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SECTION 119

DISCRIMINANT ANALYSES OF BENDIX SCANNER DATA

by

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INTRODUCTION

Reflectance data from multispectral scanners are used in remote sensing investigations of the U. S. Department of Agriculture at Weslaco, Texas. Long range objectives are: (1) identification of yield-limiting crop and soil conditions, (2) prediction of yields, and (3) automatic recognition of crop and soil types from space. In this study the reflectance data from an aircraft-borne scanner were used to test crop discrimination procedures and to explain sensor response variations in terms of ground truth.

In the spring and summer of 1969, NASA Houston sponsored overflights with the 9-channel Bendix scanner providing calibrated scanner data in the 380- to 1000-nm wavelength interval (WLI). The overflights were made on April 13, May 9, June 6, and July 9 at 2000 feet AGL. These data gave seasonal coverage from the time signals represented mainly the soil background, as a consequence of very young row crop plants, up to full canopy development where signals were dominated by the crop reflectance. NASA contracted with the Bendix Aerospace Systems Division (Ann Arbor, Michigan) to obtain the scanner data, and Weslaco provided the ground truth collection during the flights. Signature processing studies relating scanner data to ground truth were carried out at Ann Arbor (Crawford, et al., 1970; 1970a; Brenda, et al., 1970; Technical Proposal, 1969) and Weslaco. This report summarizes Weslaco's investigations. A more detailed report is in preparation (Richardson, et al., 1972). The full report discusses calibration details of the Bendix scanner and compares Bendix signature studies with Weslaco signature studies on the same data.

MATERIALS AND METHODS

Five flight lines, listed in Table I by number, length, location, and soil type, were selected for study prior to the 4 Bendix overflights.

Table II lists the fields contained in these 5 flight lines. The fields range from heavy clay to sandy loam soils. Five crop categories--citrus, corn, cotton, sorghum, and bare soil--make up most of the fields in Table II. A number of fields sampled in June were deleted (Table II) for various reasons: (1) scanner channels exceeded range of calibration; (2) sampling line did not intersect field; (3) computer was unable to read data tape; (4) equipment functioned improperly while over field; and (5) sample not representative because of cloud effects. Maturation and harvest of crops and tillage of fields occurred in some categories between the April, May, June, and July flight dates.

Two ground truth reports were prepared. A summary report (Gerbermann, et al., 1970) was prepared in 35 copies and distributed to NASA, Bendix, USDA, and other cooperators interested in using the scanner data. The other report (Gerbermann, et al., 1970a) consists primarily of photocopies of the seasonal ground truth data sheets for each individual field on each flight line.

Ground truth information was punched on IBM computer cards. The Weslaco IBM 1800 computer was used to sort ground truth according to flight date, crop category, and field condition. Sorting according to ground truth grouped all fields into similar categories so that training fields could be randomly selected to represent each crop and soil category. Selected training fields were used to determine principal axis factor scores and pattern recognition algorithm standards. These factor scores and algorithm standards were then used in classification tests involving training and all fields. Selected training fields are listed in the more complete report under preparation (Richardson, et al., 1972).

Digital scanner data were obtained on contract from Bendix. Reflectance data for each field listed in Table II were recorded on digital magnetic tape. One resolution element was sampled at the same angular displacement from nadir on nominally 200 scan lines inside the field boundaries for each field for 8 channels of the Bendix 9-channel scanner. In practice the number of sample elements per field and channel ranged from 44 to 1021 depending on field size. The ninth channel was not operative during any of the overflights.

Principal axis factor analysis was applied to the reflectance data of training fields (Veldman, 1967). This analysis yielded statistics for pattern recognition algorithms. The analysis transforms the original reflectance data into principal axis factor scores. Factor scores have the property that crop and soil differences are maximized using a minimum number of factor scores. In other words, crop and soil variations in the 8 original scanner channels are represented by fewer principal axis factor scores.

Pattern recognition algorithms based on probability error ellipses were computed on factor scores derived from training fields, rather than on the original scanner reflectance data, to take advantage of the fewer variables (Richardson, et al., 1971). The pattern recognition procedure determines the training set ellipse that a candidate set of unidentified transformed reflectance measurements most closely resembles. The ellipse the measurements correspond to identifies that measurement. Any set of measurements not corresponding to any ellipse is placed in a threshold category as not belonging to any crop or soil category tested. The error ellipse threshold was set at the 5% probability level for this study.

Recognition results were listed for training samples and all samples; and for training fields and all fields. Results listed on a per sample basis are a consideration of the identity of every resolution element using error ellipse algorithms. Results on a per field basis is a percent correct recognition classification test according to the category identified most often within a field.

Regression analysis was used to test the effect of percent plant cover (PC) and plant height (PH) on reflectance. All fields were used to calculate the correlation coefficients except citrus and water samples. Citrus (groves and water samples) were deleted from the analysis because it seemed unreasonable to consider trees and water in the same regression analysis with row crops.

Three regression models were used to test for the effect of percent ground cover and plant height on reflectance measurements. The linear model is given by

$$\hat{Y}_i = a_{i0} + a_{i1}x_i \qquad (1)$$

where $i = 1, 2, \ldots, 8$ predictions of PC ($\hat{Y}_i$) or PH ($\hat{Y}_i$) corresponding to the eight channels of reflectance data (X_i). The multiple linear model is given by

$$\hat{Y} = a_0 + a_1x_1 + a_2x_2 + \ldots + a_8x_8 \qquad (2)$$

where $\hat{Y}$ is PC or PH and $x_1, x_2, \ldots, x_8$ are the reflectance measurements of the 8-channel scanner. The multiple nonlinear model is given by

$$\hat{Y} = a_0+a_1x_1+a_2x_2 + \ldots + a_8x_8+a_9x_1^2+a_{10}x_2^2 + \ldots + a_{16}x_8^2 \qquad (3)$$

where $\hat{Y}$ is PC or PH and $x_1, x_2, \ldots, x_8$ are the reflectance measurements of the 8-channel scanner.

RESULTS AND DISCUSSION

The mean factor scores ($\bar{F}_i$) and error ellipse coefficients (C_{ij}) used as standard signatures for pattern recognition studies for the April, May, June, and July flights are listed in Tables III and IV, respectively. The indices i and j = 1, 2, ... , NF are the number of factor scores extracted from the factor analysis. These results are based on randomly selected training fields from each crop and soil category. Categories tested are ranked according to the $\bar{F}_1$ means for all flights, since factor 1 accounts for most of the total variance and therefore is the most important factor.

As can be seen in Tables V and VI, the $\bar{F}_1$ means are responsive to the percent plant cover (PC) and plant height (PH) for the categories tested in all overflights. The relation of the $\bar{F}_1$ means (Table III) to PC and PH in April and May is similar. The bare soil category has the largest $\bar{F}_1$ means in April and May. These $\bar{F}_1$ means correspond to the smallest PC and PH for bare soil for the same flights in Tables V and VI. In April the $\bar{F}_1$ means for cotton and sorghum follow bare soil; according to Tables V and VI, the PC and PH for both categories were very low. The categories with the lowest $\bar{F}_1$ means in April and May (Table III) have the highest PC and PH (Table V and VI).

The June and July flights are similar in category structure as shown in Table IV using the $\bar{F}_1$ means. The vegetative categories all have $\bar{F}_1$ means larger than the bare soil category. In general, the high $\bar{F}_1$ means for vegetation correspond to high PC and PH in Table V and VI. Also the low $\bar{F}_1$ means for bare soil correspond to low PC and PH in Tables V and VI. No water samples were taken in July. In both June and July the cotton category ranked first within the vegetation categories and by July cotton was so distinctive that recognition of cotton fields was very accurate.

The percent recognition results in Tables VII and VIII indicate that it is possible to distinguish bare soil, vegetation, and water reliably. For these recognition results, the bare soil category for April was composed of bare soil, cotton, and sorghum fields. For the other three flights, the bare soil category was composed of only uncropped fields. As was expected, higher recognition results were obtained using randomly selected training fields in each category as compared to using all fields. Recognition results on a per field basis were higher than on a per sample basis. These results show that automatic recognition procedures are feasible for general land use applications involving soil, vegetation, and water.

Requirements for more detail of specific vegetation categories will be more difficult to meet. It was not possible to distinguish any specific vegetative category in April or May with any degree of accuracy. In June and July, it was possible to distinguish citrus and cotton, respectively.

Figures 1 and 2 are factor score scatter diagrams for April and May. In general, soil and crop categories have the same arrangement of point clusters. In both diagrams, the cluster of points in the upper right corner, identified with G's, is the water category distribution. Proceeding downward and to the left are the points identifying the bare soil distributions. The vegetative distributions are about midway down and to the left in each diagram. These distributions indicate the difficulty of identifying individual vegetative categories. None of the vegetative categories has a distinctive cluster of points like the water and bare soil categories.

The diagrams in Figs. 3 and 4 are the factor score scatter diagrams for the June and July flight dates. In June, citrus (D's), water (F's) and bare soil (A's) had fairly well-defined clusters of points. Vegetative category distributions other than citrus were confused in June. In July the cotton distribution (A's) had very good separation. These two developments gave 91.0% recognition for citrus in June and 86.4% recognition for cotton in July. In both cases "false alarm" errors were low.

Any number on these diagrams between 2 and 9 means that 2 to 9 samples coincide at that point on the diagram. A percent sign (%) on the diagram indicates that 10 or more samples coincide at that point on the diagram. If a letter prints out, then only one sample occurs at that point on the diagram.

Table IX lists coefficients for correlations of PC and PH with Bendix 9-channel reflectance measurements at each WLI for each flight. In general, there is a better correlation of PC with reflectance measurements than of PH with reflectance measurements. The correlation coefficients using the linear model for individual WLI were usually statistically significant, but they are not strong enough (highest $r = .725$) to insure accurate predictions of ground cover or plant height. The multiple correlations for the linear and nonlinear model are high enough (highest $r = .875$) to possibly insure accurate predictions. For PC and PH predictions, April is the worst date. The May, June, and July flight dates have higher correlations.

The reflectance spectra for cotton, sorghum, soil, and water for the April, May, June, and July flights in Figs. 5 and 6 help to explain the correlation results in the visible and infrared WLI. For all 4 flight dates, the reflectance spectra in the visible WLI for cotton and sorghum are lower than the soil spectra. In the infrared WLI, the cotton and sorghum reflectance spectra cross over the soil spectra and become higher. That is, as the vegetative cover increases, the overall reflectance in the visible WLI decreases because vegetation reflects less light than soil in the visible range. On the other hand, in the infrared WLI, the overall reflectance increases as vegetative cover increases because vegetation reflects more light than soil.

The spectral curves for bare soil and water are different for all four flight dates. There were no water samples collected in July. It was thought that these two categories would have the least variable spectra for all flight dates. The spectra for cotton and sorghum changed from one flight date to another as expected since their PC and PH were changing. In April, cotton and bare soil have similar spectra since cotton is newly emerged seedlings that occupy little ground space. Even though cotton and sorghum are planted at the same time, sorghum grows faster, resulting in a higher PC and PH than for cotton at the same age.

CONCLUSION

Standard signatures were developed using factor scores and error ellipse coefficients that statistically describe crop, bare soil, and water categories for pattern recognition studies. The $\bar{F}_1$ means are the most important factor score for signature development. These means, when ranked in descending order of magnitude, show the relative structure among crop, bare soil, and water categories. April and May as one group and June and July as another group had similar category structure, and corresponded to PC and PH.

Results from pattern recognition studies using these signatures show that it is possible to distinguish bare soil, vegetative, and water categories accurately. In most cases, however, vegetative categories could not be adequately separated from each other. For example, in May it was not possible to distinguish citrus from other vegetation because of the high number of "false alarm" errors from sorghum, cantaloupe, and cotton. The accuracy of identifying citrus was 71.5%, but fields of sorghum, cantaloupe, and cotton were also identified as citrus.

In June, citrus was distinguishable with an acceptable degree of accuracy, 91.0%. For some reason citrus has a fairly distinctive signature in June (Fig. 3), perhaps because it is not growing as virorously as the other vegetative categories. In July cotton could be distinguished from everything else with an accuracy of 86.4%.

In general, it appears that bare soil, vegetation, and water can always be distinguished accurately using the wavelength channels available for this study. Other wavelengths recommended for vegetation discrimination (Allen, Gausman, Wiegand, 1970) were unfortunately, not available.

In some instances, as with citrus in June and cotton in July, field conditions will be such that a particular vegetative category of interest will be recognized accurately.

As shown in Table IX, there is an indication that plant cover and plant height can be predicted using Bendix 9-channel scanner reflectance measurements. For all 4 flights it was possible to predict plant cover more accurately than plant height. For all 4 flights, the visible and infrared WLI have opposite responses to PC and PH. In the visible WLI, as plant cover and plant height increased, reflectance decreased. In the infrared WLI, the opposite response occurred. In the visible WLI, the relatively low reflecting vegetation is covering the relatively high reflecting soil causing the overall reflectance to decrease with increasing plant cover. An opposite situation prevails in the infrared WLI where soil is less reflective than vegetation.

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TABLE I.--FLIGHT LINE NUMBERS, LOCATIONS, SOIL TYPES, AND LENGTH OF EACH FLIGHT LINE OVER WHICH BENDIX 9-CHANNEL SCANNER DATA WERE OBTAINED IN 1969.

Flight line	Location	Soil types present	Line length
No.			Miles
1	Research Farm Highway 88 (Mi 5 W & 12 N)	Sandy clay loam	1
3	FM Rd 1015 (Mi 3 W from Mi 12 N to Floodway)	Clay Clay loam Fine sandy loam Sandy clay loam Silty clay	7
11	"I" Rd (between Pharr and San Juan) from Exp 83 N for 5 mi.	Clay loam Sandy clay loam Fine sandy loam	5
12	FM 1426 (E of San Juan) from Rio Grande to Exp 83	Clay Silty clay loam Silty clay	7.5
13	Highway 281 (Military Highway) from Hidalgo to S of Donna then cross country to Int'l Bridge at Nuevo Progreso	Clay Silty clay Silty clay loam	17

TABLE II.--CROP GENERA, WEEDS, BARE SOIL, AND WATER, AND NUMBER OF FIELDS OF EACH BY FLIGHT DATE.

	Flight date			
Crop	4/13	5/9	6/6[a]	7/9
Cotton	73	69	42	73
Corn	19	21	8	9
Cantaloupe	7	8	4	1
Citrus	26	25	11	26
Sorghum	39	46	26	42
Pepper	1	1		1
Cabbage	1	2		
Tomato	3	3	2	
Native vegetation	2	2	2	2
Coastal Bermudagrass	2	2	2	2
Oats	3			
Onion	11	1		
Bare soil	31	41	33	49
Weeds	6			2
Carrot	5	3		
Alfalfa	1	1		1
Red cabbage	1	1		
Flax	2			
Water	9	3	6	
TOTAL	242	229	136	208

[a] Flight line 1 not included in mission for this date because scanner channels exceeded range of calibration.

TABLE III.--MEAN VALUES AND ERROR ELLIPSE COEFFICIENTS FOR PRINCIPAL AXIS FACTOR SCORES 1 AND 2 USED FOR PATTERN RECOGNITION TESTS. CROP CATEGORIES FOR THE APRIL AND MAY FLIGHTS ARE RANKED IN DESCENDING ORDER ACCORDING TO $\bar{F}_1$.

April	Factor score means ($\bar{F}_i$)		Error ellipse coefficients (C_{ij}) x 10^{-2}		
Categories	$\bar{F}_1$	$\bar{F}_2$	C_{11}	C_{12}	C_{22}
Water	1.521	.119	.116	-.150	1.586
Bare Soil	1.196	.611	.725	-.840	3.725
Cotton	1.192	.618	1.096	.065	3.717
Sorghum	.503	.555	.183	-.183	3.605
Corn	.371	.545	.309	.389	5.427
Citrus	.087	.517	.169	.278	4.265
Carrot	-1.209	.550	.232	.220	2.925
May	**Factor score means ($\bar{F}_i$)**		**Error ellipse coefficients (C_{ij}) x 10^{-2}**		
Categories	**$\bar{F}_1$**	**$\bar{F}_2$**	**C_{11}**	**C_{12}**	**C_{22}**
Water	1.830	-.307	.163	.331	2.616
Bare Soil	1.788	.321	.118	-.078	2.206
Cotton	.769	.346	.269	-.069	2.255
Cantaloupe	.355	.290	.343	.038	3.791
Citrus	- .235	.367	.078	.029	2.028
Corn	- .671	.187	.182	.139	3.339
Sorghum	- .784	.242	.123	.001	3.009

TABLE IV.--MEAN VALUES AND ERROR ELLIPSE COEFFICIENTS FOR PRINCIPAL AXIS FACTOR SCORES 1 AND 2 USED FOR PATTERN RECOGNITION TESTS. CROP CATEGORIES FOR THE JUNE AND JULY FLIGHTS ARE RANKED IN DESCENDING ORDER ACCORDING TO $\bar{F}_1$.

June	Factor score means ($\bar{F}_i$)		Error ellipse coefficients (C_{ij}) x 10^{-2}		
Categories	$\bar{F}_1$	$\bar{F}_2$	C_{11}	C_{12}	C_{22}
Cotton	1.404	-.476	.439	.026	.246
Sorghum	1.219	-1.017	1.269	-.147	.150
Corn	1.187	-.428	.642	.144	.198
Citrus	.272	-1.116	.207	-.033	.215
Bare Soil	-.676	-.671	1.044	.039	.090
Water	-1.266	.099	1.119	-.918	.925
July	**Factor score means ($\bar{F}_i$)**		**Error ellipse coefficients (C_{ij}) x 10^{-2}**		
Categories	$\bar{F}_1$	$\bar{F}_2$	C_{11}	C_{12}	C_{22}
Cotton	2.861	1.706	.428	-.687	3.073
Corn	.503	1.075	.378	-.293	1.519
Citrus	.393	1.478	.139	.057	.622
Sorghum	.367	1.273	.427	.086	.321
Bare Soil	-.787	1.968	1.047	.044	.475

TABLE V.--AVERAGE PLANT HEIGHT ($\overline{PH}$) FOR OVERFLIGHTS IN APRIL, MAY, JUNE, AND JULY FOR THE INDICATED CROP CATEGORIES. ONE STANDARD DEVIATION (s) IS GIVEN FOR EACH MEAN.

Categories	April		May		June		July	
	$\overline{PH}$	s	$\overline{PH}$	s	$\overline{PH}$	s	$\overline{PH}$	s
	cm.							
Cotton	6.2	3.6	22.1	15.3	54.9	18.1	90.7	35.6
Sorghum	19.3	15.1	50.4	28.9	111.4	35.4	80.7	49.8
Corn	60.3	47.6	94.9	66.1	141.5	88.4	153.7	90.7
Citrus	278.7	145.2	283.4	148.7	359.0	66.2	284.5	142.4
Bare soil	2.8	7.6	0.0	0.3	8.0	42.7	5.7	26.8

TABLE VI.--AVERAGE PERCENT PLANT COVER ($\overline{PC}$) FOR OVERFLIGHTS IN APRIL, MAY, JUNE, AND JULY FOR THE INDICATED CROP CATEGORIES. ONE STANDARD DEVIATION (s) IS GIVEN FOR EACH MEAN.

Categories	April		May		June		July	
	$\overline{PC}$	s	$\overline{PC}$	s	$\overline{PC}$	s	$\overline{PC}$	s
	%							
Cotton	2.5	2.5	14.8	11.2	55.9	18.3	85.0	29.6
Sorghum	12.6	13.3	46.8	33.8	77.9	24.9	75.9	30.2
Corn	39.2	33.6	52.3	35.2	61.0	38.0	52.8	30.3
Citrus	51.7	24.7	53.6	26.0	58.4	17.0	52.6	24.5
Bare soil	3.9	12.7	1.1	4.1	6.4	21.4	4.8	16.8

TABLE VII.--RECOGNITION RESULTS FOR THE APRIL, MAY, JUNE, AND JULY FLIGHTS. RESULTS ARE GIVEN SEPARATELY FOR TRAINING SAMPLES AND ALL SAMPLES CONSIDERING BARE SOIL, VEGETATION, AND WATER CATEGORIES ON A PER SAMPLE BASIS.

Categories	Training samples				All samples			
	April	May	June	July	April	May	June	July
	%	%	%	%	%	%	%	%
Bare Soil	81.9	88.9	94.6	92.4	78.7	80.7	81.7	87.4
Vegetation	85.6	86.7	92.4	96.3	58.4	57.3	96.0	56.4
Water	97.5	95.3	90.4	-	95.1	93.1	89.7	-

TABLE VIII.--RECOGNITION RESULTS FOR THE APRIL, MAY, JUNE, AND JULY FLIGHTS. RESULTS ARE GIVEN SEPARATELY FOR TRAINING FIELDS AND ALL FIELDS CONSIDERING BARE SOIL, VEGETATION, AND WATER CATEGORIES ON A PER FIELD BASIS.

Categories	Training fields				All fields			
	April	May	June	July	April	May	June	July
	%	%	%	%	%	%	%	%
Bare Soil	87.4	100.0	100.0	100.0	89.5	100.0	94.0	90.6
Vegetation	100.0	96.8	100.0	100.0	73.3	88.0	98.9	99.1
Water	100.0	100.0	100.0	-	100.0	100.0	100.0	-

TABLE IX.--CORRELATION COEFFICIENTS, r, OF PERCENT GROUND COVER (PC) AND PLANT HEIGHT (PH) WITH BENDIX 9-CHANNEL REFLECTANCE MEASUREMENTS OVER THE 380- TO 1000-nm WLI FOR APRIL, MAY, JUNE, AND JULY FLIGHTS. WATER AND CIRRUS FIELDS WERE NOT USED.

Wavelength in nm	April		May		June		July	
	PC	PH	PC	PH	PC	PH	PC	PH
	Linear model r:							
380-440	-.579**	-.429*	-.626**	-.626**	-.677**	-.616**	-.525**	-.449*
440-500	-.549**	-.417*	-.620**	-.539**	-.725**	-.649**	-.485**	-.421*
500-560	-.494**	-.389*	-.605**	-.534**	-.675**	-.611**	-.451*	-.390
560-620	-.448**	-.361	-.544**	-.461**	-.636**	-.599**	-.341	-.302
620-680	-.505**	-.392*	-.649**	-.554**	-.699**	-.626**	-.474**	-.401*
680-740	-.410*	-.336	-.624**	-.569**	-.627**	-.597**	-.302	-.268
740-860	.467**	.234	.583**	.485**	.653**	.421*	.590**	.477**
860-1000	.477**	.242	.589**	.559**	.708**	.526**	.651**	.531*
	Multiple linear model r:							
	.721**	.475	.801**	.707**	.841**	.749**	.835**	.697**
	Multiple nonlinear model r:							
	.752**	.621**	.819**	.740**	.860**	.788**	.875**	.751**

* Significant at the 5 percent probability level.
** Significant at the 1 percent probability level.

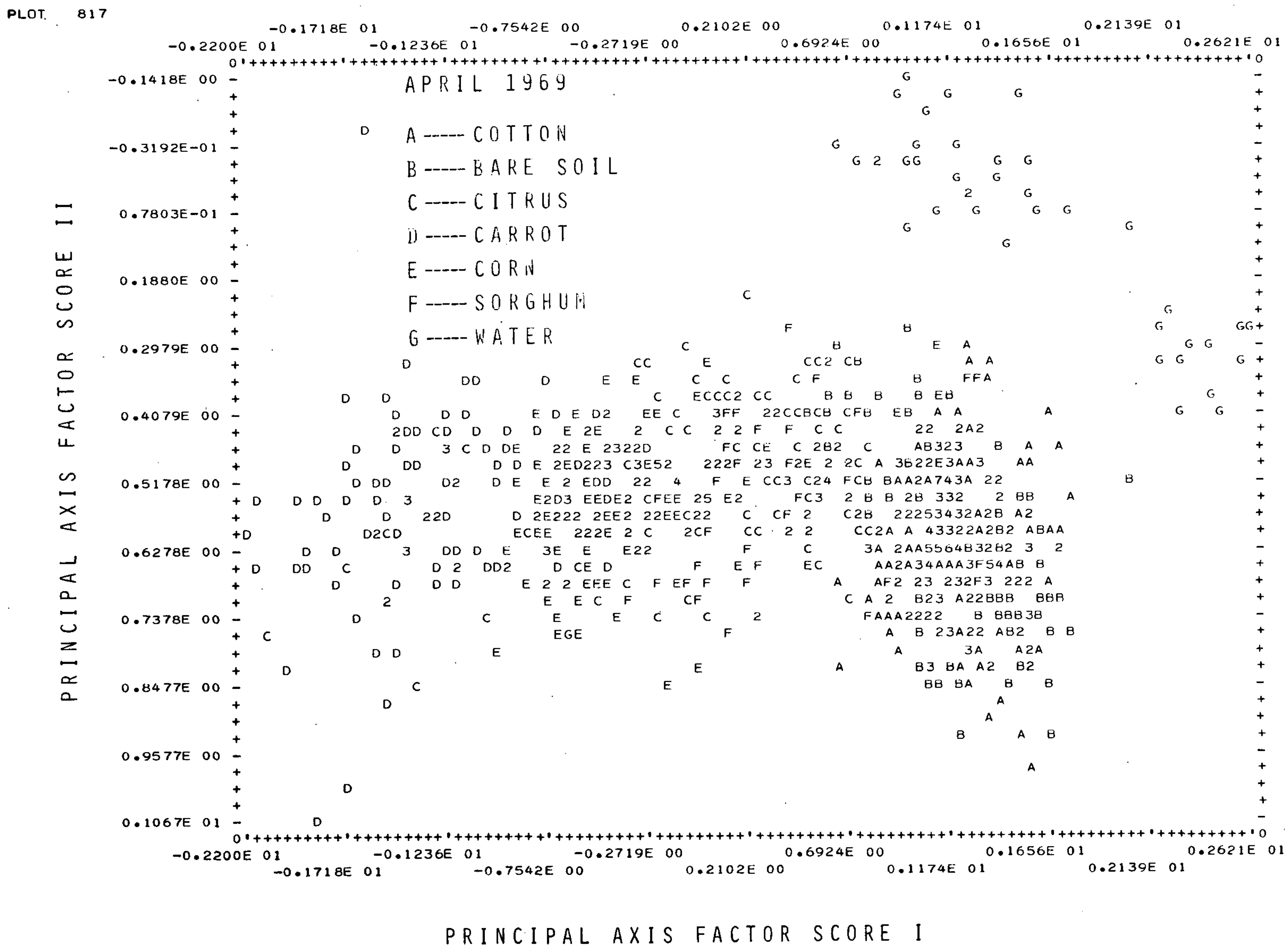

Figure 1.- Scatter diagram of principal axis factor scores 1 and 2 for cotton (A), bare soil (B), citrus (C), carrot (D), corn (E), sorghum (F), and water (G) categories during the April 1969 flight date.

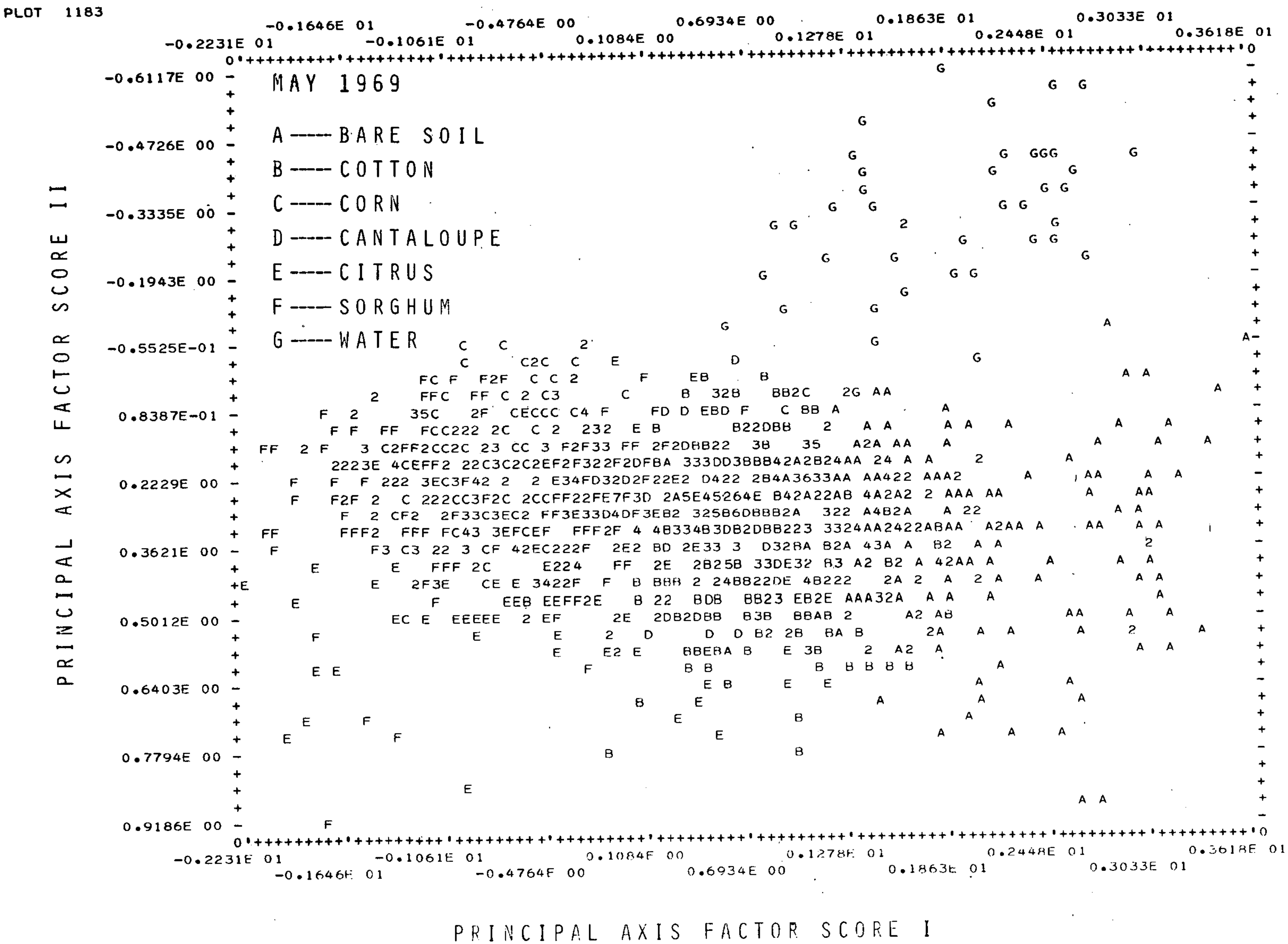

Figure 2.- Scatter diagram of principal axis factor scores 1 and 2 for bare soil (A), cotton (B), corn (C), cantaloupe (D), citrus (E), sorghum (F), and water (G) categories during the May 1969 flight date.

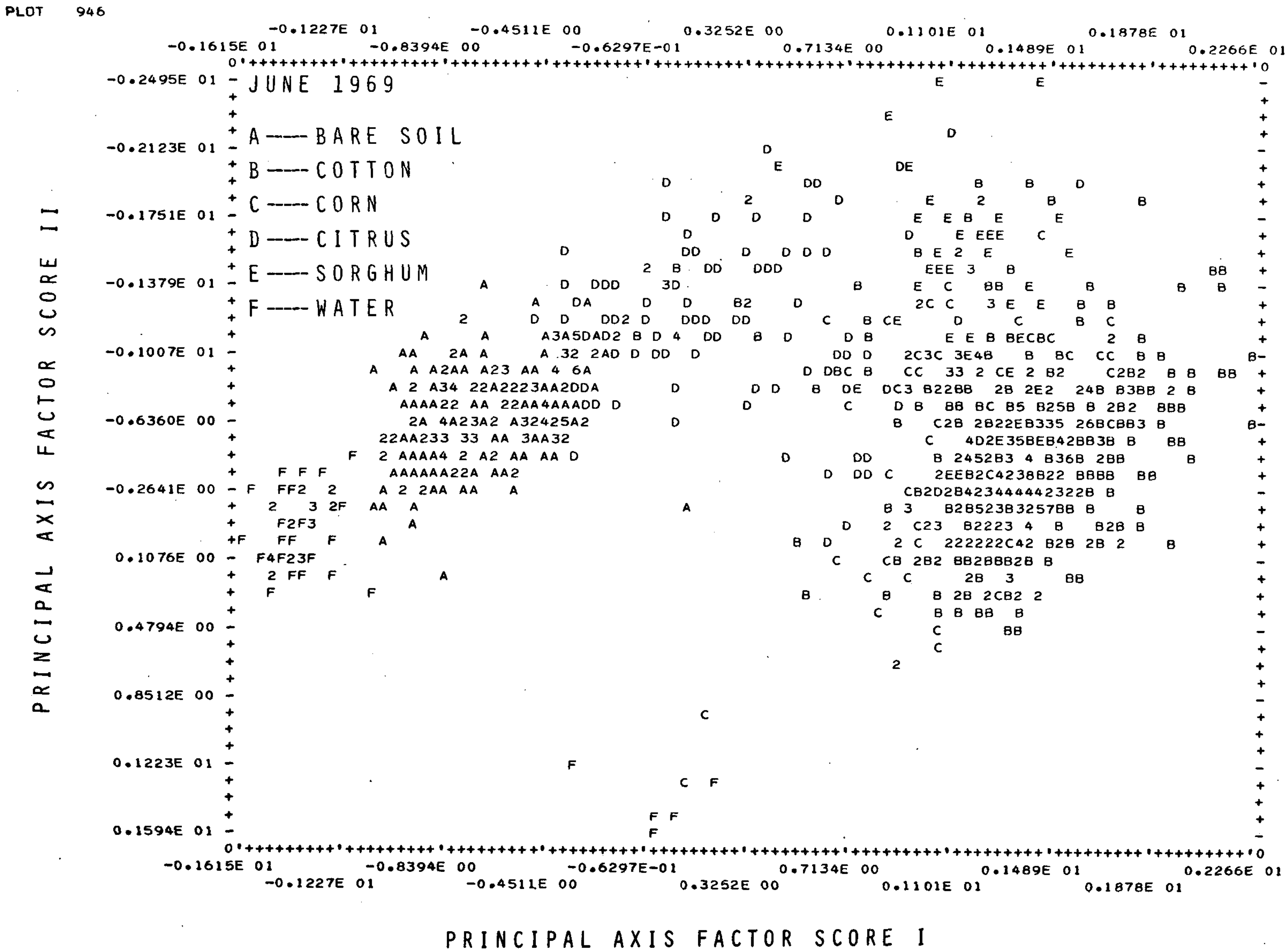

Figure 3.- Scatter diagram of principal axis factor scores 1 and 2 for bare soil (A), cotton (B), corn (C), citrus (D), sorghum (E), and water (F) categories during the June 1969 flight date.

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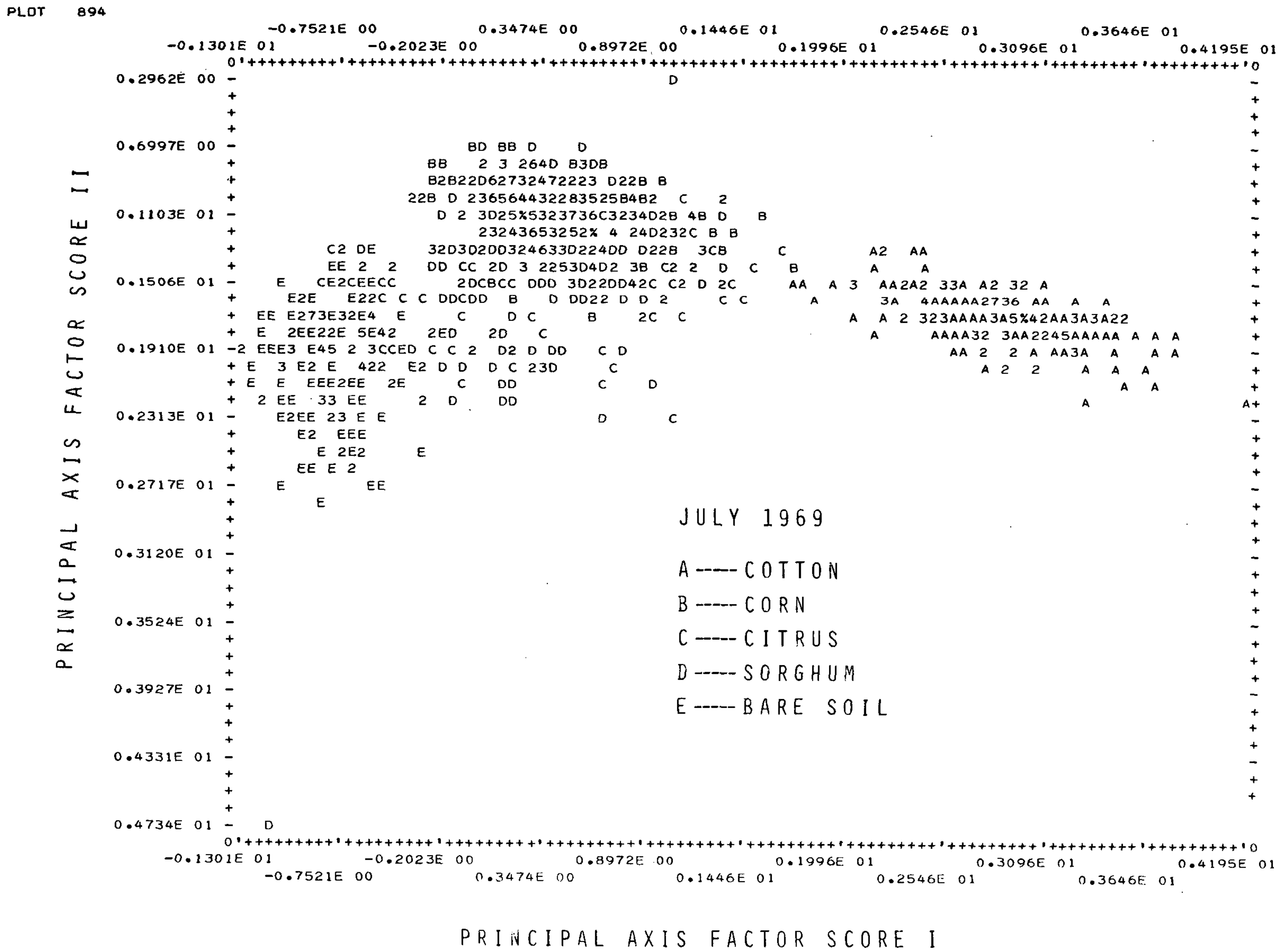

Figure 4.- Scatter diagram of principal axis factor scores 1 and 2 for cotton (A), corn (B), citrus (C), sorghum (D), and bare soil (E) categories during the July 1969 flight date.

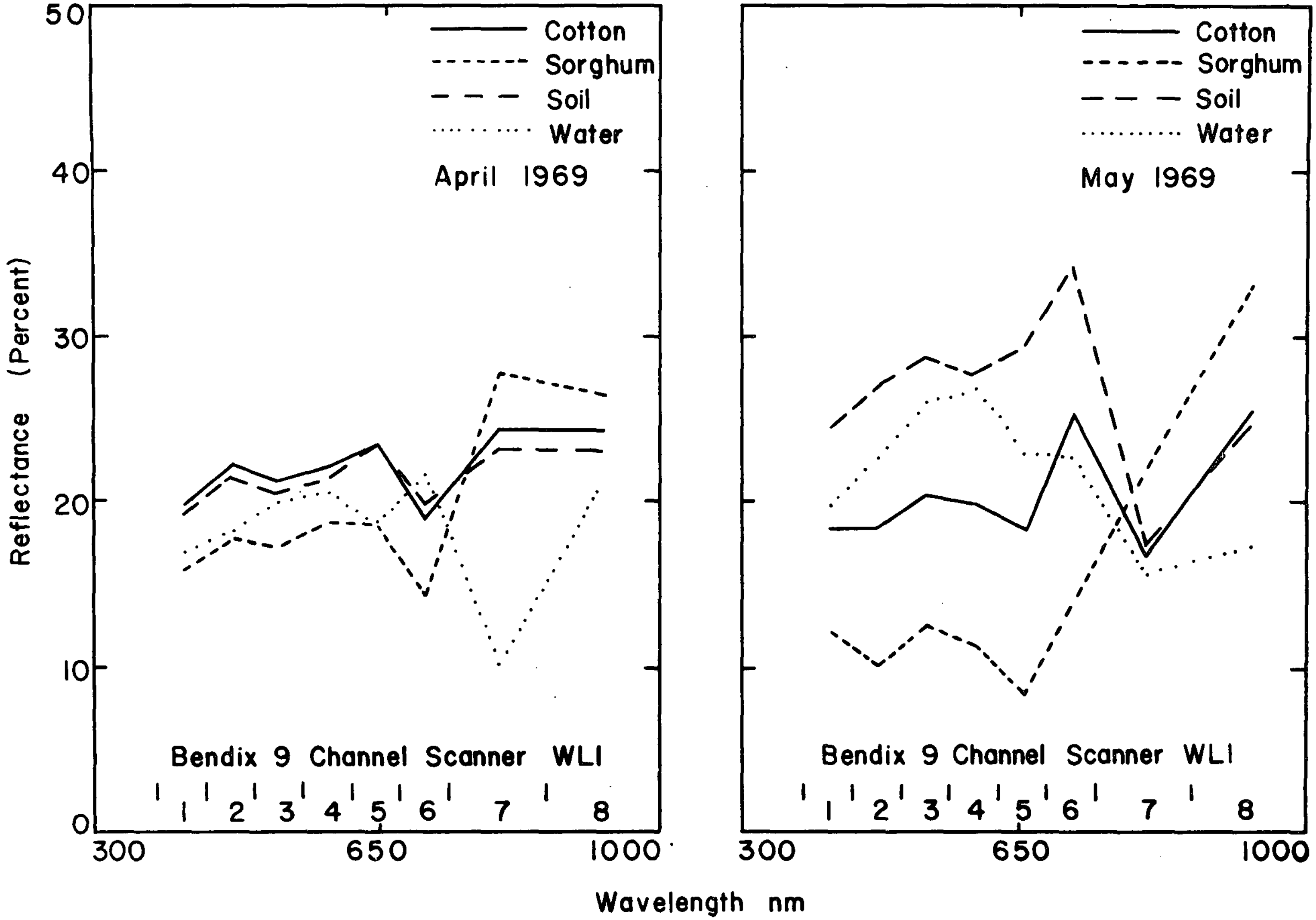

Figure 5.- Reflectance spectra of cotton, sorghum, bare soil, and water using the Bendix 9-channel scanner during April and May 1969.

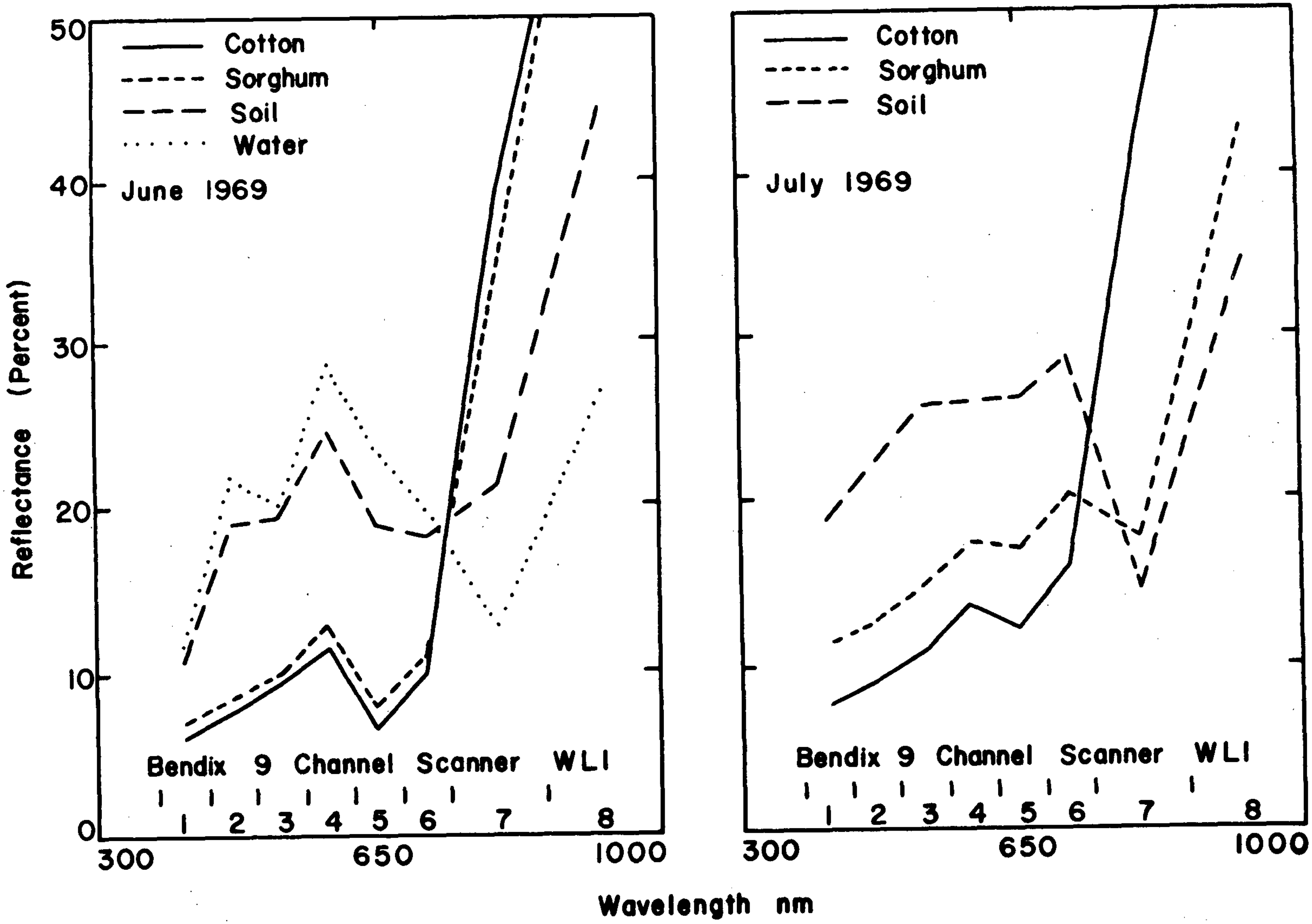

Figure 6.- Reflectance spectra of cotton, sorghum, bare soil, and water using the Bendix 9-channel scanner during June and July 1969.