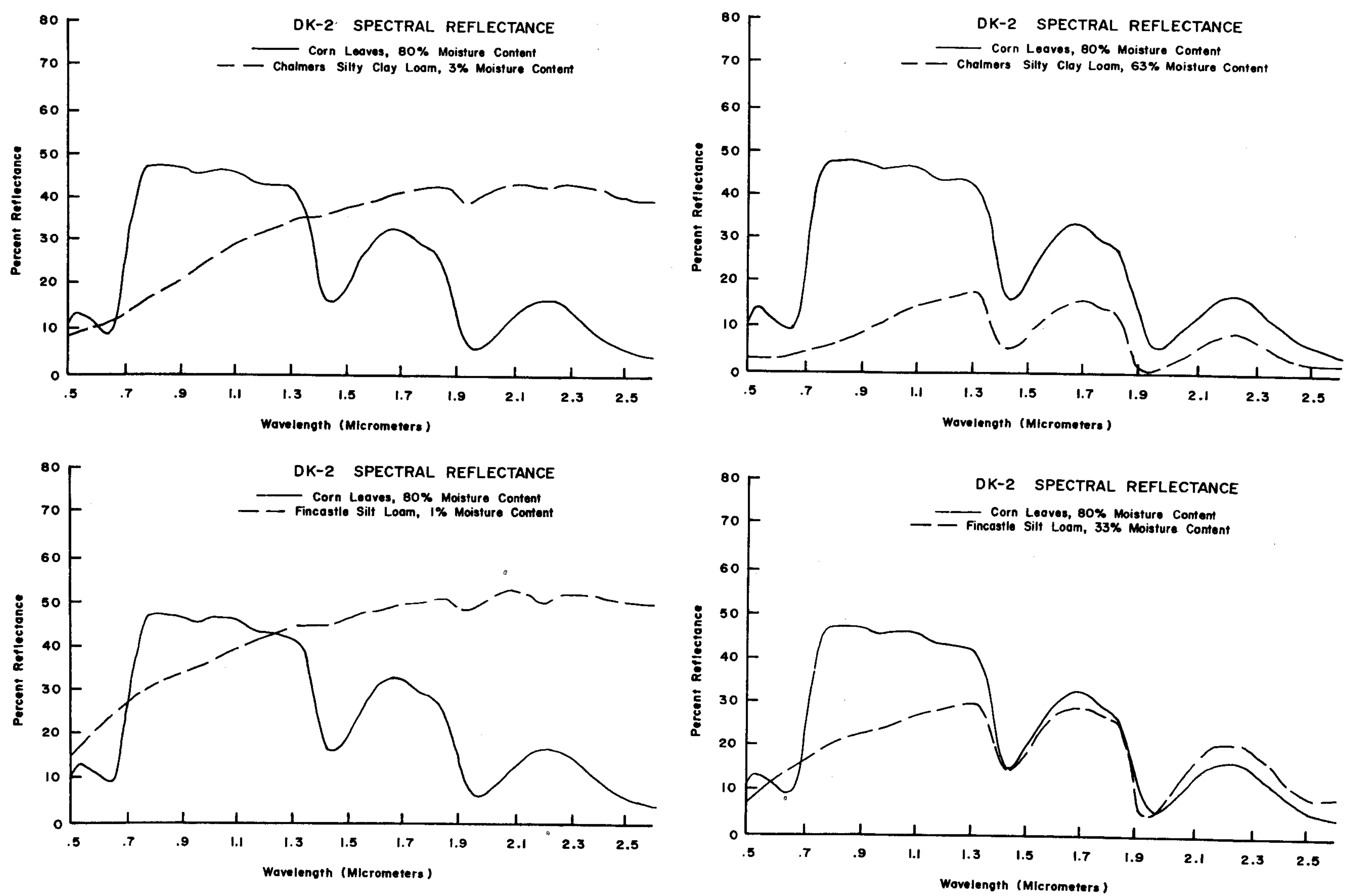

Figure 3. DK-2 spectral reflectance of maize leaves and of two soils in air dry and saturated conditions.

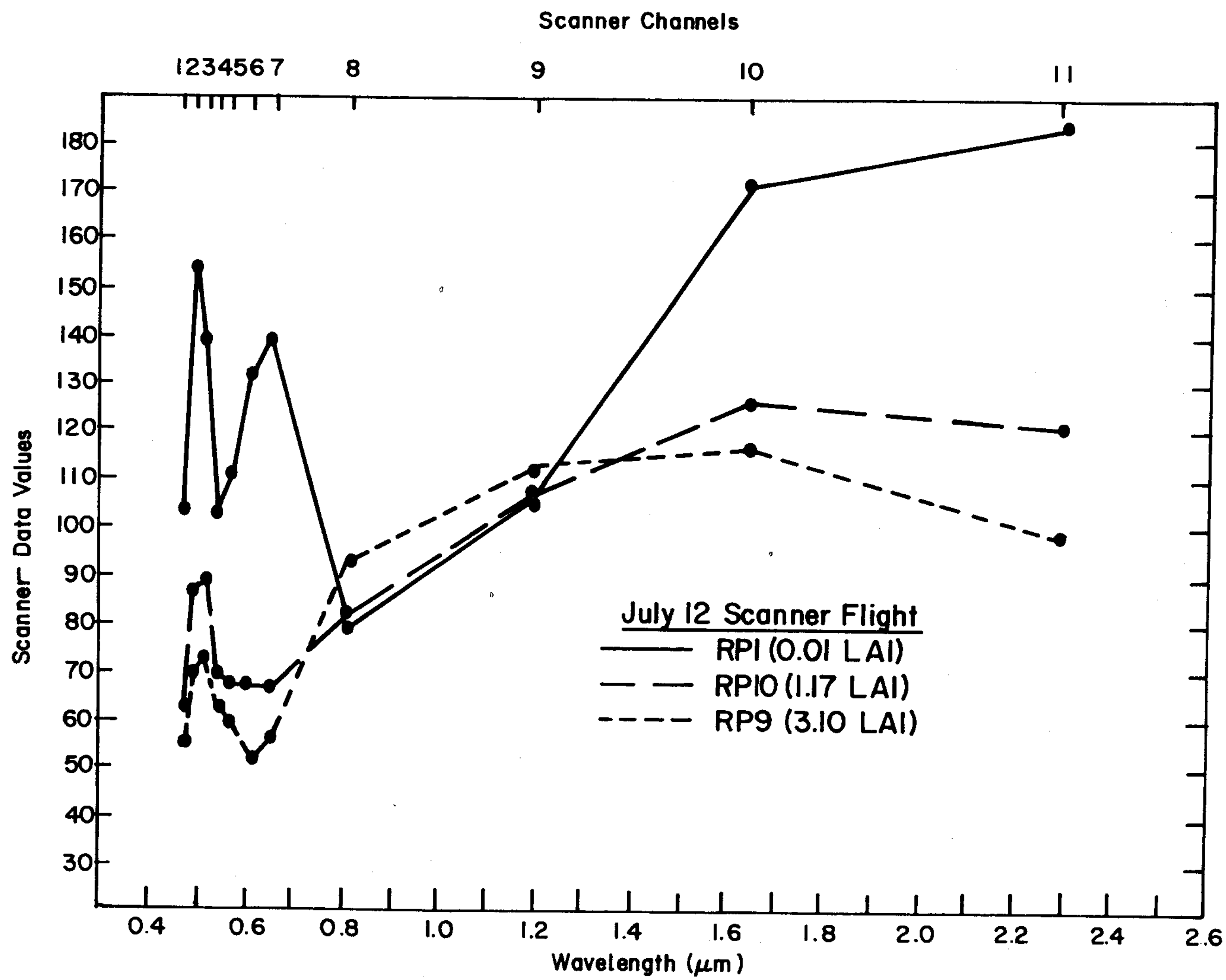

Figure 4. Uncalibrated scanner response curves for three Russell plots, July 12.

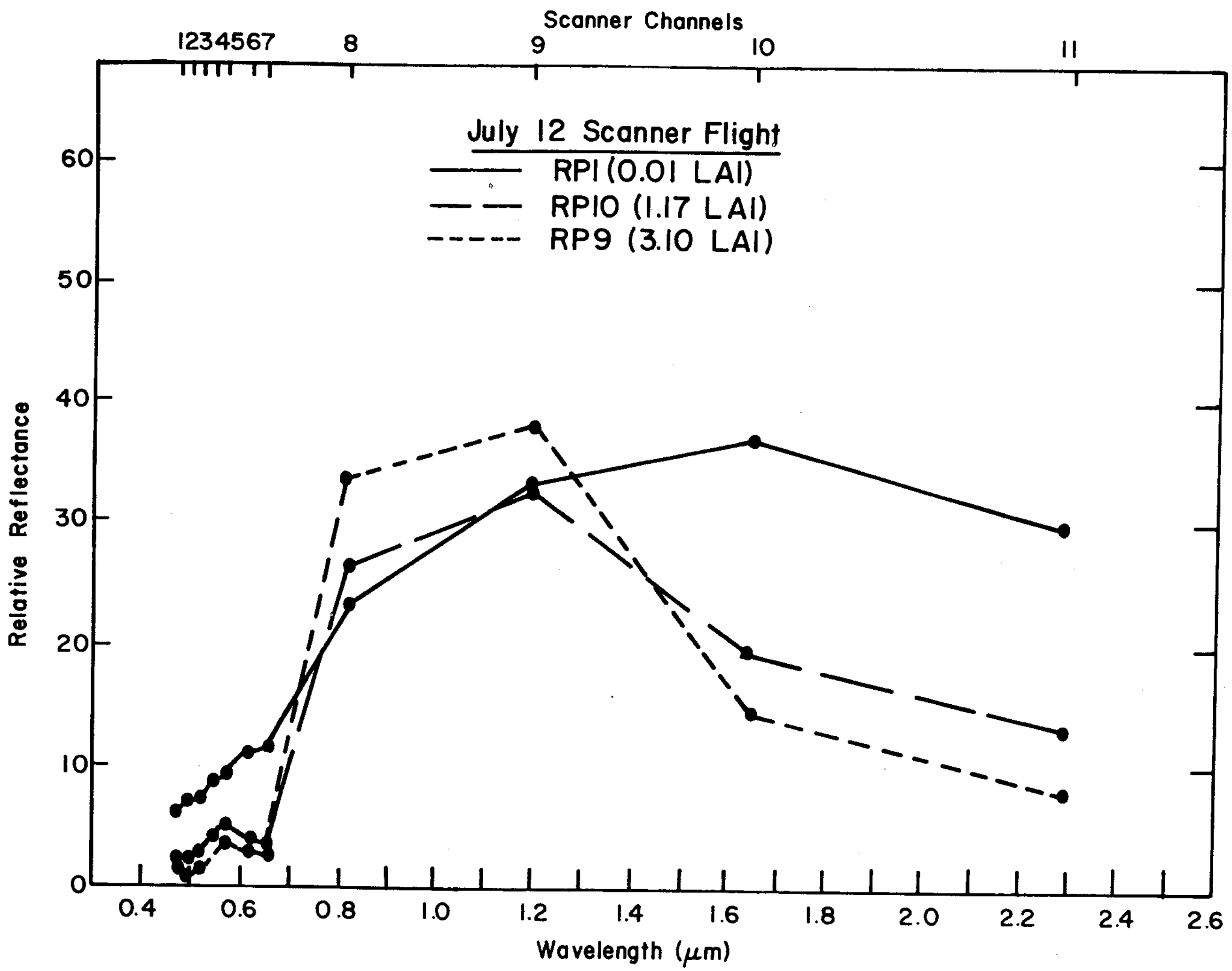

Figure 5. Normalized spectral response curves for three Russell plots, July 12.

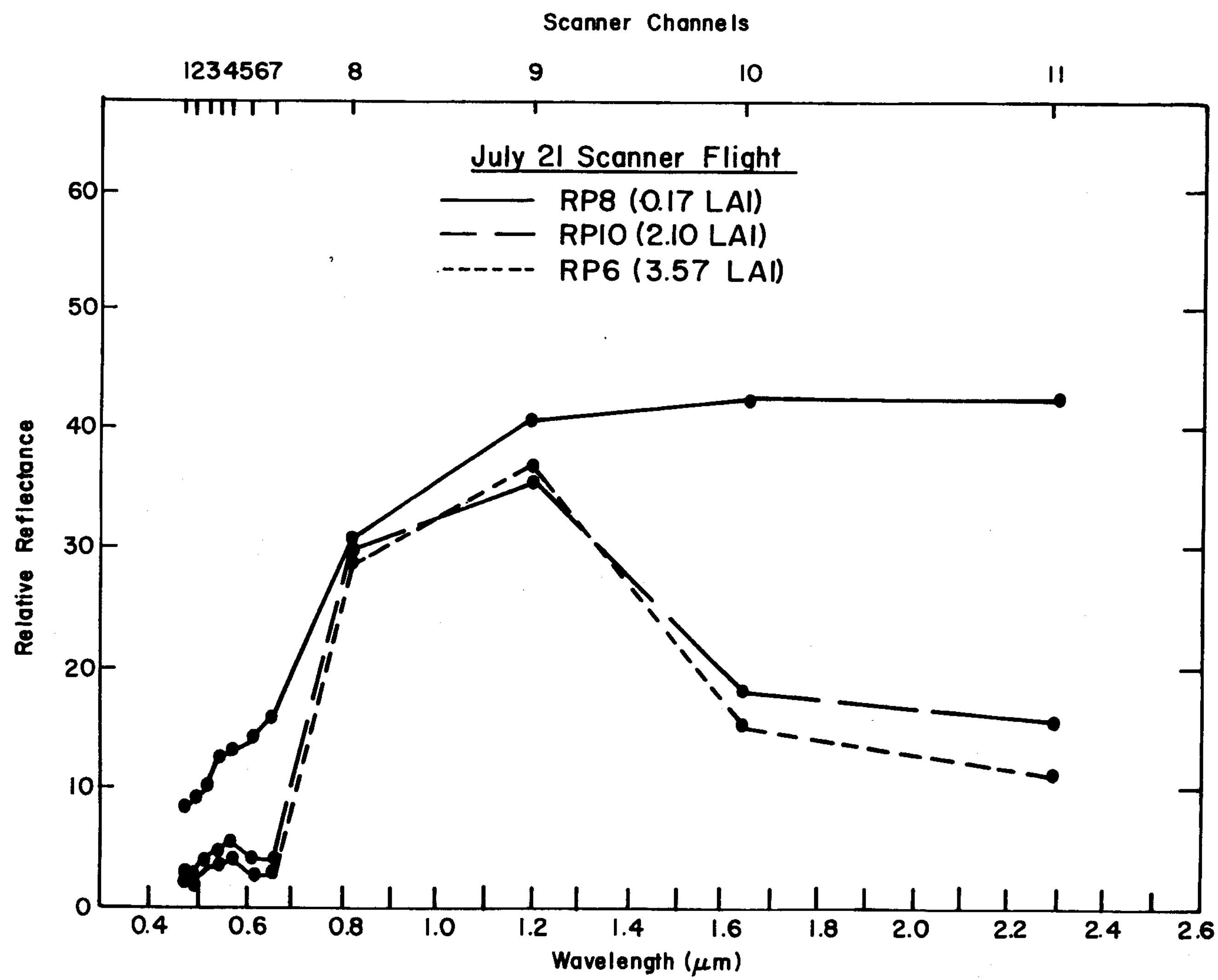

Figure 6. Normalized spectral response curves for three Russell plots, July 21.

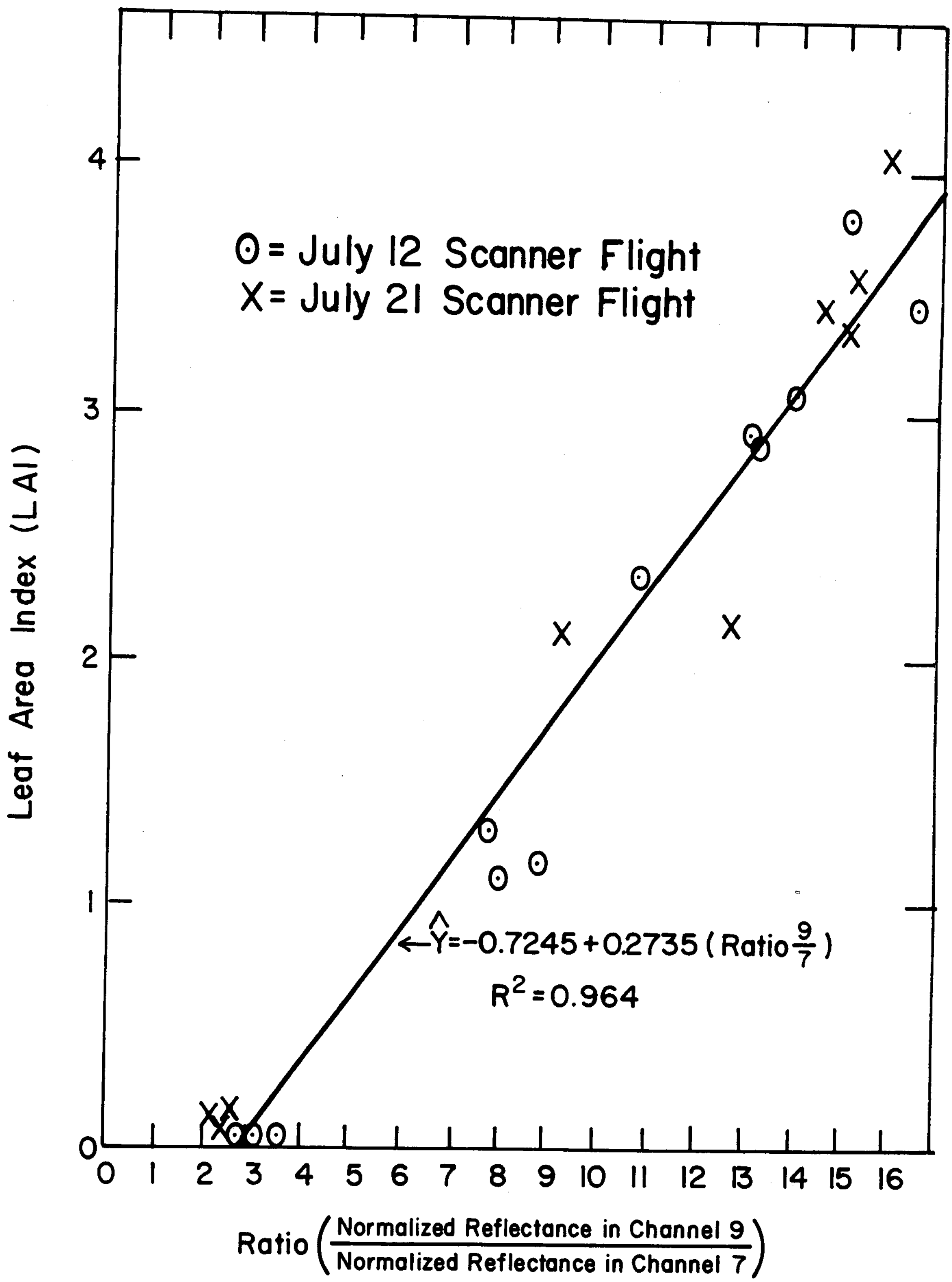

Figure 7. Leaf area index versus the ratio of normalized reflectance in channels 9/7 for two flight dates.

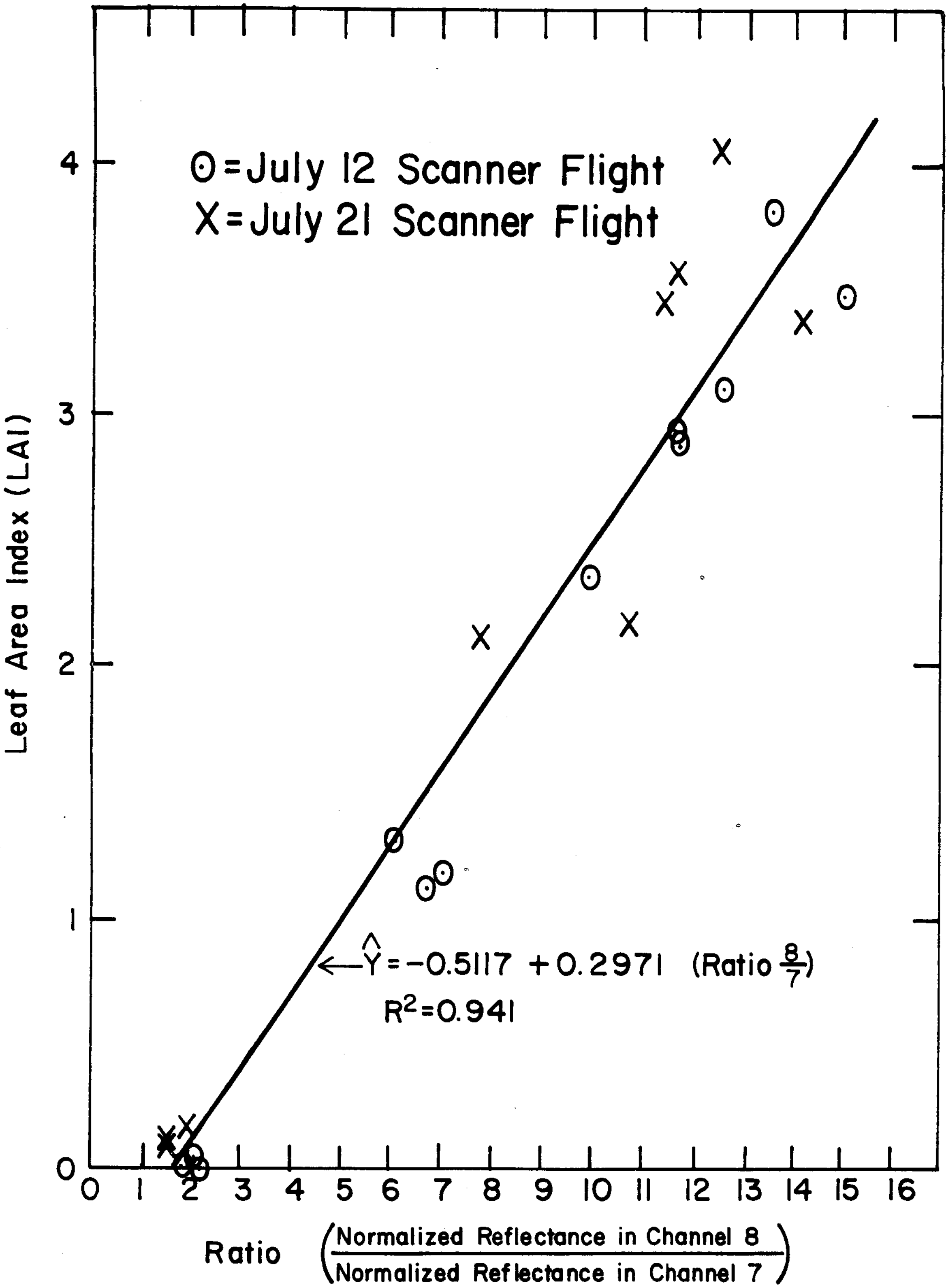

Figure 8. Leaf area index versus the ratio of normalized reflectance in channels 8/7 for two flight dates.