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SIGNATURE EXTENSION FOR SPECTRAL VARIATION IN SOILS

VOLUME IV

J. K. Berry,
J. A. Smith,
and, K. Jon Ranson

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Final Report
Earth Observations Division
NASA Johnson Spacecraft Center
NAS 9-14467

November, 1976

Department of Earth Resources
Colorado State University
Fort Collins, Colorado 80523

ORIGINAL CONTAINS

COLOR ILLUSTRATIONS

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ABSTRACT

This is the fourth and final volume in a final report series for project NAS9-14467 sponsored by the Earth Observations Division, NASA/JSC. Volumes I and II cover the period between November 15, 1974 and November 14, 1975. Volume III is concerned with further analysis of the summer field work. It covers the period between November 14, 1975 and April 1976. Volume IV is concerned with the analysis and interpretation of the 1976 field data and covers work accomplished between November 15, 1975 and November 14, 1976. Overall objectives of this two year project were to evaluate table look-up approaches to sun-angle correction and to evaluate effects of soil brightness on composite canopy spectral response. Canopy reflectance modeling was applied as a technique for evaluating these processes in conjunction with the LACIE field measurement program at Garden City, Kansas.

Volume I presents the multiplicative and additive coefficient matrices for a linear sun-angle correction approach. These coefficient tables are calculated using either measured empirical canopy reflectance functions or model derived data. These values are then incorporated into an atmospheric radiation transfer model. The dependence of the coefficient matrices on crop stage, crop type, and canopy directional reflectance variations is reviewed. Finally, a method for inferring leaf area index, an intrinsic scene characteristic, from canopy reflectance is discussed.

Volume II presents the 1974-75 field data and computer programs used in the study. A brief review of the radiometric and geometric data collection

procedures is also given. In particular, two recent methods developed by the investigators for determining plant geometry are discussed. These include the Fourier diffraction and multiple view angle approaches. The data compilation consists of canopy reflectance, constituent reflectance, leaf area indices, and leaf slope distributions for four wheat crop development stages at Garden City, Kansas during the 1974-1975 year.

Volume III is concerned with the extraction of scene feature vectors through modeling. This volume reports further analyses of the data and techniques described in Volume I and Volume II. In addition, a divergence classifier determines a relative similarity between model derived spectral responses and those of areas with unknown leaf area index. The unknown areas are assigned the index associated with the closest model response. The report demonstrates that broad categories of leaf area index can be inferred from the procedure described. The evaluation data set was insufficient, however, for testing the procedures accurately and predicting the specific leaf area indices.

Volume IV is concerned with signature extension for spectral variation in soils. The reduced 1975-1976 field data at Garden City, Kansas are presented. These data are being used to evaluate the SRVC model predictions, to compare the ERIM-SUITS model with both the SRVC results and field data, and finally, to provide a data base for reviewing multitemporal trajectories. In particular, the applicability of the "tasselled cap" transformation is reviewed. The first detailed verification of this approach utilizing actual field measured data from the LACIE field measurement program, rather than LANDSAT data, is given.

FOREWARD

The research described in this report was supported under contract NAS9-14467, issued by the National Aeronautics and Space Administration, Earth Observations Division, Johnson Spacecraft Center, Houston, Texas. Mr. T. Barnett and Mr. M. McEwen were technical monitors of the project. Field data for the project were gathered over a period of two years at the LACIE Intensive Test Sites in Garden City, Kansas. The measurements were performed in cooperation with Dr. J. C. Harlan, Remote Sensing Center, Texas A & M University. Mr. Barrett Robinson, Laboratories for Applications of Remote Sensing, Purdue University, constructed the diffuse radiometer attachment for measuring leaf transmittance.

Participating project personnel included Dr. James A. Smith, Department of Earth Resources and Principal Investigator; Dr. Joseph Berry, Research Associate, Mr. K. Jon Ranson, Research Associate, and Mr. Rick Heimes, Graduate Research Assistant. Other assistance was provided by Ms. Carol Conrad, Mr. Frank Itkowsky, Mr. Dan Kimes, and Ms. Kimberley Ralph.

The authors would particularly like to express their appreciation to Dr. Harlan and his research team for their field measurement support. The authors also express their appreciation to Mr. Bob MacDonald, Chief, Earth Observations Division for the opportunity to participate and support the Large Area Crop Inventory Experiment these past two years.

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1.0 INTRODUCTION

This is the final volume in a four-volume final report series for project NAS9-14467. The specific objectives of the efforts summarized in this volume include:

A. To compare the CSU SRVC model predictions with the ERIM model predictions and with measured field data from Finney County, Kansas in the LANDSAT spectral bands.

B. To use the SRVC model to investigate the spectral-temporal behavior of wheat signatures. In particular, to define signature aspects which vary least with soil brightness and plant population.

These objectives are broken down into the following three tasks:

1. Using SRVC, compute spectral signatures in the LANDSAT bands for wheat in the tillering, jointing, heading and ripe stages. The Finney County, Kansas field measurements program will supply data for typical plant population and soil color. Compare and explain differences obtained between the SRVC predictions, example ERIM model predictions, and the experimentally measured data.
2. Use the SRVC model to compute signatures for four crop development stages for three plant populations and three soil colors at appropriate sun-angle/view angle (36 states).
3. Use the data base established as a result of task 2 (above) to investigate the feasibility of defining coordinate transformations which minimize or isolate effects of soil brightness and plant population on the signature.

Three major activities were undertaken in conjunction with this project: a field measurements program, SRVC model simulation, and analysis of field and simulated data. The field data collection activity provided values for the input parameters of the SRVC model, and the collection of canopy reflectance allowed for model evaluation. The field measurement procedures used in this report can be subdivided into radiometric and geometric methods depending on whether they are involved with the estimate of optical or geometric intrinsic scene variables. The field techniques used in data collection are similar to those reported in Volume II of the earlier work for this project. Section 2.0 of this report presents the field data collected during the 1975-1976 field season and discusses some modifications to data collection procedures.

The SRVC model simulation results are presented in Section 3.0. Two types of model simulations were made: benchmark runs at each of the phenology phases to appraise the model's fidelity, and model executions for three soil brightness levels at three crop cover densities, for each of the four phenology stages. Several tables of simulation parameters are presented, and the magnitude of variations in canopy spectral reflectance induced by the different soil brightness levels for each crop density is discussed. The analysis of the model and field data takes two forms: the comparison of SRVC and ERIM model results with the field data (Section 4.0), and the identification of coordinate transformations for LANDSAT data to isolate soil effects (Section 5.0). The models/field comparison is made primarily by graphical presentation. The study of data transformations utilizes the recent work by the Environmental Research Institute of Michigan (Kauth and Thomas, 1976a). This approach involves transforming LANDSAT counts into a new feature space in which one of the axes is oriented to contain the maximum variation in soil brightness. The translation of LANDSAT data into the transformed space affords insight into the effect of soil brightness as a component of canopy reflectance. Conclusion and recommendations are given in Section 6.0.

2.0 REDUCED DATA SET COMPILATION

The principle field data collected by TAMU/CSU for the canopy modeling effort consists of periodic canopy reflectance, leaf area index, dry weight, leaf transmission, and geometry photographs. In addition, soil moisture, and separation of the plant material into the categories of dead, stems, heads and tillers was recorded.

This section first summarizes available data by date followed by detailed presentation of the data. Field data were collected for five phenology stages of wheat during the 1975 to 1976 field season: November 11, 1975, representing the tillering stage, April 17, 1976, representing the booting or jointing stage, May 16, 1976, representing the heading stage, and June 13, 1976, representing the ripening stage. The November 1975 data was collected on the intensive study field used in the 1974 and 1975 field seasons. The remaining data sets were collected on field 107 of the Finney County, Ks., Intensive Field Site.

The field procedures used are discussed in detail in Volume II of this Final Report Series, entitled, Signature Extension for Sun Angle. The fundamental activities can be subdivided into radiometric and geometric methods depending on whether they are involved with the estimate of optical or geometric intrinsic scene variables. The former group includes measurements of canopy and soil reflectance, global and sky irradiance, and individual leaf transmission. The geometric procedures include an estimate of leaf area index (LAI) and leaf angle distribution (LAD).

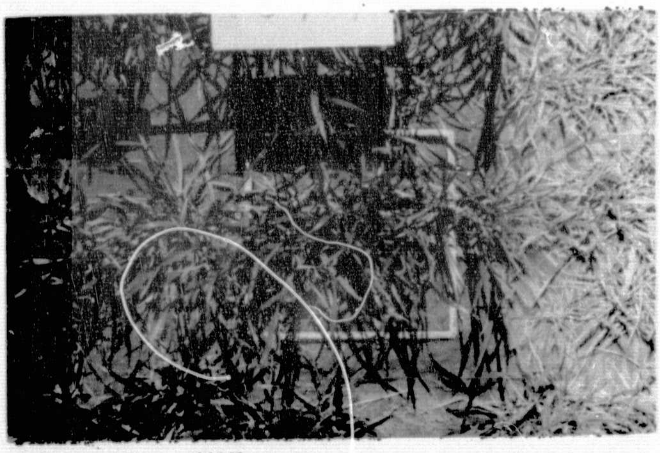
The modeling input parameters utilized in this report were collected from a single field. The field studied in the 1974-1975 field season had unusually high plant density. The management practices on the field included surface irrigation, fertilizing and double seeding rate. The field utilized in this report (1975-1976 field season) represents typical dryland farming and has a significantly lower LAI at each phenology stage. The selection of this field was made to enlarge the field measurement data set to include variability of different management practices.

The sampling design used in the 1975-76 season was basically the same as the previous period with two exceptions. Four sacred sample plots were established in the field in which repetitive radiometric measurements were made during each phenology stage (Figures 1 through 4). As the method for assessing plant surface area is destructive, a new series of plots had to be established for each reporting period during the 1974 season. Plot selection during the 1975-1976 period involved the establishment of the four sampling plots throughout the field to typify the expected population variance. The integrity of these plots for radiometric measurement was maintained throughout the season and necessary destructive sampling for determining estimated LAI was made on nearby, randomly selected plots. The second change in the experimental design consisted of utilizing a 15 inch by 30 inch plot in place of the original 2 foot by 2 foot plot. This format was adopted to more adequately deal with inter-row variance. The elongated side of the plot was oriented perpendicular to the rows and situated so it included three rows. The use of four elongated plots during this period rather than the three square plots used in the previous season, afforded a larger data set which should contain more of the field variance.

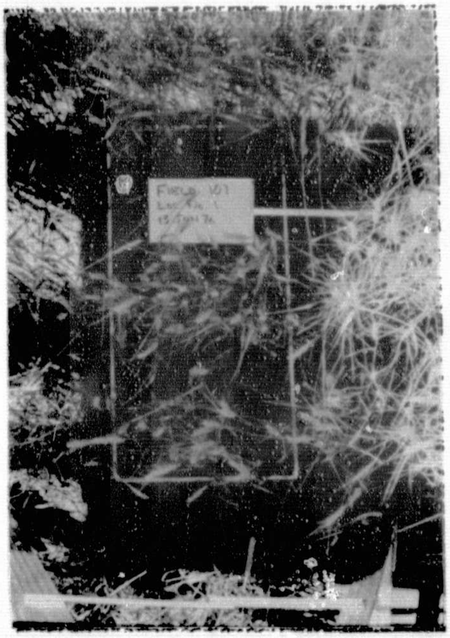
MARCH

No Photo

APRIL



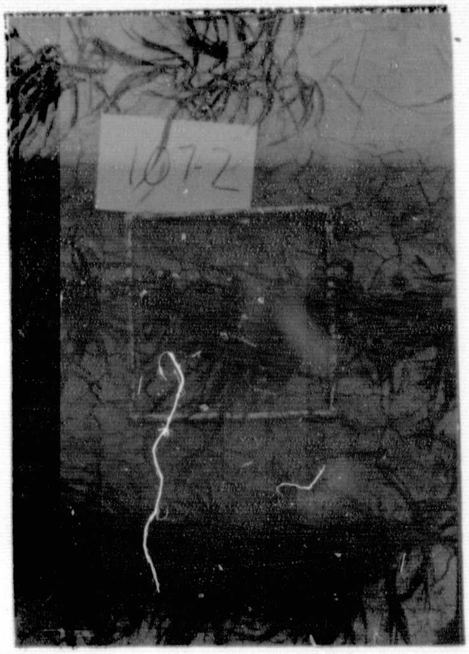
MAY



JUNE

FIGURE 1. Descriptive Photos for Sacred Plot 1.

MARCH



APRIL

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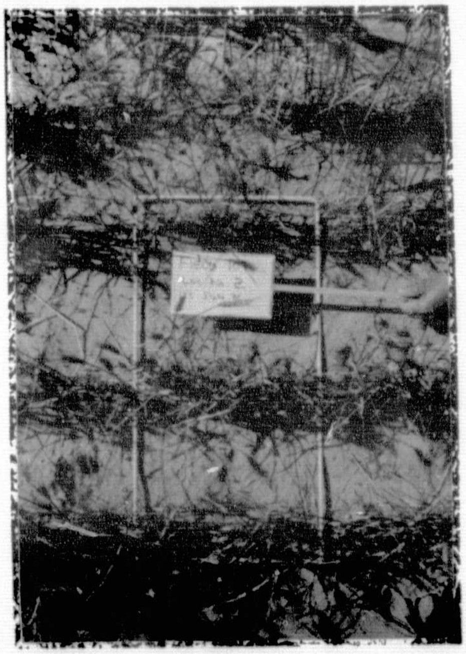
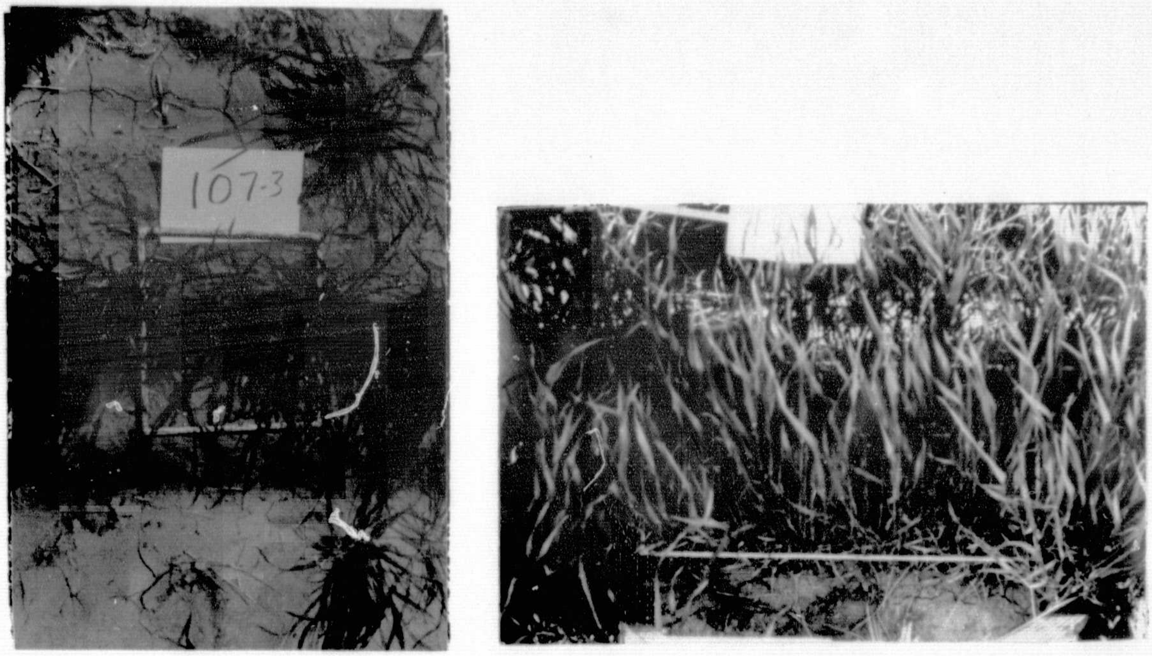
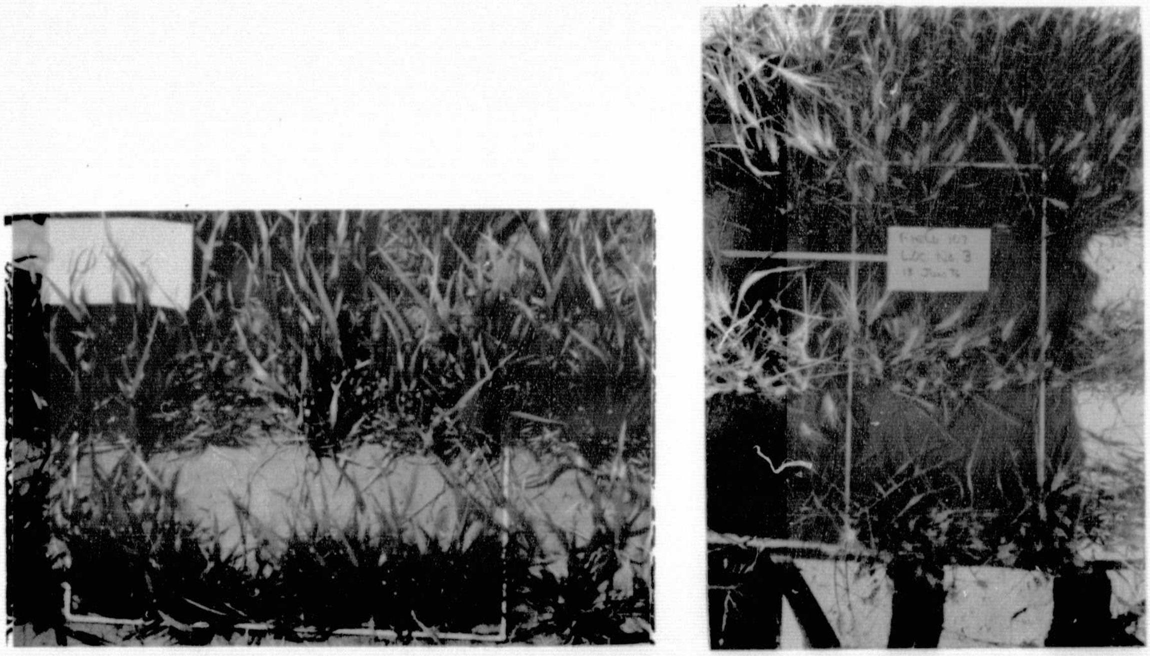


JUNE

FIGURE 2. Descriptive Photos for Sacred Plot 2.



MARCH APRIL



MAY JUNE

FIGURE 3. Descriptive Photos for Sacred Plot 3.

MARCH

No Photo

APRIL

MAY

JUNE

FIGURE 4. Descriptive Photos for Sacred Plot 4.

The field data collection procedures and data reduction techniques were fundamentally the same as the previous season. These included the use of a LANDSAT radiometer to collect canopy, constituent, irradiance, and soil radiometric measurements. Field measurement of plant surface area was made by removing the living plant material in a representative plot and measuring its one sided surface area as detected by a photoelectric surface area meter. The time involved in this tedious procedure was significantly shortened over last year by the addition of a conveyor belt assembly (Figure 5). In addition to the radiometric and geometric data collected for the modeling effort, soil moisture content was measured at each plot during each of the phenology stages (Figure 6).

Table 1 identifies the types of field data collected during each of the phenology stages. Table 2 presents the average wheat reduced canopy spectral reflectance in the LANDSAT bands for each Sacred Field Plot recorded at different times during the day during each field collection session. These data are graphically presented in Figure 7. Table 3 and Figure 8 represents the simulated LANDSAT radiance for the field collected canopy reflectance. The induced atmospheric effects and conversion from canopy reflectance to predicted satellite radiance values was achieved by executing the Turner Atmospheric Model (Turner, 1973). A visibility factor of 27 km, sun angles corresponding to measurement periods, target and background reflectance from Table 2, and vertical view angle were employed. A description of this model and its application to this project is given in Volume III of the Final Report Series, entitled, Extracting Scene Feature Vectors Through Modeling.

FIGURE 5. Conveyor Belt Assembly for Surface Area Meter

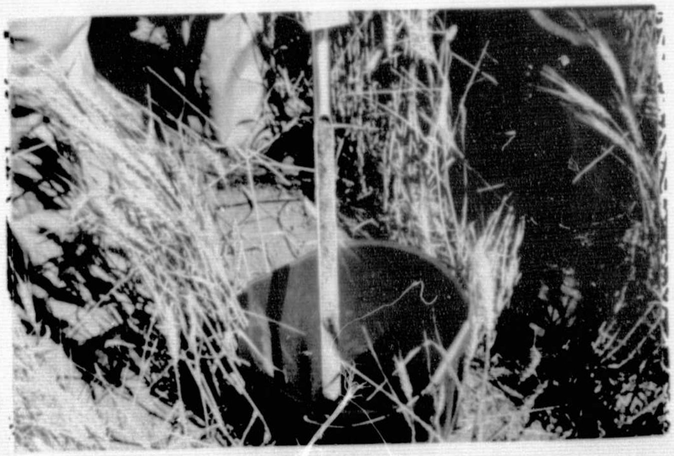


FIGURE 6. Field Collection of Soil Moisture Samples

TABLE 1

Finney County Data Collection
Summary (1976)

A. March 13, 1976 Tillering Stage Field 107

- Canopy Reflectance:

	Plot 1	Plot 2	Plot 3	Plot 4
Time:	0920 hrs.	0930	0940	0950
	1250	1300	1315	1325
	1340	1350	1400	1405
	1500	1500	1500	1515
	1530	1540	1545	1600

- Vegetation Area Index:

Plot 1	Plot 2	Plot 3	Plot 4
0.30	0.11	0.15	0.73

- Canopy Geometry: Fredholm field photos
- Leaf Transmission: Green
- 10" Row Vegetation Area:

Field	124	137	200	171	173	214	185	221
Plot 1	250.67	280.40	619.09	91.73	110.51	364.33	311.59	199.40
Plot 2	144.38	169.27	230.96	118.34	237.64	167.30	163.01	214.13

B. April 17, 1976 Booting Stage Field 107

- Canopy Reflectance:

	Plot 1	Plot 2	Plot 3	Plot 4
Time:	1000 hrs.	1020	1030	1045
	1100	1115	1130	1140
	1150	1200	1205	1215
	1220	1300	1330	1345

- Vegetation Area Index:

Plot 1	Plot 2	Plot 3	Plot 4
1.76	0.30	0.87	1.29

- Canopy Geometry: Fredholm and Fourier field photos
- Leaf Transmission: Green and yellowing
- 10" Row Vegetation Area:

Field	200	171	173	137	124	221	185	141
Plot 1	1717.17	304.56	334.28	1201.47	384.24	1209.75	546.24	281.58
Plot 2	929.36	1112.02	440.98	932.85	322.59	807.71	884.37	386.58
Plot 3	1764.43		1864.69					
Plot 4	1754.05		861.08					

TABLE 1

(Cont.)

C. May 16, 1976 Headed Field 107

- Canopy Reflectance:

	Plot 1	Plot 2	Plot 3	Plot 4
Time:	0935 hrs.	0945	0955	1000
	1045	1050	1100	1105
	1245	1300	1320	1310
	1345	1350	1400	1410

- Vegetation Area Index:

Plot 1	Plot 2	Plot 3	Plot 4
3.50	1.23	1.98	2.92

- Canopy Geometry: Fredholm and Fourier field photos

- Leaf Transmission: Green, yellowing, and dead

- 10" Row Vegetation Area:

Field	171	214	124	137	200	221	185	173
Plot 1	1182.34	480.67	1190.96	1217.77	909.60	627.80	966.56	794.58
Plot 2	1564.20	1980.10	1177.62	1726.05	393.42	795.31	908.54	692.61
Plot 3					917.92			
Plot 4					2401.78			

D. June 13, 1976 Ripening Field 107

- Canopy Reflectance:

	Plot 1	Plot 2	Plot 3	Plot 4
Time:	0945 hrs	1025	1125	1145
	1215	1230	1235	1250
	1315	1325	1330	1345
	1730	1745	1855	1800

- Vegetation Area Index:

Plot 1	Plot 2	Plot 3	Plot 4
1.77	0.82	0.57	2.76

- Canopy Geometry: Fourier field photos

- Leaf Transmission: Green, yellowing, and dead

- 10" Row Vegetation Area:

Field	200-S	200-N	185	124	214	221	137	173
Plot 1	1168.33	1360.58	239.84	205.86	287.80	630.99	522.10	432.97
Plot 2	885.31	1101.75	330.05	338.82	990.62	341.63	289.60	366.31

TABLE 2

LANDSAT RADIOMETER DATA
FOR FINNEY COUNTY FIELD SITE, KANSAS
(Averaged Over On-Off Row Set-Ups)

November 11	Band 4	5	6	7
PLOT 1				
0930	.089	.118	.181	.248
1030	.092	.109	.189	.227
1200	.092	.123	.172	.247
PLOT 2				
1000	.128	.167	.214	.239
1100	.120	.155	.202	.229
1215	.129	.160	.204	.237
PLOT 3				
1000	.093	.122	.179	.235
1115	.098	.123	.177	.219
1215	.090	.114	.164	.214
PLOT 4				
1015	.068	.082	.152	.202
1130	.068	.077	.146	.185
1230	.066	.075	.143	.181

March 13	Band 4	5	6	7
PLOT 1				
0920	.165	.185	.315	.341
1250	.138	.156	.251	.292
1340	.091	.139	.212	.287
1500	.099	.139	.223	.277
1530	.145	.161	.259	.304
PLOT 2				
0930	.163	.323	.221	.245
1300	.166	.208	.254	.287
1350	.142	.190	.262	.303
1500	.132	.183	.247	.279
1540	.192	.227	.297	.328
PLOT3				
0940	.153	.182	.242	.261
1315	.103	.136	.205	.248
1400	.119	.146	.211	.257
1500	.108	.136	.187	.239
1545	.159	.191	.271	.311
PLOT 4				
0950	.125	.102	.227	.294
1325	.064	.076	.178	.237
1405	.063	.074	.189	.244
1515	.073	.082	.208	.277
1600	.110	.111	.236	.309

APRIL 17				
PLOT 1				
1000	.040	.027	.250	.368
1100	.042	.033	.178	.352
1150	.046	.034	.247	.376
1220	.043	.031	.249	.350
PLOT 2				
1020	.164	.202	--	.366
1115	.172	.207	.328	.367
1200	.176	.198	.321	.382
1300	.161	.207	.323	.386
PLOT 3				
1030	.065	.069	.202	.291
1130	.071	.077	.188	.283
1205	.073	.126	.191	.313
1330	.080	.089	.213	.297
PLOT 4				
1045	.048	.046	.221	.309
1140	.051	.039	.248	.352
1215	.049	.041	.246	.358
1345	.052	.041	.264	.350

TABLE 2 (Continued)

LANDSAT RADIOMETER DATA FOR FINNEY COUNTY FIELD SITE, KANSAS

(Averaged Over On-Off Row Set-Ups)

May 16	Band 4	5	6	7	June 13	Band 4	5	6	7
PLOT 1					PLOT 1				
0935	.081	.066	.345	.505	0945	.155	.142	.252	.300
1045	.078	.065	.292	.489	1215	.103	.137	.226	.289
1245	.068	.060	.273	.364	1315	.116	.153	.235	.293
1345	.081	.090	.250	.416	1730	.102	.119	.229	.267
PLOT 2					PLOT 2				
0945	.120	.106	.331	.441	1025	.149	.190	.311	.380
1050	.107	.110	.281	.380	1230	.148	.187	.299	.357
1300	.127	.135	.306	.391	1325	.156	.189	.294	.356
1350	.122	.129	.289	.373	1745	.141	.183	.313	.398
PLOT 3					PLOT 3				
0955	.092	.082	.284	.413	1125	.114	.149	.233	.290
1100	.074	.069	.262	.401	1235	.127	.156	.248	.307
1320	.083	.087	.238	.342	1330	.134	.165	.234	.294
1400	.066	.073	.239	.331	1855	.124	.143	.245	.299
PLOT 4					PLOT 4				
1000	.034	.027	.207	.353	1145	.083	.101	.213	.289
1105	.041	.032	.227	.352	1250	.089	.109	.231	.289
1310	.055	.049	.225	.329	1345	.093	.109	.219	.282
1410	.050	.051	.231	.338	1800	.092	.104	.262	.332

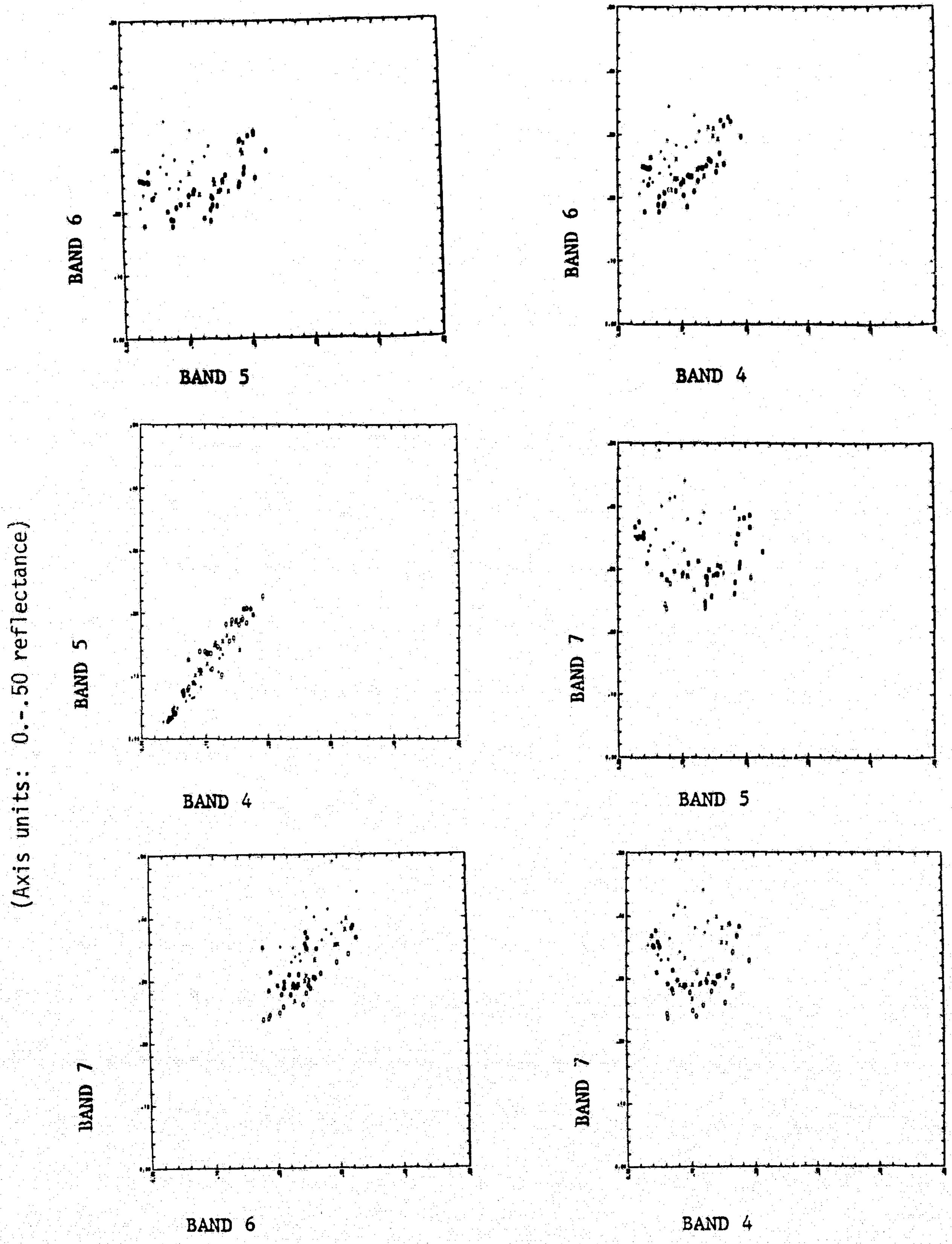


FIGURE 7. Scatter Plots of Field Measured Wheat Canopy Reflectance (1976) Composite Over All Phenology Stages (0=March, $=April, .=May, X=June).

TABLE 3

CALCULATED LANDSAT RADIANCE
FOR FINNEY COUNTY FIELD SITE, KANSAS
AVERAGE OVER-OFF ROW SET-UPS
(Radiance - $mWcm^{-2}sr^{-1}\mu m^{-1}$)

November 11	Band 4	5	6	7	March 13	Band 4	5	6	7
PLOT 1					PLOT 1				
0930	3.491	3.324	3.791	3.421	0920	6.348	5.796	7.656	5.618
1030	3.563	3.124	3.943	3.142	1250	5.553	5.003	6.170	4.827
1200	3.563	3.436	3.620	3.408	1340	4.180	4.539	5.268	4.746
					1500	4.413	4.539	5.523	4.585
					1530	5.759	5.139	6.355	5.020
PLOT 2					PLOT 2				
1000	4.420	4.422	4.418	3.302	1300	6.378	6.427	6.240	4.746
1100	4.230	4.152	4.189	3.169	1350	5.671	5.933	6.425	5.004
1215	4.444	4.264	4.227	3.275	1500	5.377	5.741	6.077	4.618
					1540	7.148	6.950	7.237	5.408
PLOT 3					PLOT 3				
1000	3.587	3.414	3.753	3.249	0940	5.994	5.714	5.962	4.328
1115	3.705	3.436	3.715	3.036	1315	4.530	4.458	5.107	4.119
1215	3.515	3.235	3.468	2.970	1400	4.997	4.730	5.246	4.263
					1500	4.675	4.458	4.693	3.974
					1545	6.171	5.960	6.634	5.133
PLOT 4					PLOT 4				
1015	2.995	2.523	3.241	2.810	0950	5.172	3.534	5.615	4.859
1130	2.995	2.412	3.128	2.585	1325	3.398	2.831	4.485	3.942
1230	2.948	2.367	3.071	2.532	1405	3.369	2.777	4.739	4.054
					1515	3.658	2.993	5.176	4.585
					1600	4.734	3.778	5.823	5.101
APRIL 17									
PLOT 1									
1000	2.860	1.596	6.516	6.415					
1100	2.921	1.767	4.753	6.141					
1150	3.043	1.795	6.442	6.552					
1220	2.951	1.710	6.491	6.106					
PLOT 2									
1115	6.954	6.786	8.439	6.398					
1200	7.080	6.524	8.265	6.655					
1300	6.608	6.786	8.315	6.724					
PLOT 3									
1030	3.626	2.796	5.340	5.097					
1130	3.811	3.025	4.997	4.960					
1205	3.872	4.435	5.071	5.430					
1330	4.088	3.370	5.609	5.199					
PLOT 4									
1045	3.104	2.138	5.805	5.405					
1140	3.196	1.938	6.467	6.141					
1215	3.135	1.995	6.418	6.243					
1345	3.227	1.995	6.860	6.106					

TABLE 3 (Cont.)

LANDSAT RADIANCE DATA
FOR FINNEY COUNTY FIELD SITE, KANSAS
(Averaged Over On-Off Row Set-Ups)

May 16	Band 4	5	6	7	June 13	Band 4	5	6	7
PLOT 1					PLOT 1				
0935	4.550	2.991	9.792	9.687	0945	7.349	5.588	7.475	5.968
1045	4.448	2.959	8.343	9.382	1215	5.492	5.423	6.749	5.755
1245	4.106	2.800	7.826	7.007	1315	5.955	5.952	7.000	5.832
1345	4.550	3.753	7.200	7.993	1730	5.457	4.830	6.833	5.328
PLOT 2					PLOT 2				
0945	5.893	4.263	9.409	8.468	1025	7.133	7.177	9.130	7.526
1050	5.444	4.390	8.044	7.130	1230	7.098	7.077	8.793	7.077
1300	6.135	5.190	8.725	7.519	1325	7.384	7.144	8.652	7.058
1350	5.962	4.998	8.262	7.178	1475	6.847	6.945	9.186	7.877
PLOT 3					PLOT 3				
0955	4.928	3.499	8.125	7.936	1125	5.883	5.819	6.944	5.774
1100	4.310	3.086	7.527	7.709	1235	6.347	6.051	7.364	6.104
1320	4.619	3.658	6.875	6.590	1330	6.596	6.348	6.972	5.852
1400	4.037	3.213	6.902	6.383	1855	6.240	5.621	7.280	5.949
PLOT 4					PLOT 4				
1000	2.948	1.756	6.035	6.799	1145	4.784	4.239	6.386	5.755
1105	3.185	1.914	6.576	6.780	1250	4.996	4.502	6.889	5.755
1310	3.662	2.452	6.522	6.345	1345	5.138	4.502	6.889	5.755
1410	3.492	2.515	6.685	6.515	1800	5.103	4.337	7.755	6.591

Measured canopy reflectance (Table 2) was utilized in calculation of LANDSAT Radiance values using Turner atmoshperic model (Turner, 1973)

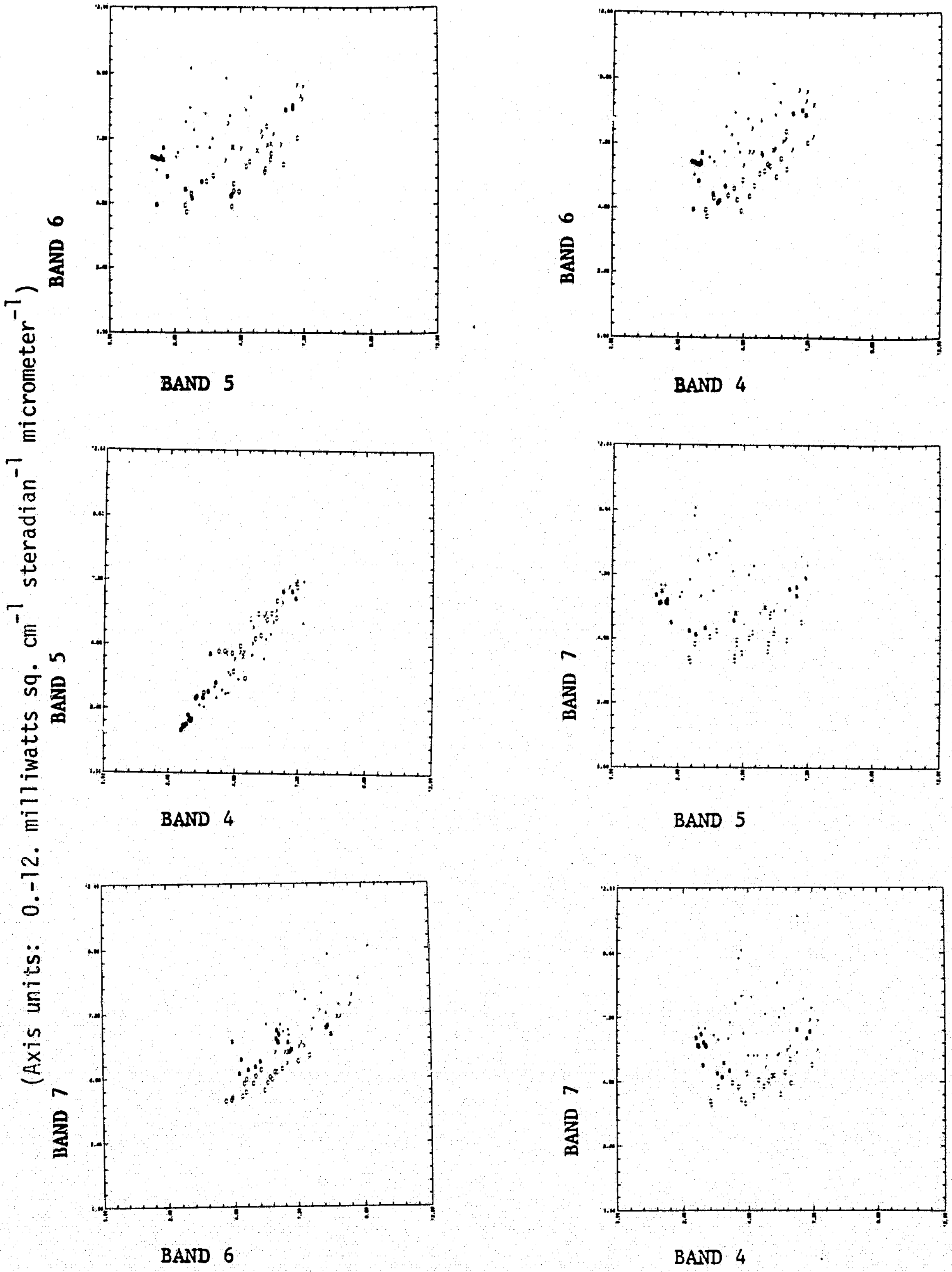


FIGURE 8. Scatter Plots of Calculated LANDSAT Radiance Using Measured Canopy Reflectance (1976). Composite Over All Phenology Stages (0=March, $=April, .=May, X=June).

Appendix A is a detailed presentation of the field data collected during the field season. Each phenological stage subsection contains a table of vegetative surface area parameters, followed by the leaf angle distribution for that stage and a complete listing of all radiometric measurements. This data presentation is consistent with that presented in Volume II of our previous reports.

3.0 SRVC LANDSAT Predicted Signatures

This section describes the modeling effort associated with the project's primary task of simulating the effects of soil brightness on wheat canopy spectral reflectance. The canopy reflectance model used in this study is Colorado State University's Solar Radiation Vegetation Canopy (SRVC) Model (Oliver and Smith, 1973, 1974). Two types of model simulations were made: benchmark model runs for each phenological stage utilizing nominal field measured input parametrs, and simulations of the four phenological stages for three plant populations in three soil colors at appropriate sun angles (36 states). The benchmark runs are used to indicate the appropriateness of the model results as compared to field canopy reflectance measurements. The soil brightness simulations are used to indicate the effects of changes in scene background on the complex wheat canopy reflectance.

Tables 4 through 6 present the general simulation constants, the leaf angle distribution, leaf optical properties and irradiance conditions used in the simulation of each phenological stage. The SRVC model input parameters can be divided into two principle classes: environmental factors, and intrinsic scene characteristics. The environmental factors include sun position, diffuse and direct irradiance, and sensor view angle. Leaf area index, leaf angle distribution, and spatial dispersion of foliage elements describe a plant canopy's geometric characteristics. The canopy's radiometric input parameters include soil reflectance and individual leaf reflectance and transmission. The methodology of the model is discussed in Volumes II and III of the Final Report Series. The direct field measurements for the model input parameters were used whenever possible.

Table 4 - General Simulation Constants by Crop Stage

	MARCH	APRIL	MAY	JUNE
Stage	Tillering	Booting	Headed	Ripening
Calendar Day	13	17	16	13
Julian Day	73	108	137	165
Year	1976	1976	1976	1976
Solar Declination	-3.23	10.20	18.92	23.17
Latitude	38 N	38 N	38 N	38 N
Longitude	101 W	101 W	101 W	101 W
Mean Solar Time	915	915	915	915
Local Standard Time	1100	1100	1100	1100
Solar Zenith Angle	56.2	46.2	40.5	38.1
Number of Samples	7	7	7	7
Number of Trials Samples	10	10	10	10
Number of Canopy Layers	1	1	1	1
Number of Constituents	1	1	1	1
Number of Wavelengths	4	4	4	4

Table 5 - Leaf Angle Distribution By Crop Stage

	PROBABILITY DENSITY			
ANGLE	MARCH	APRIL	MAY	JUNE
0	.044	.044	.031	.050
5	.044	.044	.029	.050
10	.044	.044	.046	.057
15	.044	.044	.058	.055
20	.045	.045	.056	.047
25	.046	.046	.054	.047
30	.047	.047	.053	.047
35	.048	.048	.052	.047
40	.049	.049	.056	.052
45	.051	.051	.060	.053
50	.052	.052	.059	.048
55	.054	.054	.059	.050
60	.055	.055	.063	.052
65	.057	.057	.062	.054
70	.059	.059	.059	.055
75	.062	.062	.055	.051
80	.064	.064	.051	.060
85	.067	.067	.050	.064
90	.070	.070	.046	.060

Table 7 identifies the green leaf area index used in the soil brightness simulations. Three LAI's (low, medium, and high) were identified for each phenological stage. These three plant level densities are used in the simulation to correspond to three different plant populations. The values were determined by reviewing the spread of expected plant densities measured during each phenological data collection session.

The three levels of soil brightness used in the simulation for each phenological stage (Table 8) were determined from the soil spectral reflectance curves shown in Figure 9. The field measured bare soil reflectance for each data collection period and a literature curve (Condit, 1970) of typical soil reflectance is presented. A general agreement is noted between the literature curve and the field measured values. The three soil brightness levels (normal, light, and dark) used in the simulations represent Condit's average curve plus and minus 20% respectively.

Table 9 summarizes the results of soil brightness simulations. The table identifies the reflectance in each of the LANDSAT bands for each soil brightness and plant population combination. The standard deviation associated with each reflectance prediction is shown in parenthesis. Figure 10 is a graphical representation of these data. Table 10 and Figure 11 are a similar presentation for the calculated LANDSAT radiance values using the Turner model with the SRVC model canopy reflectance as input.

Table 11 highlights the soil brightness effects on the model generated reflectance data for each phenological stage. The table identifies the percent change in canopy spectral reflectance induced by the dark and light soil curves, as compared to the simulated canopy reflectance using

Table 6 - Leaf Optical Properties and Irradiance Ratio By Crop Stage

	MARCH	APRIL	MAY	JUNE
Leaf Reflectance				
.55	.034	.078	.076	.168
.65	.027	.067	.045	.206
.75	.294	.331	.381	.437
.95	.424	.480	.450	.480
Leaf Transmittance				
.55	.034	.078	.076	.168
.65	.027	.067	.045	.206
.75	.294	.331	.381	.437
.95	.424	.480	.450	.480
Diffuse/Total Irradiance				
.55	.120	.095	.102	.079
.65	.120	.062	.067	.054
.75	.112	.068	.080	.059
.95	.118	.071	.109	.066

Table 7 - Green Leaf Area Index Corresponding to Three Plant Populations By Crop Stage At Garden City, Kansas

GREEN LEAF AREA INDEX	MARCH	APRIL	MAY	JUNE
Low	0.15	0.87	1.23	0.82
Medium	0.30	1.29	1.98	1.77
High	0.73	1.76	2.92	2.76

Table 8 - Soil Reflectance Curves Corresponding to Three Brightnesses. Average Soil Reflectance is From Condit (1970). Dark and Light Correspond to Plus and Minus 20 Percent Values.

	WAVELENGTH			
SOIL CHARACTER	0.55	0.65	0.75	0.95
Typical Dark	0.125	0.174	0.205	0.249
Average	0.156	0.218	0.256	0.311
Typical Light	0.187	0.262	0.307	0.373

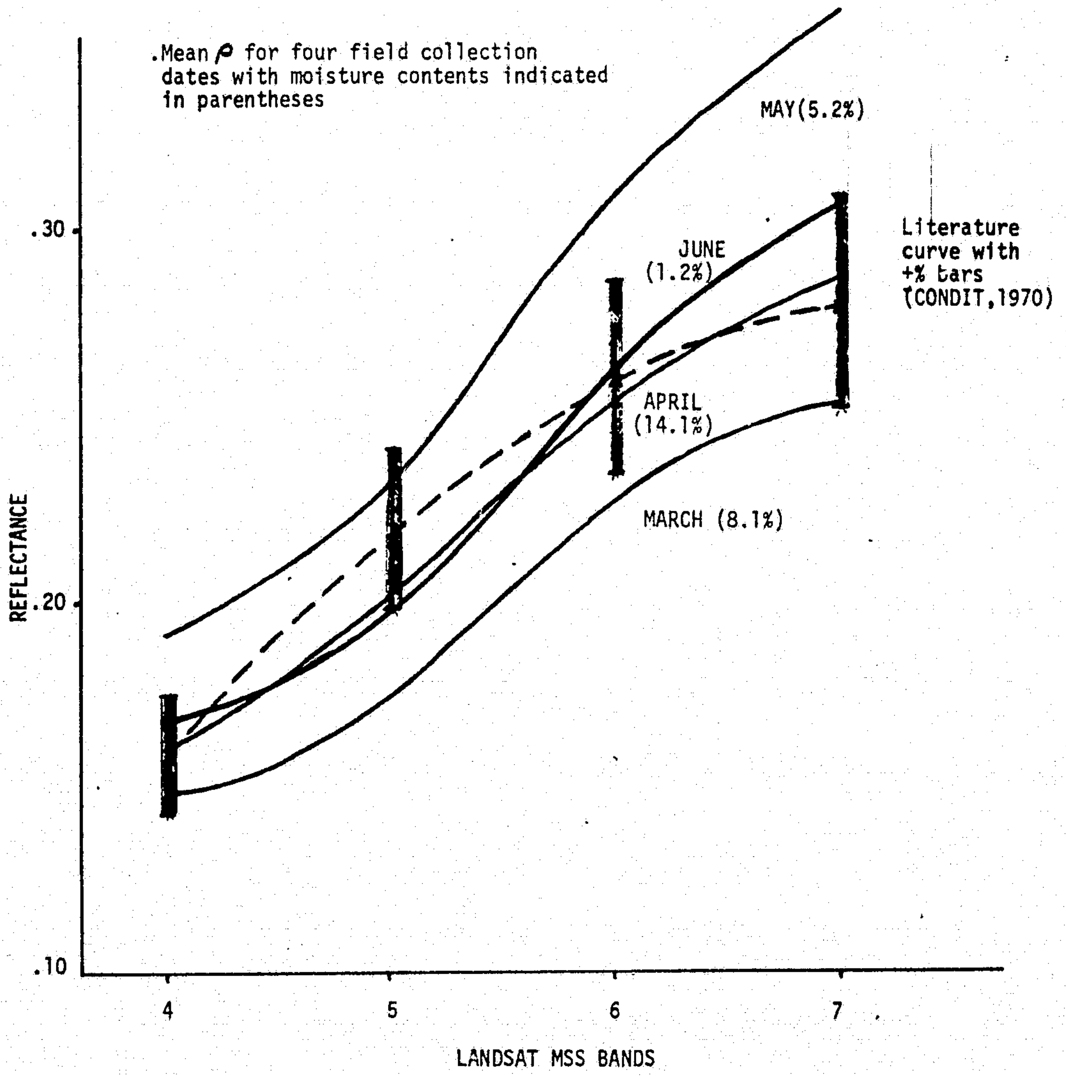


FIGURE 9. AVERAGE SOIL REFLECTANCE CURVES
(SHADED BARS REPRESENT CONDIT'S AVERAGE CURVE ± 20 PERCENT.)

Table 9. Model Calculated Mean Spectral Reflectance
(Standard Deviation in Parentheses)

Stage	Sun Angle	Soil* Brightness	LAI**	MSS 4	MSS 5	MSS 6	MSS 7
TILLERING	56.2 Z	1	1	.101(.013)	.137(.020)	.214(.014)	.279(.021)
		1	2	.082(.009)	.109(.015)	.215(.020)	.290(.032)
		1	3	.049(.012)	.058(.020)	.225(.025)	.325(.043)
		2	1	.119(.016)	.164(.024)	.241(.023)	.310(.033)
		2	2	.106(.018)	.142(.028)	.263(.027)	.354(.041)
		2	3	.059(.014)	.072(.021)	.246(.017)	.354(.023)
		3	1	.133(.020)	.182(.029)	.285(.027)	.374(.036)
		3	2	.125(.029)	.169(.043)	.287(.028)	.381(.037)
		3	3	.060(.019)	.072(.028)	.253(.028)	.366(.036)
JOINTING	46.2	1	1	.071(.020)	.078(.034)	.228(.023)	.331(.037)
		1	2	.059(.007)	.054(.009)	.239(.030)	.355(.047)
		1	3	.061(.008)	.054(.009)	.263(.027)	.393(.039)
		2	1	.075(.019)	.086(.027)	.239(.036)	.347(.050)
		2	2	.066(.014)	.064(.019)	.268(.038)	.402(.053)
		2	3	.058(.006)	.051(.005)	.258(.025)	.389(.038)
		3	1	.073(.010)	.078(.019)	.259(.009)	.384(.013)
		3	2	.064(.008)	.062(.015)	.260(.009)	.393(.015)
		3	3	.067(.010)	.062(.013)	.278(.022)	.418(.030)
HEADING	40.5	1	1	.058(.009)	.044(.012)	.261(.032)	.324(.038)
		1	2	.057(.005)	.034(.003)	.296(.025)	.361(.029)
		1	3	.058(.004)	.034(.002)	.297(.020)	.361(.022)
		2	1	.062(.010)	.053(.017)	.262(.025)	.327(.027)
		2	2	.058(.005)	.036(.007)	.297(.014)	.364(.017)
		2	3	.061(.004)	.036(.003)	.316(.021)	.386(.023)
		3	1	.065(.016)	.052(.024)	.294(.040)	.369(.047)
		3	2	.063(.009)	.044(.013)	.309(.024)	.381(.030)
		3	3	.061(.002)	.036(.001)	.321(.010)	.392(.012)
RIPE	38.1	1	1	.110(.016)	.143(.019)	.269(.055)	.312(.058)
		1	2	.118(.007)	.146(.009)	.313(.018)	.354(.018)
		1	3	.125(.007)	.154(.009)	.335(.019)	.375(.021)
		2	1	.119(.017)	.156(.025)	.294(.035)	.344(.041)
		2	2	.118(.009)	.148(.012)	.314(.017)	.359(.018)
		2	3	.130(.008)	.161(.010)	.353(.021)	.398(.023)
		3	1	.129(.017)	.172(.023)	.310(.038)	.369(.043)
		3	2	.111(.014)	.139(.017)	.308(.036)	.353(.038)
		3	3	.127(.005)	.157(.006)	.347(.014)	.392(.015)

*Soil Brightness Code

Low Soil Reflectance = 1
Average Soil Reflectance = 2
High Soil Reflectance = 3

**LAI, Plant Density Code
Low LAI = 1
Medium LAI = 2
High LAI = 3

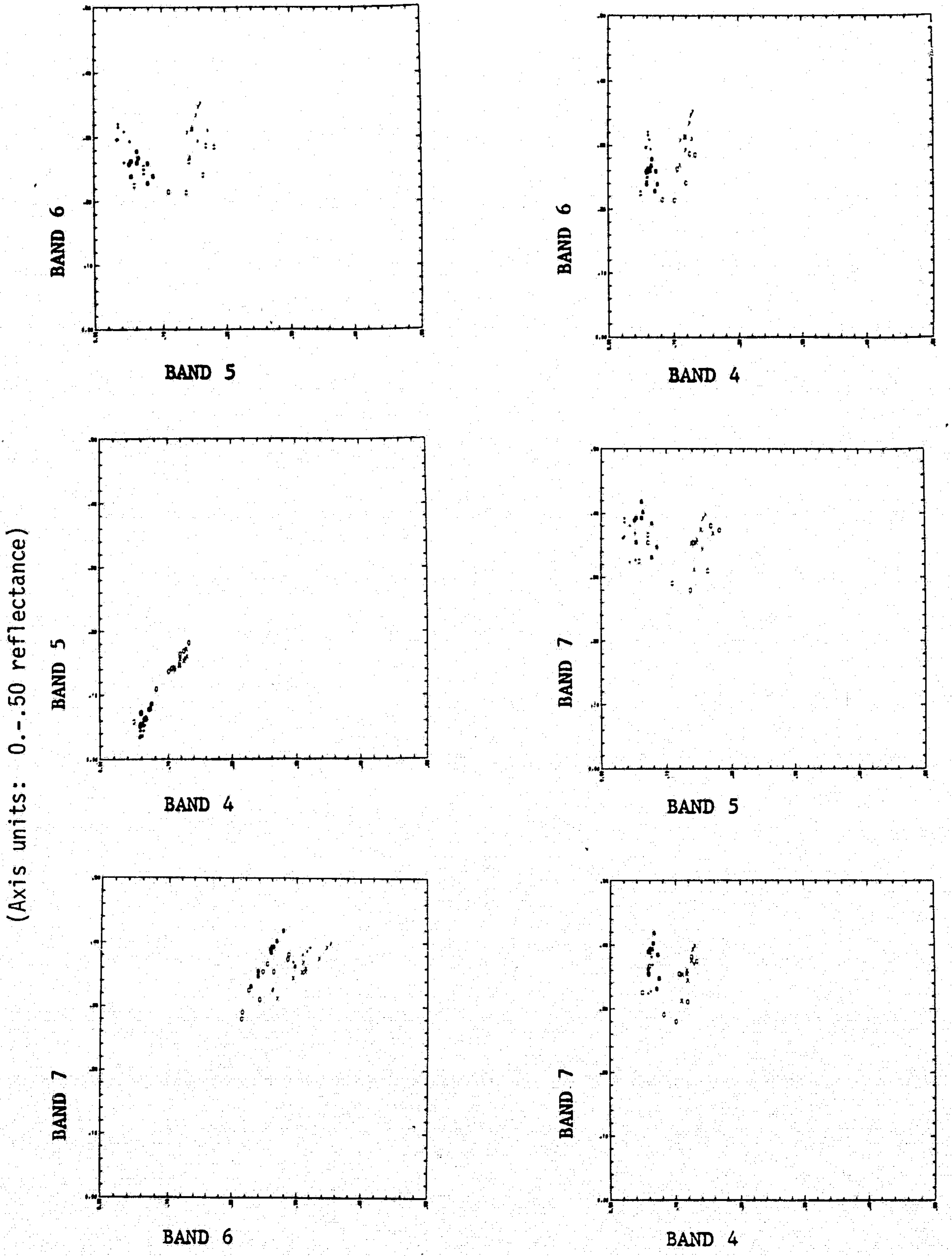


FIGURE 10. Scatter Plots of Model Generated Wheat Canopy Reflectance Composite Over All Phenology Stages (0=March, $=April, .=May, X=June).

TABLE 10.
MODEL GENERATED RADIANCE DATA
($mWcm^{-2}sr^{-1}\mu m^{-1}$)

DATE	LAI	SOIL	4	5	6	7
MAR	1	1	4.471	4.485	5.315	4.618
		2	4.997	5.221	5.939	5.117
		3	5.407	5.714	6.959	6.151
	2	1	3.919	3.724	5.338	4.795
		2	4.617	4.621	6.448	5.828
		3	5.172	5.358	7.005	6.265
	3	1	2.965	2.345	5.569	5.360
		2	3.254	2.723	6.054	5.828
		3	3.283	2.723	6.216	6.022
APR	1	1	3.811	3.054	5.976	5.781
		2	3.934	3.284	6.246	6.055
		3	3.872	3.054	6.737	6.689
	2	1	3.442	2.367	6.246	6.192
		2	3.657	2.653	6.958	6.998
		3	3.595	2.595	6.762	6.844
	3	1	3.503	2.367	6.835	6.844
		2	3.411	2.281	6.712	6.775
		3	3.688	2.595	7.204	7.273
MAY	1	1	3.764	2.294	7.499	6.251
		2	3.901	2.579	7.527	6.307
		3	4.003	2.547	8.398	7.102
	2	1	3.730	1.978	8.453	6.951
		2	3.764	2.041	8.480	7.007
		3	3.935	2.294	8.807	7.329
	3	1	3.764	1.978	8.480	6.951
		2	3.867	2.041	9.135	7.538
		3	3.867	2.041	8.999	7.424
JUNE	1	1	5.741	5.621	7.951	6.202
		2	6.061	6.051	8.652	6.824
		3	6.418	6.580	9.102	7.311
	2	1	6.026	5.720	9.186	7.019
		2	6.026	5.786	9.214	7.116
		3	5.777	5.489	9.046	6.999
	3	1	6.275	5.985	9.806	7.428
		2	6.454	6.216	10.313	7.877
		3	6.347	6.084	10.144	7.760

Soil Brightness Code

Low Soil Reflectance = 1
Average Soil Reflectance = 2
High Soil Reflectance = 3

LAI, Plant Density Code

Low LAI = 1
Medium LAI = 2
High LAI = 3

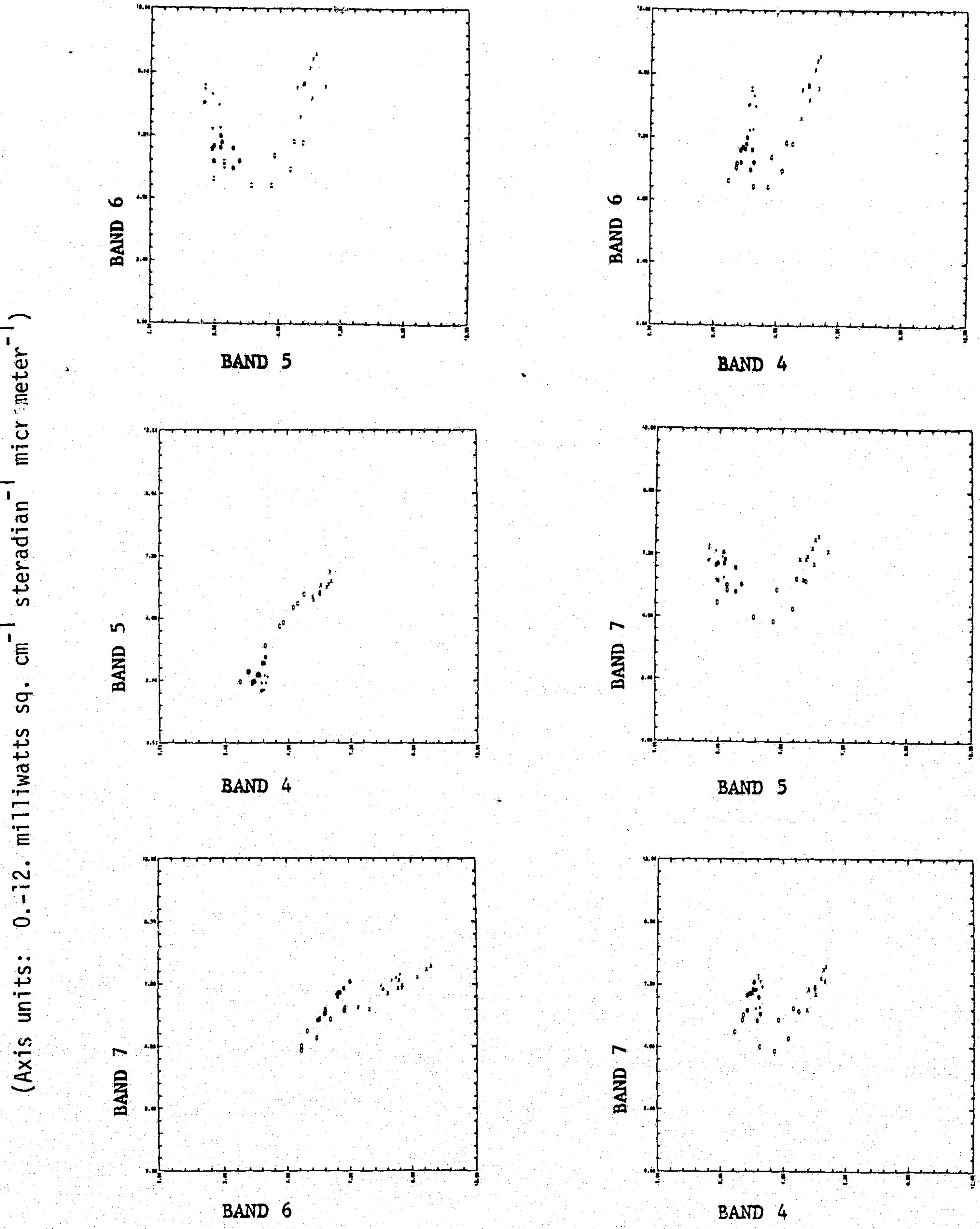


FIGURE 11. Scatter Plots of Model Generated Radiance (1976). Composite Over All Phenology Stages (0=March, $=April, .=May, X=June).

the normal soil reflectance curve. The proportional changes were calculated using the mean predicted spectral responses, without consideration of data variance. They should not be regarded as absolute figures, but as a general indication of the induced effects. For example, it is noted that there was a 15% decrease in canopy reflectance for MSS band 4 when a dark soil was simulated for a low plant density population during the tillering phenolgical stage (March). In contrast a 12% increase was noted under the bright soil conditions. Figures 12 through 15 graphically summarizes these data.

Figure 12 shows that the introduction of a dark background decreased total canopy spectral reflectance about 15% in the visible bands and 10% in the infrared band for all soil/LAI combinations in the March simulations. The bright soil simulations show a general increase in canopy reflectance, but the response is not constant for the different plant populations. The introduction of a bright soil had a relatively nominal effect at high LAI's for the March period. The variation in results shown at the low and nominal plant density levels might be explained by the interaction between the individual soil reflectance curve and the individual leaf reflectance and transmission curves. As more plant material is simulated the aggregate scene spectral reflectance tends to mimic the individual leaf curves. Also affecting the response are the different portions of shadowing.

The effects on canopy spectral reflectance shown in Figures 13 and 14 (April and May) are at a lower magnitude than those during the March period. This condition is to be expected as the canopy signal is becoming saturated by the vegetation component. The contribution of background reflectance is being lessened which is most likely caused by the proportion of first order

TABLE 11.
MODEL GENERATED SOIL EFFECTS DATA
(Proportional Change in Reflectance)

DATE	LAI	SOIL	MSS 4	MSS 5	MSS 6	MSS 7
MAR	1	1	-.15	-.16	-.11	-.10
		3	.11	.11	.18	.20
	2	1	-.22	-.23	-.18	-.18
		3	.17	.19	.09	.07
	3	1	-.16	-.19	-.08	-.08
		3	.01	0.	.02	.03
APR	1	1	-.05	-.09	-.04	-.04
		3	-.02	-.09	.08	.10
	2	1	-.10	-.15	-.10	-.11
		3	-.03	-.03	-.03	-.02
	3	1	.05	.05	.01	.01
		3	.15	.21	.07	.07
MAY	1	1	-.08	-.17	-.00	-.00
		3	.04	-.09	.12	.12
	2	1	-.01	-.05	-.00	-.00
		3	.08	.22	.04	.04
	3	1	-.04	-.05	-.06	-.06
		3	0.	0.	.01	.03
JUNE	1	1	-.07	-.08	-.08	-.09
		3	.08	.10	.05	.07
	2	1	0.	-.01	-.00	-.01
		3	-.05	-.06	-.01	-.01
	3	1	-.03	-.04	-.05	-.05
		3	-.02	-.02	-.01	-.01

NOTE: The proportional changes were calculated using the mean predicted spectral responses, without consideration of data variance.

Soil Brightness Code

Low Soil Reflectance = 1
Average Soil Reflectance = 2
High Soil Reflectance = 3

LAI, Plant Density Code

Low LAI = 1
Medium LAI = 2
High LAI = 3

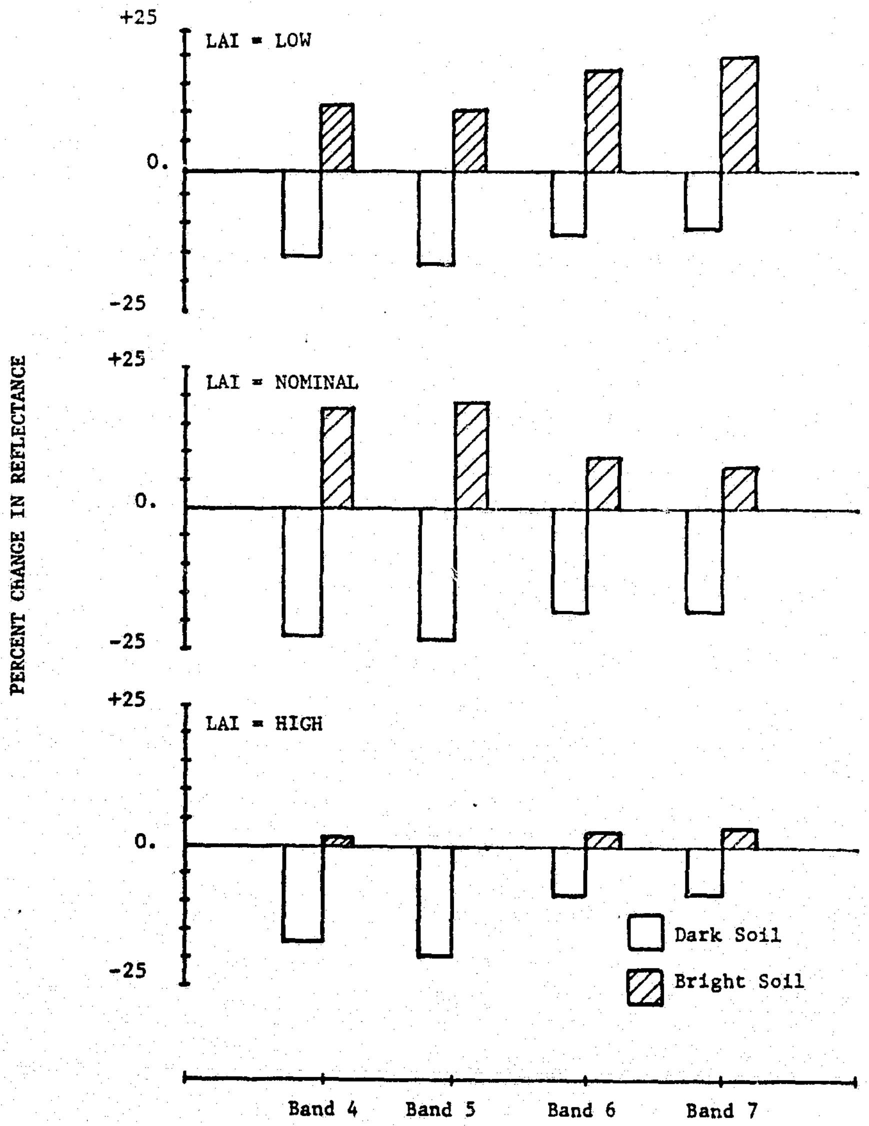


FIGURE 12 . March Soil Effects

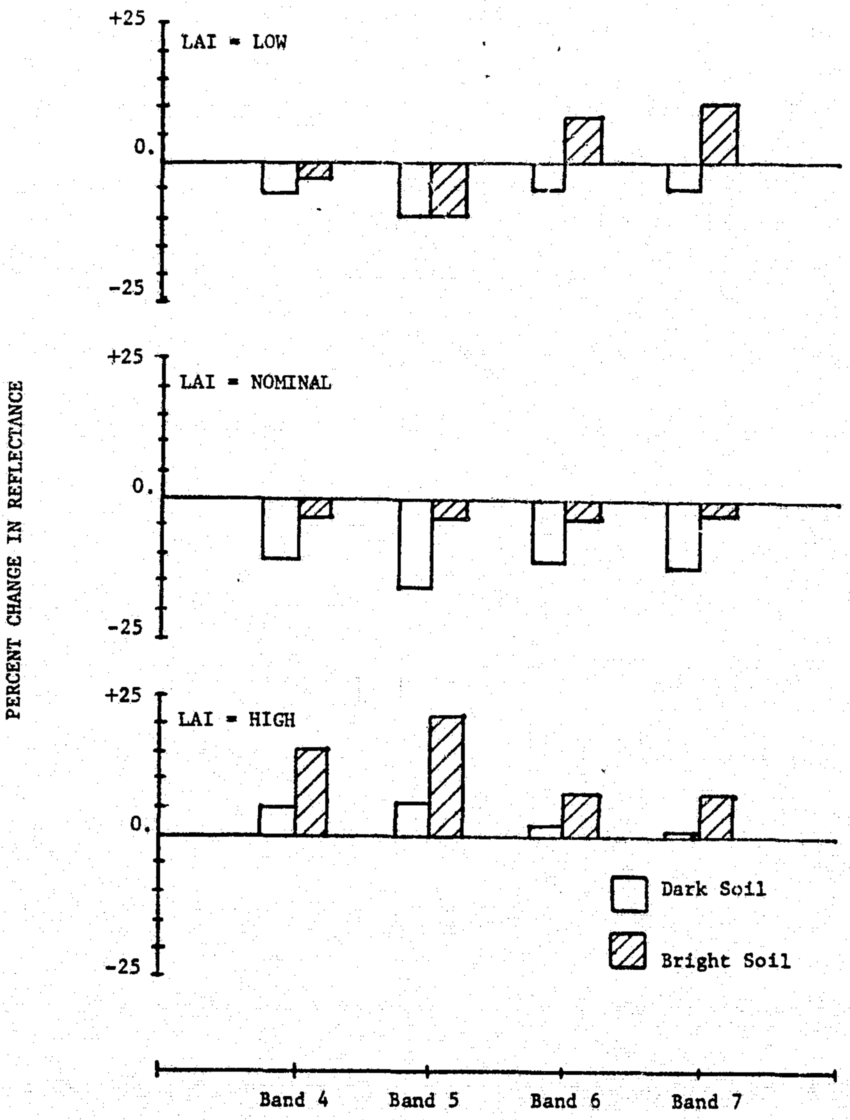


FIGURE 13 . April Soil Effects

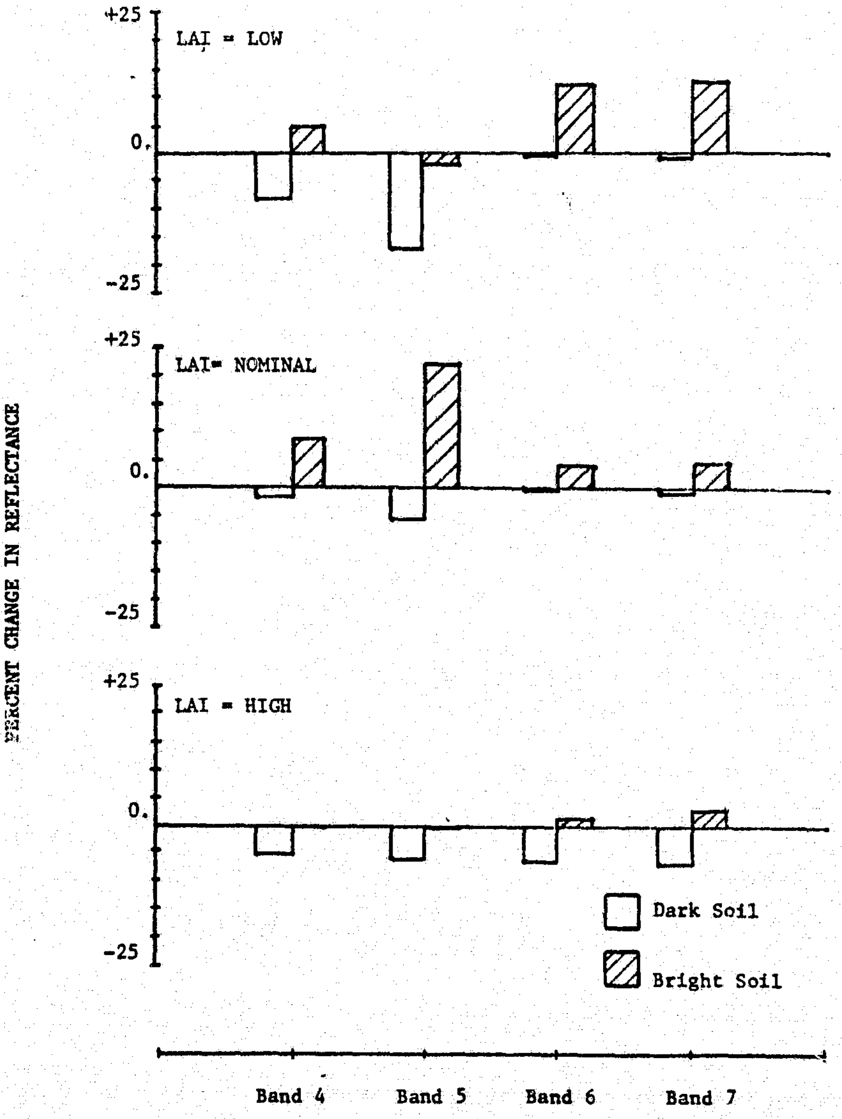


FIGURE 14. May Soil Effects

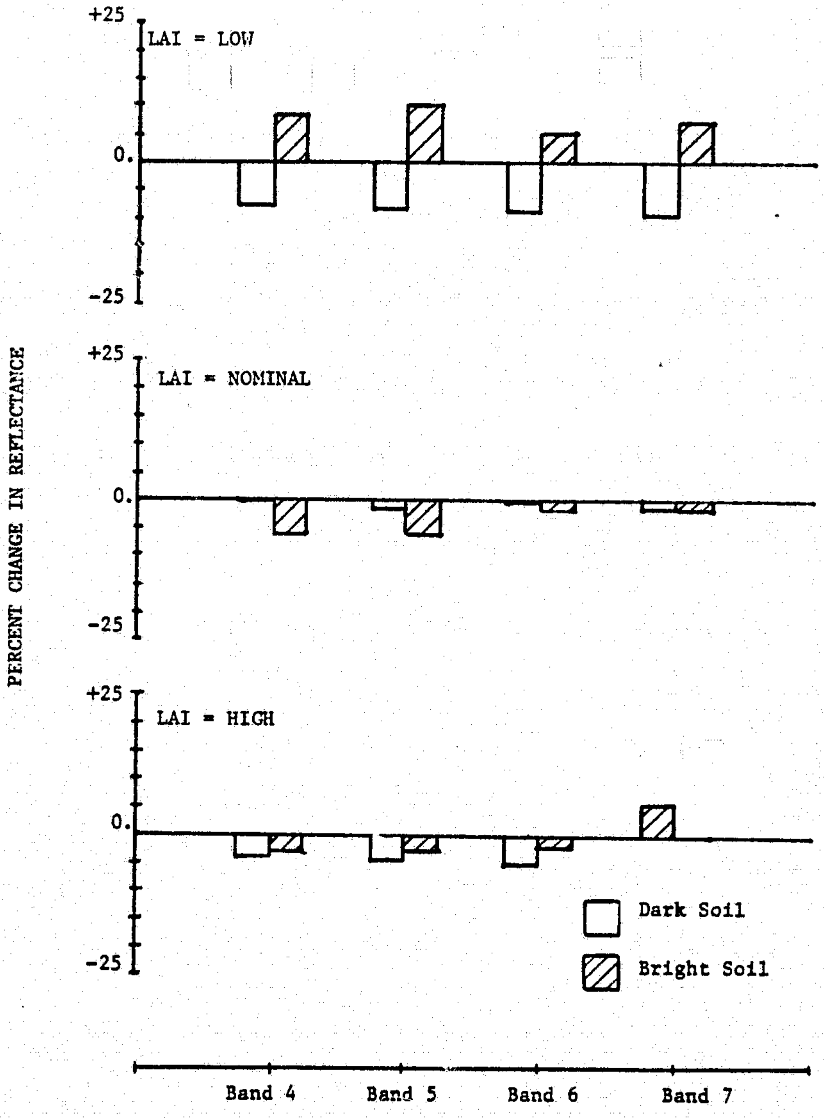


FIGURE 15. June Soil Effects

light/scene interactions with green vegetation, and effects of shadowing. The effects shown for the high density population during the May period indicates minimal response to both the dark and bright soil curves. In general, changes in the soil brightness of a wheat scene have a pronounced effect during the tillering stage with lesser effects experienced in the booting and heading stages.

Interpretation of Figure 15 (June Soil Effects) is different from those of the preceding three figures. At this stage of development the wheat canopy is beginning to senesce and turn yellow. In addition, much of the surface area presented toward the sensor is decreasing as the plant is wilting and losing some of its leaves. The optical properties of the vegetation constituents have changed dramatically. The unique interaction between the vegetative component and the background component has also changed as they have become more similar. This complex interaction is particularly apparent in the effects curve associated with the normal LAI.

4.0 COMPARISON OF SRVC AND ERIM MODEL RESULTS WITH FIELD DATA

This section compares the predicted results of the SRVC model with those of the ERIM model and field collected data. Benchmark runs of the SRVC model were made for each phenological stage using the best approximation of the model input parameters as determined by field measurements. These model predictions are compared with the average field measured canopy reflectance. Comparison of predicted values from the SRVC and ERIM models and field data are presented in several scatter plots.

Figure 16 shows the SRVC model predictions and the average field responses for each phenological stage. These curves should not be interpreted to represent absolute predictions but must be recognized to contain normal variance (10 to 20%). The agreement in the IR bands for March is excellent however, the model consistently overstates the reflectance in bands 4 and 5. This period is typically the most difficult to model due to the sharp contrast between the limited vegetative surface area and the pronounced "rowing effect". The April period shows excellent agreement in the visible bands, yet consistent model overstatement is shown in bands 6 and 7. This condition could arise from the difficulties in measuring green leaf constituent reflectance and transmission. In addition, the interaction between the bare soil component and the vegetation component discussed above may play a part. The model generally performs well during the May and June periods.

A graphical comparison of the three canopy reflectances determined from the SRVC, ERIM model, and the field measured data appears in Figures

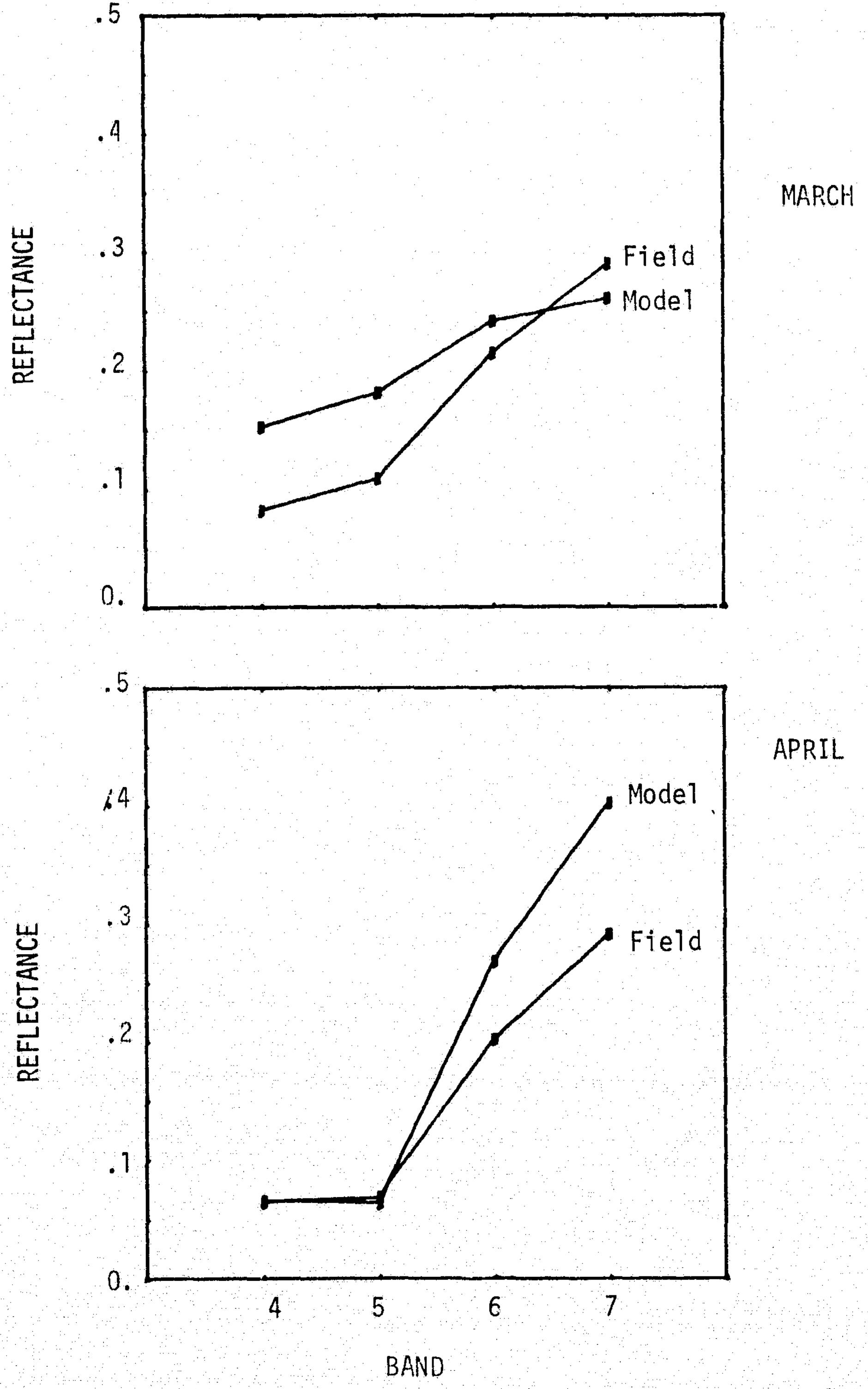


FIGURE 16 . Comparison of Model and Field Spectral Signatures

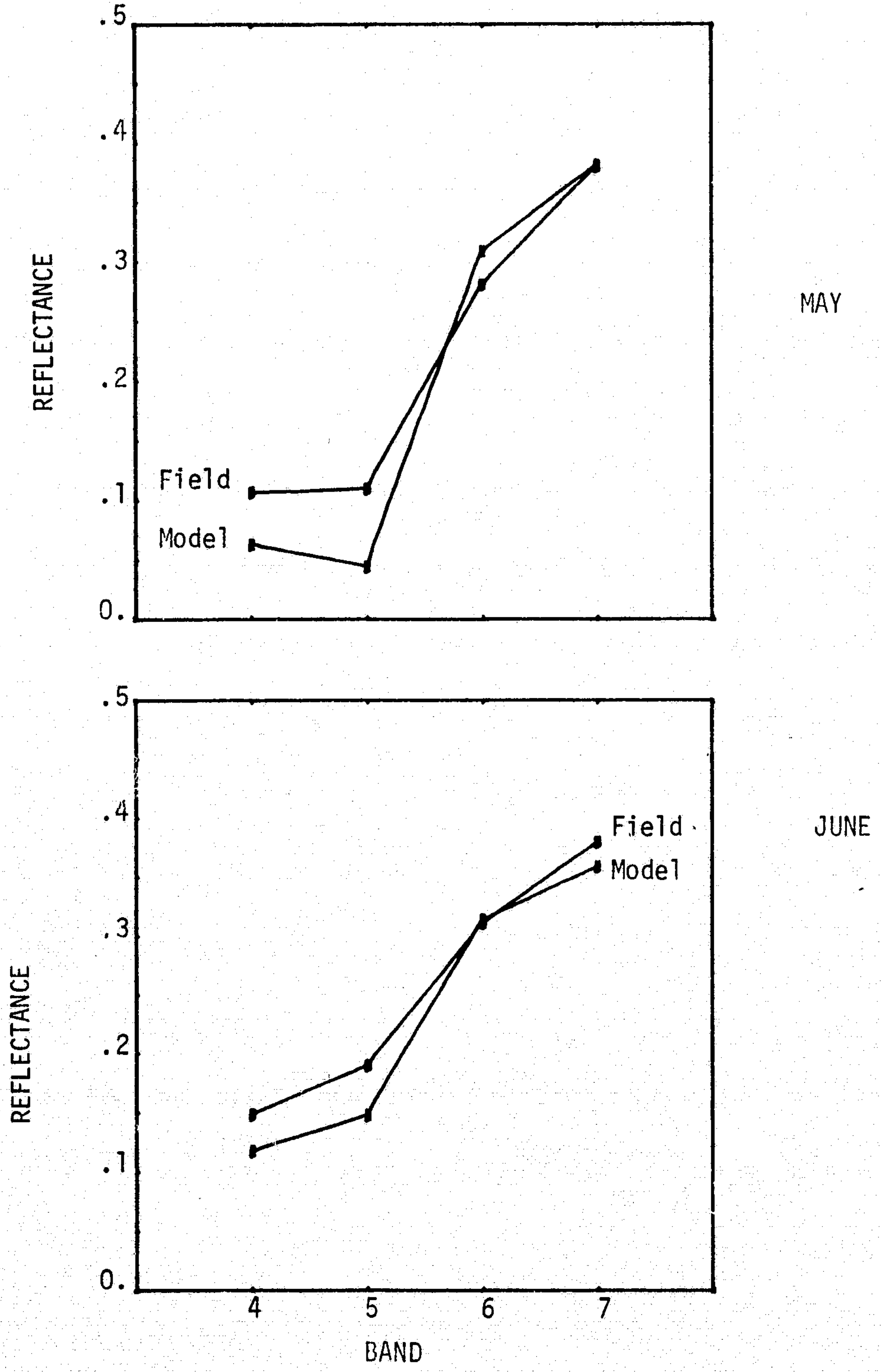
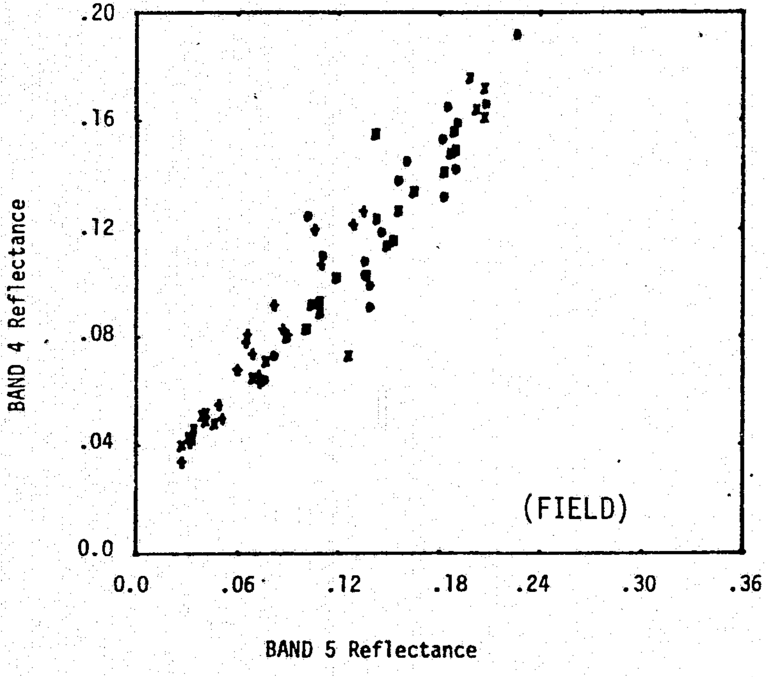
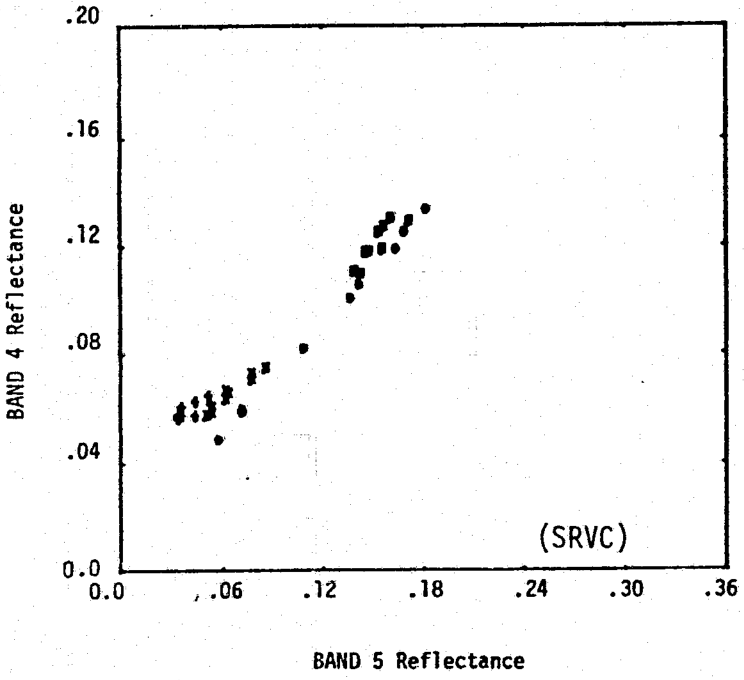
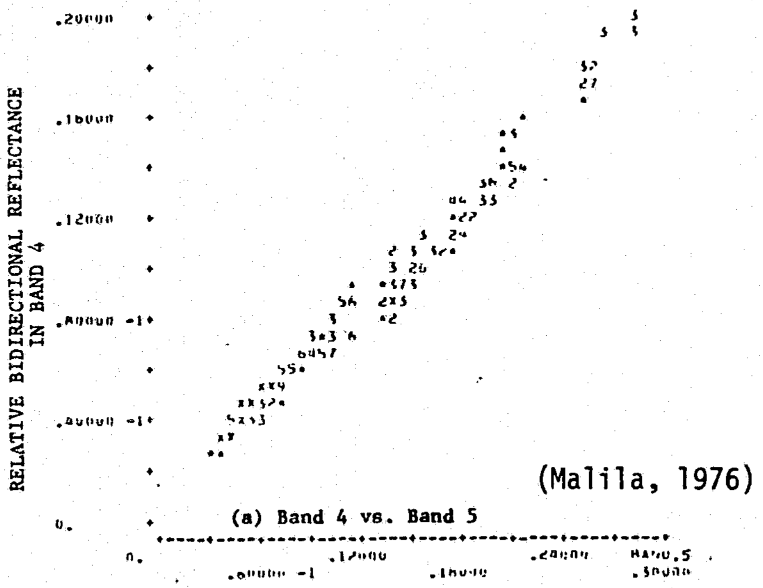


FIGURE 16. (Cont.)

17 through 22. Figures 17 through 19 identify scatter plots of the reflectance data in all phenological stages for band 4 vs 5, 5 vs 6, and 6 vs 7 respectively. Figures 20 through 22 are scatter plots in bands 5 vs 6 for the booting, heading and ripe stages. In general, there is reasonable agreement between all three data sets. Minor variations or shifts in relative clustering position are probably a function of variability in input parameters. Depending upon the resolution detail desired for wheat signature studies, it appears that both the SRVC and ERIM models may be used to augment and extend available field data. Selection of a particular approach would be dependent upon individual model characteristics. For example, the SRVC model is stochastic in nature, thus generating covariance matrices as well as the mean, and is easily modified through subroutines to describe different physical situations. On the other hand, the ERIM model is simpler to use and executes much faster.

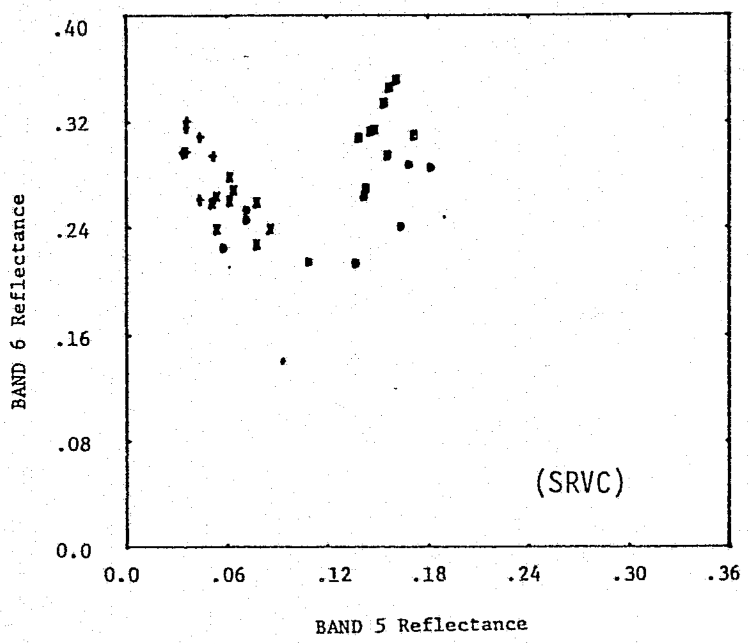


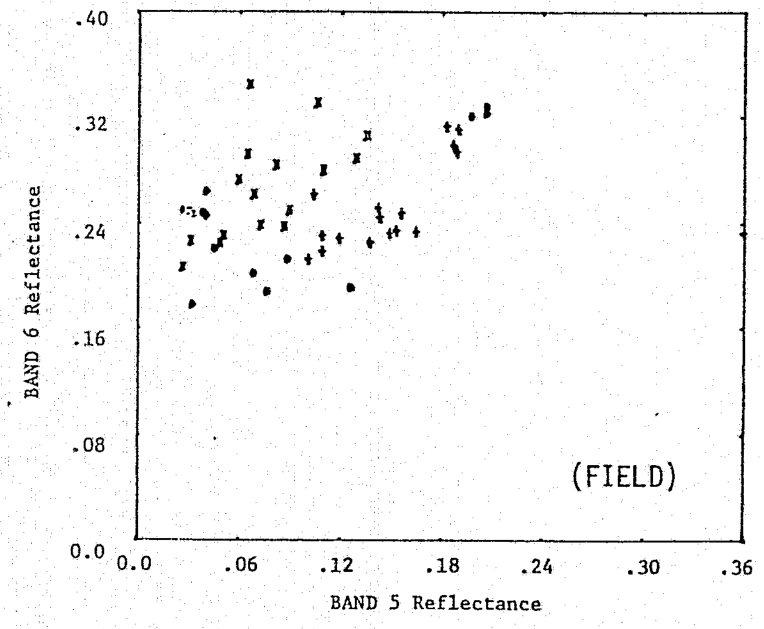




(Malila, 1976)

FIGURE 17. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 4 (All Phenological Stages)





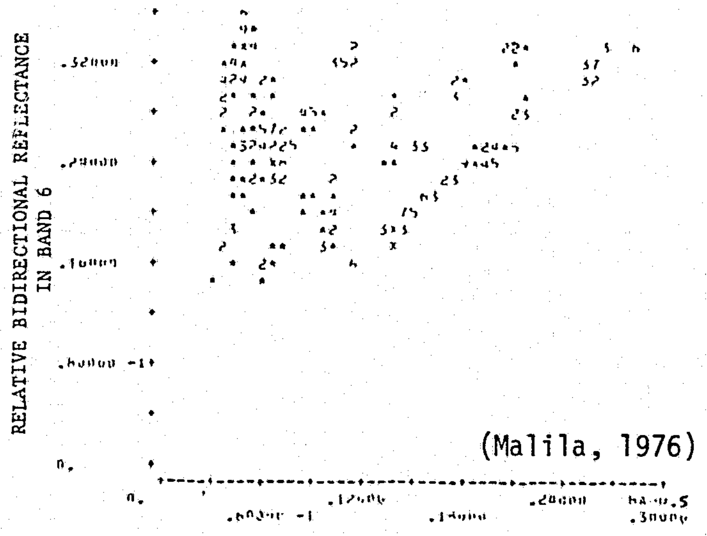


FIGURE 18. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (All Phenological Stages)

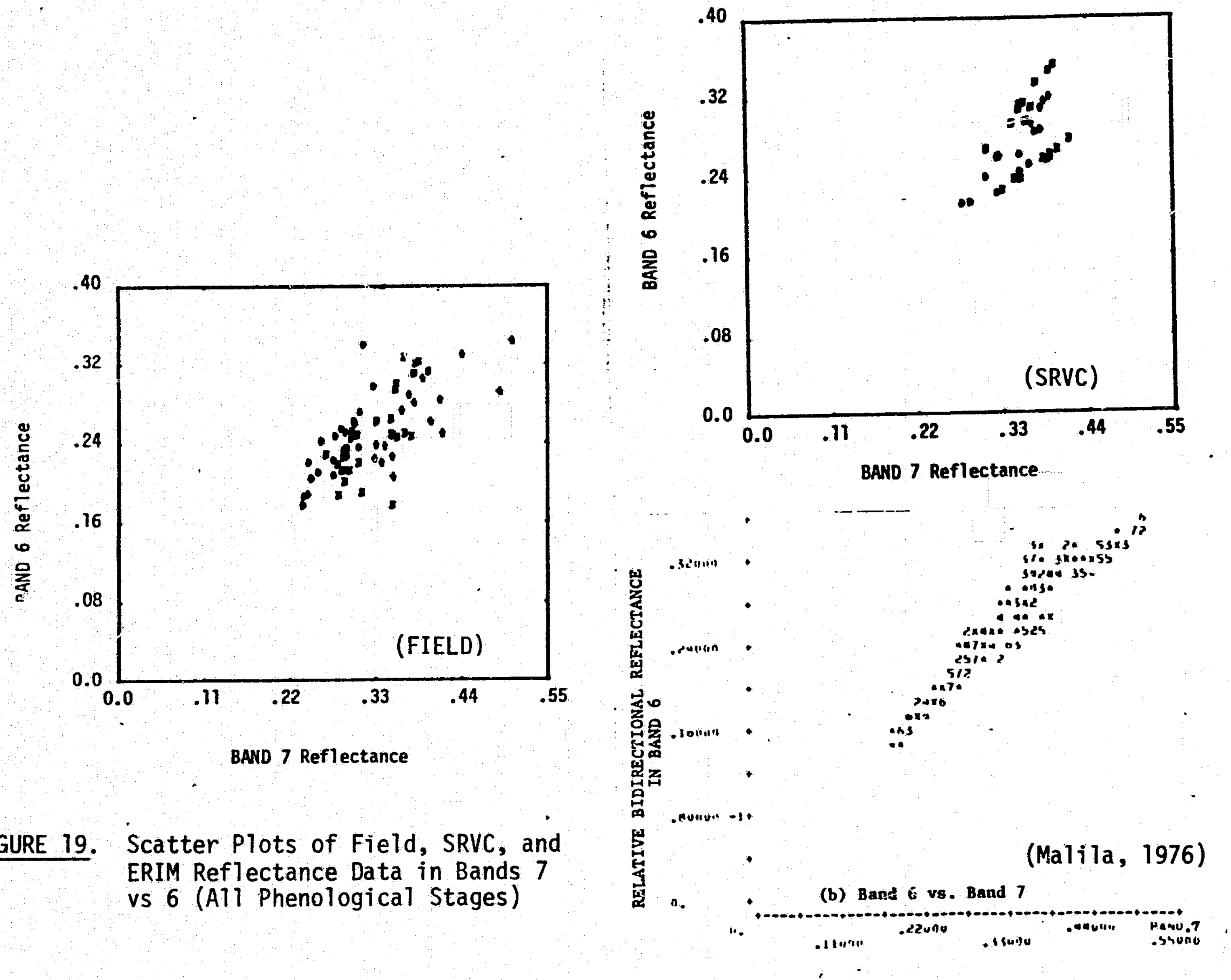
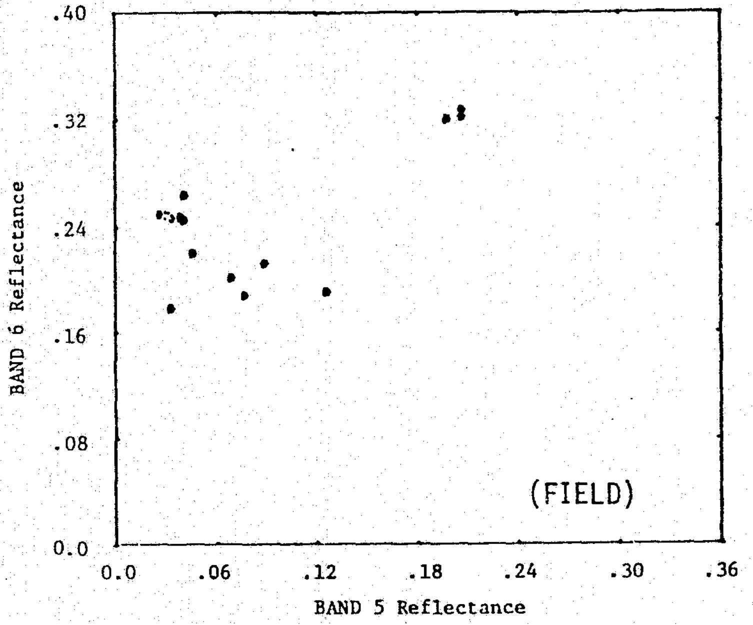
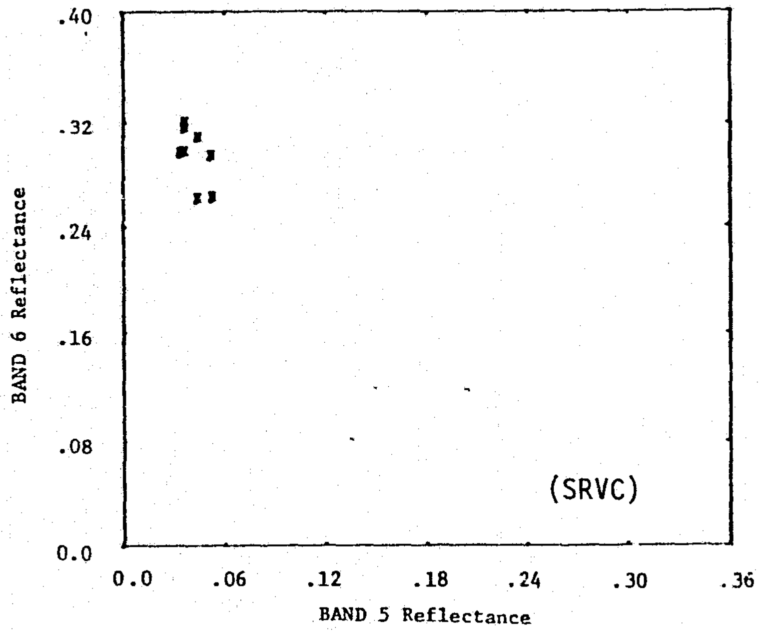


FIGURE 19. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 7 vs 6 (All Phenological Stages)





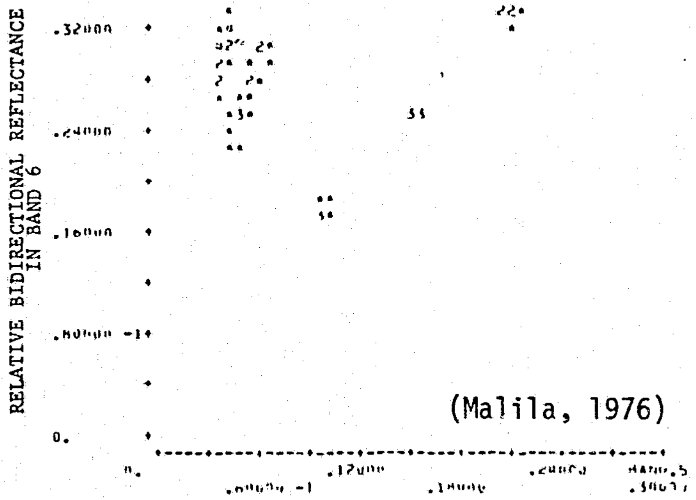
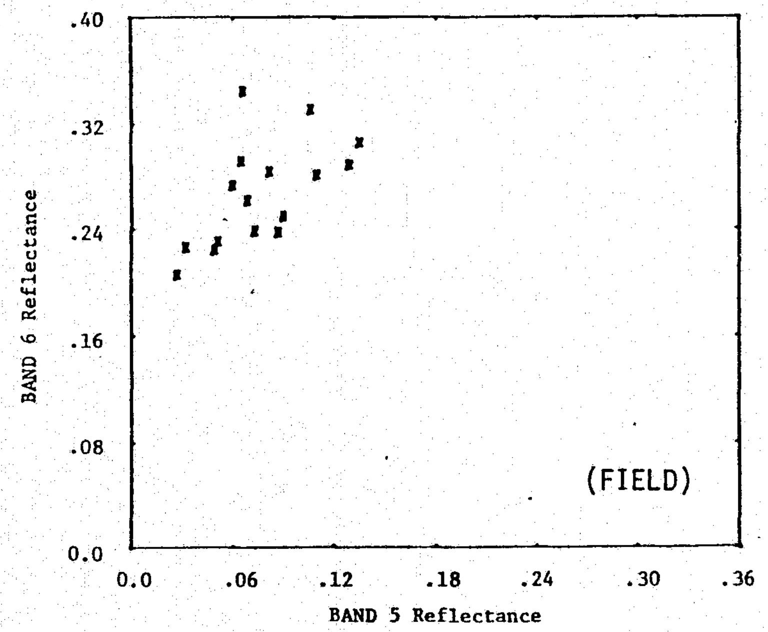
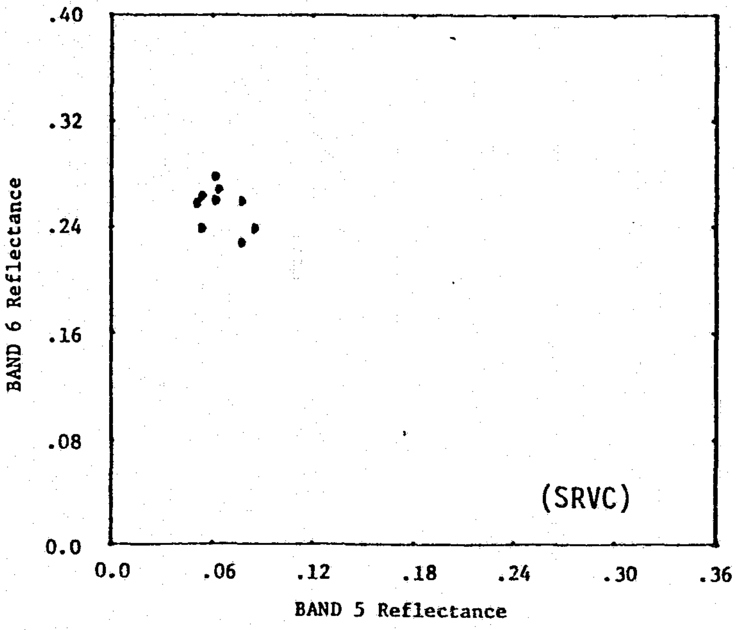


FIGURE 20. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Booting Stage).





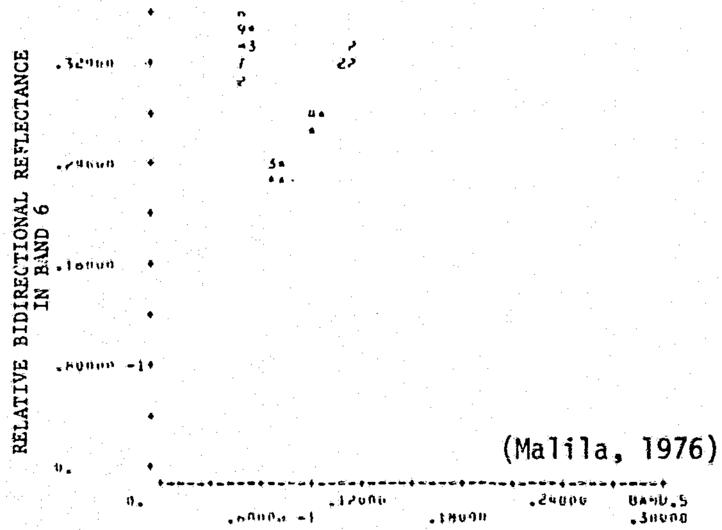
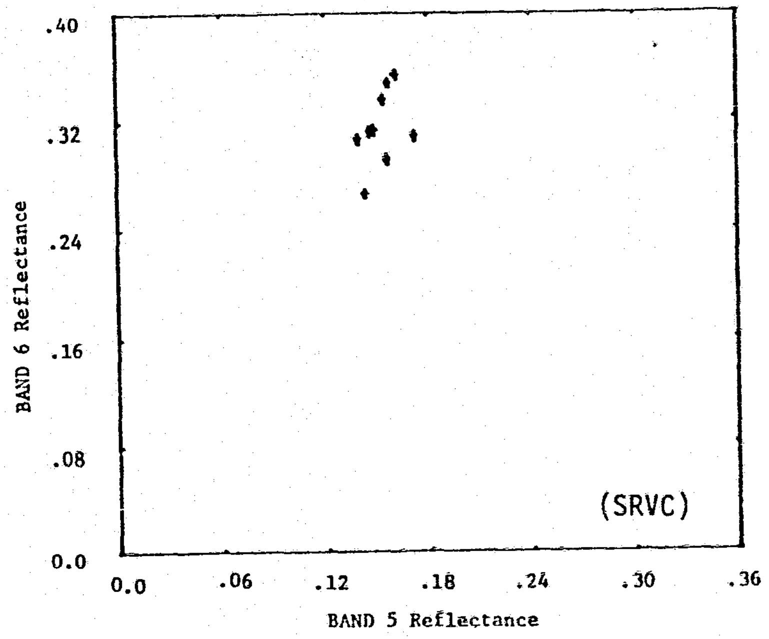
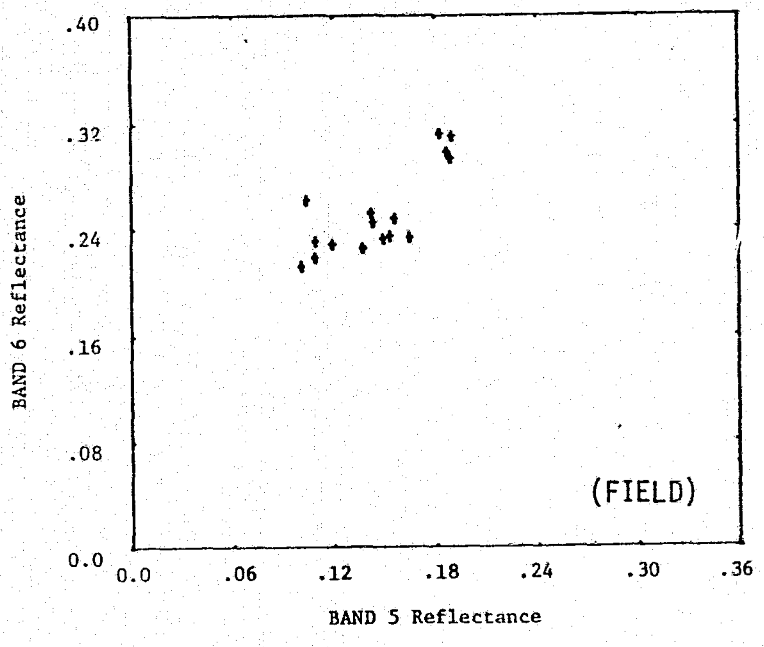


FIGURE 21. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Heading Stage)





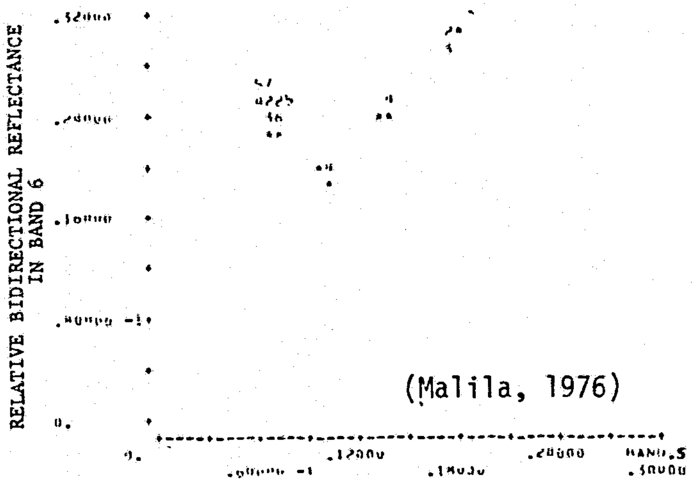


FIGURE 22. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Ripe Stage)

5.0 DATA TRANSFORMATIONS

This section describes the development and results using a fixed linear transformation of wheat responses in the four LANDSAT bands to isolate and enhance the effects of soil brightness. The discussion is divided into four subsections. The first identifies and describes the temporal trends of the model and field data presented in this report. These temporal trajectories define the pattern of development of the wheat crop, and can be a valuable source of information for both crop identification and the determination of crop status. The second subsection briefly discusses the "tasselled cap" configuration of agricultural crop spectral responses recently noted by the Environmental Research Institute of Michigan. Particular emphasis is given to the "plane of soils" projection of the data. The following subsection discusses the methodology of the fixed linear transformation and presents the results of the application of the transformation to both the model and field data used in this report. The final subsection is a discussion of the ramifications of the newly derived feature spaces.

5.1 Temporal Trends

A discussion of the temporal trajectories of LANDSAT data expressed in planar projections affords insight into the complex structure of the data. The resultant visual model of the data structure coupled with a reasonable physical interpretation has led to the development of transformed feature spaces which isolate plant development stages.

Figures 23 and 24 present the temporal trajectories for the 1975 field and model simulated data, and the 1976 field and model simulated data. Two of the possible six planar projections are represented: bands 5 vs 6, and bands 4 vs 5. These two displays were chosen to conform to the major point of the discussion of wheat trajectories presented by ERIM (Kauth and Thomas, 1976 a and b). The model data used in these displays are from the benchmark runs of both periods. All of the data sets display similar temporal responses. The bands 5 vs 6 projection shows a general triangular migration from the diagonal of the feature space toward the upper left corner and a return to the diagonal. The bands 4 vs 5 graph portrays a movement along the diagonal. In neither of the projections does any data fall below the diagonal.

A boundary region near the diagonal appears in Figure 23. All of the data lies to the left of this boundary and generally describes an upward directed triangle. Figure 24 shows a generally linear movement of the data along the diagonal. From the data patterns in these orthogonal projections it can be inferred that the three dimensional shape of the data in these projections is that of a flattened triangle. Similar interpretations of the planar projections shown previously in Figures 7 and 10 conclude that the four dimensional data structure also forms a somewhat flattened triangular shape.

A physical explanation of this shape stems from the process of normal crop development projected onto the bands 5 vs 6 feature space. Normally the spectral response of healthy green vegetation is low in band 5 and high in band 6. The responses for chlorotic plant material and bare soil are generally positively correlated, and demonstrate little

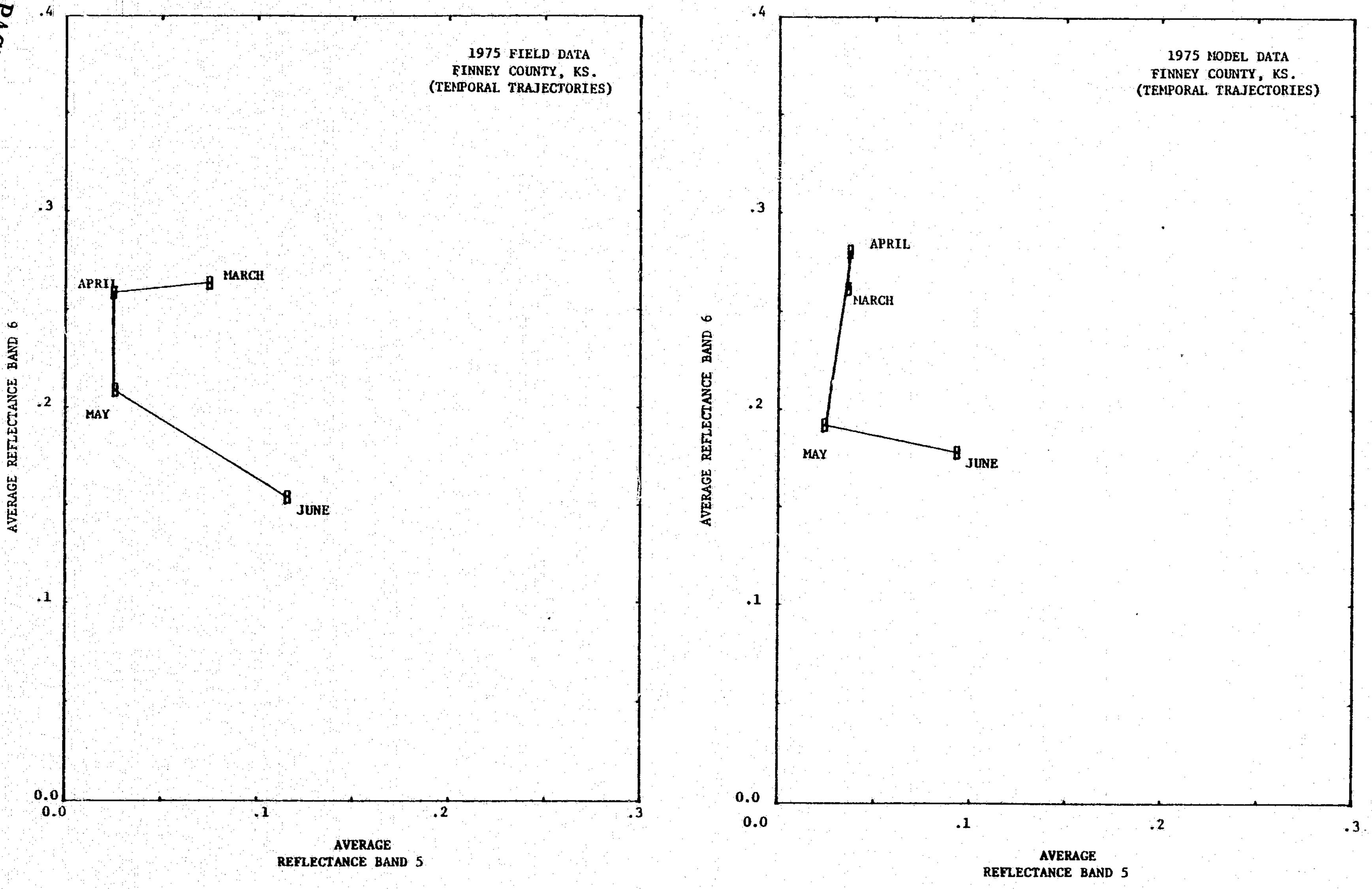


FIGURE 23. Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1975)

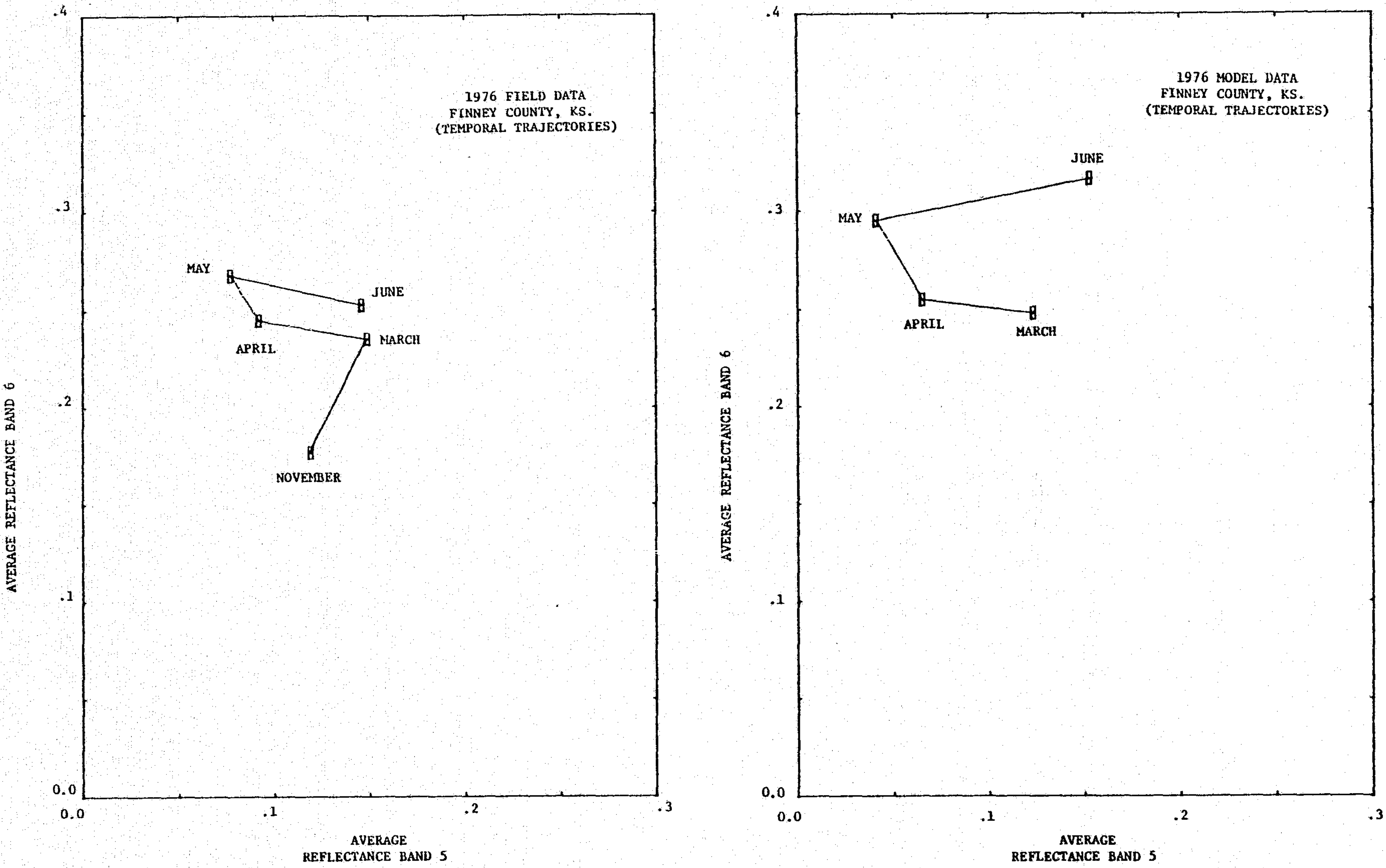


FIGURE 23 (Cont.) Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1976)

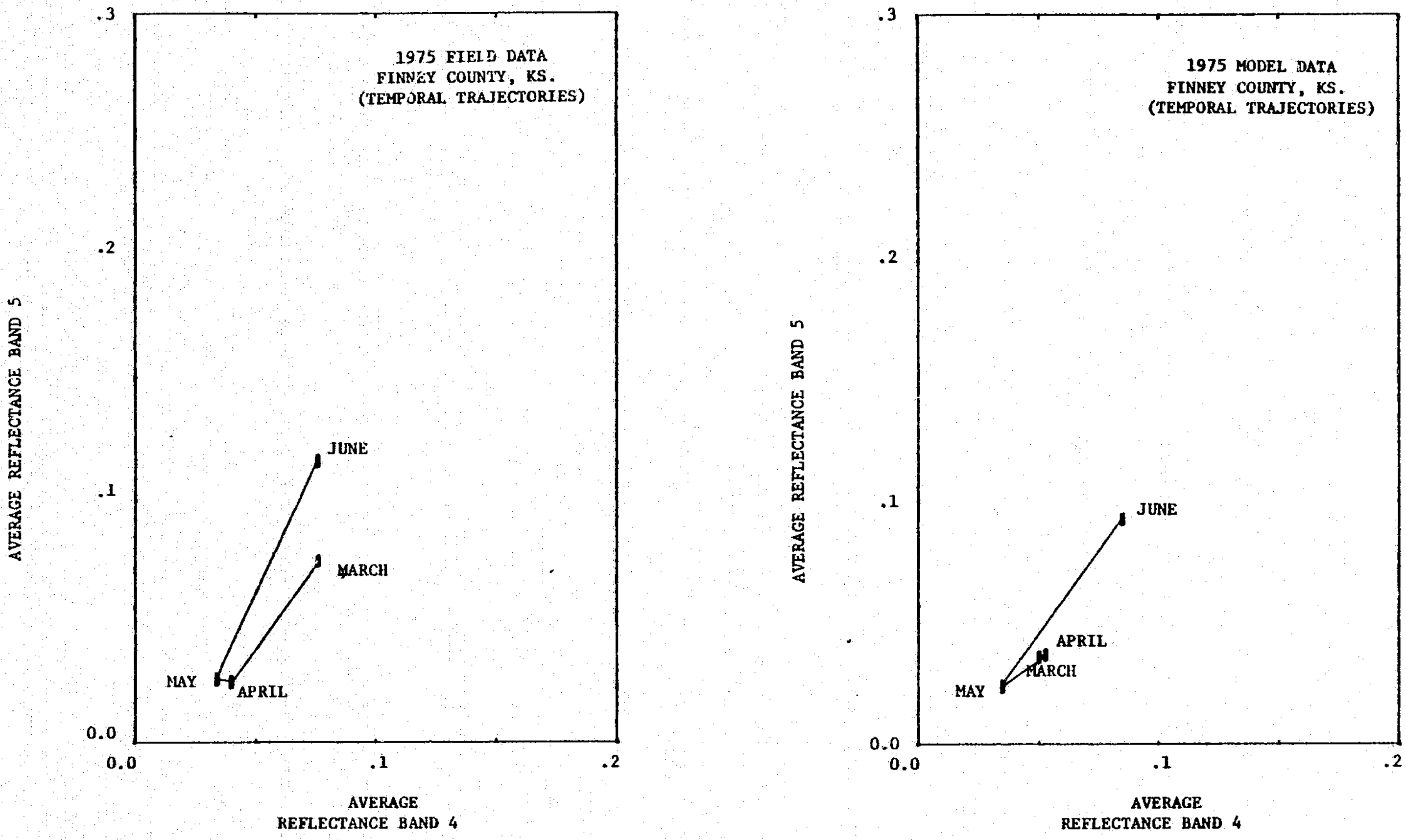


FIGURE 24. Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1975)

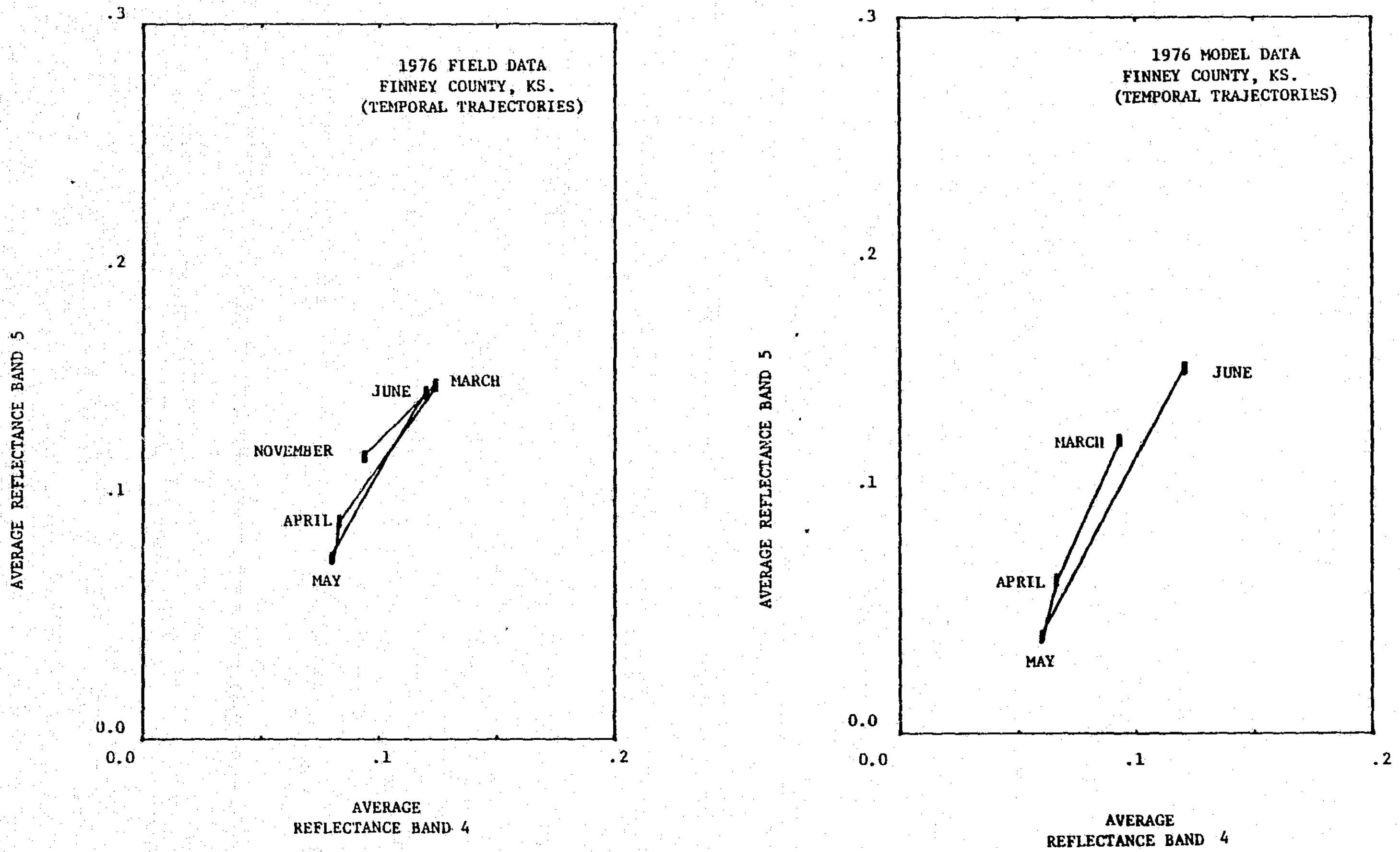


FIGURE 24 (Cont.) Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1976)

differences in bands 5 and 6. Changes in spectral response for these materials tend to have equal impact in both bands and describe a migration along the diagonal.

The crop starts its growth along the "line of soils" (diagonal), with its precise positioning determined by the brightness of the soil. As it develops, the composite reflectance, determined by the interaction of the individual soil and vegetation reflectances, generally increases in band 6 due to the presence of cellulose. The composite reflectance in band 5 generally decreases because of the presence of chlorphyll which is highly absorbing at these wavelenghts. The combined effects of these general responses denotes a movement of the data toward the upper left corner of the feature space as the canopy "greens". As the crop ripens a migration is noted back toward the diagonal, principally due to the influence of the chlorotic reflectance curve. A more detailed discussion and demonstration of these temporal response, as demonstrated in another data set, is made in the report by Kauth and Thomas (1976a).

Figure 25 shows the temporal trajectories associated with the soil brightness level simulations. A separate plot is made for each simulated plant population density and contains three trajectories representing the temporal movement of the crop under three soil brightness levels. In general the higher soil reflectance simulation for each of the plant populations demonstrated a higher response in both bands 5 and 6. In addition, as plant population density increased the "line of soils" shifted toward the left. The apparent distinctness of the triangular form is more pronounced at the higher plant density level. Also at the

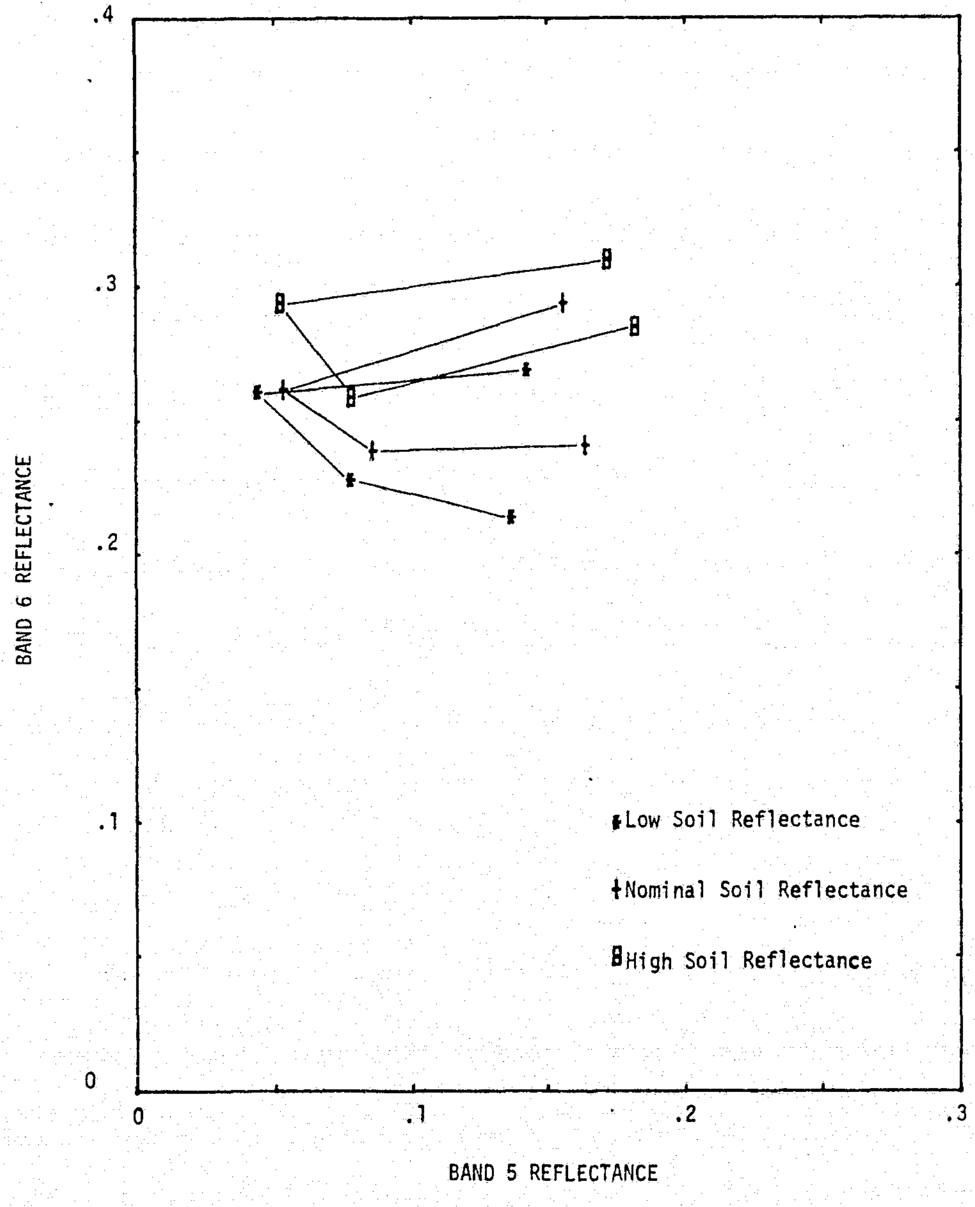


FIGURE 25 . Model Generated Temporal Trajectories (LAI = Low)

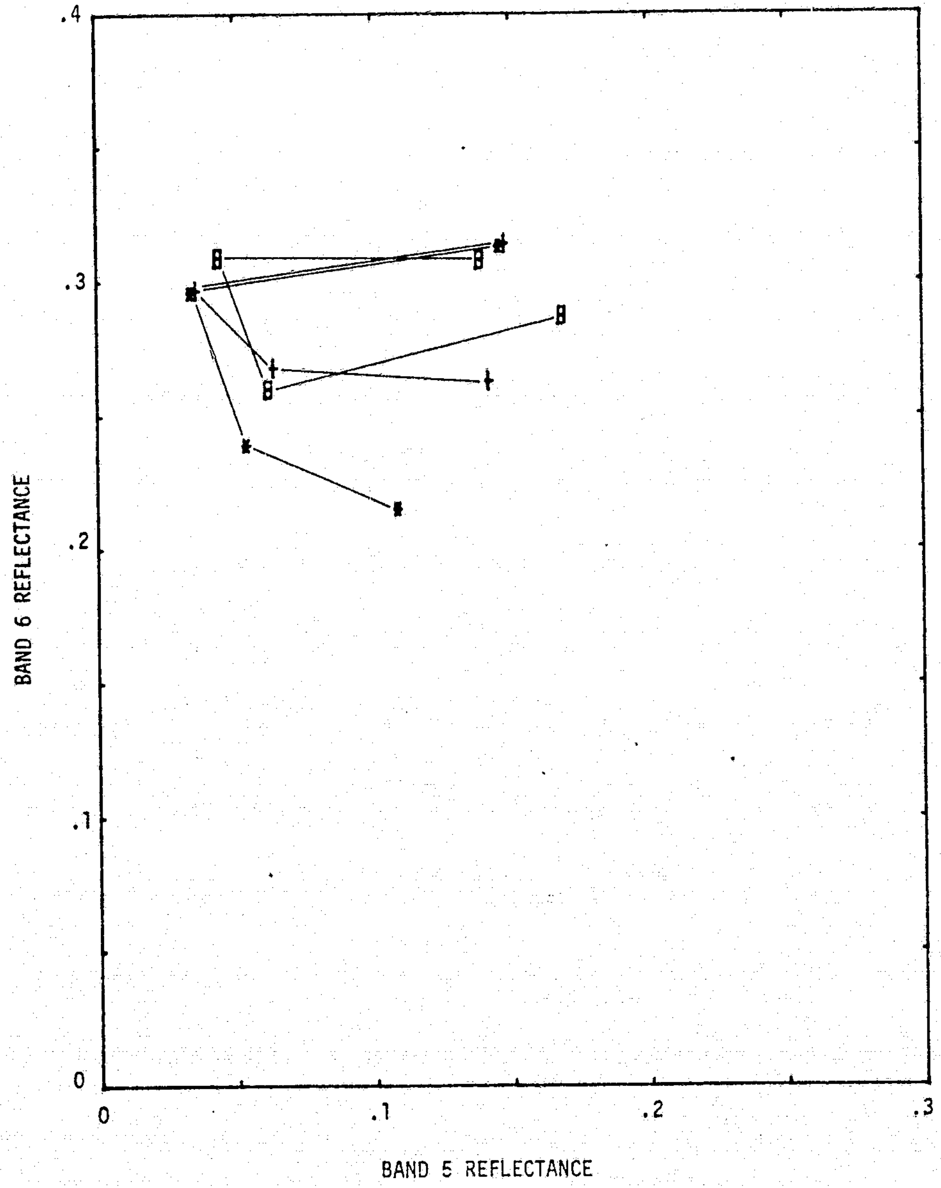


FIGURE 25 (Cont.) Model Generated Temporal Trajectories (LAI= Nominal)

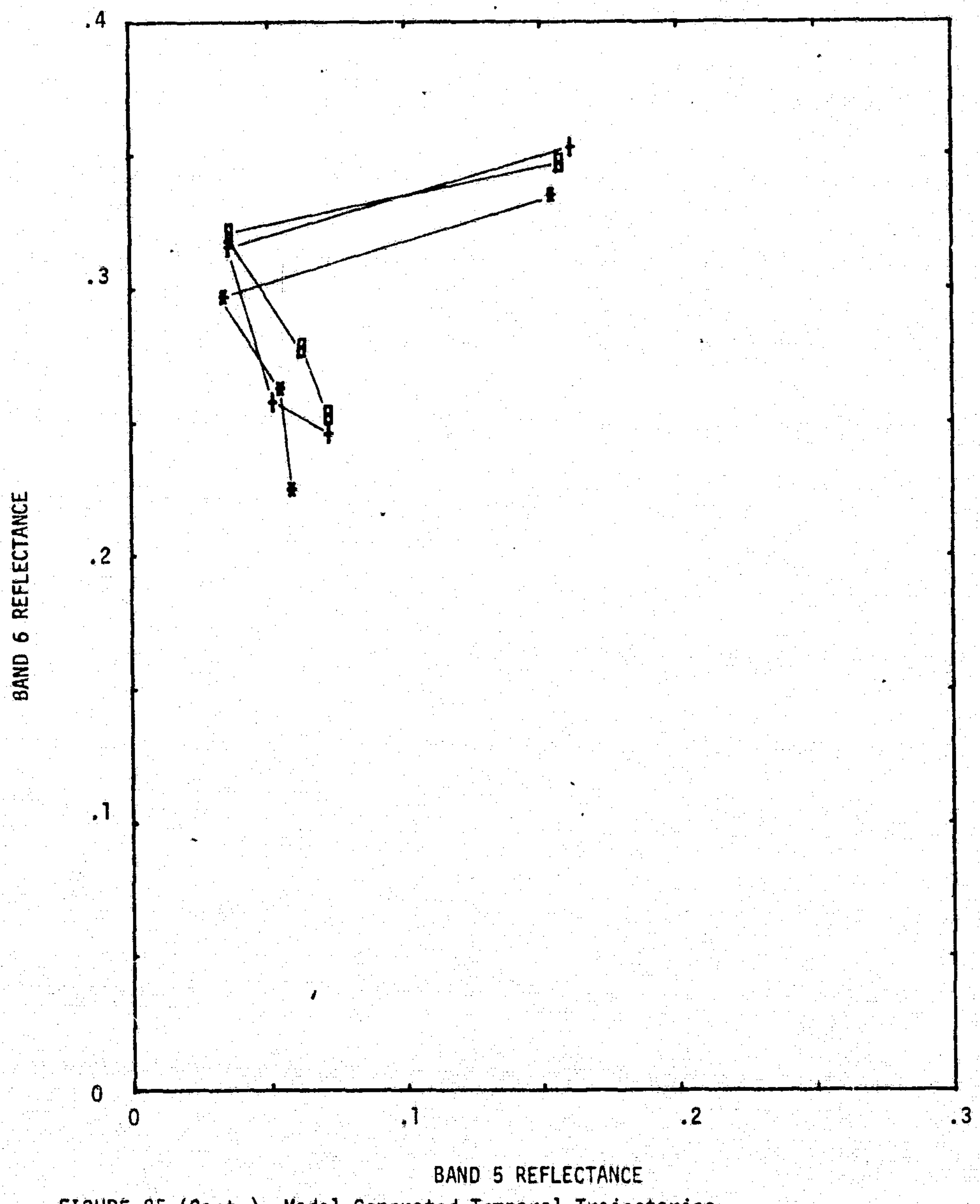


FIGURE 25 (Cont.) Model Generated Temporal Trajectories

(LAI = High)

higher density levels, soil brightness has little effect on the data displayed in the 5/6 projection.

In light of this review it can be stated that the triangular response is best observed in plant populations having relatively high LAI throughout their development, and that the overall pattern is minimally influenced by soil brightness. The dominant influence of soil color on these populations is in positioning of the pattern in the feature space. At lower plant densities, the influence of soil brightness is stronger throughout the temporal trajectory, and increases the deviation from the distinct triangular response.

5.2 The "Tasselled Cap" Concept

It was noted in the previous section that the general data structure of wheat spectral response could be visually conceptualized as a "flattened triangle" in four-space. The bands 5 vs 6 projection contained the greatest lateral spread of the data, and can be physically interpretated as the complex interaction of the individual soil and vegetation reflectance curves. Kauth (1976a) suggests that a better descriptor of this data structure is that of a "tasselled woolly cap". Figure 26 is a schematic of this concept. The crop starts its development on the "plane of soils", and as it grows, it progresses outward roughly normal to the plane of soils on a curving trajectory. The "fold of green stuff" is a plane representing the maximum "greening" of the crop. The positioning along this plane is determined primarily by soil brightness, plant density and the unique character of the radiometric and geometric parameters of the

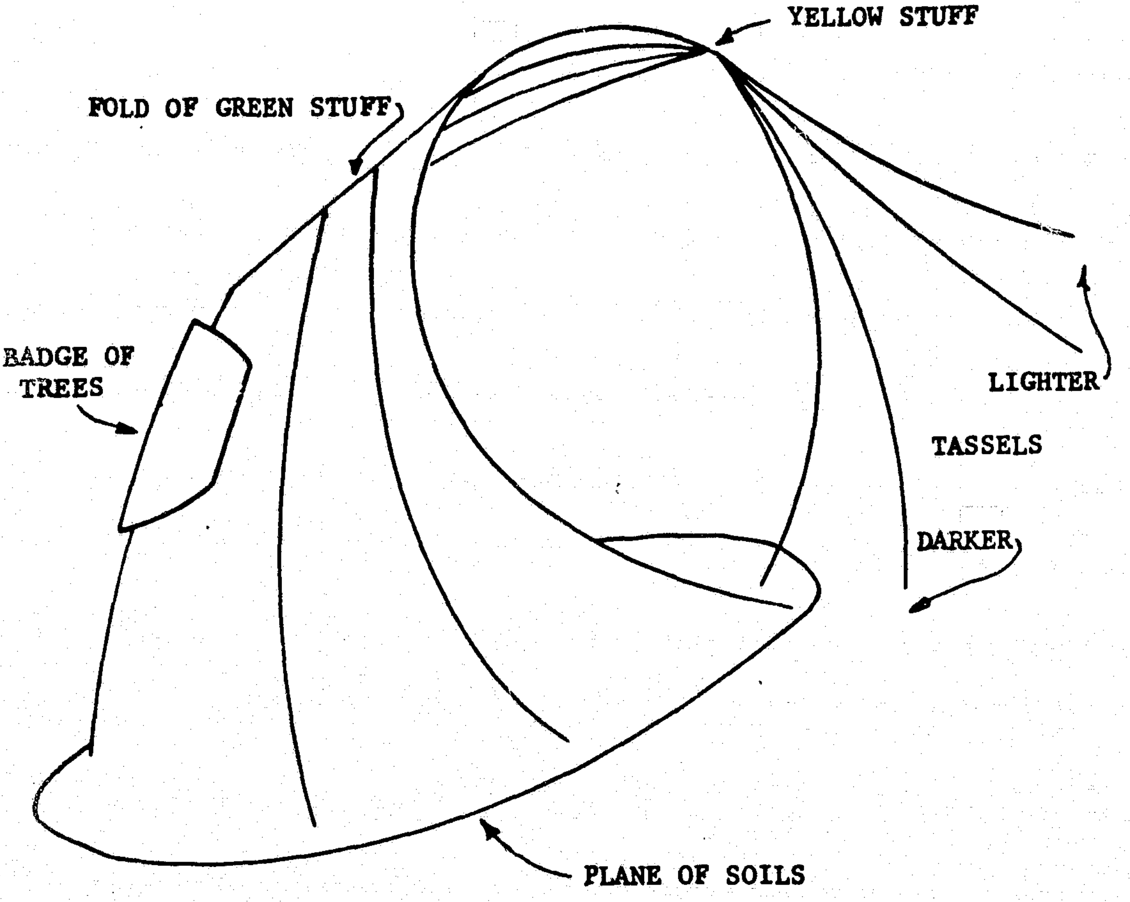


FIGURE 26. Schematic of "Tasselled Cap" Concept (Kauth and Thomas, 1976 b)

crop. As the crop ripens the spectral response folds over and converges on the region of "yellow stuff". Finally the crop progresses back to the plane of soils by any of several routes which are primarily controlled by harvesting practices and normal crop development. The effect of shadowing within the canopy is a function of crop geometry and density, and has a large influence on the convergence of the data between the "plane of soil" and the "fold of green stuff".

Of particular concern to this research is the concept of the "plane of soils". Analysis of Condit's (1970) soil reflectance measurements affords insight into the typical distribution of soil responses in the LANDSAT bands. The four-space soil data structure has a distinct diagonal in which the normalized reflectance of all the bands are equal (Kauth, 1976a). The mean reflectance of a typical soil lies near that diagonal, with its largest principal component nearly parallel to the diagonal and the remainder of the principal components relatively small. The ellipsoid of concentration associated with these principal components can be visually conceptualized as an "elongated flattened cigar", aligning with the diagonal (Kauth, ibid). This diagonal component of the feature space therefore contains the greatest variation in soil brightness, and is termed the "plane of soils".

5.3 A Fixed-Linear Transformation

The unique shape and orientation of the plane of soils and its relationship to the other major crop development features, suggests a linear transformation of the data which isolates soil brightness effects. The data transformation is designed to orient a major axis of the transformed feature space with the major direction of the "plane of soils". The remaining axes of the new feature space are orthogonal to this major axis as determined by the Grahm-Schmidt orthogonalization procedure (Curtis, 1970). In this procedure the second major axis is chosen to enhance the variation in the "green" dimension of the original data. The third axis of the feature space aligns with the "yellow" dimension. The final transformed vector is chosen to be orthogonal to the soil brightness green stuff and yellow stuff vectors and does not have a clear physical interpretation.

The equation used in this fixed transformation is,

$$u = R^T x + r$$

where,

x is the LANDSAT MSS signal vector in counts

u is the transformed vector also expressed in counts

r is an offset vector introduced to avoid negative values in the transformed data

R is a unitary matrix (the columns of R are unit vectors R_1, R_2, R_3, and R_4) which are all orthogonal to each other. The superscript T indicates the transpose of the matrix.

Thus the application of the transformation to the data (x) results in a pure rotation plus a pure translation. The components of R are determined in the manner described above utilizing field collected data. The transformation parameters used in this report are those reported in the work by Kauth and Thomas (1976b).

Program TASSEL (Appendix A) was developed to transform the data used in this study. The first major step of this program is to translate the simulated radiance values for both the model and field data into LANDSAT counts. The procedure used is based on the work by Oliver (1976):

$$\text{Counts} = N_s/N_c \times CF \times BW$$

where,

N_s is the sensor radiance expressed in milliwatts per square centimeter per steradian per micrometer

N_c is the sensor radiance gain factor

CF is the count factor

BW is the band width of the channel in micrometers

and the specific values used are, (Ref. ERTS User Handbook)

	N_c	CF	BW
Band 4	2.48	127	1
Band 5	2.00	127	1
Band 6	1.76	127	1
Band 7	4.60	63	3

Tables 12 and 13 and Figures 27 and 28 report the model and field data used in this report expressed in LANDSAT counts.

The second major step of the program transforms the data expressed as LANDSAT counts into the "tasselled cap" transformed feature space. The specific values used for R and r are,

$$R = \begin{bmatrix} .433 & -.290 & -.829 & .223 \\ .632 & -.562 & .522 & .012 \\ .586 & .600 & -.039 & -.543 \\ .264 & .491 & .194 & .810 \end{bmatrix} \qquad r = \begin{bmatrix} 32. \\ 32. \\ 32. \\ 32. \end{bmatrix}$$

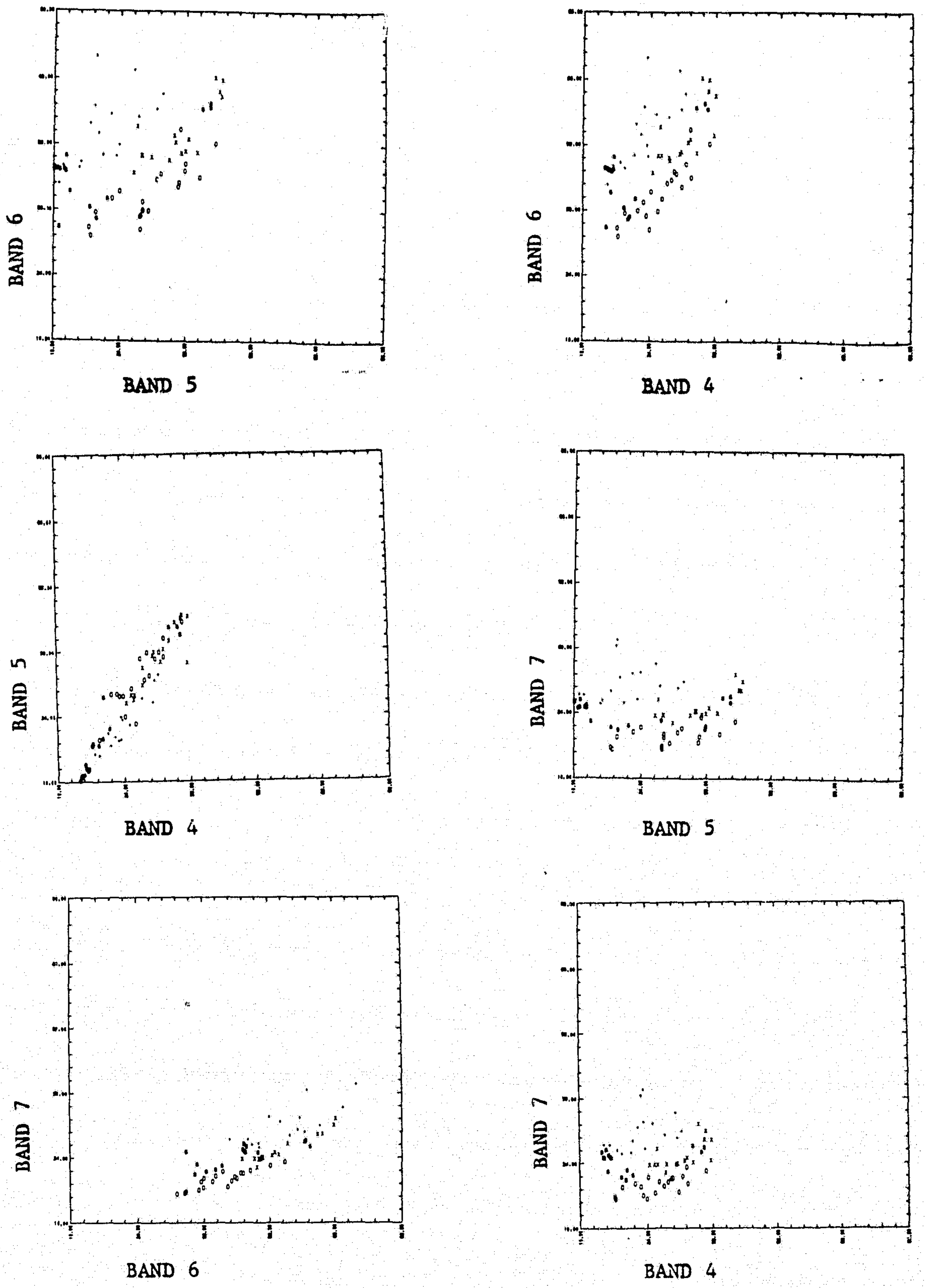
TABLE 12

CALCULATED LANDSAT COUNTS FOR FINNEY COUNTY FIELD DATA

Date	Plot	Band 4	 5	 6	 7
Mar	1	32	36	55	23
		28	31	44	19
		21	28	38	19
		22	28	39	18
		29	32	45	20
	2	32	40	45	19
		29	37	46	20
		27	36	43	18
		36	44	52	22
	3	30	36	43	17
		23	28	36	16
		25	30	37	17
		23	28	33	16
		31	37	47	21
	4	26	22	40	19
		17	17	32	16
		17	17	34	16
		18	19	37	18
		24	23	42	20
Apr	1	14	10	47	26
		14	11	34	25
		15	11	46	26
		15	10	46	25
	2	35	43	60	26
		36	41	59	27
		33	43	59	27
	3	18	17	38	20
		19	19	36	20
		19	28	36	22
		20	21	40	21
	4	15	13	41	22
		16	12	46	25
		16	12	46	25
		16	12	49	25
May	1	23	18	70	39
		22	18	60	38
		21	17	56	28
		23	23	51	32
	2	30	27	67	34
		27	27	58	30
		31	32	62	30
		30	31	59	29
	3	25	22	58	32
		22	19	54	31
		23	23	49	27
		20	20	49	26
	4	15	11	43	27
		16	12	47	27
		18	14	47	26
		17	15	48	26

TABLE 12 (Cont.)

		Band			
Date	Plot	4	5	6	7
Jun	1	37	35	53	24
		28	34	48	23
		30	37	50	23
		27	30	49	21
	2	36	45	65	30
		36	44	63	29
		37	45	62	28
		35	44	66	32
	3	30	36	50	23
		32	38	53	25
		33	40	50	24
		31	35	52	24
	4	24	26	46	23
		25	28	49	23
		26	28	49	23
		26	27	55	27



(Axis units: 10.-100. LANDSAT Counts)

FIGURE 27. Scatter Plots of Calculated Field LANDSAT Counts (O=March, $=April, .=May, X=June)

TABLE 13

MODEL GENERATED LANDSAT COUNTS

			Bands			
Date	LAI	SOIL	4	5	6	7
Mar	1	1	22	28	38	18
		2	25	33	42	21
		3	27	36	50	25
	2	1	20	23	38	19
		2	23	29	46	23
		3	26	34	50	25
	3	1	15	14	40	22
		2	16	17	43	23
		3	16	17	44	24
Apr	1	1	19	19	43	23
		2	20	20	45	24
		3	19	19	48	27
	2	1	17	15	45	25
		2	18	16	50	28
		3	18	16	48	28
	3	1	17	15	49	28
		2	17	14	48	27
		3	18	16	51	29
May	1	1	19	14	54	25
		2	19	16	54	25
		3	20	16	60	29
	2	1	19	12	60	28
		2	19	12	61	28
		3	20	14	63	30
	3	1	19	12	61	28
		2	19	12	64	30
		3	19	12	65	30
Jun	1	1	29	35	57	25
		2	31	38	62	28
		3	32	41	65	30
	2	1	30	36	66	28
		2	30	36	66	29
		3	29	34	65	28
	3	1	32	38	70	30
		2	33	39	74	32
		3	32	38	73	31

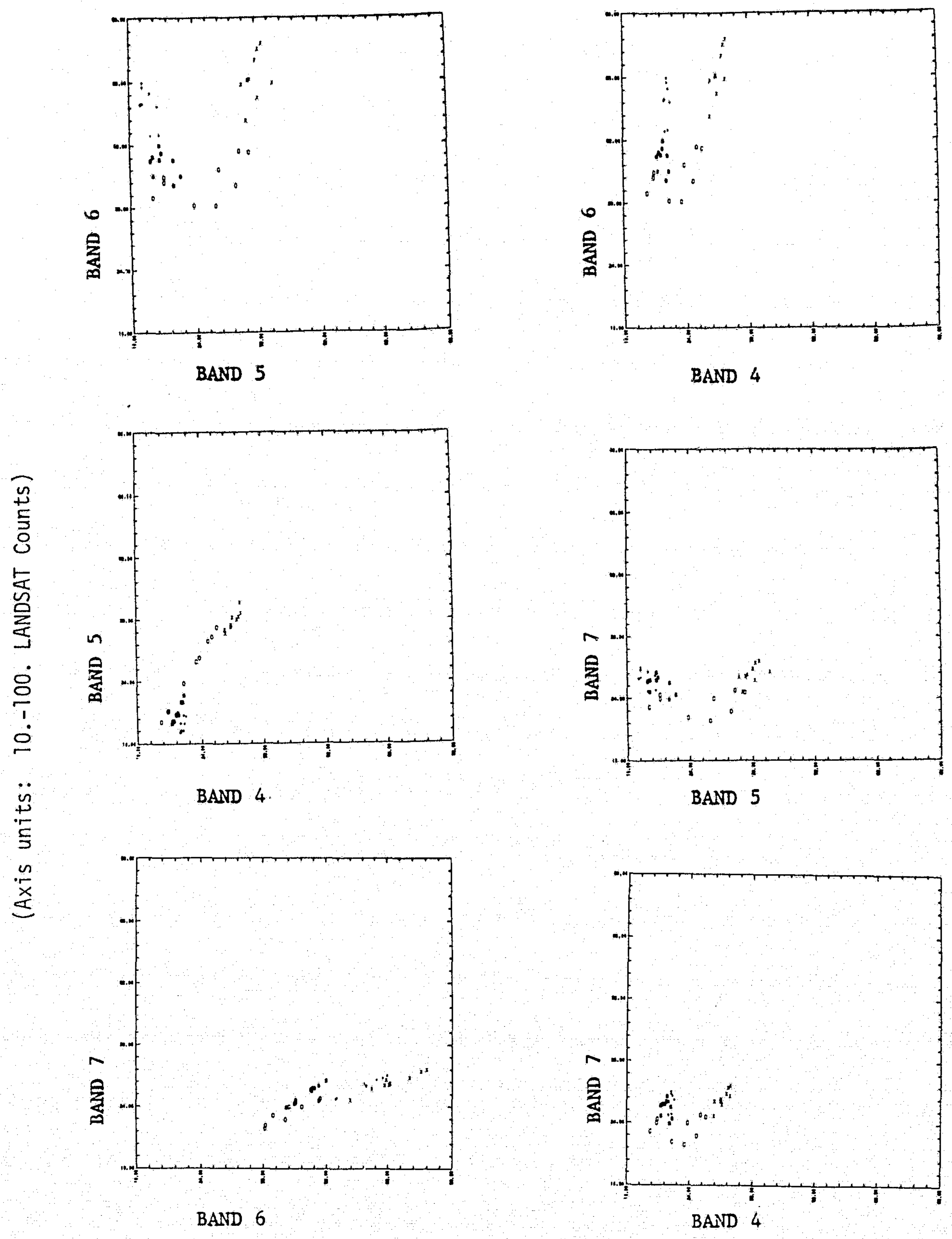


FIGURE 28. Scatter Plots of Model Generated LANDSAT Counts (O=March, $=April, .=May, X=June)

Tables 14 and 15 and Figures 29 and 30 identify the transformed LANDSAT counts associated with the field and model generated data respectively. The figures depict the two dimensional projections of the data in the transformed space corresponding to the axes of green stuff (GS), soil brightness (SB), yellow stuff (YS), and non-such (NS). These plots have excellent agreement with those reported by Kauth (1976a) for LANDSAT determined clusters. However, in addition, they represent the first published verification of his concept using ground-based field measured data. The projection in the two dimensional feature space of soil brightness and green stuff contains almost all of the variation within the transformed data set. The familiar triangular shape is present but is now rotated so that the soil line is parallel with the soil brightness axis (SB). The data spread associated with the soil brightness axis for both the model and field data is between 60 and 140 LANDSAT counts. The largest portion of the data variance is between 60 and 100 with the responses for June (X) being contained between 100 and 140. The SB versus GS projection for the model generated data displays a pronounced "U-shape". The pattern is less distinguishable in the field data. This response, with the June data extending to the right, may indicate that there may be some confusion between yellow stuff and soil brightness. This might further indicate that the selection of the R_1 vector is not truly aligned with the actual soil brightness dimension of this data.

TABLE 14

CALCULATED LANDSAT COUNTS FOR FINNEY COUNTY FIELD DATA
(Transformed)

		Band			
Date	Plot	SB	GS	YS	NS
Mar	1	107	46	26	29
		95	42	27	31
		86	41	31	32
		88	42	30	31
		97	42	26	31
	2	103	36	28	31
		100	40	29	31
		97	39	30	30
		112	38	26	31
	3	98	37	27	31
		85	39	29	31
		88	38	28	32
		84	37	28	33
		103	40	27	31
	4	86	45	24	33
		74	44	28	32
		75	45	28	31
		78	47	28	32
		87	46	26	32
Apr	1	79	63	28	32
		72	54	29	37
		80	62	28	33
		79	61	28	31
	2	117	46	27	29
		116	47	26	31
		116	47	29	30
	3	79	50	28	33
		79	47	28	34
		85	43	33	35
		83	48	28	32
	4	77	55	28	31
		80	60	27	31
		80	60	28	32
		82	62	27	30
May	1	105	76	27	32
		99	69	28	36
		93	63	27	30
		96	59	29	36
	2	111	65	25	31
		103	57	27	32
		111	57	26	31
		107	55	26	31
	3	99	63	26	33
		94	62	27	34
		93	55	27	33
		89	57	28	31
	4	78	61	29	35
		81	62	28	33
		84	58	27	32
		85	59	28	32

TABLE 14 (Cont.)

Date	Plot	Band SB	GS	YS	NS
Jun	1	108	45	21	32
		100	45	29	32
		105	43	29	32
		98	46	27	30
	2	123	50	28	31
		120	48	28	30
		121	47	27	31
		122	52	29	31
	3	104	44	28	32
		108	45	27	32
		107	41	27	33
		105	46	26	31
	4	92	49	28	32
		96	49	28	31
		96	49	27	31
		100	55	27	30

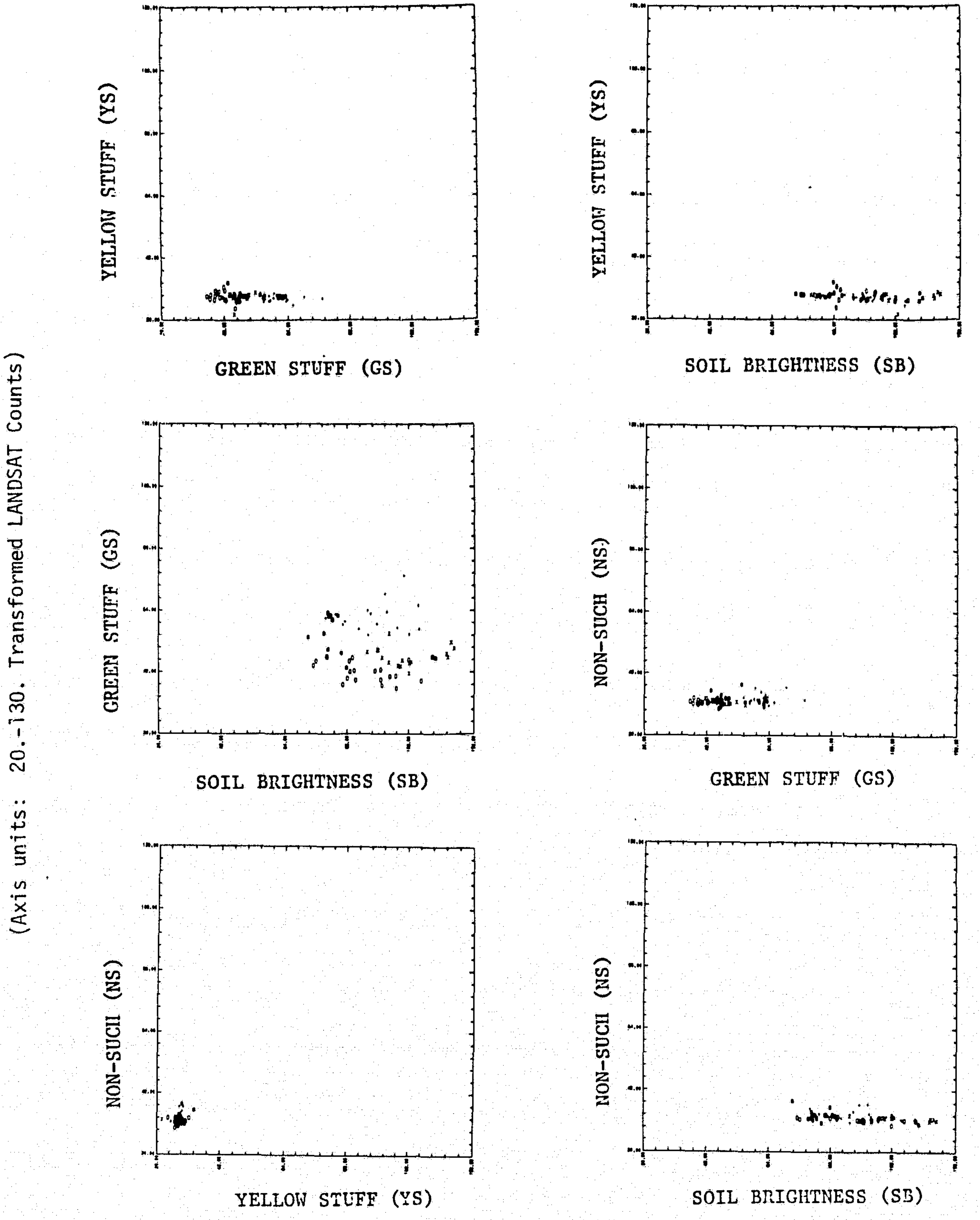
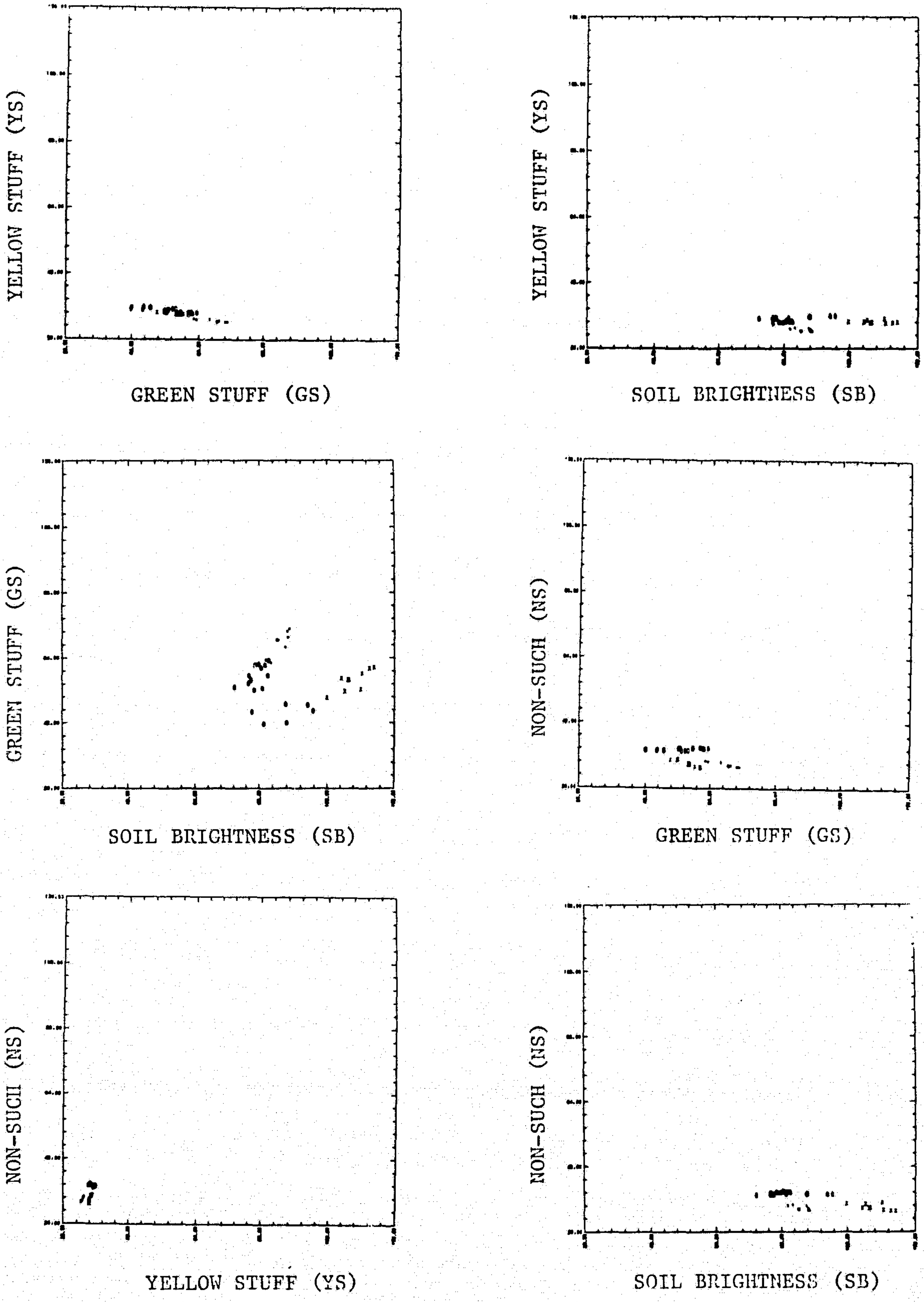


FIGURE 29. Scatter Plots of Calculated Field LANDSAT Counts (Transformed) (0=March, $=April, .=May, X=June)

TABLE 15

MODEL GENERATED LANDSAT COUNTS
(Transformed)

Date	LAI	SOIL	Bands			
			SB	GS	YS	NS
Mar	1	1	87	41	30	32
		2	94	41	30	32
		3	103	46	30	32
	2	1	83	45	30	32
		2	94	48	30	32
		3	101	48	30	32
	3	1	77	54	29	32
		2	82	55	30	32
		3	83	56	30	32
Apr	1	1	84	52	28	33
		2	86	53	29	33
		3	88	57	29	33
	2	1	82	57	28	33
		2	87	61	28	33
		3	86	60	28	33
	3	1	85	61	28	33
		2	84	61	28	33
		3	88	63	28	33
May	1	1	88	63	26	28
		2	89	62	26	29
		3	94	67	26	28
	2	1	91	69	25	27
		2	91	69	25	27
		3	95	70	26	27
	3	1	91	70	25	27
		2	94	72	25	27
		3	95	73	25	27
Jun	1	1	107	50	28	29
		2	113	52	29	29
		3	119	53	29	29
	2	1	114	56	28	27
		2	115	56	28	28
		3	112	57	28	28
	3	1	119	58	28	27
		2	123	60	28	27
		3	121	60	28	27



(Axis units: 20.-130. Transformed LANDSAT Counts)

FIGURE 30. Scatter Plots of Model Generated LANDSAT Counts (Transformed) (0=March, $=April, .=May, X=June)

5.4 Discussion

The effect of the transformation on the original LANDSAT counts data is to increase the apparent size of the tasselled cap by changing the four-space perspective so as to view the cap directly from the side. The data structure is more easily conceptualized from the orthogonal plane of projections in this transformed space. The dynamics of the data becomes more apparent and the physical determinants of the temporal trajectory can be isolated.

Of particular interest to this research is the dimension of soil brightness (SB). As noted earlier the influence of soil brightness is shown as the data spread along the SB axis in the transformed space. Detailed review of the model data displayed in Figure 30 reveals a general increasing response along the soil brightness axis for the simulated increases in scene soil reflectance. This is particularly apparent for the March data (0). In general, it can be stated that increases in soil brightness within a phenological stage results in increased SB axis response. However, the comparison of responses at different phenological stages does not afford a relative ranking of scene soil brightness. This is particularly apparent in the differences between the June model data (X in Figure 30) which were generated using the same three soil reflectance levels as those for April ($). Consideration of a single field's relative response along the SB axis for each phenological stage should afford insight as to its soil reflectance. This information is useful in developing training set statistics and their signature extension. The relative response of individual fields in the emergent or tillering stages would be of particular value in the early categorization of wheat response over a broad area.

In addition to the use of the transformed data for field statistics and extensions, image display of the SB band isolated soil brightness variability in the scene. Similar displays of the green stuff and yellow stuff bands show relative field variation in these components. Concurrent interpretation of the individual images should greatly assist in the field categorization and the review of classification. Kauth (1976b) suggests other potential uses of the transformed data which include feature selection and corrections for environmental factors such as sun angle and atmospheric dynamics.

Two important contributions of this research with respect to the tasel1ed cap concept are apparent. First it identifies an additional data set for wheat canopy reflectance derived from actual field measurements which displays the tasselled cap structure. This data set is especially applicable in analyzing the transformed space because of the accompanying detailed record of scene variables corresponding to individual canopy reflectances. Secondly, the model generated data set is particularly valuable in analyzing the soil brightness dimensions of the derived feature space, since this varaible was varied in a known and controlled manner.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The results of the research reported in this paper can be categorized into three types: field data base, model simulations for soil effects, and data transformations to isolate soil effects. Section 2.0 discussed the collection procedures used in the field measurements and presented the data in a series of graphs and tables. The results of the model simulation were presented in Section 3.0, while Section 4.0 benchmarked these results with those of the field collected data and another canopy model. Section 5.0 discussed the temporal trajectory associated with both the model and field data and identified a linear transformation which can be used to isolate soil effects.

The field data set presented is particularly useful as it expands the detailed data base collected in the 1974-75 field season. The field selected for study during the recent field season was drastically different in management practices. These differences proved valuable for the evaluation of the model fidelity under diverse conditions and provided insight into the magnitude of variance between fields in the same general vicinity. The use of sacred plots for periodic radiometric measurements of the canopy afforded a strong data set to illustrate temporal influences.

General agreement among the SRVC. the ERIM model and the field data was noted. The simulated data for June, representing the ripe phenological stage, recorded the largest disagreement between the three data sources. The soil effect simulations showed that the soil component of scene reflectance was generally most influencial in the March and June periods. In addition, increases in canopy density at any phenological stage tended to limit soil effects. In the two dimensional feature space (Bands 5 vs 6) the temporal trajectories of denser plant populations portrayed a more distinct triangular shape, and were shifted upward toward the left.

The investigation of a linear transformation to enhance soil effects demonstrated the "tasselled cap" structural form in both the field and model data. The soil brightness axis of the derived feature space expresses relative differences in soil brightness within a given phenological stage. Relative ranking along this axis for responses in different phenological stages does not appear appropriate. Further research is necessary to confirm the applicability of this approach to signature extension problems between diverse regions. The transformed data, however, should have significant influence on training set selection and interpretation of classification results.

It is recommended that analysis and further interpretation of the "green stuff" and "yellow stuff" transformed axes be performed. Two complete years of measurements of canopy reflectance and concurrent constituent optical properties now are available. A modeling effort to simulate different levels of constituent reflectances would reinforce these data.

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APPENDIX A: FIELD DATA PRESENTATION (1975-1976)

A. Tillering : March 13, 1976
B. Booting : April 17, 1976
C. Headed : May 16, 1976
D. Ripening : June 13, 1976

FIELD DATA SET PRESENTATION

A. MARCH 13, 1976 TILLERING STAGE FIELD 107

Crop Type: Eagle Wheat

Height: 7-10 cm

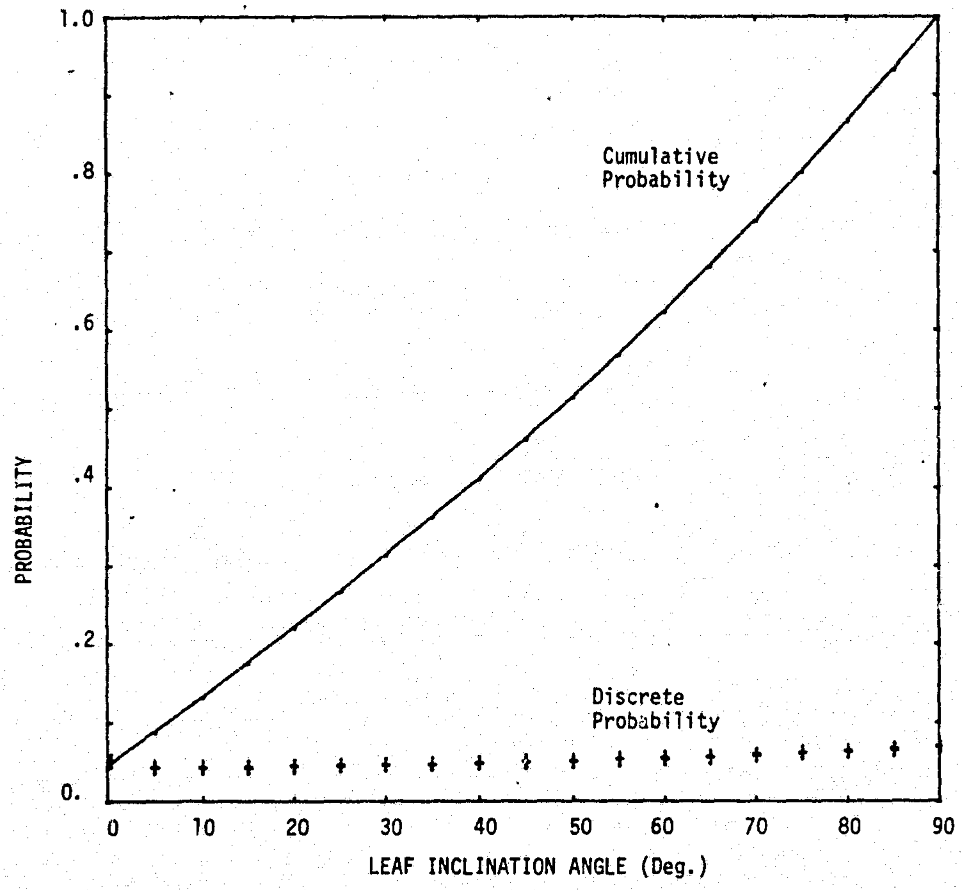
Chlorotic: 0%

Weeds: 0%

Soil: Dry

Wind: 15-20 mph W-SW

	PLOT 1	PLOT 2	PLOT 3	PLOT 4
Vegetative Area Index	0.30	0.11	0.15	0.73
Live Leaves	0.19	0.07	0.10	0.45
Dead Leaves	0.06	0.03	0.02	0.21
Live Stems	0.05	0.01	0.03	0.07
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	0.00	0.00	0.00	0.00
Dry Weight	10.4 gm	3.6	4.6	23.2
Live Leaves	5.6	2.0	2.8	13.5
Dead Leaves	2.2	1.1	0.6	6.8
Live Stems	2.6	0.5	1.2	2.9
Dead Stems	0.0	0.0	0.0	0.0
Seed Heads	0.0	0.0	0.0	0.0
Number of Plants (10" row)	7	5	7	6
Number of Tillers (10" row)	60	23	30	119
Live	60	23	30	119
Dead	0	0	0	0
Average Tillers/Plant	9.0	4.2	6.8	17.8
Live	9.0	4.2	6.8	17.8
Dead	0.0	0.0	0.0	0.0
Average Vegetation Area/Plant	39.90	15.79	21.44	63.04
Green Leaves	25.85	8.54	15.48	33.67
Yellow Leaves	0.38	0.69	0.00	0.67
Dead Leaves	7.32	4.15	2.84	12.18
Live Stems	6.35	2.41	3.12	16.52
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	0.00	0.00	0.00	0.00
Soil Moisture				
0-1 in.	--	8.0	7.1	9.1
1-6 in.	--	19.1	17.6	24.9
6-18 in.	--	22.3	20.7	23.9
18-22 in.	--	20.9	13.2	21.7



ANGLE (DEG)	0	5	10	15	20	25	30	35
	40	45	50	55	60	65	70	75
	80	85	90					
P(X)	.044	.044	.044	.044	.045	.046	.047	.048
	.049	.051	.052	.054	.055	.057	.059	.062
	.064	.067	.070					

LEAF ANGLE DISTRIBUTION
FOR MARCH 13, 1976

```
DATE      TIME    CROP AND LOCATION   PLOT NUMBER   ORIENTATION       REFLECTANCE= BAND1 BAND2 BAND3 BAND4
031476    0920       WHEAT CSU           107.1         ON ROW                      .130  .148  .348  .321
031476    0921       WHEAT CSU           107.1        OFF ROW                      .063  .167  .250  .350
031476    0922       WHEAT CSU           107.1         ON ROW                      .267  .235  .375  .400
031476    0923       WHEAT CSU           107.1        OFF ROW                      .200  .188  .286  .294
031376    1250       WHEAT CSU           107.1        OFF ROW                      .142  .157  .253  .304
031376    1252       WHEAT CSU           107.1         ON ROW                      .133  .154  .249  .280
031376    1339       WHEAT CSU           107.1         ON ROW                      .078  .135  .214  .294
031376    1340       WHEAT CSU           107.1        OFF ROW                      .104  .142  .209  .279
031376    1455       WHEAT CSU           107.1         ON ROW                      .107  .132  .214  .277
031376    1457       WHEAT CSU           107.1        OFF ROW                      .091  .140  .231  .277
031376    1532       WHEAT CSU           107.1         ON ROW                      .145  .156  .259  .297
031376    1534       WHEAT CSU           107.1        OFF ROW                      .450  .166  .259  .311
031376    1253       WHEAT CSU           DIF P        ERCENT                       .089  .066  .060  .071
031476    0926       WHEAT CSU            DIF         PERCENT                      .417  .300  .320  .276
031376    1341       WHEAT CSU            DIF         PERCENT                      .104  .090  .073  .076
031376    1459       WHEAT CSU            DIF         PERCENT                      .137  .149  .150  .160
031376    1342       WHEAT CSU           107.1          SOIL                       .113  .161  .218  .271
031376    0925       WHEAT CSU           107.1          SOIL                       .174  .154  .211  .227
031376    1254       WHEAT CSU           107.1          SOIL                       .120  .150  .207  .241
031376    1430       WHEAT CSU           TRANS          GREEN                      .034  .027  .323  .455
031376    1430       WHEAT CSU           TRANS          GREEN                     *.000 *.000  .265  .392
031476    0931       WHEAT CSU           107.2         ON ROW                      .182  .333  .227  .240
031476    0932       WHEAT CSU           107.2        OFF ROW                      .143  .313  .214  .250
031476    0934       WHEAT CSU            DIF         PERCENT                      .313  .323  .250  .225
031376    1304       WHEAT CSU           107.2         ON ROW                      .190  .223  .274  .296
031376    1305       WHEAT CSU           107.2        OFF ROW                      .142  .192  .233  .278
031376    1348       WHEAT CSU           107.2         ON ROW                      .128  .185  .252  .309
031376    1349       WHEAT CSU           107.2         ON ROW                      .142  .193  .262  .301
031-76    1350       WHEAT CSU           107.2        OFF ROW                      .156  .193  .271  .300
031376    1501       WHEAT CSU           107.2         ON ROW                      .121  .176  .244  .275
031376    1502       WHEAT CSU           107.2        OFF ROW                      .144  .189  .250  .283
031376    1540       WHEAT CSU           107.2         ON ROW                      .195  .224  .300  .330
031376    1541       WHEAT CSU           107.2        OFF ROW                      .189  .224  .294  .325
031476    0934       WHEAT CSU            DIF         PERCENT                      .313  .323  .250  .225
031376    1306       WHEAT CSU            DIF         PERCENT                      .108  .088  .076  .068
031376    1351       WHEAT CSU            DIF         PERCENT                      .120  .105  .086  .100
031376    1542       WHEAT CSU            DIF         PERCENT                      .176  .134  .124  .107
031376    1352       WHEAT CSU           107.2          SOIL                       .147  .189  .243  .268
031376    0935       WHEAT CSU           107.2          SOIL                       .188  .258  .281  .325
031376    1308       WHEAT CSU           107.2          SOIL                       .159  .192  .269  .278
031476    0940       WHEAT CSU           107.3         ON ROW                      .133  .188  .250  .278
031476    0941       WHEAT CSU           107.3        OFF ROW                      .172  .176  .233  .243
031476    0943       WHEAT CSU            DIF         PERCENT                      .444  .364  .370  .337
031376    1315       WHEAT CSU           107.3         ON ROW                      .105  .141  .199  .246
031376    1316       WHEAT CSU           107.3        OFF ROW                      .100  .131  .208  .249
031376    1357       WHEAT CSU           107.3         ON ROW                      .114  .148  .215  .260
031376    1359       WHEAT CSU           107.3        OFF ROW                      .124  .144  .206  .253
031376    1506       WHEAT CSU           107.3        OFF ROW                      .099  .136  .167  .245
031376    1507       WHEAT CSU           107.3         ON ROW                      .116  .136  .206  .232
031376    1547       WHEAT CSU           107.3         ON ROW                      .152  .191  .267  .319
031376    1548       WHEAT CSU           107.3        OFF ROW                      .166  .191  .274  .303
031376    1401       WHEAT CSU           107.3          SOIL                       .143  .189  .225  .267
031376    0942       WHEAT CSU           107.3          SOIL                       .185  .182  .259  .273
031376    1320       WHEAT CSU           107.3          SOIL                       .122  .179  .226  .253
031376    1319       WHEAT CSU            DIF         PERCENT                      .096  .076  .068  .070
031376    1400       WHEAT CSU            DIF         PERCENT                      .124  .115  .105  .110
031376    1549       WHEAT CSU            DIF         PERCENT                      .185  .144  .130  .119
031476    0946       WHEAT CSU           107.4         ON ROW                      .107  .086  .222  .294
031476    0948       WHEAT CSU           107.4        OFF ROW                      .143  .118  .231  .294
031476    0950       WHEAT CSU            DIF         PERCENT                      .357  .294  .260  .118
031376    1321       WHEAT CSU           107.4         ON ROW                      .062  .074  .192  .241
031376    1322       WHEAT CSU           107.4        OFF ROW                      .066  .077  .164  .234
031376    1405       WHEAT CSU           107.4         ON ROW                      .061  .070  .201  .251
031376    1406       WHEAT CSU           107.4        OFF ROW                      .065  .077  .177  .236
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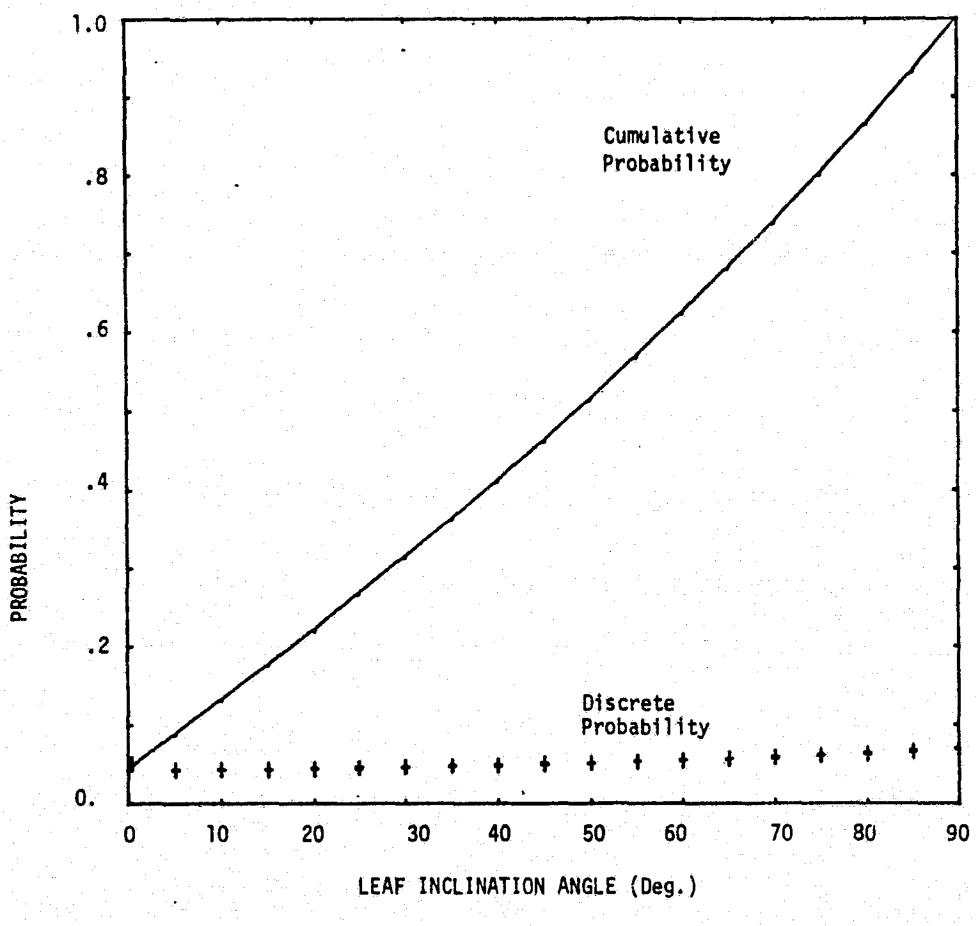
031376   1511        WHEAT CSU        107.4        ON ROW              .065   .082   .217   .277
031376   1513        WHEAT CSU        107.4       OFF ROW              .081   .082   .199   .277
031376   1554        WHEAT CSU        107.4        ON ROW              .106   .111   .236   .309
031376   1555        WHEAT CSU        107.4       OFF ROW              .113   .111   .236   .309
031376   1408        WHEAT CSU        107.4        SOIL                .084   .100   .134   .149
031376   0949        WHEAT CSU        107.4        SOIL                .167   .172   .217   .233
031376   1330        WHEAT CSU        107.4        SOIL                .088   .116   .146   .184
031376   1327        WHEAT CSU         DIF        PERCENT              .106   .088   .068   .078
031376   1407        WHEAT CSU         DIF        PERCENT              .126   .118   .100   .105
031376   1556        WHEAT CSU         DIF        PERCENT              .185   .142   .128   .117
```

B. APRIL 17, 1976 BOOTING STAGE FIELD 107

Crop Type:	Eagle Wheat	Weeds:	0%
Height:	30-35 cm	Soil:	Wet
Chlorotic:	0%	Wind:	10-15 mph SW

	PLOT 1	PLOT 2	PLOT 3	PLOT 4
Vegetative Area Index	1.76	0.30	0.87	1.29
Live Leaves	1.16	0.21	0.64	0.90
Dead Leaves	0.13	0.05	0.09	0.09
Live Stems	0.47	0.04	0.14	0.30
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	0.00	0.00	0.00	0.00
Dry Weight	79.5 gm	12.4	33.4	55.9
Live Leaves	33.9	5.9	17.0	26.6
Dead Leaves	9.0	3.5	5.7	6.1
Live Stems	36.6	3.0	10.7	23.2
Dead Stems	0.0	0.0	0.0	0.0
Seed Heads	0.0	0.0	0.0	0.0
Number of Plants (10" row)	9	1	1	2
Number of Tillers (10" row)	89	6	17	34
Live	89	6	17	34
Dead	0	0	0	0
Average Tillers/Plant	10.4	5.6	8.0	25.4
Live	10.4	5.6	8.0	25.4
Dead	0.0	0.0	0.0	0.0
Average Vegetation Area/Plant	192.21	136.52	100.39	445.04
Green Leaves	144.11	88.62	70.69	336.48
Yellow Leaves	9.23	15.84	3.46	0.00
Dead Leaves	5.78	1.85	11.10	24.80
Live Stems	33.09	30.21	15.14	83.76
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	0.00	0.00	0.00	0.00
Soil Moisture				
0-1 in.	--	16.0	13.5	12.7
1-6 in.	--	25.0	24.1	28.4
6-18 in.	--	21.9	21.6	25.9
18-22 in.	--	18.9	17.3	20.1



ANGLE (DEG)	0	5	10	15	20	25	30	35
	40	45	50	55	60	65	70	75
	80	85	90					
P(X)	.044	.044	.044	.044	.045	.046	.047	.048
	.049	.051	.052	.054	.055	.057	.059	.062
	.064	.067	.070					

LEAF ANGLE DISTRIBUTION
FOR APRIL 17, 1976

DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
041876	1043	WHEAT CSU	107.4	OFF ROW	.052	.053	.227	.316
041876	1044	WHEAT CSU	107.4	ON ROW	.043	.038	.214	.301
041876	1046	WHEAT CSU	107.4	SOIL	.051	.176	.205	.245
041876	1045	WHEAT CSU	DIF	PERCENT	.095	.062	.068	.071
041876	1135	WHEAT CSU	107.4	OFF ROW	.058	.043	.250	.035
041876	1135	WHEAT CSU	107.4	ON ROW	.046	.034	.246	.343
041876	1138	WHEAT CSU	107.4	OFF ROW	.053	.039	.258	.378
041876	1140	WHEAT CSU	107.4	ON ROW	.045	.039	.238	.338
041876	1136	WHEAT CSU	DIF	PERCENT	.104	.077	.074	.083
041876	1211	WHEAT CSU	107.4	OFF ROW	.052	.040	.252	.384
041876	1213	WHEAT CSU	107.4	ON ROW	.045	.040	.237	.346
041876	1214	WHEAT CSU	107.4	OFF ROW	.052	.041	.256	.350
041876	1215	WHEAT CSU	107.4	ON ROW	.048	.041	.238	.345
041876	1214	WHEAT CSU	DIF	PERCENT	.159	.145	.141	.145
041876	1214	WHEAT CSU	107.4	SOIL	.162	.212	.231	.295
041876	1343	WHEAT CSU	107.4	OFF ROW	.053	.039	.231	.427
041876	1342	WHEAT CSU	107.4	ON ROW	.049	.039	.257	.351
041876	1345	WHEAT CSU	107.4	OFF ROW	.056	.042	.268	.377
041876	1345	WHEAT CSU	107.4	ON ROW	.048	.042	.248	.343
041876	1343	WHEAT CSU	DIF	PERCENT	.139	.117	.116	.126
041876	1344	WHEAT CSU	107.4	SOIL	.167	.176	.248	.262
041876	1034	WHEAT CSU	107.3	OFF ROW	.067	.070	.186	.284
041876	1035	WHEAT CSU	107.3	ON ROW	.063	.067	.217	.302
041876		WHEAT CSU	107.3	SOIL	.167	.232	.283	.344
041876	1036	WHEAT CSU	DIF	PERCENT	.097	.061	.066	.067
041876	1123	WHEAT CSU	107.3	OFF ROW	.073	.077	.198	.282
041876	1125	WHEAT CSU	107.3	ON ROW	.069	.014	.204	.279
041876	1126	WHEAT CSU	107.3	OFF ROW	.073	.083	.192	.275
041876	1131	WHEAT CSU	107.3	ON ROW	.070	.075	.167	.294
041876	1125	WHEAT CSU	DIF	PERCENT	.108	.086	.094	.104
041876	1205	WHEAT CSU	107.3	OFF ROW	.075	.126	.179	.296
041876	1205	WHEAT CSU	107.3	ON ROW	.068	.122	.194	.315
041876	1207	WHEAT CSU	107.3	OFF ROW	.075	.126	.190	.318
041876	1207	WHEAT CSU	107.3	ON ROW	.075	.130	.201	.321
041876	1206	WHEAT CSU	DIF	PERCENT	.167	.197	.192	.145
041876	1207	WHEAT CSU	107.3	SOIL	.073	.143	.136	.213
041876	1329	WHEAT CSU	107.3	OFF ROW	.092	.104	.222	.323
041876	1330	WHEAT CSU	107.3	ON ROW	.069	.033	.206	.295
041876	1333	WHEAT CSU	107.3	OFF ROW	.088	.089	.218	.281
041876	1333	WHEAT CSU	107.3	OFF ROW	.069	.080	.206	.288
041876	1330	WHEAT CSU	DIF	PERCENT	.119	.098	.095	.103
041876	1332	WHEAT CSU	107.3	SOIL	.223	.278	.346	.394
041876	1021	WHEAT CSU	107.2	OFF ROW	.166	.202	.050	.368
041876	1022	WHEAT CSU	107.2	ON ROW	.162	.202	.312	.364
041876	1025	WHEAT CSU	107.2	SOIL	.227	.279	.349	.393
041876	1024	WHEAT CSU	DIF	PERCENT	.122	.073	.073	.075
041876	1114	WHEAT CSU	107.2	OFF ROW	.171	.211	.345	.386
041876	1114	WHEAT CSU	107.2	ON ROW	.175	.205	.318	.380
041876	1120	WHEAT CSU	107.2	OFF ROW	.172	.211	.324	.356
041876	1120	WHEAT CSU	107.2	ON ROW	.169	.202	.324	.347
041876	1115	WHEAT CSU	DIF	PERCENT	.145	.128	.132	.140
041876	1158	WHEAT CSU	107.2	OFF ROW	.174	.186	.318	.387
041876	1158	WHEAT CSU	107.2	ON ROW	.178	.184	.326	.381
041876	1200	WHEAT CSU	107.2	OFF ROW	.173	.214	.316	.383
041876	1200	WHEAT CSU	107.2	ON ROW	.177	.208	.323	.375
041876	1159	WHEAT CSU	DIF	PERCENT	.130	.107	.099	.103
041876	1159	WHEAT CSU	107.2	SOIL	.235	.289	.354	.395
041876	1301	WHEAT CSU	107.2	OFF ROW	.127	.212	.318	.389
041876	1301	WHEAT CSU	107.2	ON ROW	.172	.206	.325	.383
041876	1304	WHEAT CSU	107.2	OFF ROW	.173	.204	.323	.394
041876	1304	WHEAT CSU	107.2	ON ROW	.173	.204	.327	.378
041876	1303	WHEAT CSU	DIF	PERCENT	.109	.084	.084	.092
041876	1303	WHEAT CSU	107.2	SOIL	.244	.305	.359	.403
041876	1312	WHEAT CSU	107.2	GREEN 1	.076	.054	.313	.540

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041576   1315   WHEAT CSU   107.2   GREEN 2    .080  .070  .348  .525
041576   1221   WHEAT CSU   107.2   GREEN 1    .415  .384  .652  .722
041576   1001   WHEAT CSU   107.1   OFF ROW    .038  .023  .260  .375
041576   1107   WHEAT CSU   107.1   OFF ROW    .044  .035  .184  .368
041576   1003   WHEAT CSU   107.1   ON  ROW    .042  .030  .240  .360
041576   1107   WHEAT CSU   107.1   ON  ROW    .040  .024  .172  .336
032576   1007   WHEAT CSU   107.1   SOIL       .104  .129  .165  .199
041576   1005   WHEAT CSU   DIFF    PERCENT    .104  .068  .080  .078
041576   1108   WHEAT CSU   DIFF    PERCENT    .096  .058  .049  .076
041576   1147   WHEAT CSU   107.1   OFF ROW    .051  .037  .273  .381
041576   1220   WHEAT CSU   107.1   OFF ROW    .046  .034  .262  .362
041576   1148   WHEAT CSU   107.1   ON  ROW    .043  .032  .231  .323
041576   1227   WHEAT CSU   107.1   ON  ROW    .046  .031  .230  .325
041576   1154   WHEAT CSU   107.1   OFF ROW    .046  .036  .269  .355
041576   1227   WHEAT CSU   107.1   OFF ROW    .046  .031  .267  .379
041576   1155   WHEAT CSU   107.1   ON  ROW    .041  .030  .224  .319
041576   1228   WHEAT CSU   107.1   ON  ROW    .036  .028  .237  .333
041576   1149   WHEAT CSU   DIFF    PERCENT    .123  .111  .114  .128
041576   1222   WHEAT CSU   DIFF    PERCENT    .146  .126  .131  .141
041576   1154   WHEAT CSU   107.1   SOIL       .094  .107  .189  .190
041576   1222   WHEAT CSU   107.1   SOIL       .096  .115  .157  .184
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C. MAY 16, 1976 HEADED FIELD 107

Crop Type: Eagle Wheat

Height: 74-79 cm

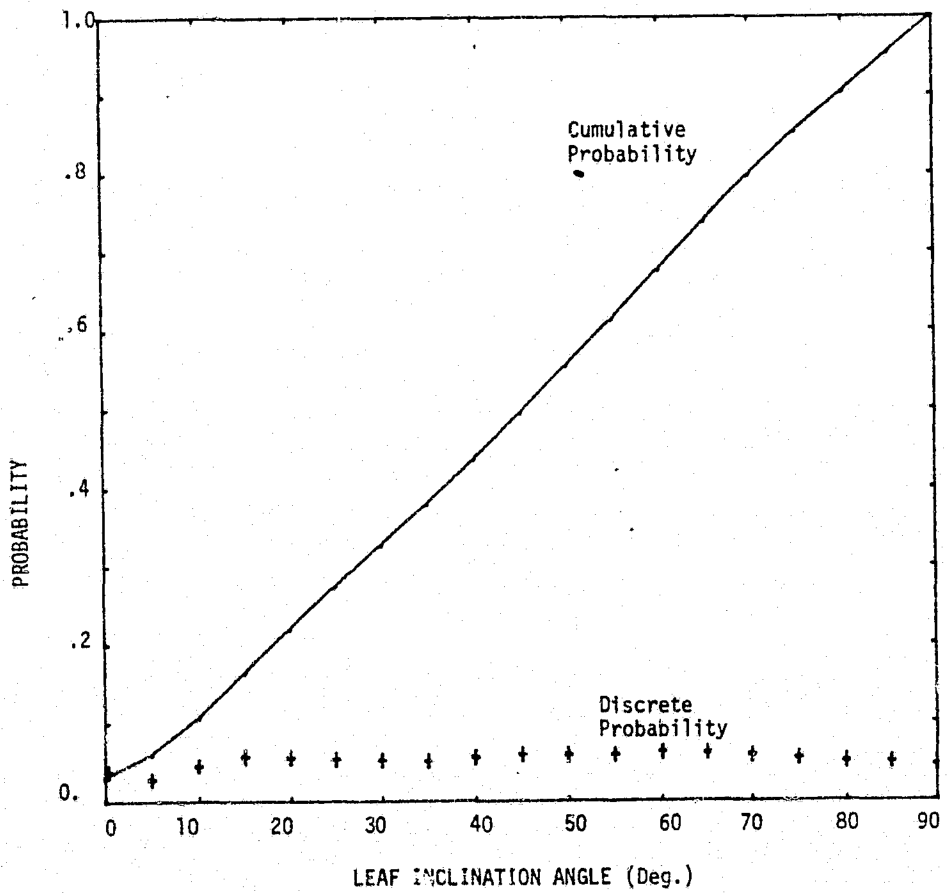
Chlorotic: 0%

Weeds: --

Soil: --

Wind: --

	PLOT 1	PLOT 2	PLOT 3	PLOT 4
Vegetative Area Index	3.50	--	--	2.92
Live Leaves	1.38	0.78	0.90	1.01
Dead Leaves	0.41	--	0.07	0.39
Live Stems	1.54	0.45	1.01	1.39
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	0.17	--	--	0.13
Dry Weight	313.4 gm	--	--	281.3
Live Leaves	58.6	37.1	43.6	50.6
Dead Leaves	26.8	--	5.3	26.1
Live Stems	206.8	62.2	135.1	187.6
Dead Stems	0.0	0.0	0.0	0.0
Seed Heads	21.2	--	--	17.0
Number of Plants (10" row)	6	3	3	3
Number of Tillers (10" row)	56	13	21	20
Live	--	--	--	--
Dead	--	--	--	--
Average Tillers/Plant	4.2	5.0	5.8	11.0
Live	4.2	5.0	5.8	11.0
Dead	0.0	0.0	0.0	0.0
Average Vegetation Area/Plant	154.93	150.46	183.78	266.13
Green Leaves	58.24	93.43	65.97	98.74
Yellow Leaves	18.55	20.73	19.66	18.01
Dead Leaves	12.51	3.75	3.10	28.89
Live Stems	59.10	32.55	89.42	113.75
Dead Stems	0.00	0.00	0.00	0.00
Seed Heads	6.53	0.00	5.63	6.74
Soil Moisture				
0-1 in.	--	4.1	4.1	6.8
1-6 in.	--	20.8	14.0	24.5
6-18 in.	--	25.1	17.6	24.5
18-22 in.	--	18.9	14.9	23.9



ANGLE (DEG)	0	5	10	15	20	25	30	35
	40	45	50	55	60	65	70	75
	80	85	90					
P(X)	.031	.029	.046	.058	.056	.054	.053	.052
	.056	.060	.059	.059	.063	.062	.059	.055
	.051	.050	.046					

LEAF ANGLE DISTRIBUTION
FOR MAY 16, 1976

C.2

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 DATE     TIME    CROP AND LOCATION    PLOT NUMBER    ORIENTATION    REFLECTANCE= BAND1 BAND2 BAND3 BAND4

051776    1005       WHEAT CSU          107.4          ON  ROW                    .034  .027  .224  .359
051776    1009       WHEAT CSU          107.4          SOIL                       .186  .223  .264  .316
051776    1004       WHEAT CSU          107.4          OFF ROW                    .034  .027  .190  .346
051776    1008       WHEAT CSU          DIFF           PERCENT                    .107  .080  .075  .082
051776    1106       WHEAT CSU          107.4          OFF ROW                    .041  .032  .210  .361
051776    1107       WHEAT CSU          107.4          ON  ROW                    .041  .032  .243  .343
051776    1108       WHEAT CSU          107.4          SOIL                       .210  .238  .308  .346
051776    1107       WHEAT CSU          DIFF           PERCENT                    .105  .078  .007  .075
051776    1307       WHEAT CSU          107.4          OFF ROW                    .059  .049  .227  .339
051776    1407       WHEAT CSU          107.4          OFF ROW                    .048  .052  .225  .316
051776    1309       WHEAT CSU          107.4          ON ROW                     .051  .049  .223  .319
051776    1408       WHEAT CSU          107.4          ON ROW                     .052  .049  .236  .360
051776    1311       WHEAT CSU          DIFF           PERCENT                    .088  .066  .073  .070
051776    1410       WHEAT CSU          DIFF           PERCENT                    .100  .075  .070  .074
051776    0955       WHEAT CSU          107.3          OFF ROW                    .098  .101  .265  .410
051776    1058       WHEAT CSU          107.3          OFF ROW                    .079  .080  .245  .412
051776    0956       WHEAT CSU          107.3          ON ROW                     .086  .063  .302  .415
051776    1059       WHEAT CSU          107.3          ON  ROW                    .069  .057  .278  .390
051776               WHEAT CSU          107.3          SOIL                       .202  .245  .340  .396
051776               WHEAT CSU          107.3          SOIL                       .199  .255  .330  .390
051776    0951       WHEAT CSU          DIFF           PERCENT                    .129  .096  .086  .094
051776    1100       WHEAT CSU          DIFF           PERCENT                    .102  .067  .080  .109
051776    1320       WHEAT CSU          107.3          OFF ROW                    .072  .090  .213  .318
051776    1358       WHEAT CSU          107.3          OFF ROW                    .057  .075  .224  .307
051776    1321       WHEAT CSU          107.3          ON  ROW                    .094  .084  .262  .366
051776    1359       WHEAT CSU          107.3          ON ROW                     .075  .070  .254 0.000
051776    1321       WHEAT CSU          DIFF           PERCENT                    .090  .067  .067  .080
051776    1400       WHEAT CSU          DIFF           PERCENT                    .093  .070  .067  .079
051776               WHEAT CSU          TRANS           GREEN                     .088  .053  .398  .581
051776               WHEAT CSU          TRANS           GREEN                     .065  .038  .364  .512
051776               WHEAT CSU          TRANS           YELLOW                   0.000  .348  .520  .546
051776               WHEAT CSU          TRANS           DEAD                      .084  .141  .225  .274
051776    0944       WHEAT CSU          107.2          OFF ROW                    .132  .118  .331  .441
051776    1051       WHEAT CSU          107.2          OFF ROW                    .109  .119  .264  .389
051776    0945       WHEAT CSU          107.2          ON  ROW                    .107  .094  .331  .441
051776    1052       WHEAT CSU          107.2          ON  ROW                    .104  .100  .298  .370
051776    0947       WHEAT CSU          107.2          SOIL                       .239  .291  .376  .426
051776    1054       WHEAT CSU          107.2          SOIL                       .232  .298  .356  .400
051776    0946       WHEAT CSU          DIFF           PERCENT                    .126  .094  .083  .088
051776    1053       WHEAT CSU          DIFF           PERCENT                    .104  .074  .082  .089
051776    1300       WHEAT CSU          107.2          OFF ROW                    .130  .155  .306  .392
051776    1350       WHEAT CSU          107.2          OFF ROW                    .129  .144  .285  .371
051776    1301       WHEAT CSU          107.2          ON  ROW                    .123  .115  .306  .390
051776    1351       WHEAT CSU          107.2          ON  ROW                    .115  .113  .292  .374
051776    1303       WHEAT CSU          DIFF           PERCENT                    .087  .069  .072  .081
051776    1352       WHEAT CSU          DIFF           PERCENT                    .100  .076  .071  .077
051776    1305       WHEAT CSU          107.2          SOIL                       .227  .289  .358  .404
051776    1355       WHEAT CSU          107.2          SOIL                       .240  .299  .371  .417
051776    0935       WHEAT CSU          107.1          OFF ROW                    .081  .074  .305  .530
051776    1044       WHEAT CSU          107.1          OFF ROW                    .075  .082  .241  .577
051776    0936       WHEAT CSU          107.1          ON  ROW                    .081  .058  .384  .480
051776    1045       WHEAT CSU          107.1          ON ROW                     .080  .047  .342  .400
051776    0938       WHEAT CSU          107.1          SOIL                       .135  .169  .265  .335
051776    1047       WHEAT CSU          107.1          SOIL                       .151  .198  .286  .362
051776    0937       WHEAT CSU          DIFF           PERCENT                    .122  .085  .099  .115
051776    1046       WHEAT CSU          DIFF           PERCENT                    .085  .063  .080  .100
051776    1245       WHEAT CSU          107.1          OFF ROW                    .073  .084  .233  .420
051776    1344       WHEAT CSU          107.1          OFF ROW                    .079  .101  .237  .391
051776    1247       WHEAT CSU          107.1          ON  ROW                    .062  .035  .312  .307
051776    1345       WHEAT CSU          107.1          ON ROW                     .083  .079  .263  .441
051776    1059       WHEAT CSU          DIFF           PERCENT                    .073  .055  .074  .102
051776    1346       WHEAT CSU          DIFF           PERCENT                    .090  .065  .081  .095
051776    1347       WHEAT CSU          107.1          SOIL                       .151  .186  .274  .330
051776    1251       WHEAT CSU          107.1          SOIL                       .143  .188  .259  .324
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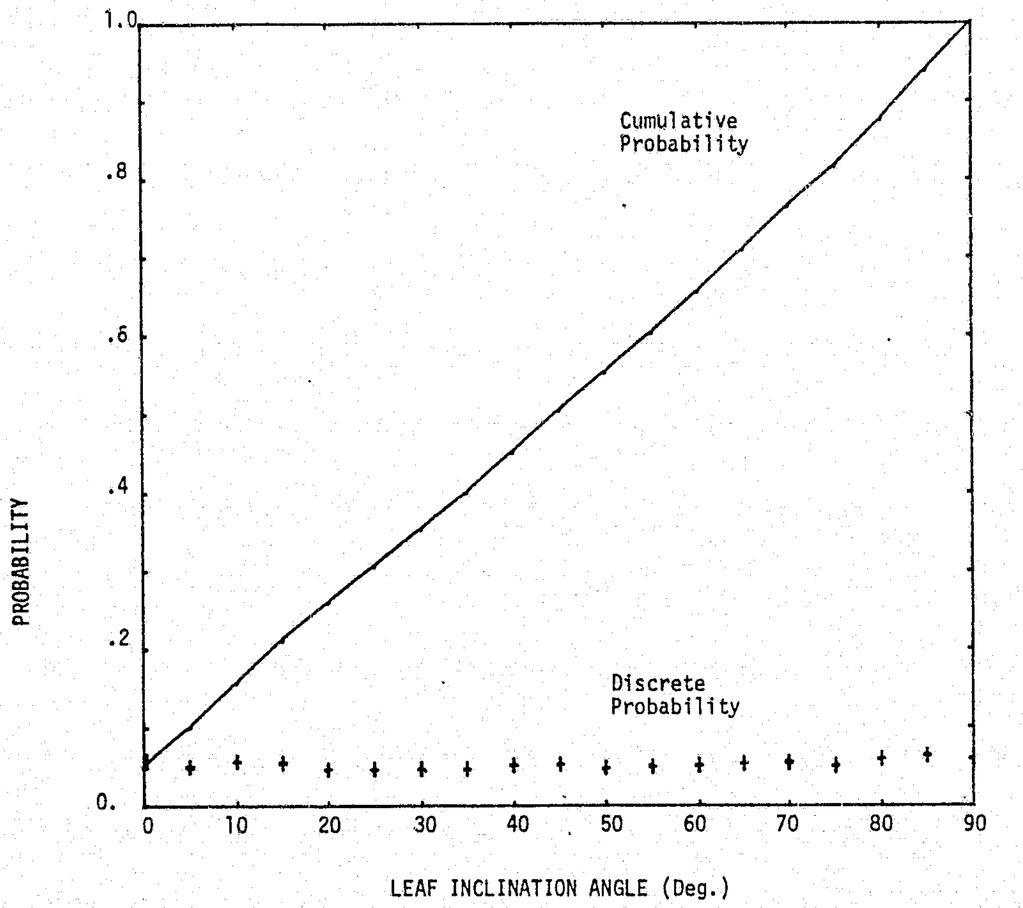
D. JUNE 13, 1976 RIPENING FIELD 107

Crop Type: Eagle Wheat
Height: 65-70 cm
Chlorotic: 24%

Weeds: 5-10%
Soil: Dry
Wind: W

	PLOT 1	PLOT 2	PLOT 3	PLOT 4
Vegetative Area Index	--	--	--	--
Live Leaves	0.00	--	0.00	0.00
Dead Leaves	0.89	0.34	0.57	1.30
Live Stems	0.88	0.48	--	1.46
Dead Stems	--	--	--	--
Seed Heads	--	--	--	--
Dry Weight	232.6 gm	--	205.1	366.6
Live Leaves	0.0	--	0.0	7.85
Dead Leaves	38.7	15.7	25.4	58.2
Live Stems	96.1	54.5	72.6	163.2
Dead Stems	2.7	0.1	2.6	2.9
Seed Heads	95.1	54.0	104.5	134.5
Number of Plants (10" row)	--	--	--	--
Number of Tillers (10" row)	25	8	21	31
Live	--	2	--	--
Dead	--	6	--	--
Average Tillers/Plant	9.0	4.6	7.4	10.0
Live	8.0	4.4	5.2	9.0
Dead	1.0	0.2	2.2	1.0
Average Vegetation Area/Plant	--	--	--	--
Green Leaves	0.00	0.00	0.00	0.00
Yellow Leaves	0.00	0.00	0.00	2.92
Dead Leaves	95.87	38.87	42.51	132.86
Live Stems	123.36	68.25	67.44	137.66
Dead Stems	2.28	0.23	4.97	6.20
Seed Heads	--	--	--	--
Soil Moisture				
0-1 in.	--	1.4	0.7	1.6
1-6 in.	--	10.0	7.5	13.7
6-18 in.	--	13.5	11.0	15.0
18-22 in.	--	11.0	10.5	16.5



ANGLE (DEG)	0	5	10	15	20	25	30	35
	40	45	50	55	60	65	70	75
	80	85	90					
P(X)	.050	.050	.057	.055	.047	.047	.047	.047
	.052	.053	.048	.050	.052	.054	.055	.051
	.060	.064	.060					

LEAF ANGLE DISTRIBUTION
FOR JUNE 13, 1976

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DATE     TIME    CROP AND LOCATION    PLOT NUMBER    ORIENTATION    REFLECTANCE= BAND1 BAND2 BAND3 BAND4

061276   1145       WHEAT CSU            107.4          ON ROW                   .064  .105  .180  .323
061276   1146       WHEAT CSU            107.4         OFF ROW                   .080  .083  .217  .296
061276   1147       WHEAT CSU            107.4         OFF ROW                   .104  .137  .230  .277
061276   1148       WHEAT CSU             DIF          PERCENT                   .072  .048  .057  .068
061276   1248       WHEAT CSU            107.4          ON ROW                   .090  .125  .240  .350
061276   1247       WHEAT CSU            107.4         OFF ROW                   .086  .096  .259  .260
061276   1247       WHEAT CSU            107.4         OFF ROW                   .093  .105  .213  .251
061276   1249       WHEAT CSU            107.4          ON ROW                   .086  .108  .213  .294
061276   1250       WHEAT CSU             DIF          PERCENT                   .071  .050  .061  .071
061276   1341       WHEAT CSU            107.4          ON ROW                   .102  .118  .258  .291
061276   1242       WHEAT CSU            107.4         OFF ROW                   .084  .107  .206  .257
061276   1343       WHEAT CSU            107.4         OFF ORW                   .087  .098  .176  .266
061276   1344       WHEAT CSU            107.4          ON ORW                   .098  .112  .236  .314
061276   1345       WHEAT CSU             DIF          PERCENT                   .069  .046  .052  .067
061276   1141       WHEAT CSU            107.4            SOIL                   .161  .194  .238  .283
061276   1801       WHEAT CSU            107.4          ON ROW                   .096  .130  .250  .390
061276   1802       WHEAT CSU            107.4         OFF ORW                   .072  .068  .242  .259
061276   1803       WHEAT CSU            107.4         OFF ROW                   .128  .105  .359  .310
061276   1803       WHEAT CSU            107.4          ON ROW                   .072  .111  .195  .368
061276   1804       WHEAT CSU             DIF          PERCENT                   .112  .074  .078  .092
061276   1251       WHEAT CSU            107.4            SOIL                   .164  .192  .240  .277
061276              WHEAT CSU            TRANS          GREEN1                   .053  .032  .383  .555
061276              WHEAT CSU            TRANS          GREEN2                   .147  .141  .428  .513
061276              WHEAT CSU            TRANS          GREEN3                   .248  .287  .509  .561
061276              WHEAT CSU            TRANS          GREEN4                   .256  .322  .493  .549
061276              WHEAT CSU            TRANS          GREEN5                   .138  .249  .373  .427
061276   1126       WHEAT CSU            107.3          ON ROW                   .116  .144  .245  .300
061276   1127       WHEAT CSU            107.3         OFF ROW                   .108  .148  .224  .284
061276   1128       WHEAT CSU            107.3         OFF ROW                   .116  .164  .215  .290
061276   1129       WHEAT CSU            107.3          ON ROW                   .116  .138  .249  .287
061276   1130       WHEAT CSU             DIF          PERCENT                   .079  .054  .059  .066
061276   1237       WHEAT CSU            107.3          ON ROW                   .152  .152  .293  .330
061276   1236       WHEAT CSU            107.3         OFF ROW                   .114  .144  .208  .270
061276   1238       WHEAT CSU            107.3         OFF ROW                   .121  .167  .239  .301
061276   1239       WHEAT CSU            107.3          ON ROW                   .121  .161  .251  .328
061276   1240       WHEAT CSU             DIF          PERCENT                   .072  .056  .058  .070
061276   1330       WHEAT CSU            107.3          ON ROW                   .135  .160  .207  .296
061276   1331       WHEAT CSU            107.3         OFF ROW                   .127  .160  .222  .271
061276   1332       WHEAT CSU            107.3         OFF ROW                   .130  .165  .237  .291
061276   1333       WHEAT CSU            107.3          ON ROW                   .142  .174  .270  .319
061276   1334       WHEAT CSU             DIF          PERCENT                   .069  .054  .063  .072
061276   1331       WHEAT CSU            107.3            SOIL                   .149  .190  .245  .293
061276   1854       WHEAT CSU            107.3          ON ROW                   .117  .164  .229  .330
061276   1853       WHEAT CSU            107.3         OFF ROW                   .146  .147  .271  .298
061276   1854       WHEAT CSU            107.3         OFF ROW                   .117  .136  .236  .287
061276   1855       WHEAT CSU            107.3          ON ROW                   .117  .124  .243  .282
061276   1856       WHEAT CSU             DIF          PERCENT                   .102  .073  .079  .090
061276   1240       WHEAT CSU            107.3            SOIL                   .167  .202  .266  .310
061276   1025       WHEAT CSU            107.2          ON ROW                   .141  .188  .314  .397
061276   1024       WHEAT CSU            107.2         OFF ROW                   .157  .138  .320  .366
061276   1025       WHEAT CSU            107.2         OFF ROW                   .172  .224  .314  .397
061276   1028       WHEAT CSU             DIF          PERCENT                   .096  .060  .062  .066
061276   1227       WHEAT CSU            107.2          ON ROW                   .149  .180  .298  .362
061276   1226       WHEAT CSU            107.2         OFF ROW                   .156  .218  .298  .367
061276   1229       WHEAT CSU            107.2         OFF ROW                   .130  .177  .267  .324
061276   1228       WHEAT CSU            107.2          ON ROW                   .156  .171  .333  .373
061276   1231       WHEAT CSU             DIF          PERCENT                   .071  .050  .054  .061
061276   1321       WHEAT CSU            107.2          ON ROW                   .171  .181  .340  .380
061276   1322       WHEAT CSU            107.2         OFF ROW                   .164  .221  .302  .374
061276   1323       WHEAT CSU            107.2         OFF ROW                   .142  .186  .250  .319
061276   1323       WHEAT CSU            107.2         OFF ROW                   .145  .166  .294  .349
061276   1325       WHEAT CSU             DIF          PERCENT                   .069  .052  .060  .072
061276   1329       WHEAT CSU            107.2            SOIL                   .167  .192  .299  .354
061276   1743       WHEAT CSU            107.2          ON ROW                   .129  .174  .286  .399
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DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
061276	1145	WHEAT CSU	107.4	ON ROW	.064	.105	.180	.323
061276	1146	WHEAT CSU	107.4	OFF ROW	.080	.083	.217	.286
061276	1147	WHEAT CSU	107.4	OFF ROW	.104	.137	.230	.277
061276	1148	WHEAT CSU	DIF	PERCENT	.072	.048	.057	.068
061276	1248	WHEAT CSU	107.4	ON ROW	.090	.125	.240	.350
061276	1247	WHEAT CSU	107.4	OFF ROW	.086	.096	.259	.260
061276	1247	WHEAT CSU	107.4	OFF ROW	.093	.105	.213	.251
061276	1249	WHEAT CSU	107.4	ON ROW	.086	.108	.213	.294
061276	1250	WHEAT CSU	DIF	PERCENT	.071	.050	.061	.071
061276	1341	WHEAT CSU	107.4	ON ROW	.102	.118	.258	.291
061276	1242	WHEAT CSU	107.4	OFF ROW	.084	.107	.206	.257
061276	1343	WHEAT CSU	107.4	OFF ORW	.087	.098	.176	.266
061276	1344	WHEAT CSU	107.4	ON ORW	.098	.112	.236	.314
061276	1345	WHEAT CSU	DIF	PERCENT	.069	.046	.052	.067
061276	1141	WHEAT CSU	107.4	SOIL	.161	.194	.238	.283
061276	1801	WHEAT CSU	107.4	ON ROW	.096	.130	.250	.390
061276	1802	WHEAT CSU	107.4	OFF ORW	.072	.068	.242	.259
061276	1803	WHEAT CSU	107.4	OFF ROW	.128	.105	.359	.310
061276	1803	WHEAT CSU	107.4	ON ROW	.072	.111	.195	.368
061276	1804	WHEAT CSU	DIF	PERCENT	.112	.074	.078	.092
061276	1251	WHEAT CSU	107.4	SOIL	.164	.192	.240	.277
061276		WHEAT CSU	TRANS	GREEN1	.053	.032	.383	.555
061276		WHEAT CSU	TRANS	GREEN2	.147	.141	.428	.513
061276		WHEAT CSU	TRANS	GREEN3	.248	.287	.509	.561
061276		WHEAT CSU	TRANS	GREEN4	.256	.322	.493	.549
061276		WHEAT CSU	TRANS	GREEN5	.138	.249	.373	.427
061276	1126	WHEAT CSU	107.3	ON ROW	.116	.144	.245	.300
061276	1127	WHEAT CSU	107.3	OFF ROW	.108	.148	.224	.284
061276	1128	WHEAT CSU	107.3	OFF ROW	.116	.164	.215	.290
061276	1129	WHEAT CSU	107.3	ON ROW	.116	.138	.249	.287
061276	1130	WHEAT CSU	DIF	PERCENT	.079	.054	.059	.066
061276	1237	WHEAT CSU	107.3	ON ROW	.152	.152	.293	.330
061276	1236	WHEAT CSU	107.3	OFF ROW	.114	.144	.208	.270
061276	1238	WHEAT CSU	107.3	OFF ROW	.121	.167	.239	.301
061276	1239	WHEAT CSU	107.3	ON ROW	.121	.161	.251	.328
061276	1240	WHEAT CSU	DIF	PERCENT	.072	.056	.058	.070
061276	1330	WHEAT CSU	107.3	ON ROW	.135	.160	.207	.296
061276	1331	WHEAT CSU	107.3	OFF ROW	.127	.160	.222	.271
061276	1332	WHEAT CSU	107.3	OFF ROW	.130	.165	.237	.291
061276	1333	WHEAT CSU	107.3	ON ROW	.142	.174	.270	.319
061276	1334	WHEAT CSU	DIF	PERCENT	.069	.054	.063	.072
061276	1331	WHEAT CSU	107.3	SOIL	.149	.190	.245	.293
061276	1854	WHEAT CSU	107.3	ON ROW	.117	.164	.229	.330
061276	1853	WHEAT CSU	107.3	OFF ROW	.146	.147	.271	.298
061276	1854	WHEAT CSU	107.3	OFF ROW	.117	.136	.236	.287
061276	1855	WHEAT CSU	107.3	ON ROW	.117	.124	.243	.282
061276	1856	WHEAT CSU	DIF	PERCENT	.102	.073	.079	.090
061276	1240	WHEAT CSU	107.3	SOIL	.167	.202	.266	.310
061276	1025	WHEAT CSU	107.2	ON ROW	.141	.188	.314	.397
061276	1024	WHEAT CSU	107.2	OFF ROW	.157	.188	.320	.366
061276	1025	WHEAT CSU	107.2	OFF ROW	.172	.224	.314	.397
061276	1028	WHEAT CSU	DIF	PERCENT	.096	.060	.062	.066
061276	1227	WHEAT CSU	107.2	ON ROW	.149	.180	.298	.362
061276	1226	WHEAT CSU	107.2	OFF ROW	.156	.218	.298	.367
061276	1229	WHEAT CSU	107.2	OFF ROW	.130	.177	.267	.324
061276	1228	WHEAT CSU	107.2	ON ROW	.156	.171	.333	.373
061276	1231	WHEAT CSU	DIF	PERCENT	.071	.050	.054	.061
061276	1321	WHEAT CSU	107.2	ON ROW	.171	.181	.340	.380
061276	1322	WHEAT CSU	107.2	OFF ROW	.164	.221	.302	.374
061276	1323	WHEAT CSU	107.2	OFF ROW	.142	.186	.250	.319
061276	1323	WHEAT CSU	107.2	OFF ROW	.145	.166	.294	.349
061276	1325	WHEAT CSU	DIF	PERCENT	.069	.052	.060	.072
061276	1329	WHEAT CSU	107.2	SOIL	.167	.192	.299	.354
061276	1743	WHEAT CSU	107.2	ON ROW	.129	.174	.286	.399

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061276   1742    WHEAT CSU    107.2    OFF ROW        .164  .197  .321  .367
061276   1745    WHEAT CSU    107.2    OFF ROW        .143  .163  .300  .362
061276   1743    WHEAT CSU    107.2     ON ROW        .129  .197  .343  .463
061276   1746    WHEAT CSU     DIF    PERCENT         .114  .079  .079  .090
061276   1232    WHEAT CSU    107.2       SOIL        .193  .245  .326  .367
061376   0945    WHEAT CSU    107.1     ON ROW        .155  .154  .267  .333
061376   0947    WHEAT CSU    107.1    OFF ROW        .155  .130  .237  .267
061376   0945    WHEAT CSU    107.1       SOIL        .207  .182  .249  .302
061376   0948    WHEAT CSU     DIF    PERCENT         .147  .075  .071  .076
061376   1211    WHEAT CSU    107.1     ON ROW        .118  .137  .275  .328
061376   1212    WHEAT CSU    107.1    OFF ROW        .107  .146  .208  .284
061376   1214    WHEAT CSU    107.1    OFF ROW        .084  .119  .196  .246
061376   1215    WHEAT CSU    107.1     ON ROW        .103  .149  .227  .299
061376   1216    WHEAT CSU     DIF    PERCENT         .073  .054  .055  .062
061376   1311    WHEAT CSU    107.1     ON ROW        .127  .160  .259  .319
061376   1312    WHEAT CSU    107.1    OFF ROW        .116  .157  .207  .277
061376   1314    WHEAT CSU    107.1    OFF ROW        .102  .134  .226  .275
061376   1315    WHEAT CSU    107.1     ON ROW        .120  .160  .248  .300
061376   1316    WHEAT CSU     DIF    PERCENT         .073  .057  .060  .067
061376   0955    WHEAT CSU    107.1       SOIL        .198  .182  .225  .271
061376   1730    WHEAT CSU    107.1     ON ROW        .106  .107  .232  .240
061376   1731    WHEAT CSU    107.1    OFF ROW        .113  .126  .220  .244
061376   1732    WHEAT CSU    107.1    OFF ROW        .088  .117  .238  .271
061376   1733    WHEAT CSU    107.1     ON ROW        .100  .126  .226  .312
061376   1734    WHEAT CSU     DIF    PERCENT         .106  .078  .073  .081
061376   1217    WHEAT CSU    107.1       SOIL        .145  .185  .247  .299
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061276   1742   WHEAT CSU   107.2   OFF ROW   .164  .197  .321  .367
061276   1745   WHEAT CSU   107.2   OFF ROW   .143  .163  .300  .362
061276   1743   WHEAT CSU   107.2    ON ROW   .129  .197  .343  .463
061276   1746   WHEAT CSU    DIF    PERCENT   .114  .079  .079  .090
061276   1232   WHEAT CSU   107.2      SOIL   .193  .245  .326  .367
061376   0945   WHEAT CSU   107.1    ON ROW   .155  .154  .267  .333
061376   0947   WHEAT CSU   107.1   OFF ROW   .155  .130  .237  .267
061376   0945   WHEAT CSU   107.1      SOIL   .207  .182  .249  .302
061376   0948   WHEAT CSU    DIF    PERCENT   .147  .075  .071  .076
061376   1211   WHEAT CSU   107.1    ON ROW   .118  .137  .275  .328
061376   1212   WHEAT CSU   107.1   OFF ROW   .107  .146  .208  .284
061376   1214   WHEAT CSU   107.1   OFF ROW   .084  .119  .196  .246
061376   1215   WHEAT CSU   107.1    ON ROW   .103  .149  .227  .299
061376   1216   WHEAT CSU    DIF    PERCENT   .073  .054  .055  .062
061376   1311   WHEAT CSU   107.1    ON ROW   .127  .160  .259  .319
061376   1312   WHEAT CSU   107.1   OFF ROW   .116  .157  .207  .277
061376   1314   WHEAT CSU   107.1   OFF ROW   .102  .134  .226  .275
061376   1315   WHEAT CSU   107.1    ON ROW   .120  .160  .248  .300
061376   1316   WHEAT CSU    DIF    PERCENT   .073  .057  .060  .067
061376   0555   WHEAT CSU   107.1      SOIL   .198  .182  .225  .271
061376   1730   WHEAT CSU   107.1    ON ROW   .106  .107  .232  .240
061376   1731   WHEAT CSU   107.1   OFF ROW   .113  .126  .220  .244
061376   1732   WHEAT CSU   107.1   OFF ROW   .088  .117  .238  .271
061376   1733   WHEAT CSU   107.1    ON ROW   .100  .126  .226  .312
061376   1734   WHEAT CSU    DIF    PERCENT   .106  .078  .073  .081
061376   1217   WHEAT CSU   107.1      SOIL   .145  .185  .247  .299
```

APPENDIX B: PROGRAM LISTINGS

A. PROGRAM TASSEL
B. PROGRAM SCATPLT

A. PROGRAM TASSEL

```
      PROGRAM TASSEL(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
     X  TAPE7=PUNCH)
C
C         THIS PROGRAM COMPUTES TASSELED CAP TRANSFORMATION FOR LANDSAT
C         DATA VECTORS
C
      DIMENSION X(4),U(4),R(4,4),RT(4,4),O(4),RADMAX(4),BW(4),CNTMAX(4),
     Z  XCNTS(4)
      DATA (RADMAX(I),I=1,4)/2.48,2.00,1.76,4.60/
      DATA (CNTMAX(I),I=1,4)/3*(127.),63./
      DATA (BW(I),I=1,4)/3*(.1),.3/
C
C  READ SWITCH -- C = PUNCH COUNTS, TC = PUNCH TRANSFORMED COUNTS
C
      READ(5,5) SW
    5 FORMAT(A2)
C
C  READ THE TRANSFORMATION MATRIX, R, AND COMPUTE ITS TRANSPOSE, RT,
C  AND READ THE OFFSET VECTOR, O
C
      DO 20 J=1,4
      READ(5,10) (R(I,J),I=1,4)
   10 FORMAT(4F10.6)
      DO 20 I=1,4
   20 RT(J,I) = R(I,J)
      READ(5,10) (O(I),I=1,4)
C
C  PRINT HEADINGS AND CONSTANT MATRICES
C
      WRITE(6,30)
   30 FORMAT(1H1,35X,52HTASSELED CAP TRANSFORMATION FOR LANDSAT DATA VEC
     XTORS/)
      WRITE(6,35)
   35 FORMAT(19H0TRANSFORM MATRIX =)
      DO 45 I=1,4
      WRITE(6,40) (R(I,J),J=1,4)
   40 FORMAT(1H ,4(F10.5))
   45 CONTINUE
      WRITE(6,50)
   50 FORMAT(/32H TRANSPOSE OF TRANSFORM MATRIX =)
      DO 55 I=1,4
      WRITE(6,40) (RT(I,J),J=1,4)
   55 CONTINUE
      WRITE(6,60)
   60 FORMAT(/16H OFFSET VECTOR =)
      WRITE(6,40) (O(I),I=1,4)
C
C  READ THE LANDSAT MSS SIGNAL VECTOR, X, CONVERT IT TO COUNTS, XCNTS,
C  AND COMPUTE THE TRANSFORMED VECTOR, U
C
   77 READ(5,70) (X(I),I=1,4),CID
   70 FORMAT(4(F8.4),32X,A10)
      IF (X(1).EQ.999.) GO TO 999
      DO 200 I=1,4
      U(I) = 0.
      DO 100 J=1,4
      XCNTS(J) = (X(J)/RADMAX(J)) * CNTMAX(J) + BW(J)
  100 U(I) = U(I) + RT(I,J) * XCNTS(J)
  200 U(I) = U(I) + O(I)
```

```
C
C  PRINT LANDSAT AND TRANSFORMED VECTORS
C
      WRITE(6,80) (X(I),I=1,4),CID
   80 FORMAT(/23H LANDSAT VECTOR =       ,4(F10.5),5X,A10)
      WRITE(6,85) (XCNTS(I),I=1,4)
   85 FORMAT(23H VECTOR IN COUNTS =     ,4(F10.5))
      WRITE(6,90) (U(I),I=1,4)
   90 FORMAT(23H TRANSFORMED VECTOR =  ,4(F10.5))
      IF (SW.EQ.2HTC) GO TO 350
      WRITE(7,300) (XCNTS(I),I=1,4),SW,CID
  300 FORMAT(4(F10.5),25X,A2,3X,A10)
  350 IF (SW.EQ.2HC ) GO TO 450
      WRITE(7,400) (U(I),I=1,4),SW,CID
  400 FORMAT(4(F10.5),25X,A2,3X,A10)
  450 CONTINUE
      GO TO 77
C
  999 STOP
      END
```

B. PROGRAM SCATPLT

```
      PROGRAM SCATPLT(INPUT,OUTPUT,FILMPR,TAPE5=INPUT,TAPE6=OUTPUT,
     *TAPE7=FILMPR,FILMPL)
      DIMENSION MA(10,2),DATA(200,10),LSYMB(200,1),IDES(3)
    5 LL=0
C         READ MAIN HEADER CARD
C               LAB = LABEL
C           NPLOT = NUMBER OF SCATTER PLOTS (10 MAX)
C           NCOLS = NUMBER OF COLUMNS OF DATA (10 MAX)
C              MA = ARRAY WITH CHANNEL PAIRS TO BE PLOTTED(10 PAIRS MAX)
C            IDES = DATA DESCRIPTION
      READ(5,10)LAB,NPLOT,NCOLS,((MA(I,J),J=1,2),I=1,10),IDES
   10 FORMAT(A10,2I5,20I1,3A10)
C         READ MINIMUM AND MAXIMUM DATA VALUES FOR PLOTTING
      READ(5,12)XMIN,XMAX,YMIN,YMAX
   12 FORMAT(4F5.1)
      JJ=0
      WRITE(6,57)(IDES(N),N=1,3)
   15 CONTINUE
C         READ SUBHEADER CARD
C               NPTS = NUMBER OF DATA ROWS IN SUBSET
C            ICHARS = PLOT SYMBOL TO REPRESENT SUBSET DATA
      READ(5,20)NPTS,ICHAR
      IF(EOF(5))55,22
   20 FORMAT(I5,A1)
   22 KK=JJ+1   $   MM=JJ+NPTS
C         READ DATA IN SUBSET
      DO 50 I=KK,MM
      READ(5,25)(DATA(I,K),K=1,NCOLS)
   25 FORMAT(4F8.3)
      LSYMB(I,1)=ICHAR
      WRITE(6,26)LSYMB(I,1),(DATA(I,K),K=1,NCOLS)
   26 FORMAT(1H ,A1,5X,4F10.3)
   50 CONTINUE
      JJ=JJ+NPTS
      GO TO 15
C         AFTER ALL DATA IS READ AND ASSIGNED APPROPRIATE SYMBOL WRITE
C      CHANNELS TO BE SCATTER PLOTTED,SYMBOL AND CHANNEL DATA ON A
C      FRAME OF MICROFILM
   55 CONTINUE
      WRITE(7,57)(IDES(N),N=1,3)
   57 FORMAT(1H ,10X,3A10)
      DO 175 LL=1,NPLOT
      WRITE(7,60)LAB,MA(LL,1),MA(LL,2)
   60 FORMAT(1H ,5X,12HSCATTER PLOT,5X,A10,I3,4H VS ,I3)
      WRITE(7,70)
   70 FORMAT(1H ,1X,6HSYMBOL,4X,1HX,8X,1HY)
      DO 100 J=1,MM
      WRITE(7,75)LSYMB(J,1),DATA(J,MA(LL,1)),DATA(J,MA(LL,2))
   75 FORMAT(1H ,3X,A1,4X,F6.3,3X,F6.3)
  100 CONTINUE
C         SET UP PLOT FORMAT
      CALL MAP(XMIN,XMAX,YMIN,YMAX,.1,1.0,.1,1.0)
      CALL GRDFMT(7H(F10.2),7H(F10.2))
      CALL PERIML(5,5,5,5)
      CALL FRSTPT(0,0)
C         PLOT APPROPRIATE CHANNEL DATA
      DO 150 M=1,MM
      CALL PSYM(DATA(M,MA(LL,1)),DATA(M,MA(LL,2)),LSYMB(M,1),1,0,1)
  150 CONTINUE


      CALL FRAME
C         REPEAT FOR NUMBER OF CHANNEL PAIRS
  175 CONTINUE
      STOP
      END
```

APPENDIX C: PROGRAM TASSEL OUTPUT

A. Field Data Transformations

B. Model Data Transformations

A. FIELD DATA TRANSFORMATIONS

```
                                        TASSELED CAP TRANSFORMATION FOR LANDSAT DATA VECTORS

TRANSFORM MATRIX =
     .43259   -.28972   -.82943    .22303
     .63248   -.56199    .52244    .01170
     .58572    .59953   -.03899   -.52450
     .26414    .49070    .19386    .80982

TRANSPOSE OF TRANSFORM MATRIX =
     .43258    .63248    .58572    .26414
    -.28972   -.56199    .59953    .49070
    -.82943    .52244   -.03899    .19386
     .22303    .01170   -.52450    .80982

OFFSET VECTOR =
   32.00000  32.00000  32.00000  32.00000

LANDSAT VECTOR =            6.34820   5.79570   7.65610   5.61760      MAR 1 0920
VECTOR IN COUNTS =         32.50893  36.80269  55.24572  23.08101
TRANSFORMED VECTOR =      107.79462  46.34609  26.58377  29.39614

LANDSAT VECTOR =            5.55320   5.00270   6.17000   4.82700      MAR 1 1250
VECTOR IN COUNTS =         28.43776  31.76714  44.52216  19.83267
TRANSFORMED VECTOR =       95.70981  42.33246  27.11814  31.42317

LANDSAT VECTOR =            4.18040   4.53920   5.26860   4.74640      MAR 1 1340
VECTOR IN COUNTS =         21.40769  28.82392  38.01774  19.50151
TRANSFORMED VECTOR =       86.90997  41.96118  31.60084  32.46421

LANDSAT VECTOR =            4.41310   4.53920   5.52260   4.58530      MAR 1 1500
VECTOR IN COUNTS =         22.59934  28.82392  39.85039  18.83960
TRANSFORMED VECTOR =       88.32415  42.38997  30.41267  31.73263

LANDSAT VECTOR =            5.75890   5.13920   6.35530   5.02040      MAR 1 1530
VECTOR IN COUNTS =         29.49114  32.63392  45.85927  20.62730
TRANSFORMED VECTOR =       97.70676  42.73171  26.79918  31.61044

LANDSAT VECTOR =            6.37770   6.42680   6.23950   4.74640      MAR 2 1300
VECTOR IN COUNTS =         32.66000  40.81018  45.02366  19.50151
TRANSFORMED VECTOR =      103.46207  36.16526  28.25673  31.93944

LANDSAT VECTOR =            5.67070   5.93280   6.42480   5.00430      MAR 2 1350
VECTOR IN COUNTS =         29.03947  37.67328  46.36077  20.56115
TRANSFORMED VECTOR =      100.97494  40.29871  29.77420  31.25205

LANDSAT VECTOR =            5.37720   5.74090   6.07740   4.61760      MAR 2 1500
VECTOR IN COUNTS =         27.53647  36.45471  43.85397  18.97231
TRANSFORMED VECTOR =       97.66610  39.13643  30.17394  30.93073

LANDSAT VECTOR =            7.14790   6.94960   7.23730   5.40770      MAR 2 1540
VECTOR IN COUNTS =         36.60417  44.12996  52.22370  22.21859
TRANSFORMED VECTOR =      112.20283  38.80678  26.96576  31.28188

LANDSAT VECTOR =            5.99430   5.71360   5.96170   4.32780      MAR 3 0940
VECTOR IN COUNTS =         30.69662  36.28136  43.01909  17.78161
TRANSFORMED VECTOR =       98.11995  37.23348  27.26397  31.10715

LANDSAT VECTOR =            4.52960   4.45750   5.10720   4.11870      MAR 3 1315
VECTOR IN COUNTS =         23.19594  28.30512  36.85309  16.92248
TRANSFORMED VECTOR =       85.99202  39.77087  29.39202  31.87928
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LANDSAT VECTOR =             4.99650   4.72990   5.24550   4.20340      MAR 3 1400
VECTOR IN COUNTS =          25.59692  30.03486  37.85177  17.51701
TRANSFORMED VECTOR =        86.86232  38.99654  28.38987  32.39043

LANDSAT VECTOR =             4.67530   4.45750   4.69250   3.97400      MAR 3 1500
VECTOR IN COUNTS =          23.94206  28.30512  33.86065  16.32796
TRANSFORMED VECTOR =        84.40501  37.40891  28.77458  33.13376

LANDSAT VECTOR =             6.17110   5.96020   6.63350   5.13330      MAR 3 1545
VECTOR IN COUNTS =          31.60200  37.84737  47.86673  21.09117
TRANSFORMED VECTOR =       103.21556  40.62146  27.78369  31.46496

LANDSAT VECTOR =             5.17210   3.53400   5.61500   4.85920      MAR 4 0950
VECTOR IN COUNTS =          26.48616  22.44090  40.51733  19.96497
TRANSFORMED VECTOR =        86.65616  45.80304  24.04625  33.08646

LANDSAT VECTOR =             3.39800   2.83050   4.48540   3.94190      MAR 4 1325
VECTOR IN COUNTS =          17.40195  17.97367  32.36624  16.19697
TRANSFORMED VECTOR =        74.13092  44.20946  28.83503  32.23105

LANDSAT VECTOR =             3.36920   2.77650   4.73850   4.05440      MAR 4 1405
VECTOR IN COUNTS =          17.25356  17.63077  34.19259  16.65830
TRANSFORMED VECTOR =        75.04206  45.76668  28.79661  31.61055

LANDSAT VECTOR =             3.65830   2.99270   5.17640   4.58530      MAR 4 1515
VECTOR IN COUNTS =          18.73404  19.00364  37.35243  18.83960
TRANSFORMED VECTOR =        78.97775  47.53101  28.58567  32.06593

LANDSAT VECTOR =             4.73370   3.77810   5.82300   5.10110      MAR 4 1600
VECTOR IN COUNTS =          24.24112  23.99093  42.01824  20.95887
TRANSFORMED VECTOR =        87.80701  46.96991  26.85230  32.62154

LANDSAT VECTOR =             2.85960   1.59580   6.51580   6.41480      APR 1 1000
VECTOR IN COUNTS =          14.64392  10.13333  47.01742  26.35646
TRANSFORMED VECTOR =        79.24463  63.18400  28.42421  32.06795

LANDSAT VECTOR =             2.92080   1.76680   4.75320   6.14050      APR 1 1100
VECTOR IN COUNTS =          14.95732  11.21918  34.29866  25.22945
TRANSFORMED VECTOR =        72.31966  54.30466  29.00897  37.90886

LANDSAT VECTOR =             3.04320   1.79530   6.44210   6.55200      APR 1 1150
VECTOR IN COUNTS =          15.58413  11.40015  46.48561  26.92017
TRANSFORMED VECTOR =        80.29000  62.15744  28.43622  33.02790

LANDSAT VECTOR =             2.95130   1.70980   6.49120   6.10120      APR 1 1220
VECTOR IN COUNTS =          15.11351  10.85723  46.83991  25.06852
TRANSFORMED VECTOR =        79.46674  61.91252  28.17402  31.24745

LANDSAT VECTOR =             6.95370   6.78590   8.43810   6.39760      APR 2 1115
VECTOR IN COUNTS =          35.60967  43.09046  60.88856  26.28579
TRANSFORMED VECTOR =       117.26467  46.86971  27.69817  29.79689

LANDSAT VECTOR =             7.07960   6.52350   8.26500   6.65490      APR 2 1200
VECTOR IN COUNTS =          36.25440  41.42422  59.63949  27.34296
TRANSFORMED VECTOR =       116.03733  47.38923  26.54654  31.43245

LANDSAT VECTOR =             6.60800   6.78590   8.31450   6.72360      APR 2 1300
VECTOR IN COUNTS =          33.83935  43.09046  59.99668  27.62523
TRANSFORMED VECTOR =       116.33027  47.50516  29.46046  30.95455

LANDSAT VECTOR =             3.62600   2.79590   5.33940   5.09690      APR 3 1030
VECTOR IN COUNTS =          18.56863  17.75396  38.52862  20.94161
TRANSFORMED VECTOR =        79.35995  50.01786  28.43151  33.0997[illegible]
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```
LANDSAT VECTOR =                3.31050   3.02530   4.99720   4.96030     APR 3 1130
VECTOR IN COUNTS =             19.51376  19.21065  36.06008  20.38036
TRANSFORMED VECTOR =           79.39607  47.16995  29.39541  34.16789

LANDSAT VECTOR =                3.37220   4.43530   5.07060   5.47290     APR 3 1205
VECTOR IN COUNTS =             19.82941  28.16416  36.56879  22.40648
TRANSFORMED VECTOR =           85.70155  43.39736  33.19960  35.77115

LANDSAT VECTOR =                4.08790   3.36980   5.60860   5.19940     APR 3 1330
VECTOR IN COUNTS =             20.93400  21.39823  40.47115  21.30275
TRANSFORMED VECTOR =           83.93710  48.65579  29.37941  32.99214

LANDSAT VECTOR =                3.10440   2.13790   5.83450   5.40450     APR 4 1045
VECTOR IN COUNTS =             15.89753  13.57566  41.89474  22.20545
TRANSFORMED VECTOR =           77.36137  55.77215  28.57824  31.71833

LANDSAT VECTOR =                3.19630   1.93800   6.46670   6.14090     APR 4 1140
VECTOR IN COUNTS =             16.36815  12.30630  46.66312  25.22945
TRANSFORMED VECTOR =           80.85965  60.69783  27.92465  31.75108

LANDSAT VECTOR =                3.13500   1.99510   6.41740   6.24330     APR 4 1215
VECTOR IN COUNTS =             16.05423  12.66888  46.30892  25.65182
TRANSFORMED VECTOR =           80.85723  60.57985  28.47015  32.21319

LANDSAT VECTOR =                3.22700   1.99510   6.85930   6.10620     APR 4 1345
VECTOR IN COUNTS =             16.52536  12.66888  49.49969  25.08852
TRANSFORMED VECTOR =           82.78120  62.07997  27.84577  30.18847

LANDSAT VECTOR =                4.55050   2.99060   9.79200   9.68730     MAY 1 0935
VECTOR IN COUNTS =             23.30296  18.99031  70.65818  39.80217
TRANSFORMED VECTOR =          105.99064  76.46892  27.55421  32.59192

LANDSAT VECTOR =                4.44780   2.95890   8.34340   9.38220     MAY 1 1045
VECTOR IN COUNTS =             22.77704  18.78901  60.20522  38.54860
TRANSFORMED VECTOR =           99.18220  69.85243  28.04980  36.93959

LANDSAT VECTOR =                4.10570   2.80040   7.82590   7.00730     MAY 1 1245
VECTOR IN COUNTS =             21.02516  17.78254  56.47026  28.79086
TRANSFORMED VECTOR =           93.02274  63.89827  27.23104  30.59406

LANDSAT VECTOR =                4.55050   3.75330   7.20040   7.99340     MAY 1 1345
VECTOR IN COUNTS =             23.30296  23.83345  51.95743  32.84245
TRANSFORMED VECTOR =           96.26209  59.12033  29.46439  36.82091

LANDSAT VECTOR =                5.89280   4.26300   9.40870   8.46840     MAY 2 0945
VECTOR IN COUNTS =             30.17684  27.07005  67.89232  34.79408
TRANSFORMED VECTOR =          111.13156  65.82101  25.21096  31.61448

LANDSAT VECTOR =                5.44410   4.39060   8.04360   7.31040     MAY 2 1050
VECTOR IN COUNTS =             27.87906  27.88031  58.04189  30.03621
TRANSFORMED VECTOR =          103.62372  57.79104  27.00183  32.42502

LANDSAT VECTOR =                6.13490   5.18960   8.72540   7.51900     MAY 2 1300
VECTOR IN COUNTS =             31.41662  32.95396  62.96169  30.89328
TRANSFORMED VECTOR =          111.47100  57.28494  26.69267  31.38700

LANDSAT VECTOR =                5.96190   4.99760   8.26160   7.17780     MAY 2 1350
VECTOR IN COUNTS =             30.53070  31.73476  59.61495  29.49140
TRANSFORMED VECTOR =          107.98610  55.53241  26.64925  31.79524

LANDSAT VECTOR =                4.92800   3.49880   8.12540   7.93640     MAY 3 0955
VECTOR IN COUNTS =             25.23613  22.21738  58.63215  32.60825
TRANSFORMED VECTOR =           99.92386  63.35524  26.71101  33.54261
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LANDSAT VECTOR =             4.31080   3.08560   7.52650   7.70870      MAY 3 1100
VECTOR IN COUNTS =          22.07547  19.59483  54.31054  31.67270
TRANSFORMED VECTOR =        94.11954  62.69479  27.94957  34.31606
-------------------------------------------------------------------------------------
LANDSAT VECTOR =             4.61910   3.65780   6.87460   6.59080      MAY 3 1320
VECTOR IN COUNTS =          23.65426  23.22703  49.60649  27.07959
TRANSFORMED VECTOR =        93.13131  55.12206  27.83067  33.45836

LANDSAT VECTOR =             4.03730   3.21280   6.90170   6.38280      MAY 3 1400
VECTOR IN COUNTS =          20.67488  20.40128  49.80204  26.22498
TRANSFORMED VECTOR =        89.94406  57.27117  28.65227  31.96616

LANDSAT VECTOR =             2.94800   1.75640   6.03450   6.79900      MAY 4 1000
VECTOR IN COUNTS =          15.09661  11.15314  43.54440  27.93502
TRANSFORMED VECTOR =        79.46822  61.17213  29.02295  35.28079
-------------------------------------------------------------------------------------
LANDSAT VECTOR =             3.18560   1.91430   6.57620   6.78010      MAY 4 1105
VECTOR IN COUNTS =          16.31335  12.15580  47.45326  27.85737
TRANSFORMED VECTOR =        81.89770  62.56152  28.37012  33.45081

LANDSAT VECTOR =             3.66200   2.45170   6.52200   6.34500      MAY 4 1310
VECTOR IN COUNTS =          18.75298  15.56956  47.06216  26.06967
TRANSFORMED VECTOR =        84.41090  58.82451  27.79879  32.79228

LANDSAT VECTOR =             3.49170   2.51520   6.68470   6.51520      MAY 4 1410
VECTOR IN COUNTS =          17.88088  15.97152  48.23619  26.76897
TRANSFORMED VECTOR =        85.16024  59.89829  28.82192  32.55301
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LANDSAT VECTOR =             7.34850   5.58820   7.47540   5.96830      JUN 1 0945
VECTOR IN COUNTS =          37.63143  35.48507  53.94181  24.52193
TRANSFORMED VECTOR =       108.79422  45.52781  21.97681  32.17398

LANDSAT VECTOR =             5.49240   5.42330   6.74900   5.75470      JUN 1 1215
VECTOR IN COUNTS =          28.12640  34.43795  48.70017  23.64431
TRANSFORMED VECTOR =       100.71831  45.29691  29.34775  32.28035

LANDSAT VECTOR =             5.95450   5.95150   7.00020   5.83240      JUN 1 1315
VECTOR IN COUNTS =          30.49280  37.79202  50.51281  23.96356
TRANSFORMED VECTOR =       105.00937  43.96975  29.12850  32.15518
-------------------------------------------------------------------------------------
LANDSAT VECTOR =             5.45690   4.83030   6.83270   5.32780      JUN 1 1730
VECTOR IN COUNTS =          27.94461  30.67240  49.30414  21.83031
TRANSFORMED VECTOR =        98.14849  46.96719  27.16768  30.45854

LANDSAT VECTOR =             7.13330   7.17720   9.13000   7.52570      JUN 2 1025
VECTOR IN COUNTS =          36.52940  45.57522  65.88125  30.92081
TRANSFORMED VECTOR =       123.36269  50.47451  28.93734  31.16596

LANDSAT VECTOR =             7.09750   7.07760   8.79280   7.07730      JUN 2 1230
VECTOR IN COUNTS =          36.34607  44.94276  63.44805  29.07647
TRANSFORMED VECTOR =       120.99156  48.52025  28.49669  30.90192
-------------------------------------------------------------------------------------
LANDSAT VECTOR =             7.38440   7.14400   8.65240   7.05790      JUN 2 1325
VECTOR IN COUNTS =          37.81527  45.36440  62.43493  28.99876
TRANSFORMED VECTOR =       121.27933  47.21113  27.52242  31.70136

LANDSAT VECTOR =             6.84680   6.94490   9.18630   7.87700      JUN 2 1745
VECTOR IN COUNTS =          35.06224  44.10011  66.28751  32.36420
TRANSFORMED VECTOR =       122.43426  52.68040  29.64756  31.77728

LANDSAT VECTOR =             5.88330   5.81930   6.94440   5.77410      JUN 3 1125
VECTOR IN COUNTS =          30.12819  36.95255  50.11016  23.72402
TRANSFORMED VECTOR =       104.02159  44.18821  28.96161  32.08124
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LANDSAT VECTOR =              6.34650    6.05060    7.36350    6.10440      JUN 3 1235
VECTOR IN COUNTS =           32.50022   38.42131   53.13435   25.08112
TRANSFORMED VECTOR =        103.10643   45.15458   27.90669   32.14028

LANDSAT VECTOR =              6.59640    6.34840    6.97230    5.85180      JUN 3 1330
VECTOR IN COUNTS =           33.77995   40.31234   50.31148   24.04327
TRANSFORMED VECTOR =        107.92851   41.51941   27.74206   33.08794

LANDSAT VECTOR =              6.23950    5.62120    7.27960    5.94890      JUN 3 1855
VECTOR IN COUNTS =           31.95228   35.69462   52.52893   24.44222
TRANSFORMED VECTOR =        105.62146   46.16923   26.83638   31.78632

LANDSAT VECTOR =              4.78410    4.23880    6.38640    5.75470      JUN 4 1145
VECTOR IN COUNTS =           24.49922   25.91638   46.08368   23.64431
TRANSFORMED VECTOR =         92.85949   49.00616   28.52869   32.75573

LANDSAT VECTOR =              4.99630    4.50150    6.88850    5.75470      JUN 4 1250
VECTOR IN COUNTS =           25.58589   28.58452   49.70679   23.64431
TRANSFORMED VECTOR =         96.50675   49.92691   28.35761   31.11728

LANDSAT VECTOR =              5.13790    4.50150    6.88850    5.75470      JUN 4 1345
VECTOR IN COUNTS =           26.31102   28.58452   49.70679   23.64431
TRANSFORMED VECTOR =         96.82043   49.71593   27.75617   31.27901

LANDSAT VECTOR =              5.10250    4.33730    7.75520    6.57050      JUN 4 1800
VECTOR IN COUNTS =           25.12974   27.54185   35.76082   27.07836
TRANSFORMED VECTOR =        100.65272   55.78899   27.78368   30.72710
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B. MODEL DATA TRANSFORMATIONS

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                                  TASSELED CAP TRANSFORMATION FOR LANDSAT DATA VECTORS

   TRANSFORM MATRIX =
        .43258    -.28972    -.82943     .22303
        .63248    -.56199     .52244     .01170
        .58572     .59953    -.03899    -.52450
        .26414     .49070     .19386     .80982

   TRANSPOSE OF TRANSFORM MATRIX =
        .43258     .63248     .58572     .26414
       -.28972    -.56149     .59953     .49070
       -.82943     .52244    -.03899     .19386
        .22303     .01170    -.52450     .80982

   OFFSET VECTOR =
     32.00000  32.00000  32.00000  32.00000

   LANDSAT VECTOR =              4.47130    4.48480    5.31480    4.61740       MAR L1 S1
   VECTOR IN COUNTS =           22.89738   28.47848   38.35111   18.97231
   TRANSFORMED VECTOR =         87.39138   41.66391   30.06918   32.68980

   LANDSAT VECTOR =              4.99650    5.22120    5.93860    5.11720       MAR L1 S2
   VECTOR IN COUNTS =           25.58692   33.13462   42.85240   21.02502
   TRANSFORMED VECTOR =         94.69108   41.96267   30.50384   32.64496

   LANDSAT VECTOR =              5.40650    5.71360    6.95840    6.15120       MAR L1 S3
   VECTOR IN COUNTS =           27.68651   36.28136   50.21118   25.27341
   TRANSFORMED VECTOR =        103.00928   46.09367   30.93258   32.73056

   LANDSAT VECTOR =              3.91910    3.72380    5.33790    4.79480       MAR L2 S1
   VECTOR IN COUNTS =           20.06958   23.64613   38.51780   19.70037
   TRANSFORMED VECTOR =         83.40171   45.65610   30.02467   32.50395

   LANDSAT VECTOR =              4.61700    4.62090    6.44800    5.82770       MAR L2 S2
   VECTOR IN COUNTS =           23.64351   29.34271   46.52818   23.94425
   TRANSFORMED VECTOR =         94.36351   48.30417   30.54687   32.60302

   LANDSAT VECTOR =              5.17210    5.35780    7.00490    6.26450       MAR L2 S3
   VECTOR IN COUNTS =           26.48616   34.02203   50.54672   25.73892
   TRANSFORMED VECTOR =        101.38054   49.14076   30.82499   32.63741

   LANDSAT VECTOR =              2.96540    2.34490    5.56880    5.35930       MAR L3 S1
   VECTOR IN COUNTS =           15.18572   14.89011   40.18395   22.01973
   TRANSFORMED VECTOR =         77.33958   54.12887   29.88567   32.31642

   LANDSAT VECTOR =              3.25370    2.72250    6.05430    5.82770       MAR L3 S2
   VECTOR IN COUNTS =           16.66209   17.28787   43.68728   23.94425
   TRANSFORMED VECTOR =         82.05507   55.39832   30.15030   32.39447

   LANDSAT VECTOR =              3.28250    2.72250    6.21630    6.02180       MAR L3 S3
   VECTOR IN COUNTS =           16.80958   17.28787   44.85626   24.74174
   TRANSFORMED VECTOR =         83.01421   56.44776   30.13700   32.46056

   LANDSAT VECTOR =              3.81060    3.05400    5.97600    5.78090       APR L1 S1
   VECTOR IN COUNTS =           19.51396   19.39290   43.12227   23.75196
   TRANSFORMED VECTOR =         84.23839   52.95598   29.86938   33.19627

   LANDSAT VECTOR =              3.93380    3.28360    6.24580    6.05490       APR L1 S2
   VECTOR IN COUNTS =           20.14486   20.85986   45.06912   24.87774
   TRANSFORMED VECTOR =         86.87111   53.67346   29.25012   33.24460

   LANDSAT VECTOR =              3.87220    3.05400    6.73690    6.68930       APR L1 S3
   VECTOR IN COUNTS =           19.82941   19.39290   48.61286   27.48430
   TRANSFORMED VECTOR =         88.57665   57.98782   29.11721   33.40934
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LANDSAT VECTOR =              3.44170    2.36650    6.24580    6.19190      APR L2 S1
VECTOR IN COUNTS =           17.62433   15.02727   45.06912   25.44063
TRANSFORMED VECTOR =         82.24638   57.95257   28.40696   33.07026

LANDSAT VECTOR =              3.65680    2.65270    6.95820    6.99830      APR L2 S2
VECTOR IN COUNTS =           18.72635   16.84464   50.20974   28.75388
TRANSFORMED VECTOR =         87.73845   61.31985   28.88467   33.32408

LANDSAT VECTOR =              3.59530    2.59540    6.76150    6.84380      APR L2 S3
VECTOR IN COUNTS =           18.41142   16.48079   48.79037   28.11909
TRANSFORMED VECTOR =         86.39305   60.45313   28.88807   33.47998

LANDSAT VECTOR =              3.50310    2.36650    6.83520    6.84380      APR L3 S1
VECTOR IN COUNTS =           17.93926   15.02727   49.32218   28.11909
TRANSFORMED VECTOR =         85.58098   61.72562   28.49958   33.07873

LANDSAT VECTOR =              3.41100    2.28080    6.71230    6.77510      APR L3 S2
VECTOR IN COUNTS =           17.46762   14.48308   48.43535   27.83682
TRANSFORMED VECTOR =         84.43877   61.49791   28.58632   33.20373

LANDSAT VECTOR =              3.68750    2.59540    7.20430    7.27330      APR L3 S3
VECTOR IN COUNTS =           18.88357   16.48079   51.98557   29.88378
TRANSFORMED VECTOR =         88.93492   63.09789   28.71398   33.33847

LANDSAT VECTOR =              3.76430    2.29370    7.49930    6.25050      MAY L1 S1
VECTOR IN COUNTS =           19.27686   14.56499   54.11427   25.68140
TRANSFORMED VECTOR =         88.03015   63.27472   26.48921   28.88411

LANDSAT VECTOR =              3.90070    2.57850    7.52650    6.30720      MAY L1 S2
VECTOR IN COUNTS =           19.97536   16.37347   54.31054   25.91437
TRANSFORMED VECTOR =         89.65263   62.28799   26.89219   29.14677

LANDSAT VECTOR =              4.00320    2.54490    8.39800    7.10200      MAY L1 S3
VECTOR IN COUNTS =           20.50026   16.17281   60.59920   29.17996
TRANSFORMED VECTOR =         94.29874   67.62135   26.73986   28.60742

LANDSAT VECTOR =              3.73020    1.97750    8.45250    6.95050      MAY L2 S1
VECTOR IN COUNTS =           19.10223   12.55712   60.99247   28.55749
TRANSFORMED VECTOR =         91.47306   69.98970   25.87444   27.54316

LANDSAT VECTOR =              3.76430    2.04070    8.47980    7.00730      MAY L2 S2
VECTOR IN COUNTS =           19.27686   12.95844   61.18947   28.79086
TRANSFORMED VECTOR =         91.97945   69.94519   25.97682   27.67247

LANDSAT VECTOR =              3.93490    2.29370    8.80730    7.32940      MAY L2 S3
VECTOR IN COUNTS =           20.15050   14.56499   63.55268   30.11427
TRANSFORMED VECTOR =         95.10723   70.85543   26.25594   27.71834

LANDSAT VECTOR =              3.76430    1.97750    8.47980    6.95050      MAY L3 S1
VECTOR IN COUNTS =           19.27686   12.55712   61.18947   28.55749
TRANSFORMED VECTOR =         91.66398   70.05621   25.72192   27.47879

LANDSAT VECTOR =              3.86660    2.04070    9.13520    7.53790      MAY L3 S3
VECTOR IN COUNTS =           19.80073   12.95844   65.91877   30.97094
TRANSFORMED VECTOR =         95.55197   73.69854   25.78054   27.07426

LANDSAT VECTOR =              3.86660    2.04070    8.99850    7.42420      MAY L3 S2
VECTOR IN COUNTS =           19.80073   12.95844   64.93236   30.50378
TRANSFORMED VECTOR =         94.85081   72.87792   25.72844   27.21332

LANDSAT VECTOR =              5.74110    5.62120    7.95130    6.20150      JUN L1 S1
VECTOR IN COUNTS =           29.39999   35.69462   57.37586   25.48008
TRANSFORMED VECTOR =        107.63047   50.32384   28.96555   29.51534
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LANDSAT VECTOR =              6.06130    6.05060    9.65240    6.82410       JUN L1 S2
VECTOR IN COUNTS =           31.03972   38.42131   62.43493   28.03815
TRANSFORMED VECTOR =        113.70326   52.60471   29.32869   29.33165

LANDSAT VECTOR =              6.41790    6.58020    9.10190    7.31120       JUN L1 S3
VECTOR IN COUNTS =           32.86586   41.73427   65.67848   30.03960
TRANSFORMED VECTOR =        119.04866   53.11236   29.83250   29.69717

LANDSAT VECTOR =              6.02570    5.72020    9.18630    7.01890       JUN L2 S1
VECTOR IN COUNTS =           30.85742   36.32327   66.28751   28.83852
TRANSFORMED VECTOR =        114.76537   56.53909   28.38875   27.89333

LANDSAT VECTOR =              6.02570    5.78630    9.21440    7.11630       JUN L2 S2
VECTOR IN COUNTS =           30.85742   36.74300   66.49027   29.23871
TRANSFORMED VECTOR =        115.25531   56.62114   28.67771   28.11597

LANDSAT VECTOR =              5.77660    5.48920    9.04570    6.99940       JUN L2 S3
VECTOR IN COUNTS =           29.58178   34.85642   65.27295   28.75840
TRANSFORMED VECTOR =        112.67039   57.08545   28.70448   28.05891

LANDSAT VECTOR =              6.27520    5.98450    9.80560    7.42820       JUN L3 S1
VECTOR IN COUNTS =           32.13510   38.00157   70.75632   30.52021
TRANSFORMED VECTOR =        119.44124   58.73012   28.35759   27.21590

LANDSAT VECTOR =              6.45360    6.21600   10.31330    7.87700       JUN L3 S2
VECTOR IN COUNTS =           33.04868   39.47160   74.41984   32.36420
TRANSFORMED VECTOR =        123.39906   60.74053   28.58247   27.00863

LANDSAT VECTOR =              6.34650    6.08370   10.14400    7.75990       JUN L3 S3
VECTOR IN COUNTS =           32.50022   38.63149   73.19818   31.88367
TRANSFORMED VECTOR =        121.78783   60.40305   28.55283   27.12761
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