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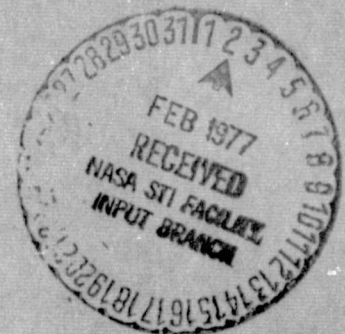
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Final Report
Earth Observations Division
NASA Johnson Spacecraft Center
NAS 9-14467

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.

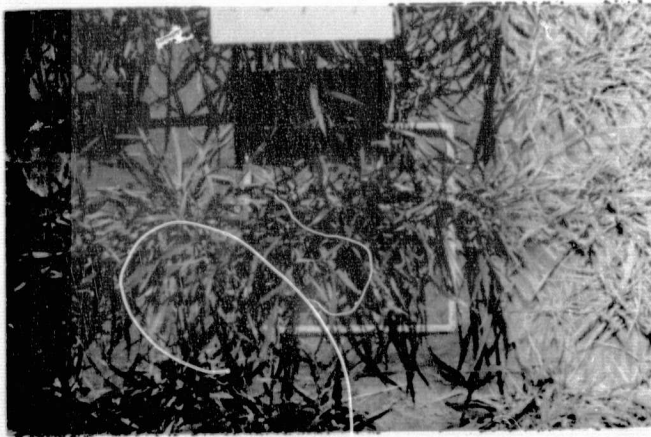
The sampling design used in the 1975-76 season was basically the same as the previous period with two exceptions. Four sacred sample plots were established in the field in which repetitive radiometric measurements were made during each phenology stage (Figures 1 through 4). As the method for assessing 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.



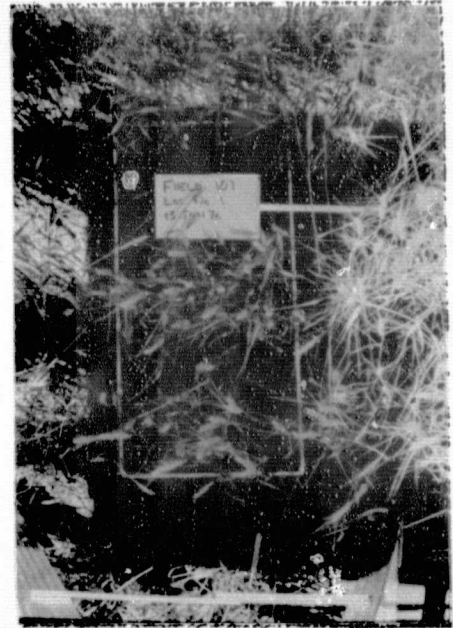
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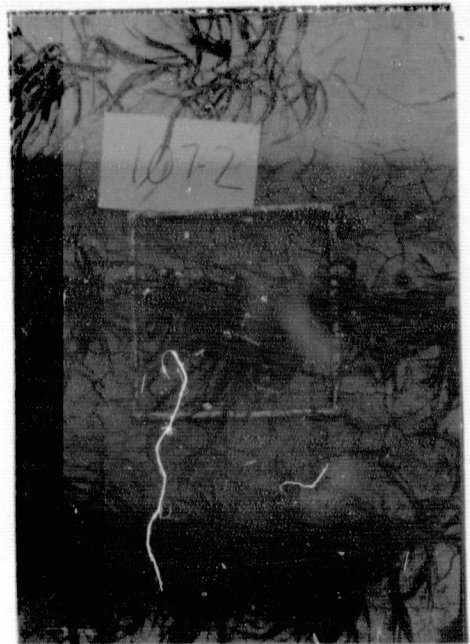
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FIGURE 1. Descriptive Photos for Sacred Plot 1.

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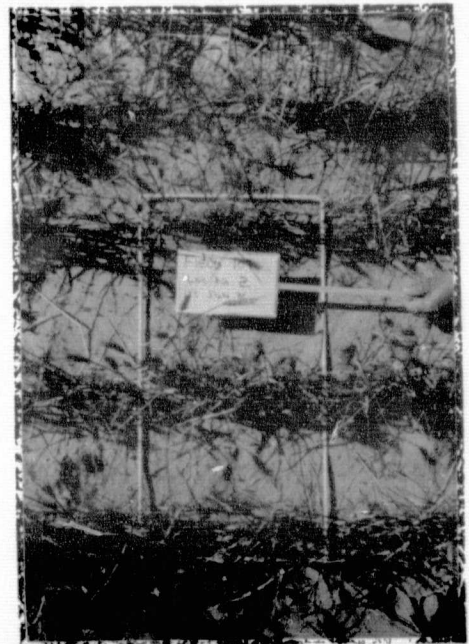
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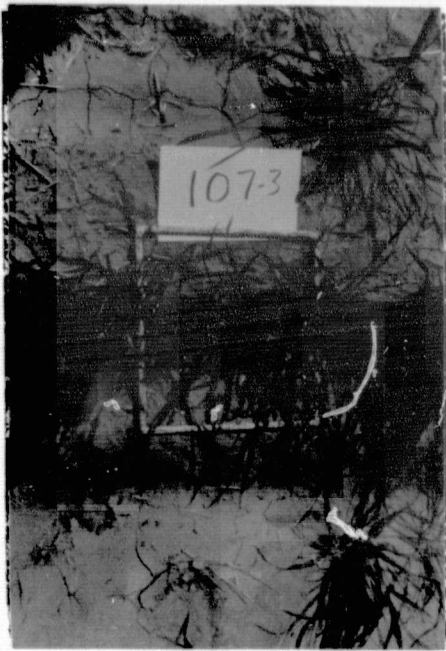


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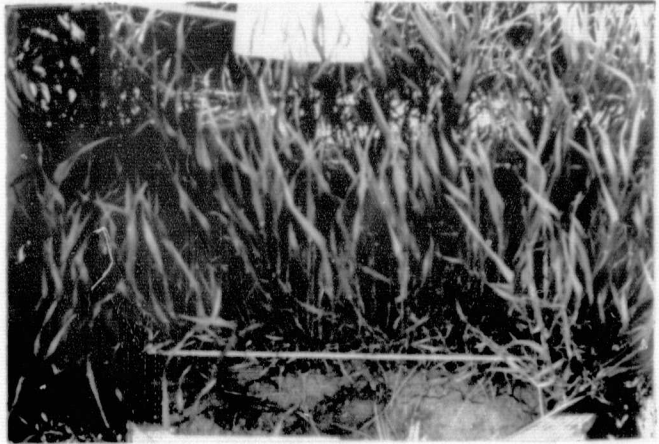


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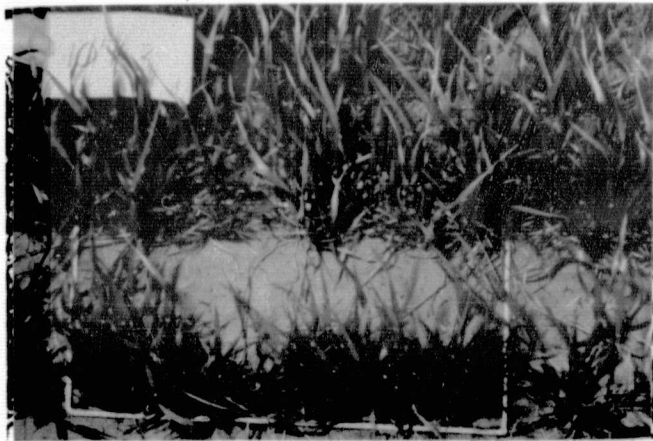
FIGURE 2. Descriptive Photos for Sacred Plot 2.



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FIGURE 3. Descriptive Photos for Sacred Plot 3.

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FIGURE 4. Descriptive Photos for Sacred Plot 4.

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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 photo-electric 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

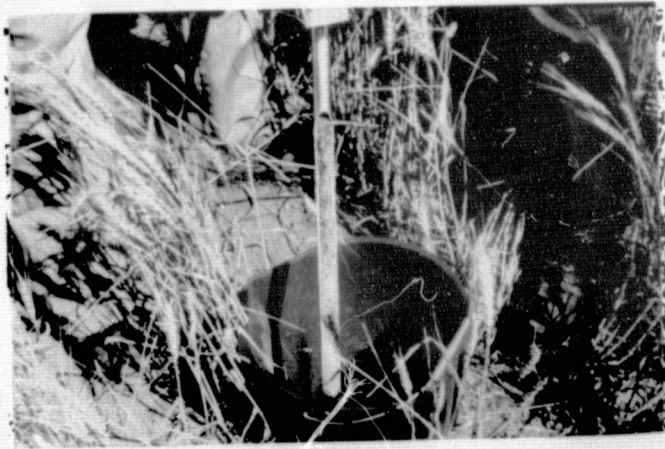


FIGURE 6. Field Collection of Soil Moisture Samples

TABLE 1

Finney County Data Collection
Summary (1976)

A. March 13, 1976 Tillering Stage Field 107

- Canopy Reflectance:

	<u>Plot 1</u>	<u>Plot 2</u>	<u>Plot 3</u>	<u>Plot 4</u>
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:

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:

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

- Vegetation Area Index:

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					

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TABLE 1
(Cont.)

C. May 16, 1976 Headed Field 107

- Canopy Reflectance:

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

- Vegetation Area Index:

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:

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

- Vegetation Area Index:

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

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TABLE 2
 LANDSAT RADIOMETER DATA
 FOR FINNEY COUNTY FIELD SITE, KANSAS
 (Averaged Over On-Off Row Set-Ups)

<u>November 11</u>	Band 4	5	6	7	<u>March 13</u>	Band 4	5	6	7
PLOT 1					PLOT 1				
0930	.089	.118	.181	.248	0920	.165	.185	.315	.341
1030	.092	.109	.189	.227	1250	.138	.156	.251	.292
1200	.092	.123	.172	.247	1340	.091	.139	.212	.287
					1500	.099	.139	.223	.277
					1530	.145	.161	.259	.304
PLOT 2					PLOT 2				
1000	.128	.167	.214	.239	0930	.163	.323	.221	.245
1100	.120	.155	.202	.229	1300	.166	.208	.254	.287
1215	.129	.160	.204	.237	1350	.142	.190	.262	.303
					1500	.132	.183	.247	.279
					1540	.192	.227	.297	.328
PLOT 3					PLOT 3				
1000	.093	.122	.179	.235	0940	.153	.182	.242	.261
1115	.098	.123	.177	.219	1315	.103	.136	.205	.248
1215	.090	.114	.164	.214	1400	.119	.146	.211	.257
					1500	.108	.136	.187	.239
					1545	.159	.191	.271	.311
PLOT 4					PLOT 4				
1015	.068	.082	.152	.202	0950	.125	.102	.227	.294
1130	.068	.077	.146	.185	1325	.064	.076	.178	.237
1230	.066	.075	.143	.181	1405	.063	.074	.189	.244
					1515	.073	.082	.208	.277
					1600	.110	.111	.236	.309

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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)

<u>May 16</u>	Band 4	5	6	7	<u>June 13</u>	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

(Axis units: 0.-.50 reflectance)

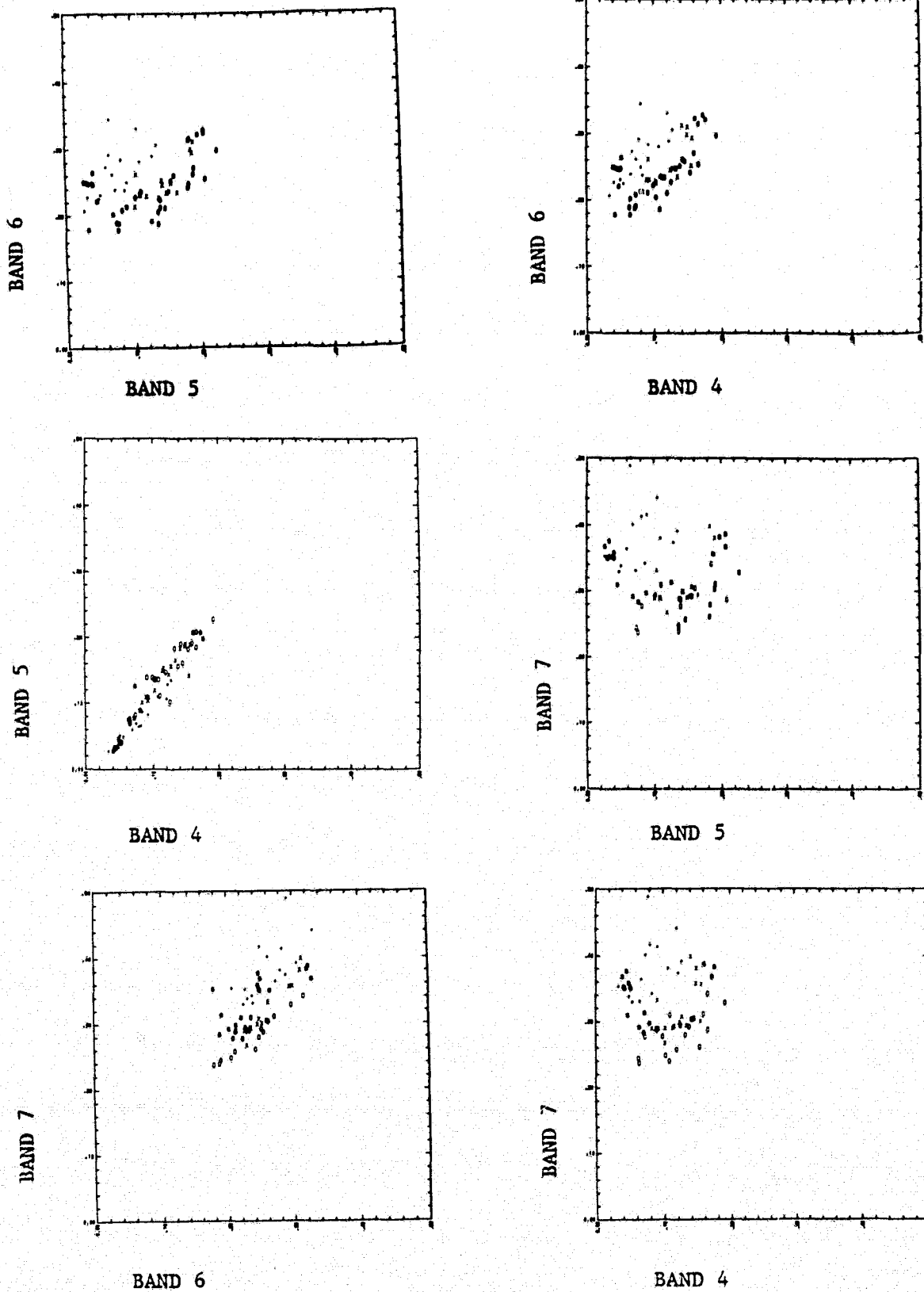


FIGURE 7. Scatter Plots of Field Measured Wheat Canopy Reflectance (1976) Composite Over All Phenology Stages (O=March, \$=April, .=May, X=June).

TABLE 3
 CALCULATED LANDSAT RADIANCE
 FOR FINNEY COUNTY FIELD SITE, KANSAS
 AVERAGE OVER-OFF ROW SET-UPS
 (Radiance - $\text{mWcm}^{-2}\text{sr}^{-1}\mu\text{m}^{-1}$)

<u>November 11</u>	Band 4	5	6	7	<u>March 13</u>	Band 4	5	6	7
<u>PLOT 1</u>					<u>PLOT 1</u>				
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
<u>PLOT 2</u>					<u>PLOT 2</u>				
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
<u>PLOT 3</u>					<u>PLOT 3</u>				
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
<u>PLOT 4</u>					<u>PLOT 4</u>				
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
<u>APRIL 17</u>									
<u>PLOT 1</u>									
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					
<u>PLOT 2</u>									
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					
<u>PLOT 3</u>									
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					
<u>PLOT 4</u>									
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					

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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 atmospheric model (Turner, 1973)

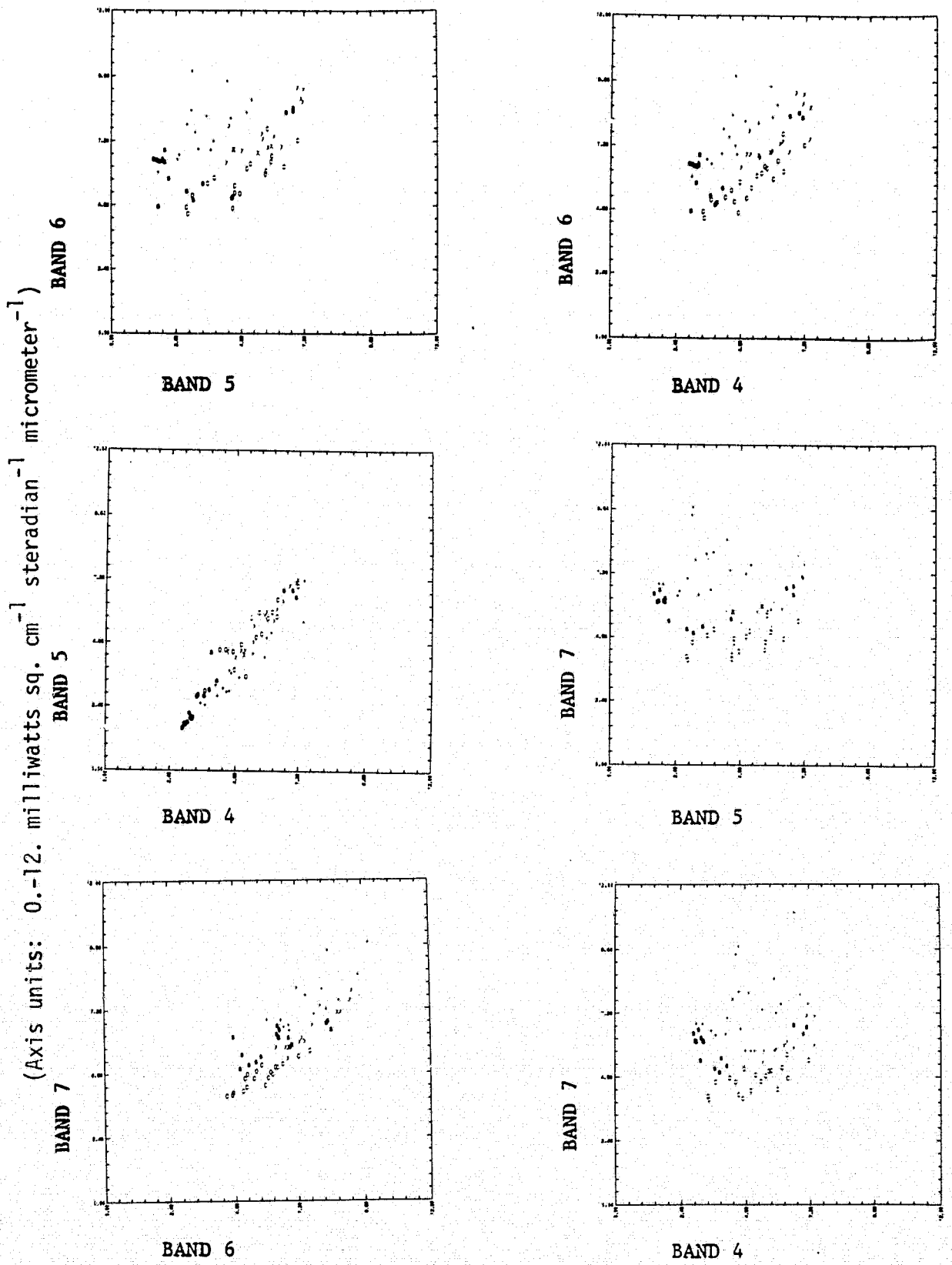


FIGURE 8. Scatter Plots of Calculated LANDSAT Radiance Using Measured Canopy Reflectance (1976). Composite Over All Phenology Stages (0=March, \$=April, .=May, X=June).

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 parameters, 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

	<u>MARCH</u>	<u>APRIL</u>	<u>MAY</u>	<u>JUNE</u>
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	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

<u>ANGLE</u>	<u>PROBABILITY DENSITY</u>			
	<u>MARCH</u>	<u>APRIL</u>	<u>MAY</u>	<u>JUNE</u>
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

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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

	<u>MARCH</u>	<u>APRIL</u>	<u>MAY</u>	<u>JUNE</u>
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

<u>GREEN LEAF AREA INDEX</u>	<u>MARCH</u>	<u>APRIL</u>	<u>MAY</u>	<u>JUNE</u>
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.

	<u>WAVELENGTH</u>			
<u>SOIL CHARACTER</u>	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

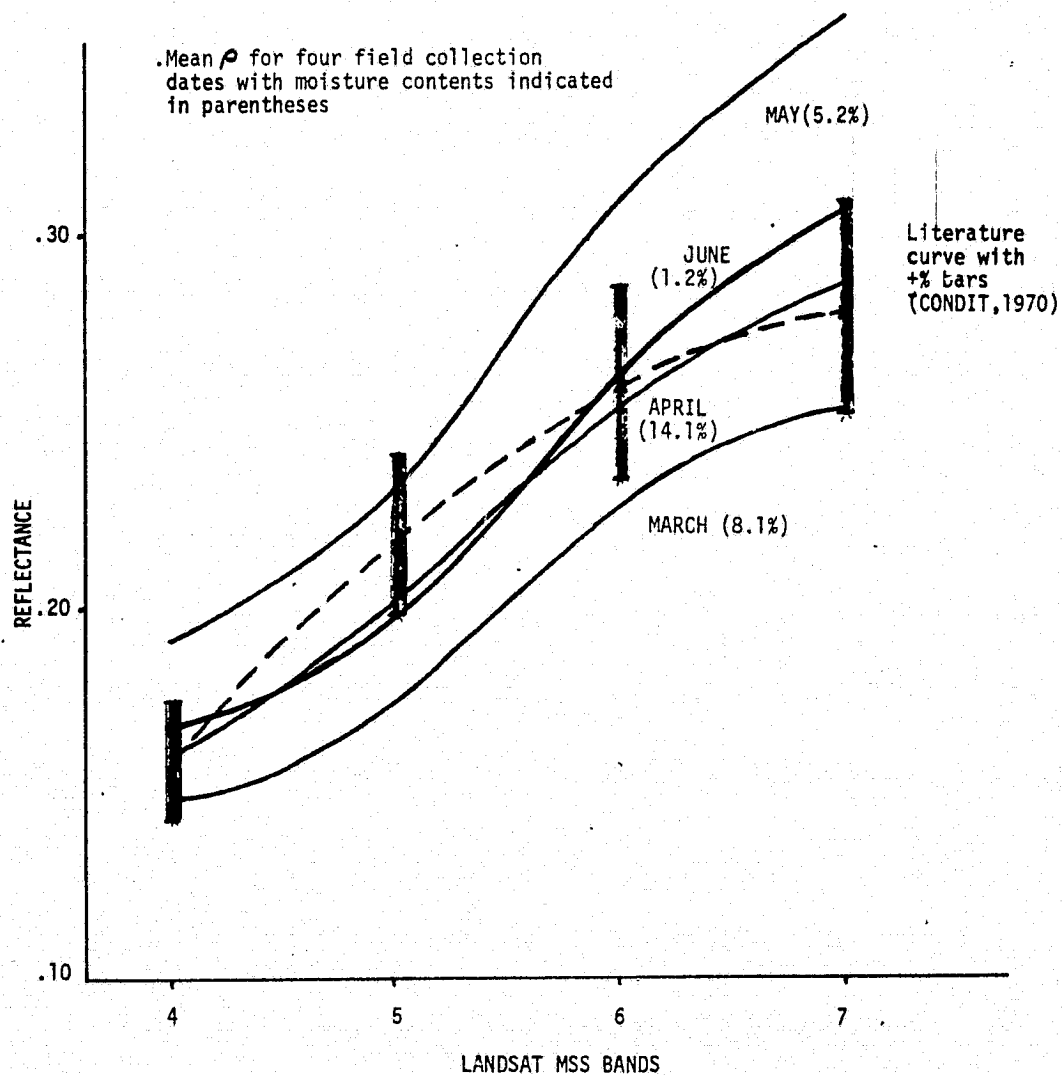


FIGURE 9. AVERAGE SOIL REFLECTANCE CURVES
(SHADED BARS REPRESENT CONDIT'S AVERAGE CURVE \pm 20 PERCENT.)

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

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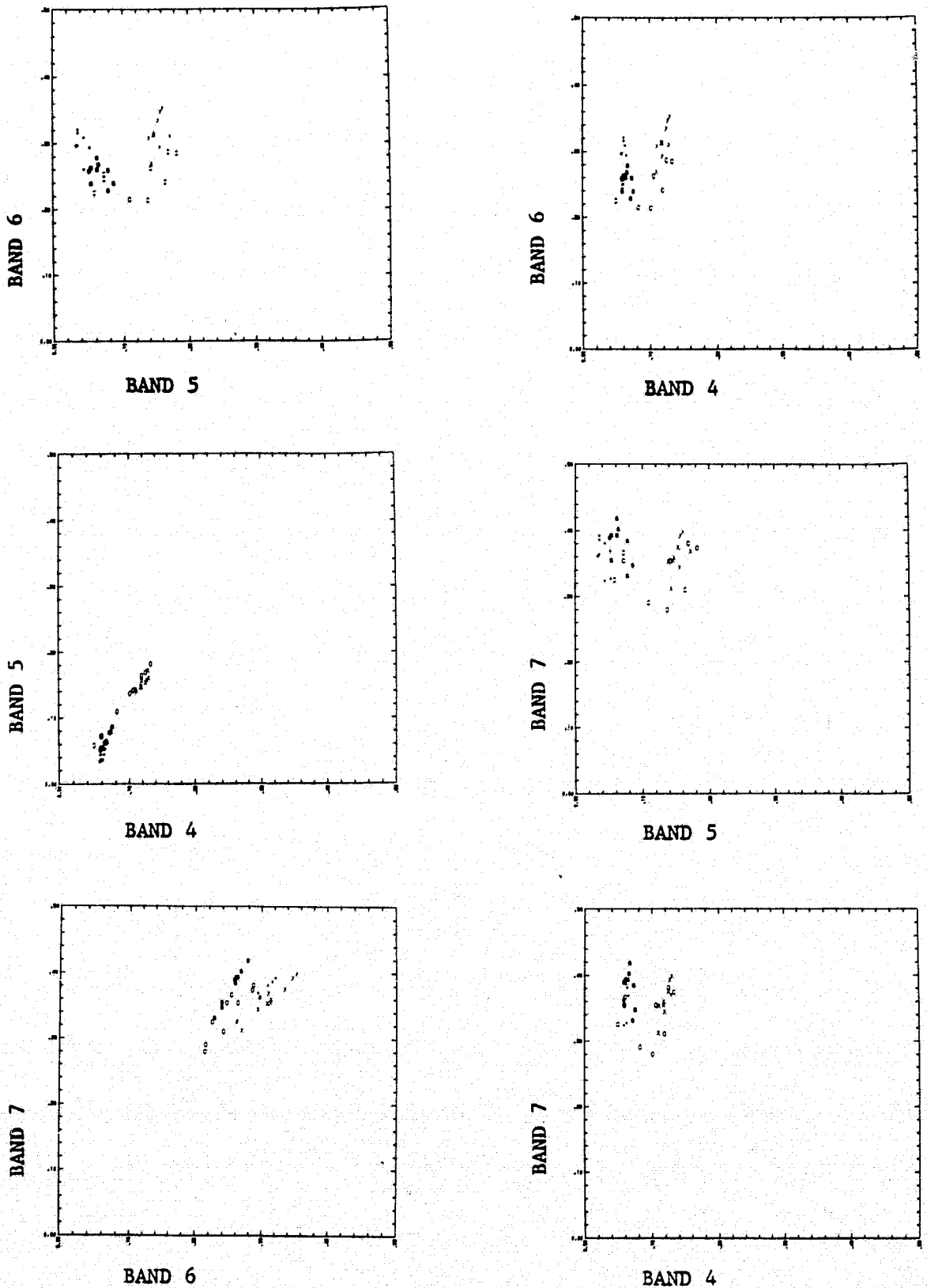


FIGURE 10. Scatter Plots of Model Generated Wheat Canopy Reflectance Composite Over All Phenology Stages (0=March, \$=April, .=May, X=June).

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

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

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(Axis units: 0.-12. milliwatts sq. cm⁻¹ steradian⁻¹ micrometer⁻¹)

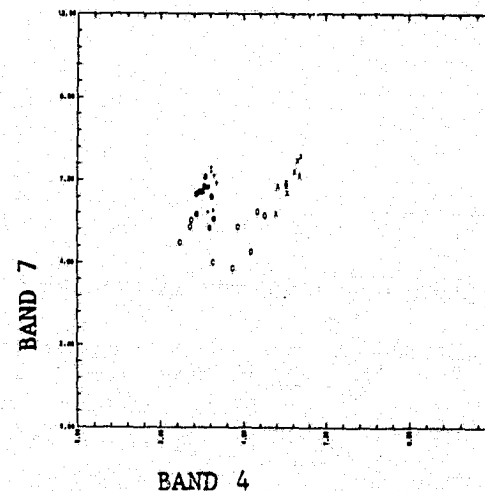
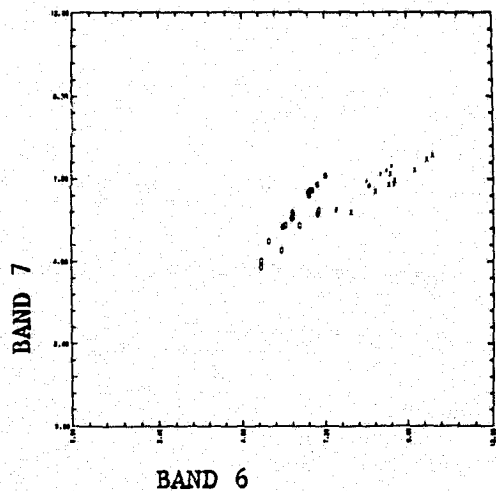
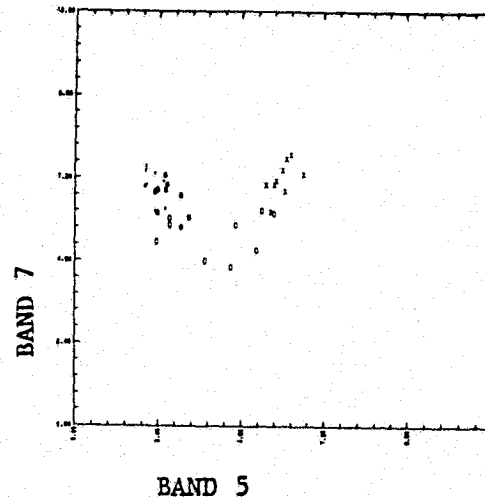
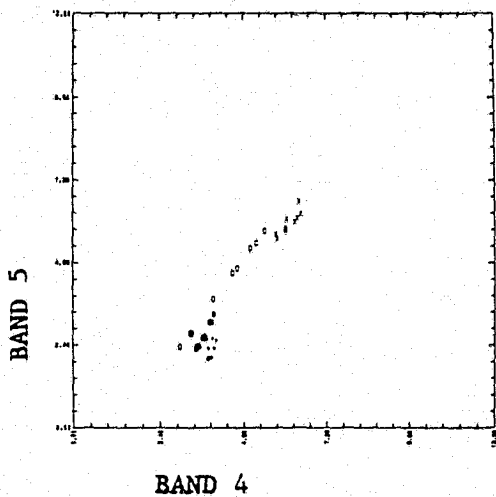
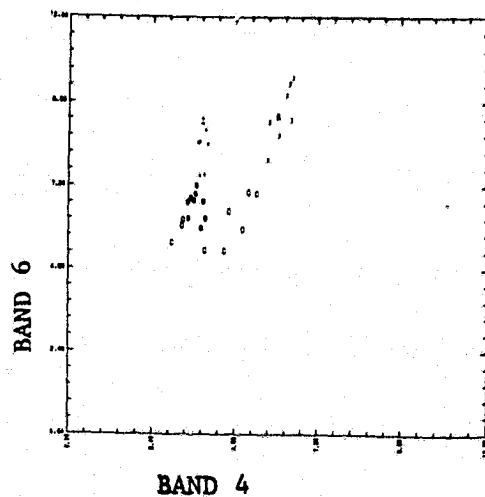
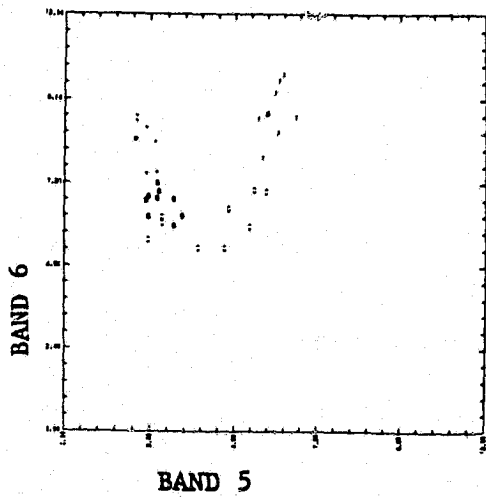


FIGURE 11. Scatter Plots of Model Generated Radiance (1976). Composite Over All Phenology Stages (O=March, \$=April, .=May, X=June).

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 phenological stage (March). In contrast a 12% increase was noted under the bright soil conditions. Figures 12 through 15 graphically summarize 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 II.
 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

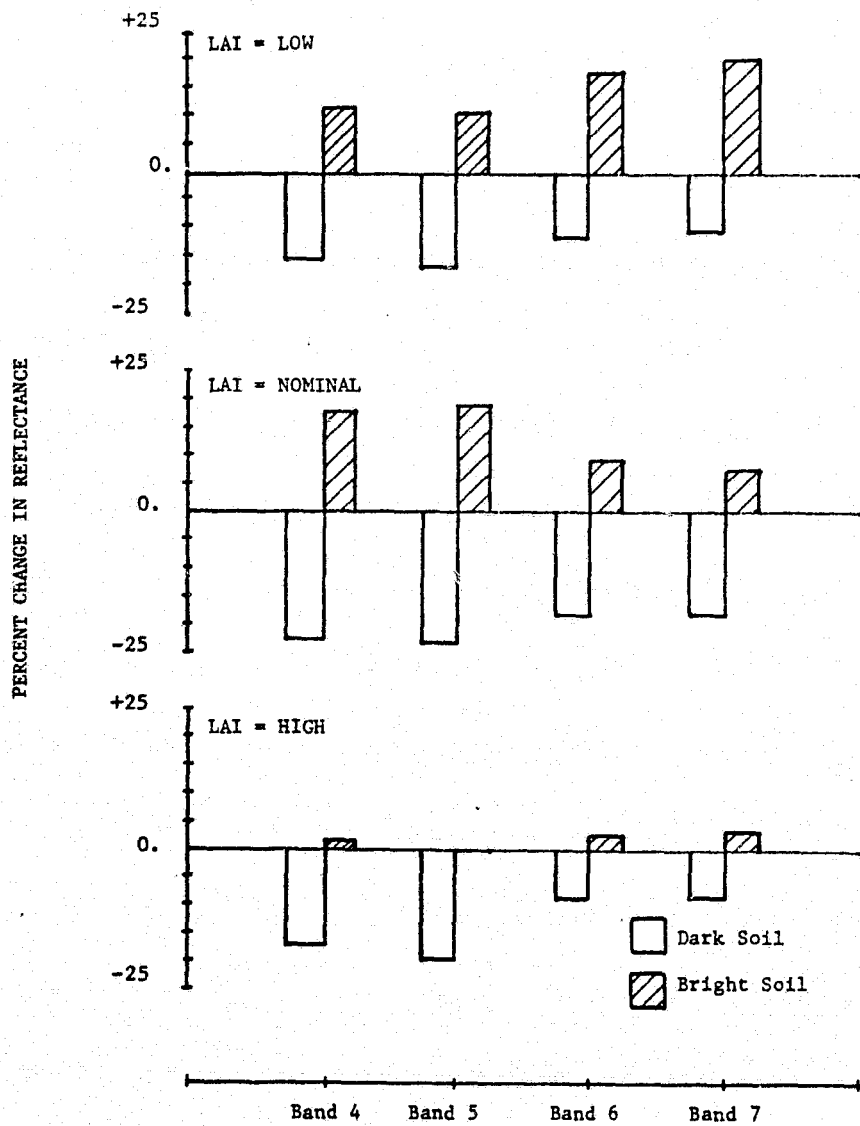


FIGURE 12 . March Soil Effects

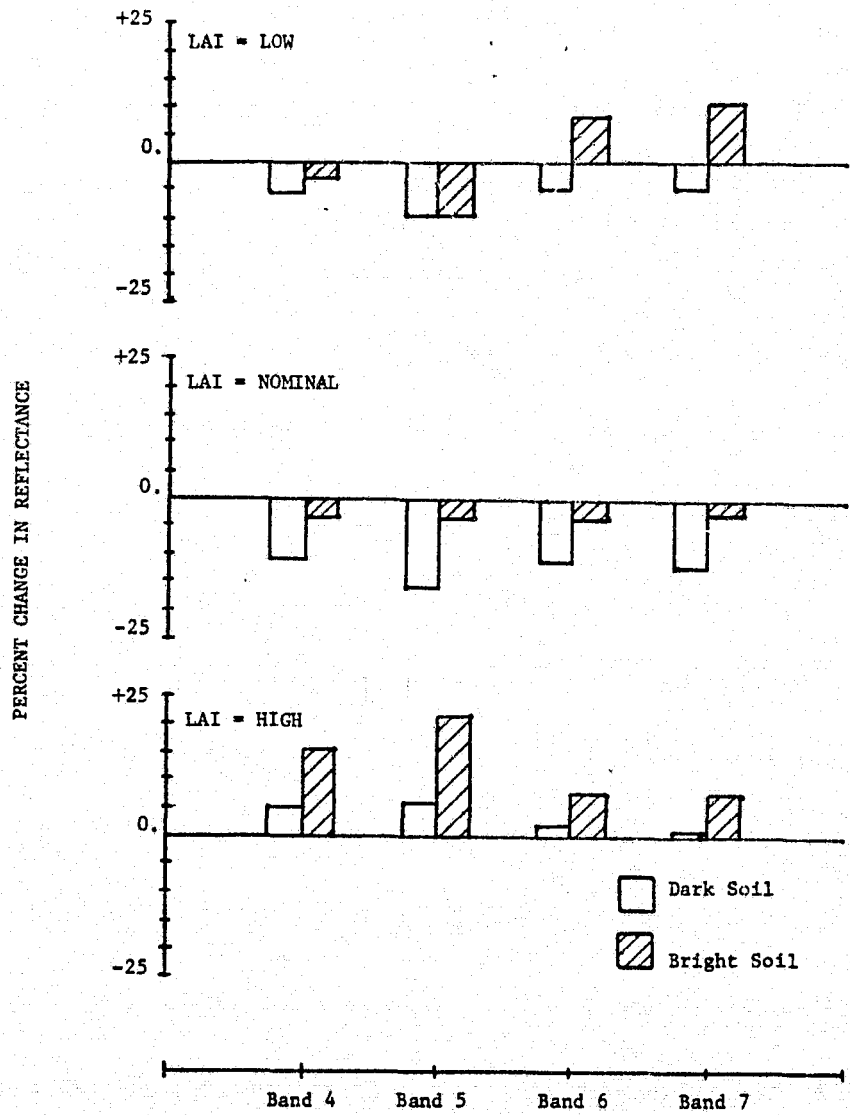


FIGURE 13. April Soil Effects

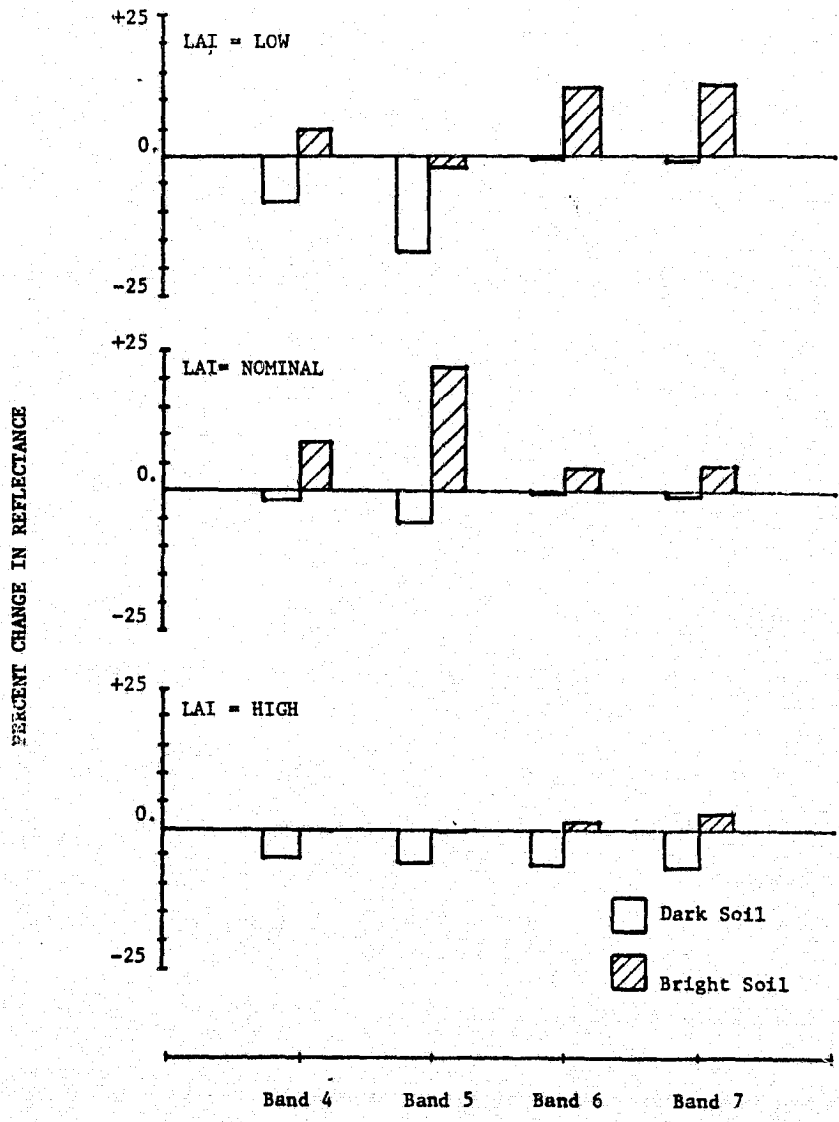


FIGURE 14 . May Soil Effects

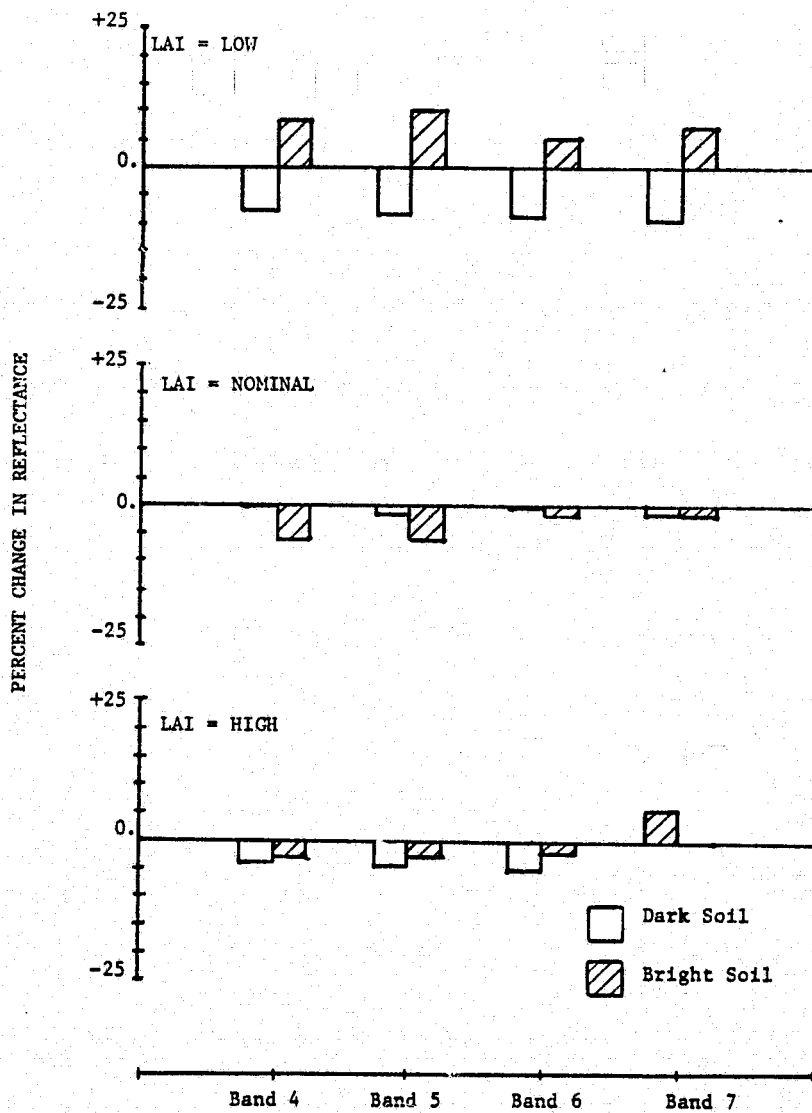


FIGURE 15. June Soil Effects

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

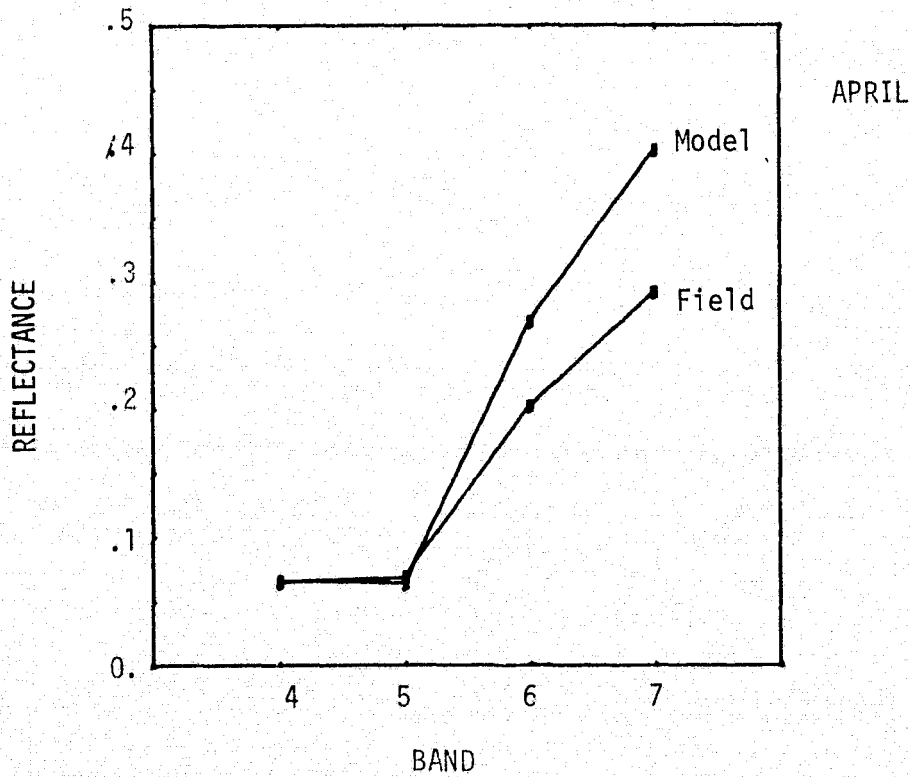
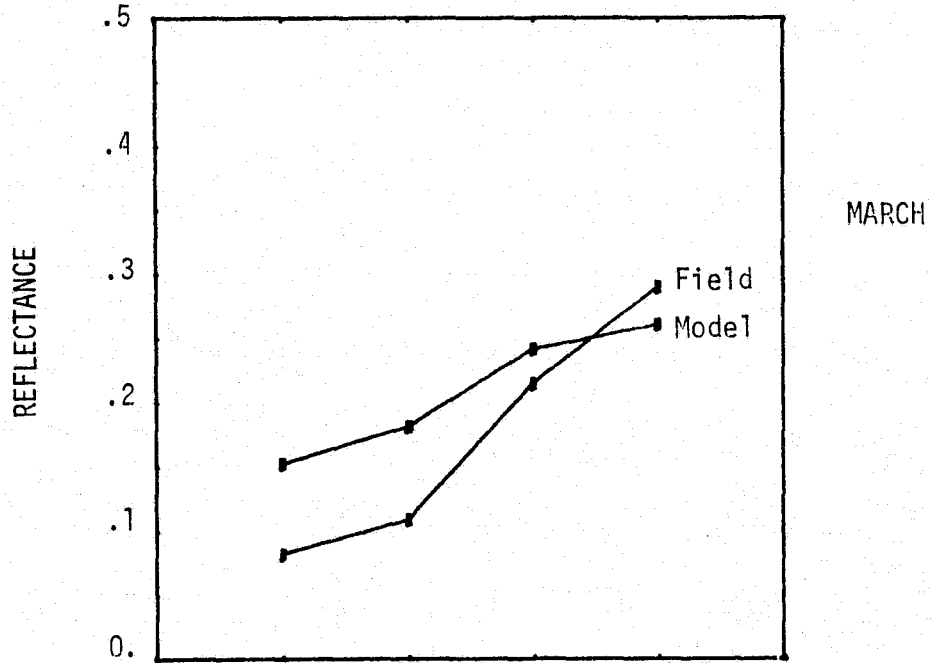
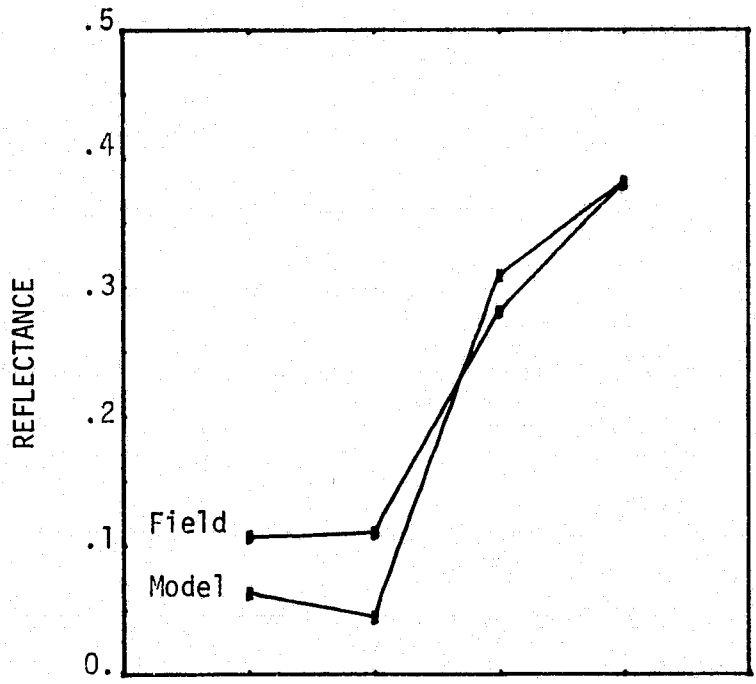
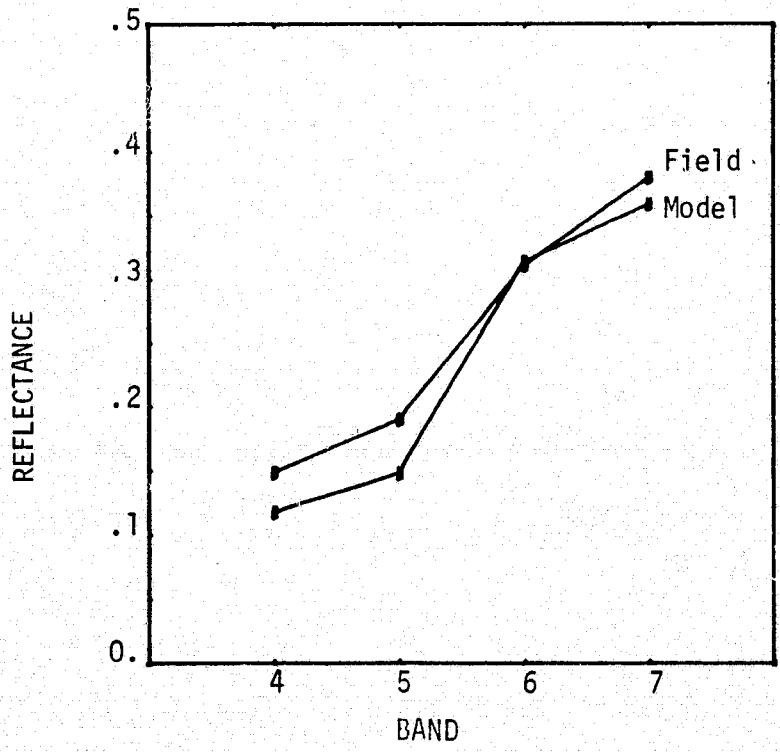


FIGURE 16 . Comparison of Model and Field Spectral Signatures



MAY



JUNE

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.

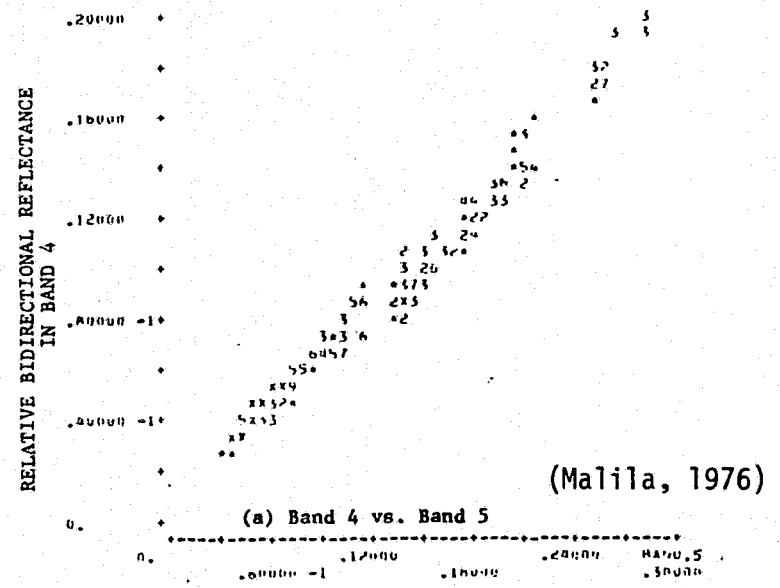
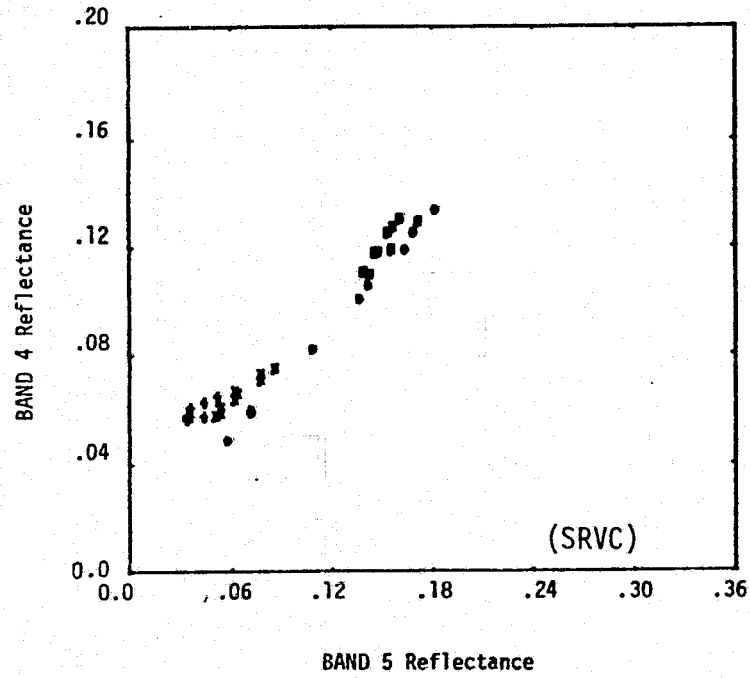
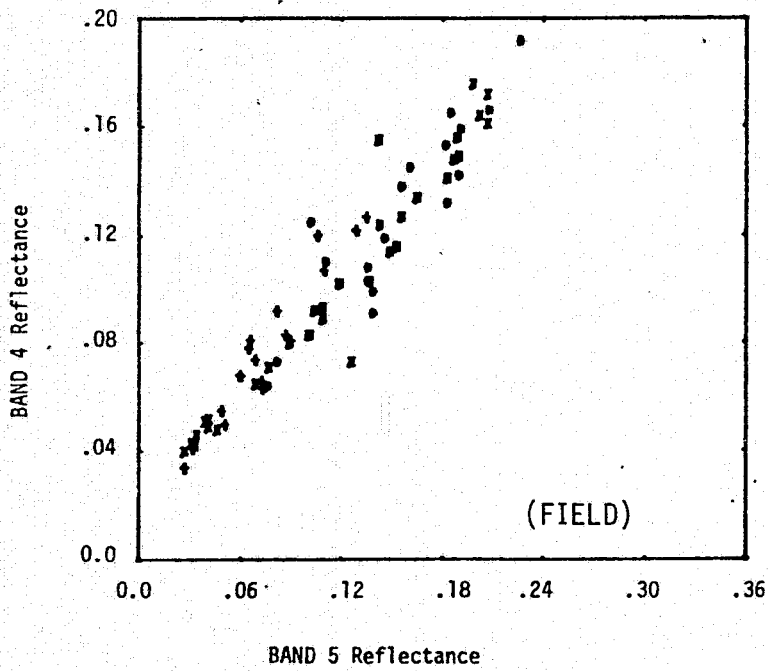


FIGURE 17. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 4 (All Phenological Stages)

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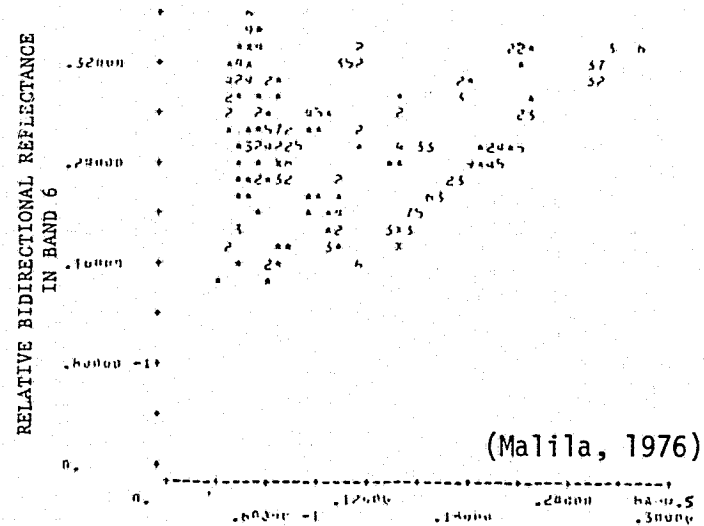
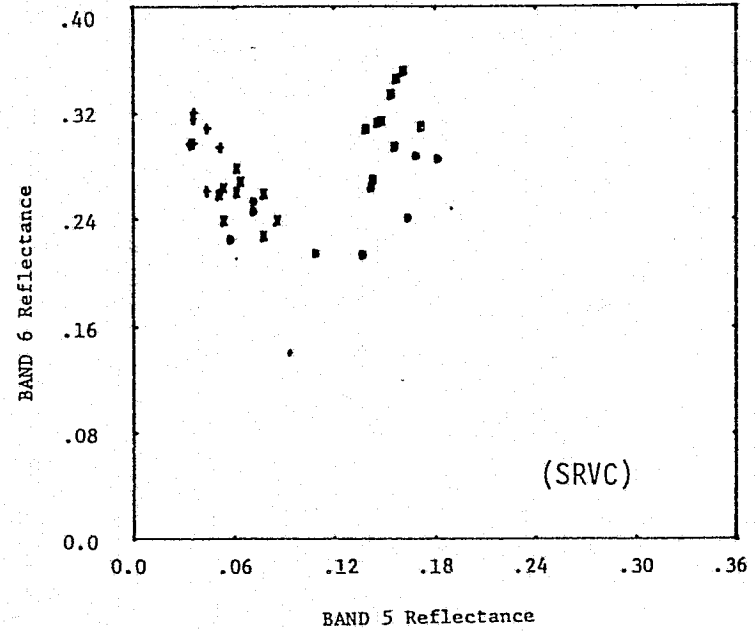
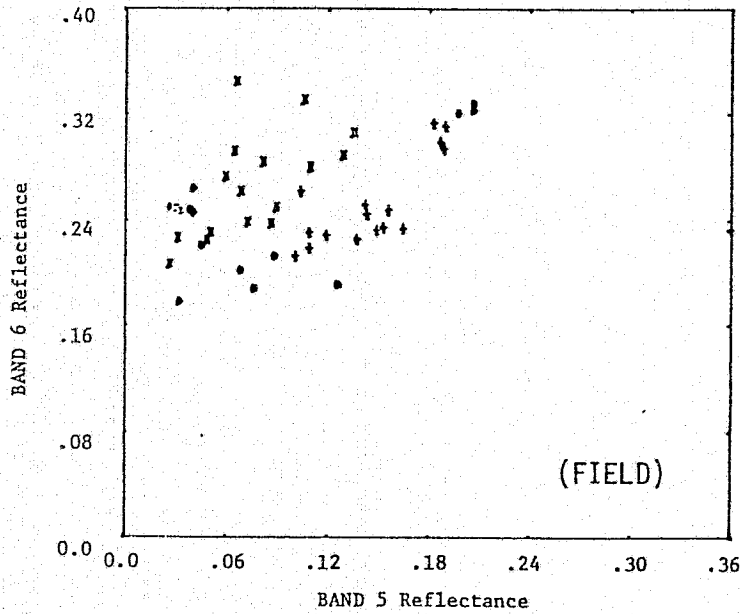


FIGURE 18. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (All Phenological Stages)

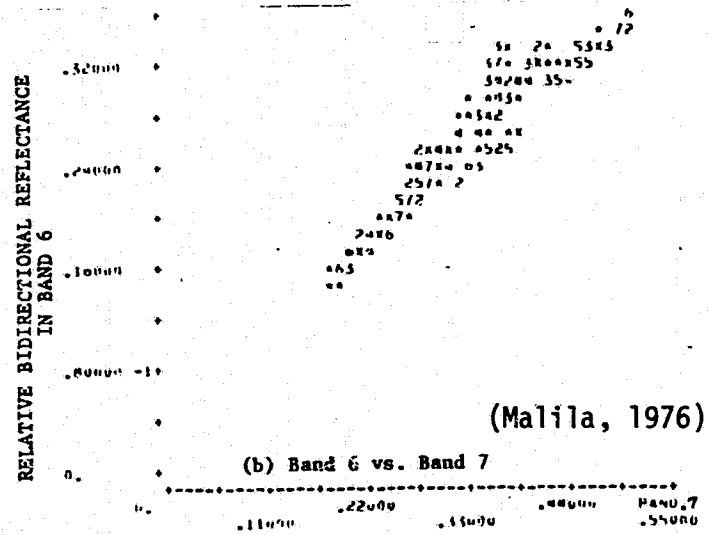
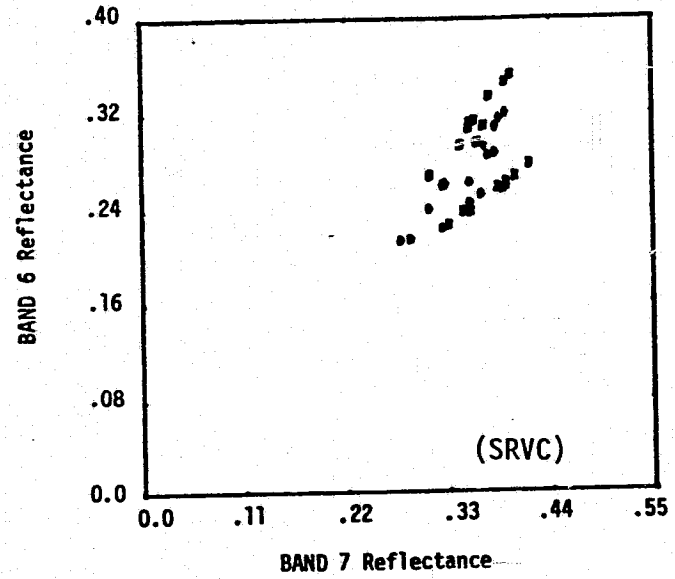
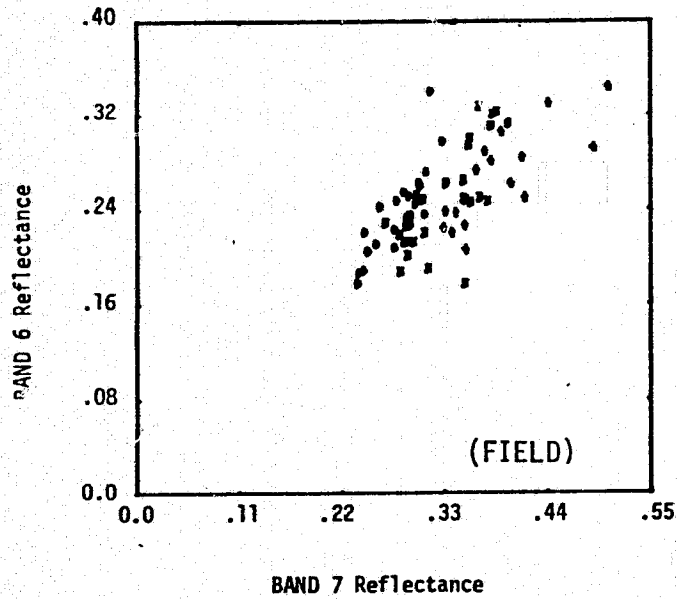


FIGURE 19. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 7 vs 6 (All Phenological Stages)

(Malila, 1976)

(b) Band 6 vs. Band 7

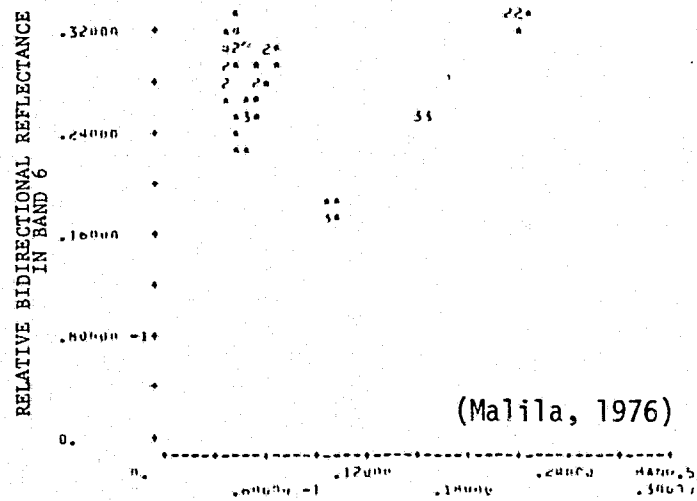
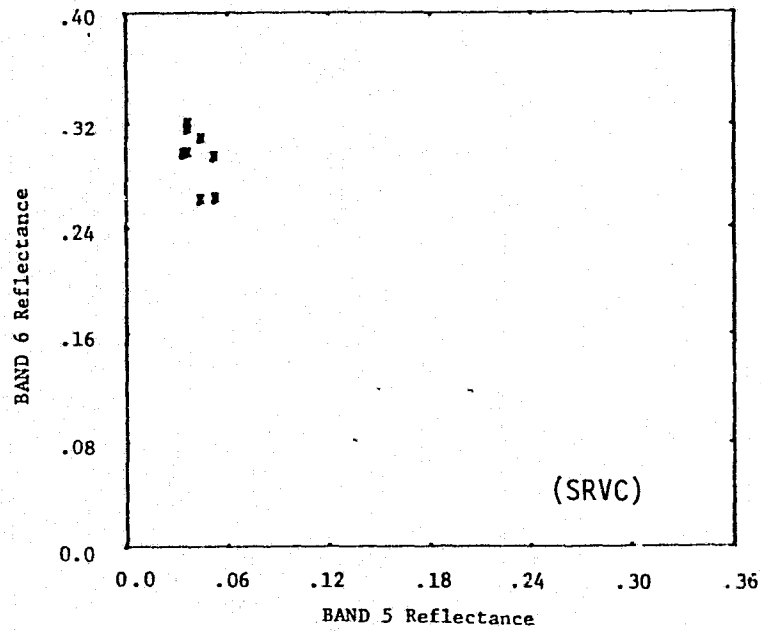
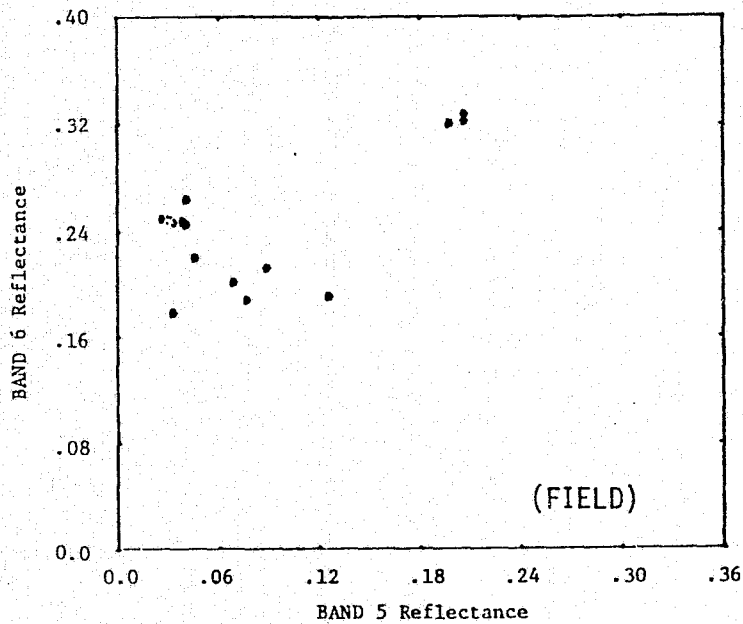


FIGURE 20. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Booting Stage).

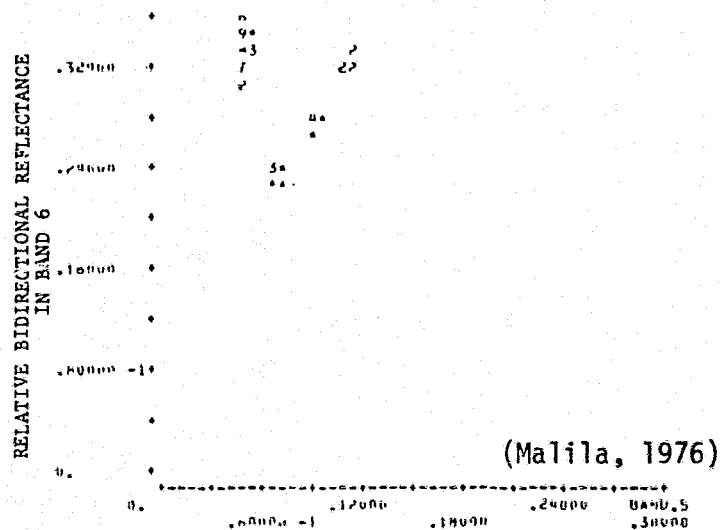
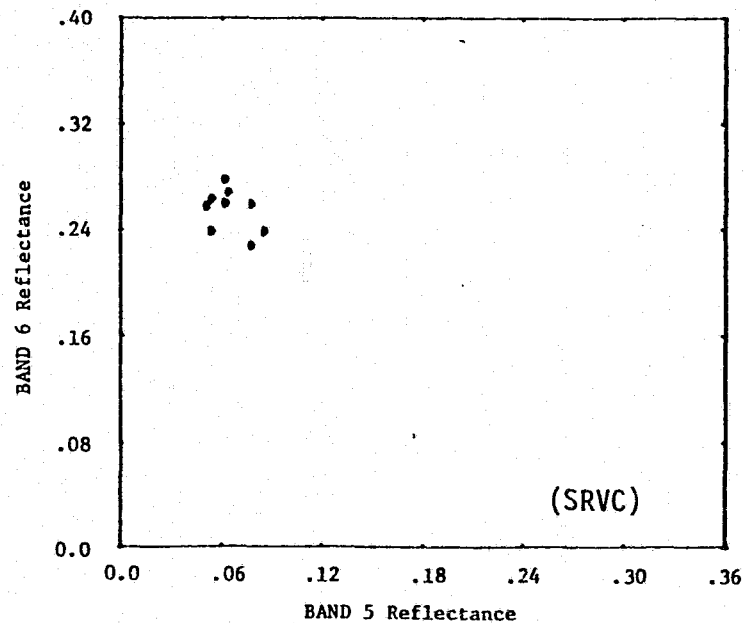
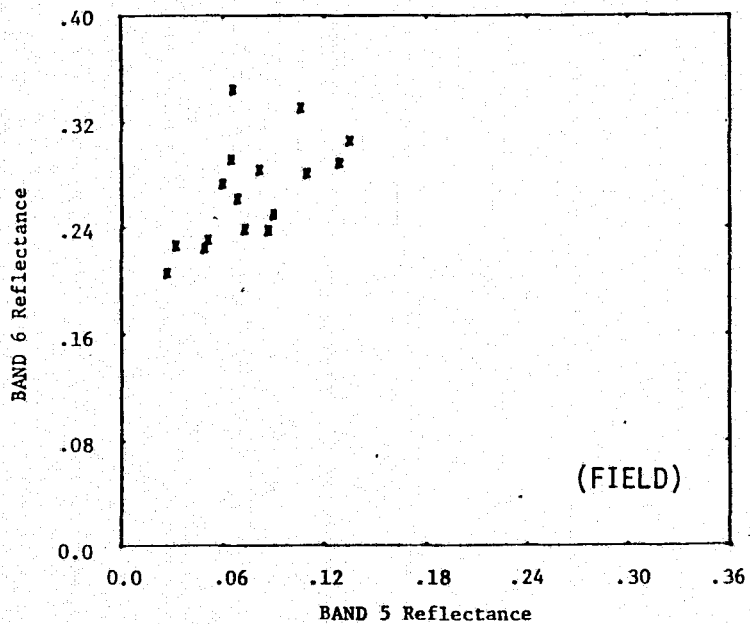


FIGURE 21. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Heading Stage)

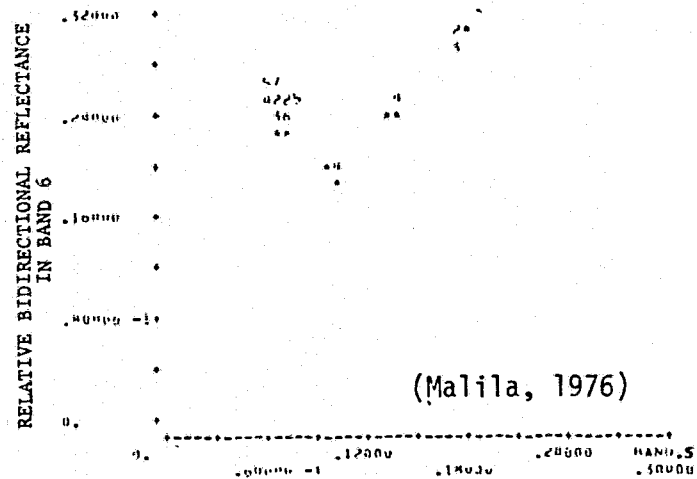
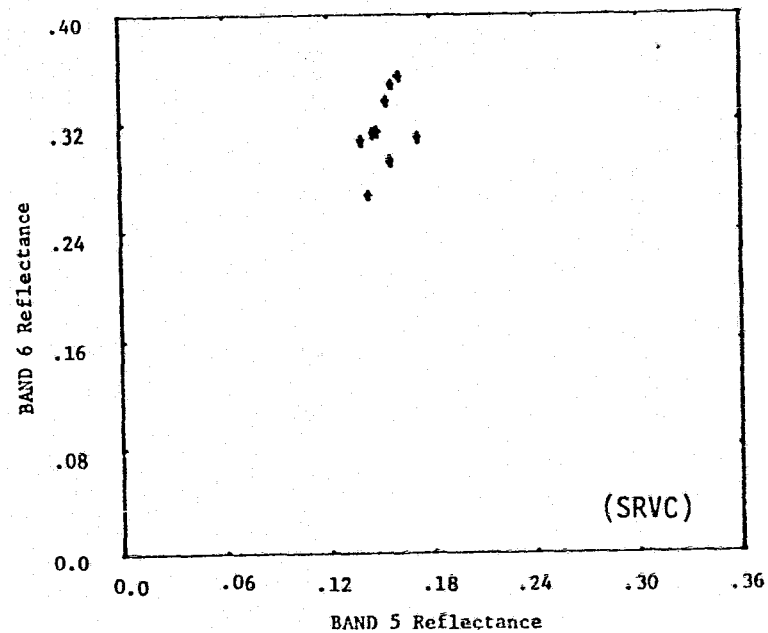
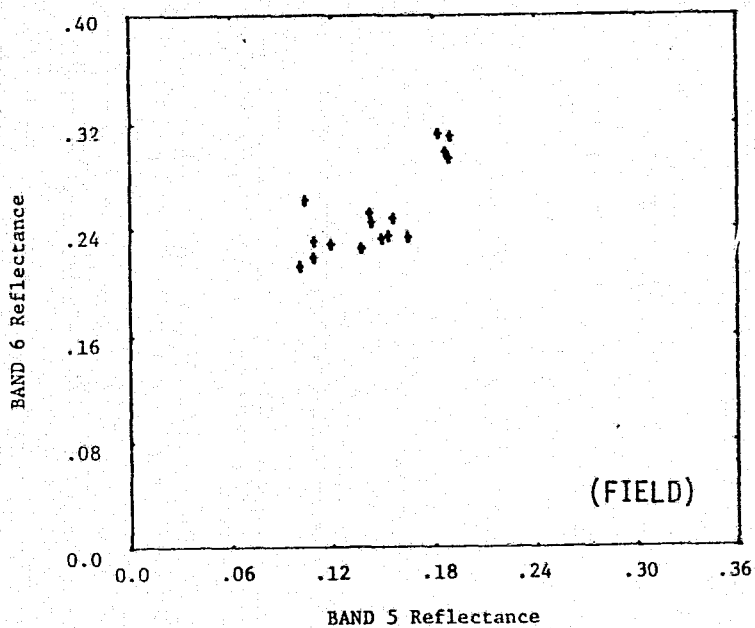


FIGURE 22. Scatter Plots of Field, SRVC, and ERIM Reflectance Data in Bands 5 vs 6 (Ripe Stage)

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

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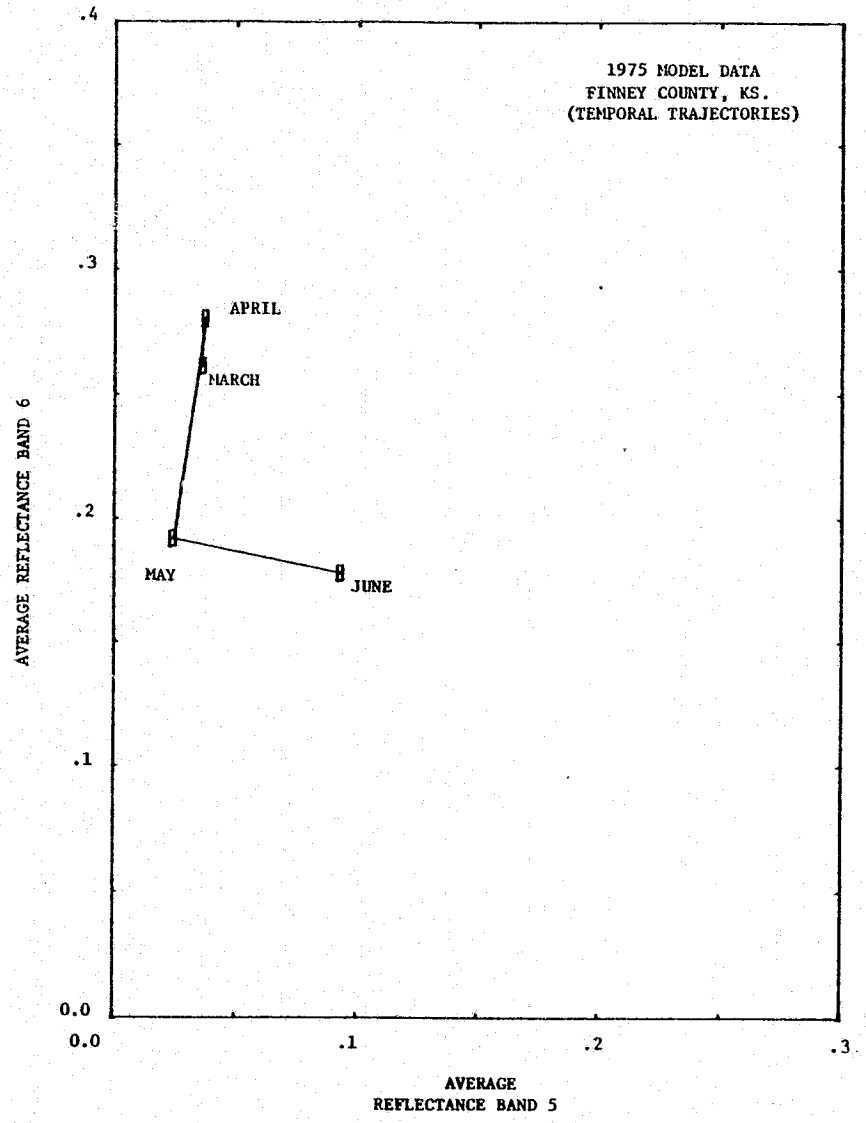
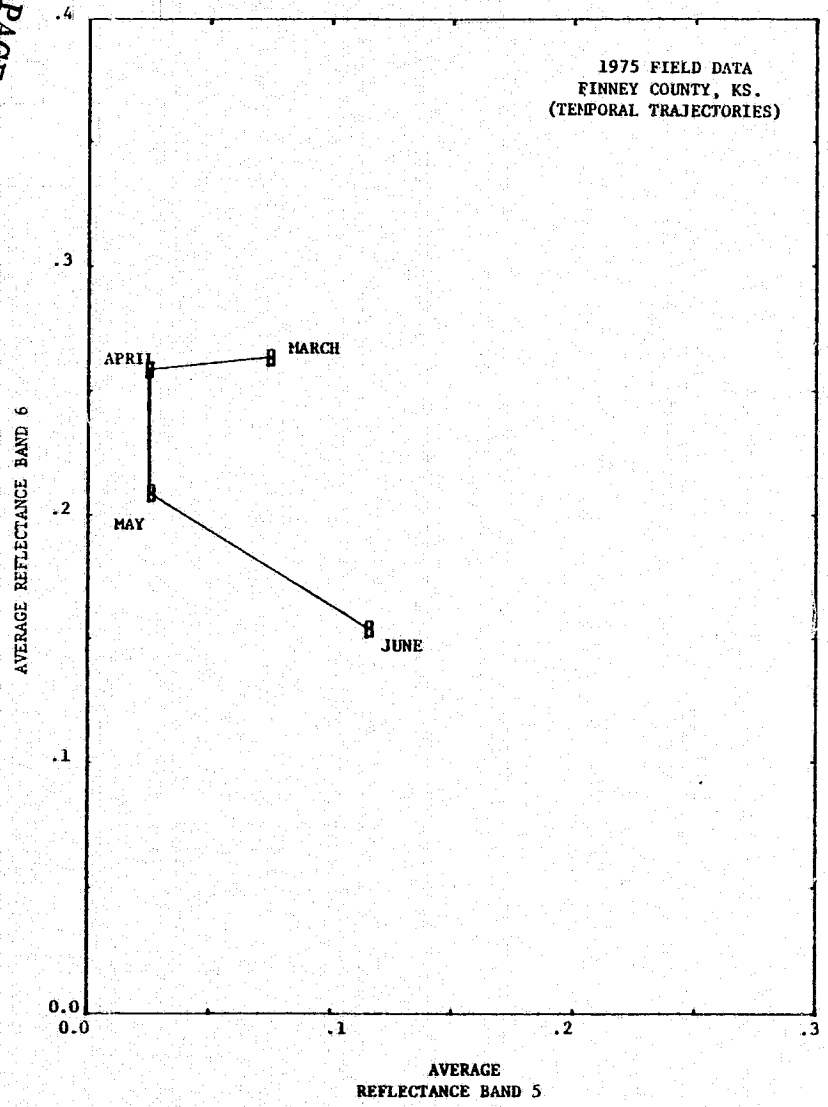


FIGURE 23. Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1975)

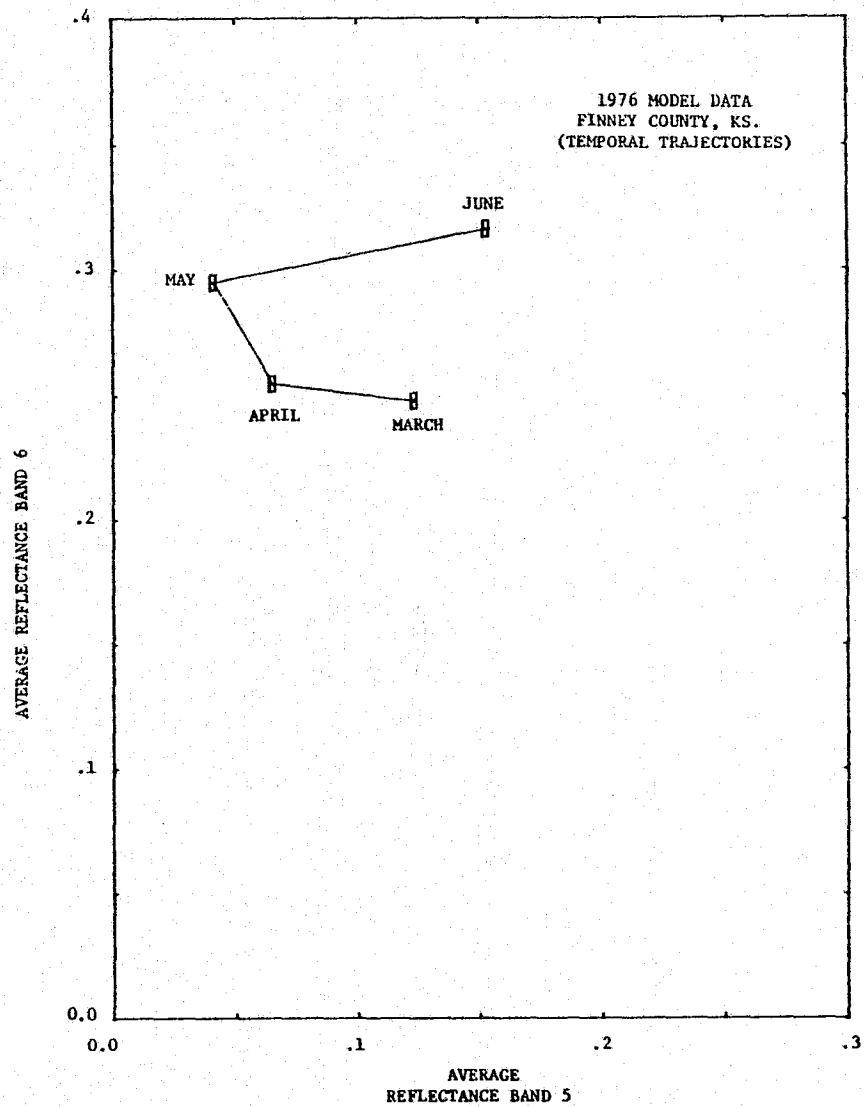
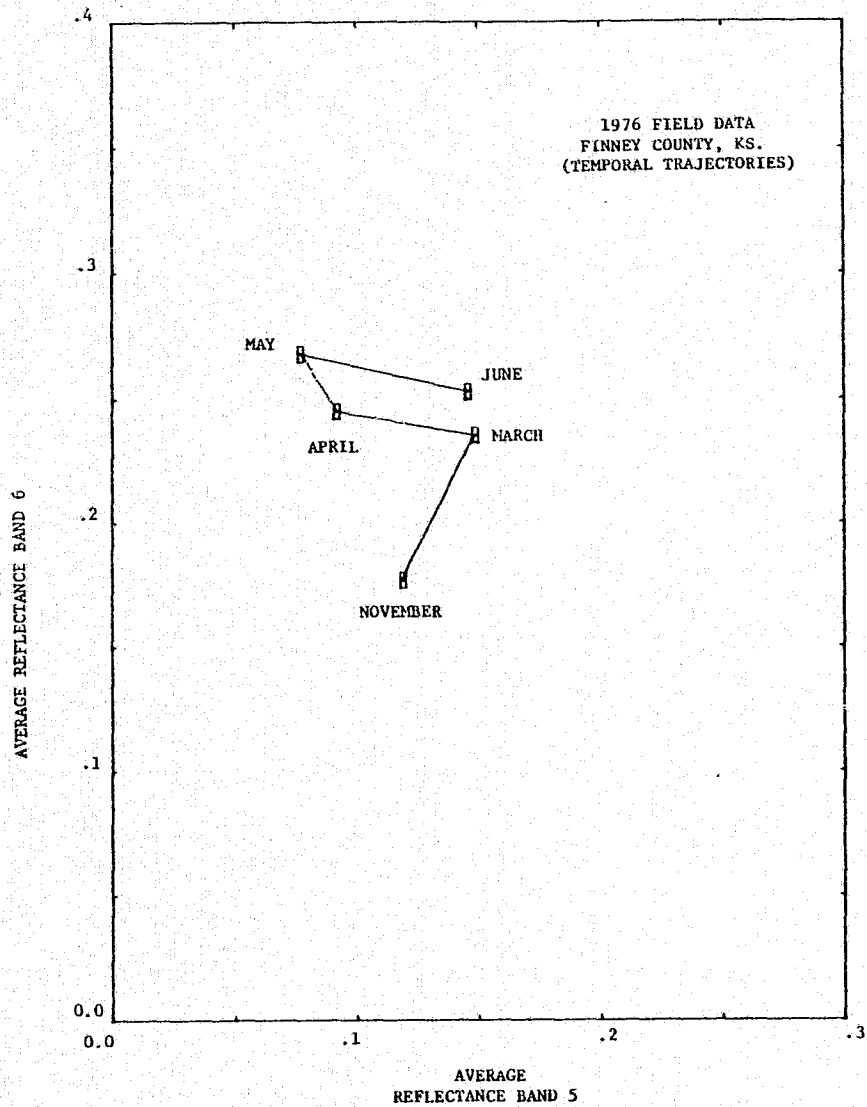


FIGURE 23 (Cont.) Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1976)

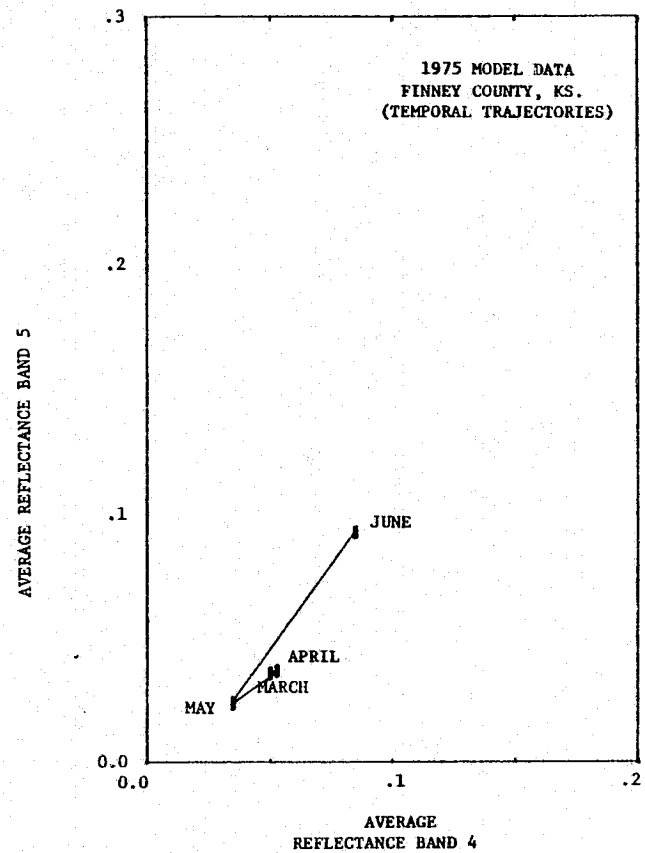
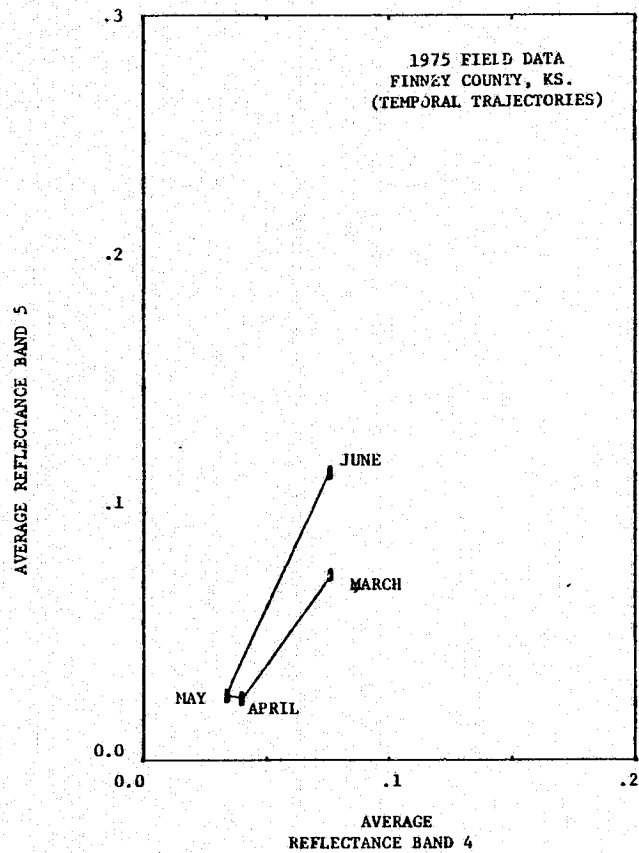


FIGURE 24. Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1975)

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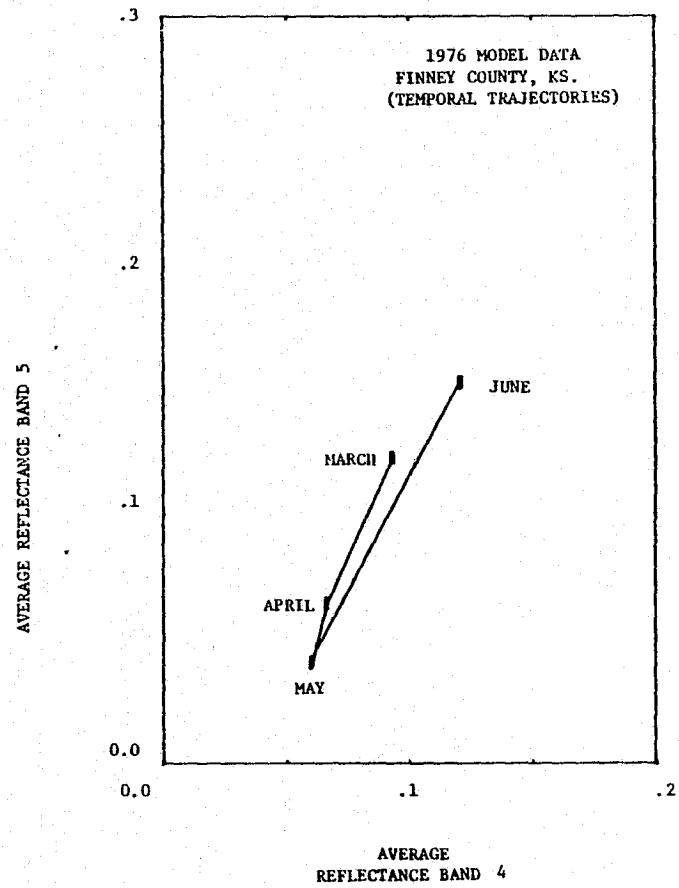
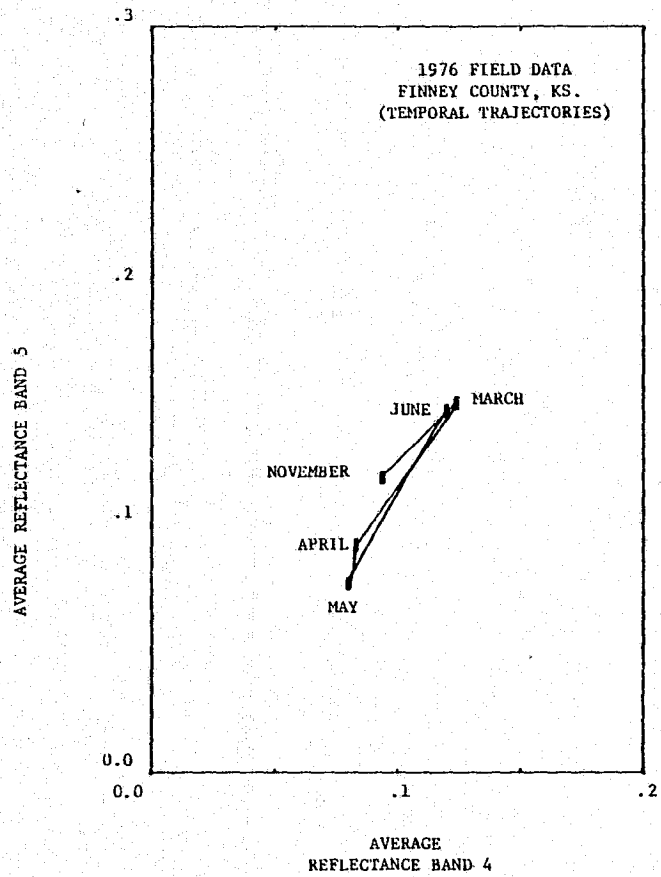


FIGURE 24 (Cont.) Temporal Trajectories for Model and Field Reflectance Data (Bands 5 vs 6 and 4 vs 5, 1976)

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 chlorophyll which is highly absorbing at these wavelengths. 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

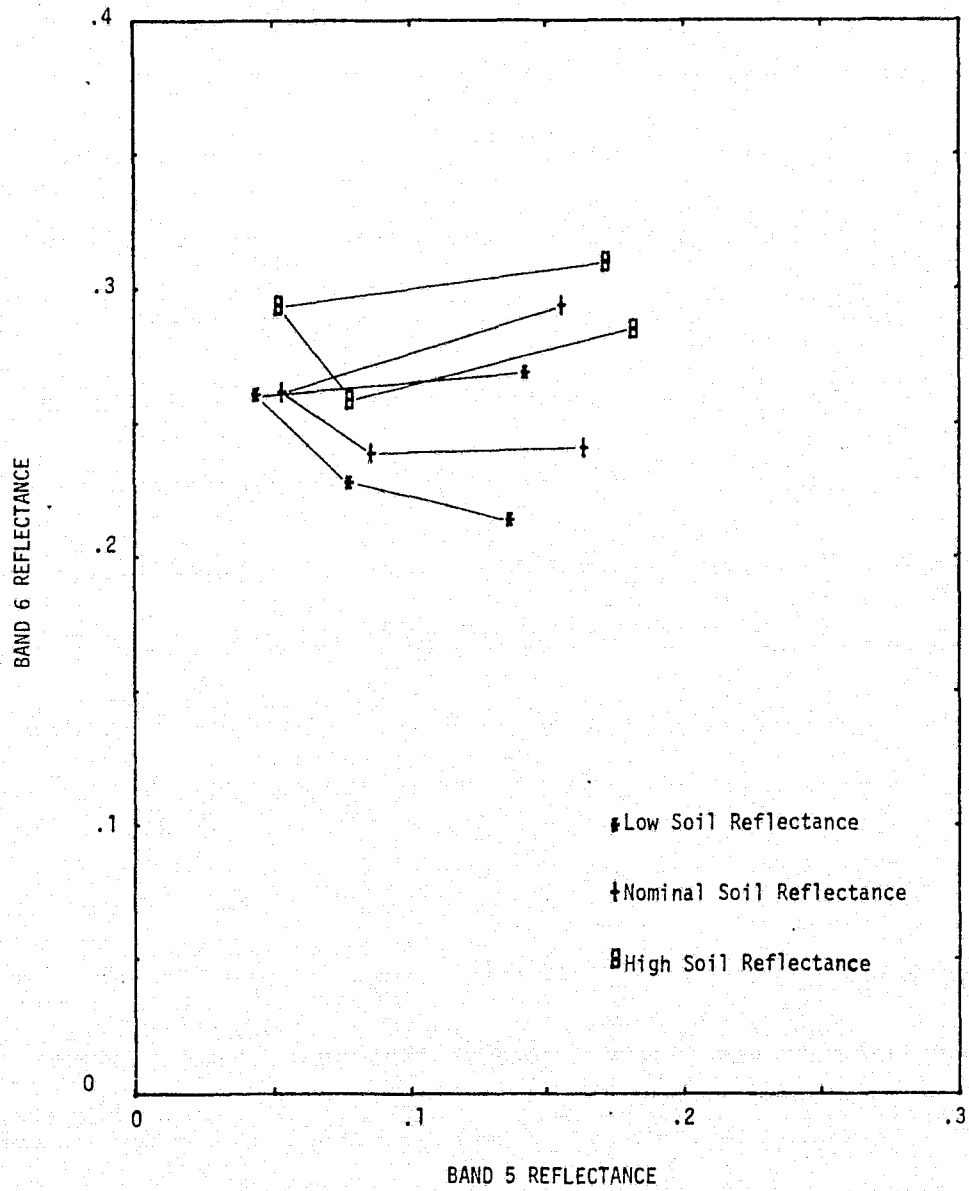


FIGURE 25 . Model Generated Temporal Trajectories
(LAI = Low)

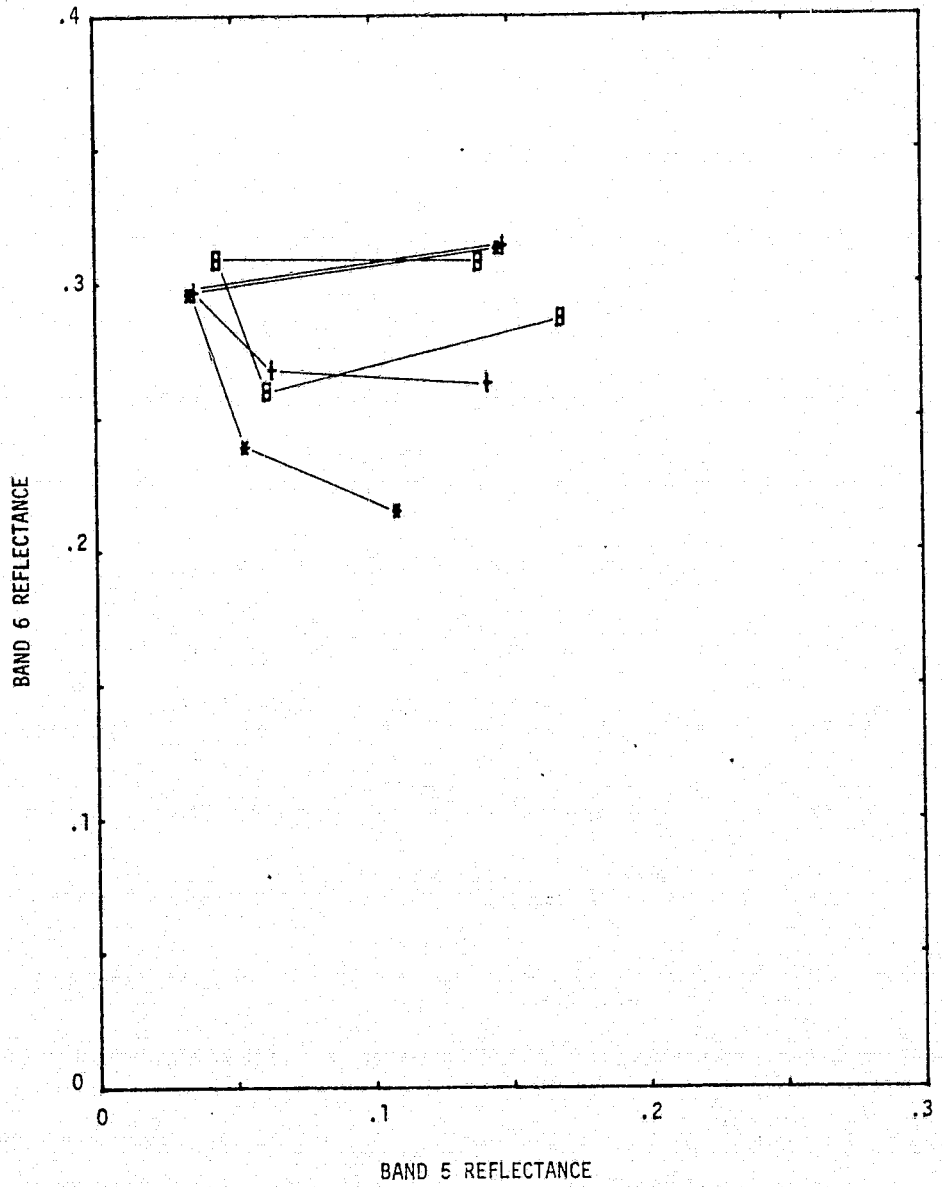


FIGURE 25 (Cont.) Model Generated Temporal Trajectories
(LAI= Nominal)

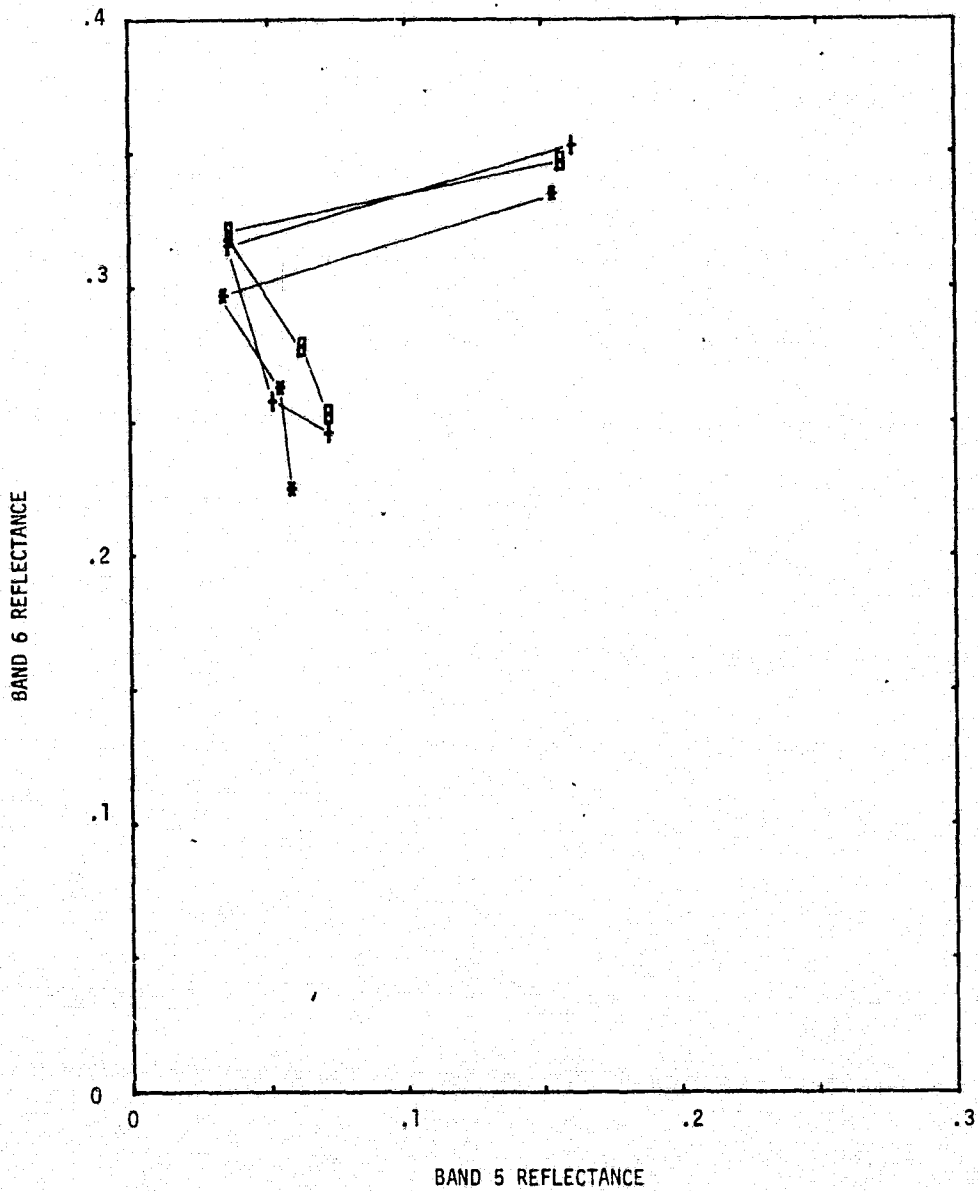


FIGURE 25 (Cont.) Model Generated Temporal Trajectories
(LAI = High)

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 interpreted 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

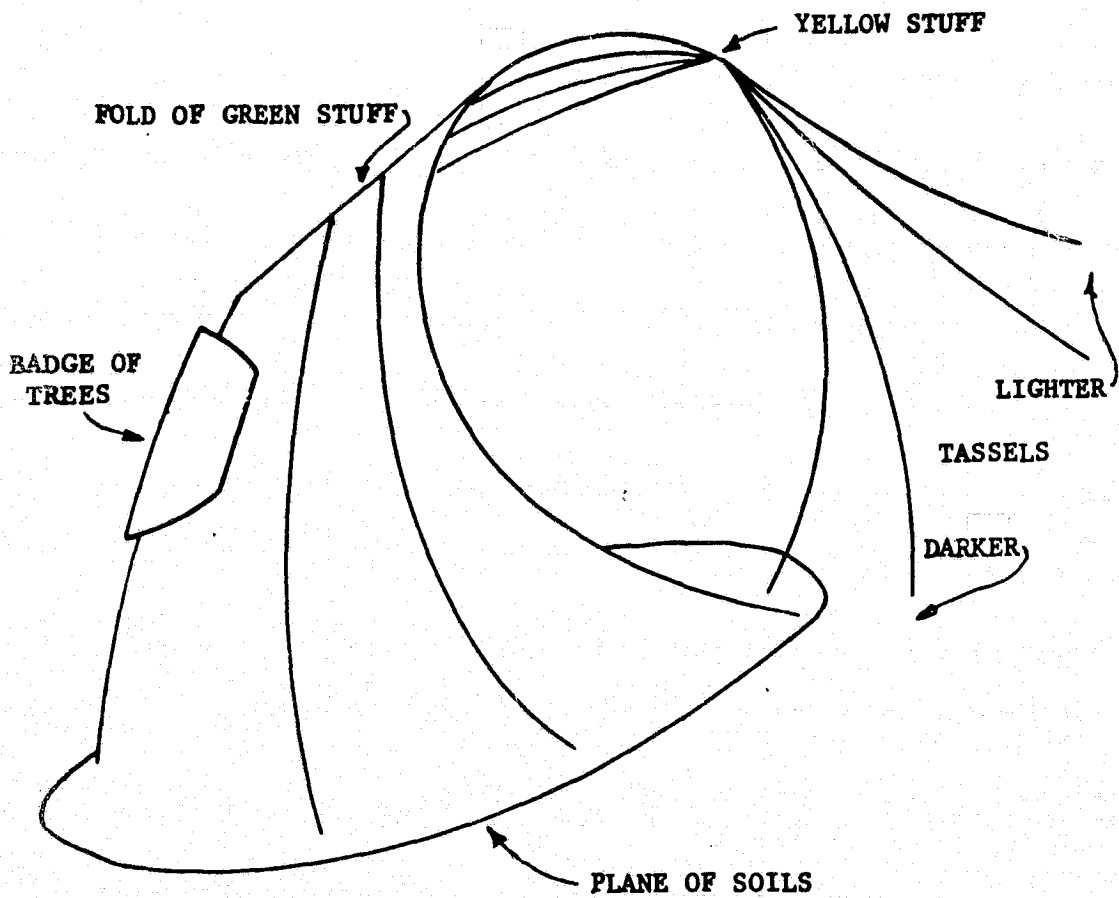


FIGURE 26. Schematic of "Tasselled Cap" Concept (Kauth and Thomas, 1976 b)

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 Gram-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,

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

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

TABLE 12 (Cont.)

Date	Plot	Band			
		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

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

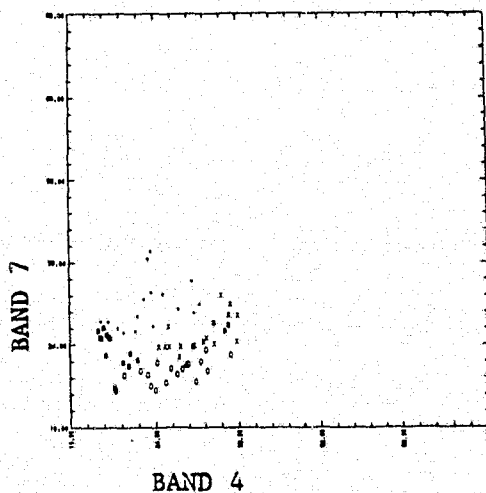
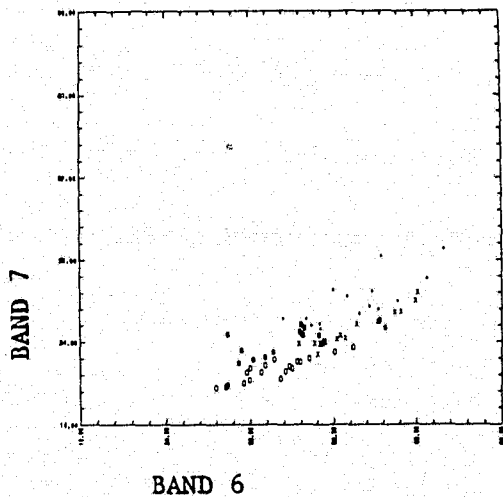
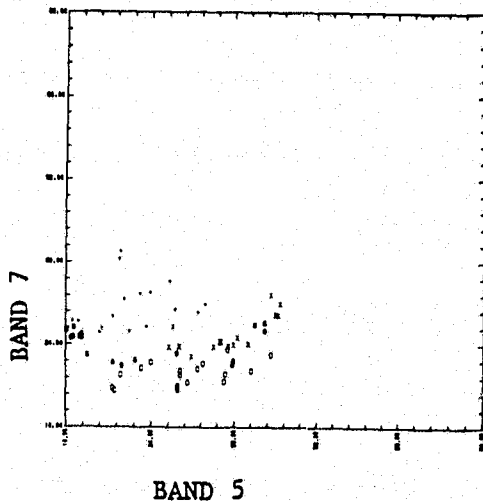
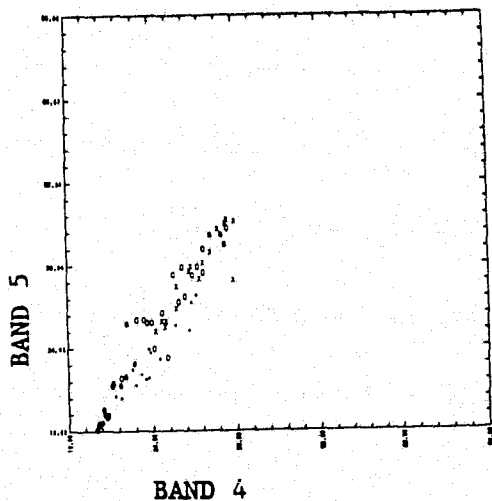
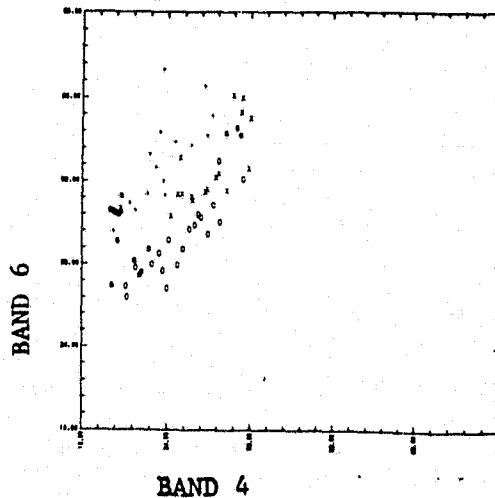
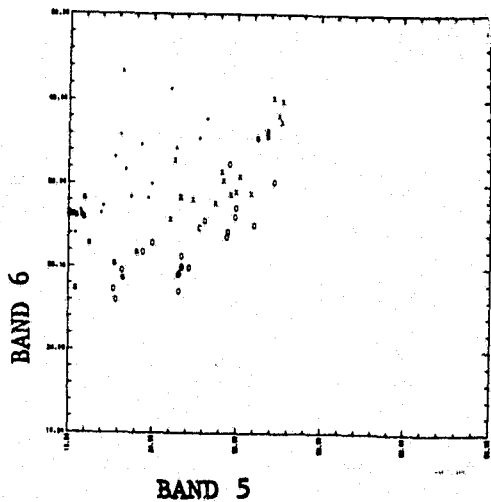


FIGURE 27. Scatter Plots of Calculated Field LANDSAT Counts (O=March, \$=April, .=May, X=June)

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

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

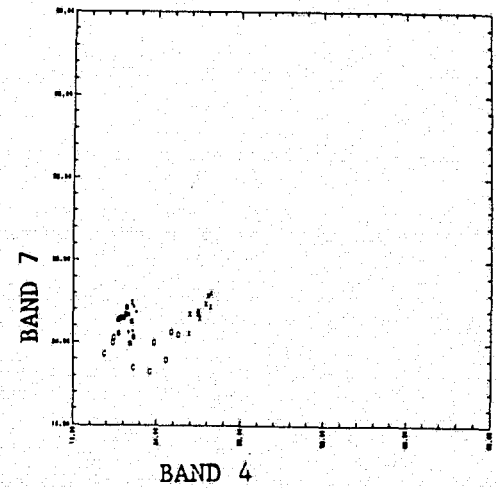
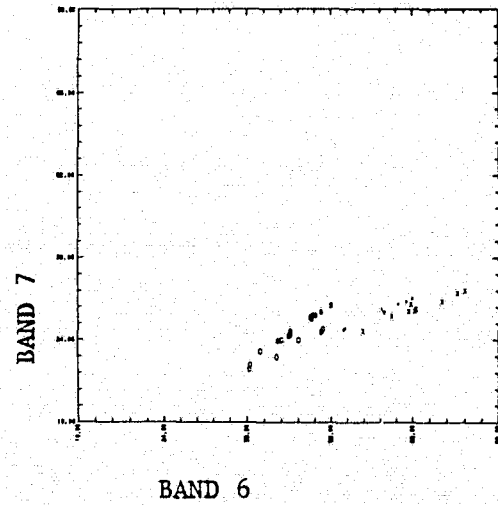
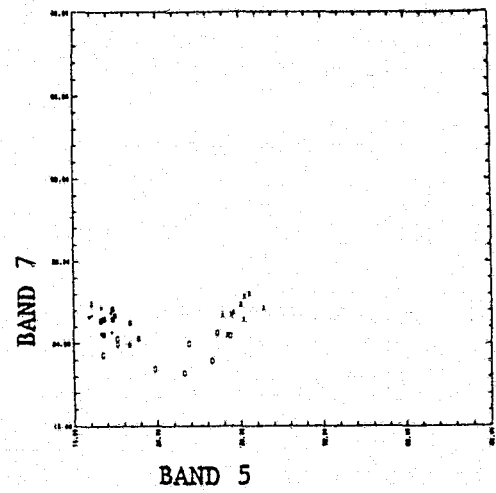
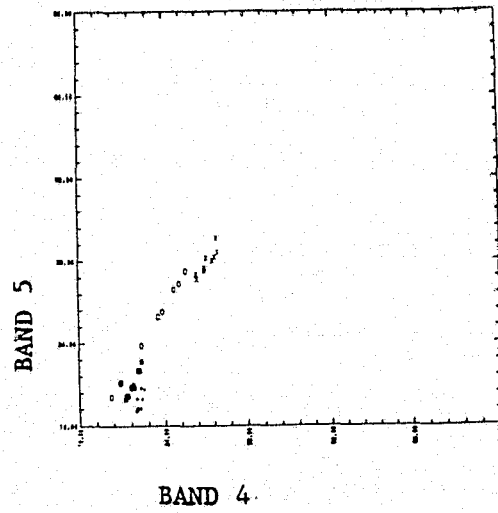
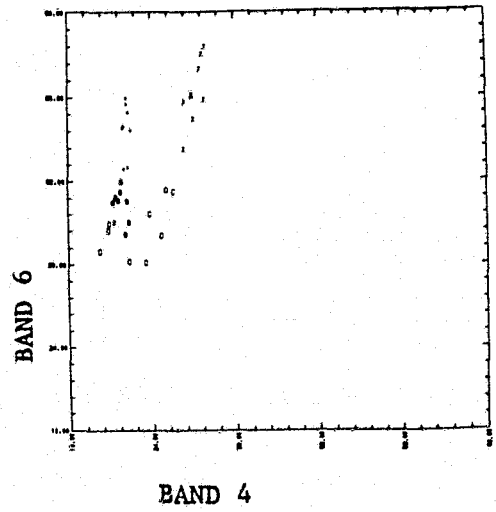
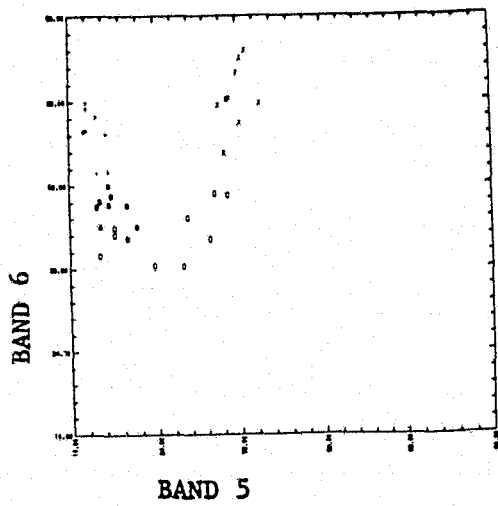


FIGURE 28. Scatter Plots of Model Generated LANDSAT Counts
(O=March, \$=April, .=May, X=June)

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)

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

TABLE 14 (Cont.)

Date	Plot	SB	GS	Band	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

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

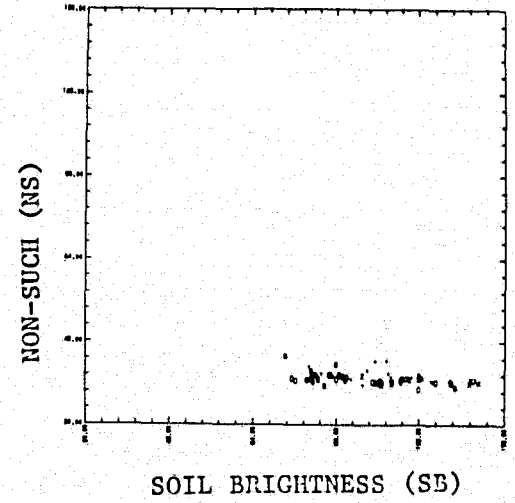
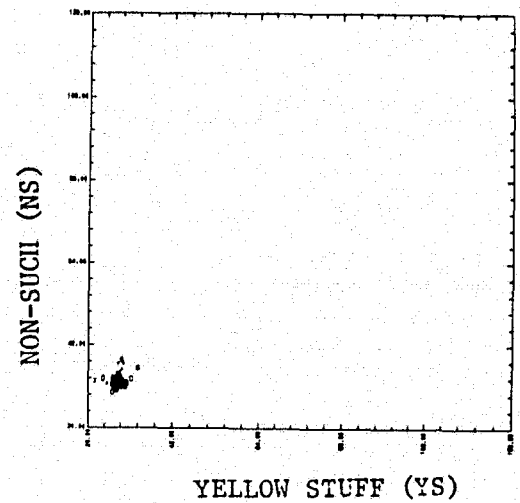
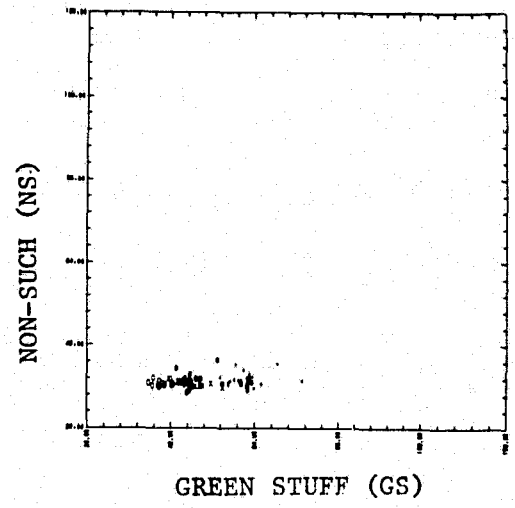
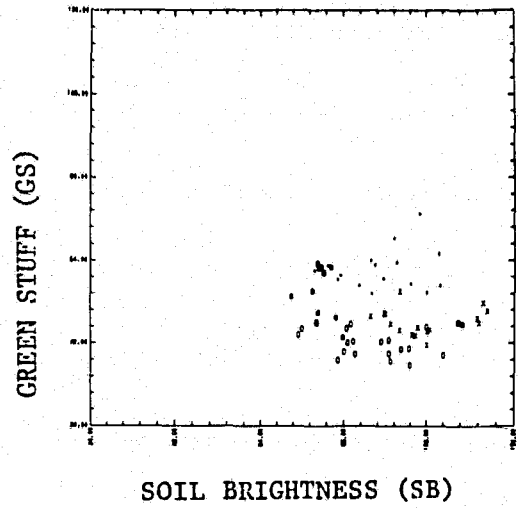
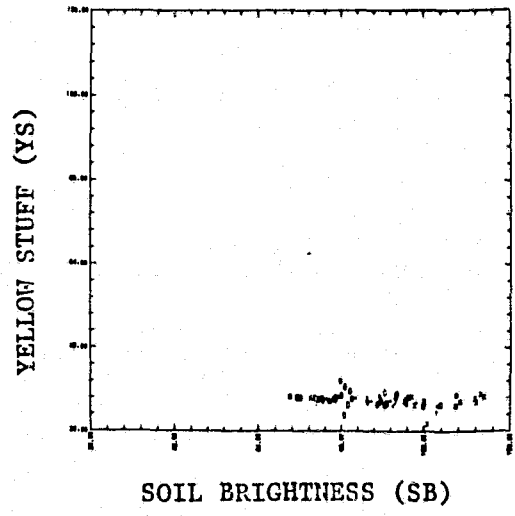
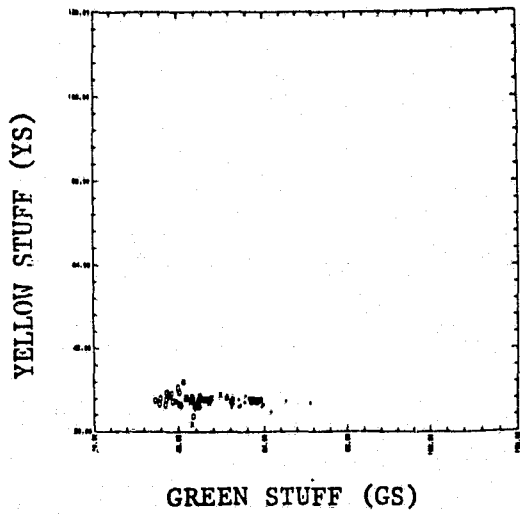


FIGURE 29. Scatter Plots of Calculated Field LANDSAT Counts (Transformed)
(O=March, \$=April, . =May, X=June)

TABLE 15
 MODEL GENERATED LANDSAT COUNTS
 (Transformed)

Date	LAI	SOIL	SB	Bands		
				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)

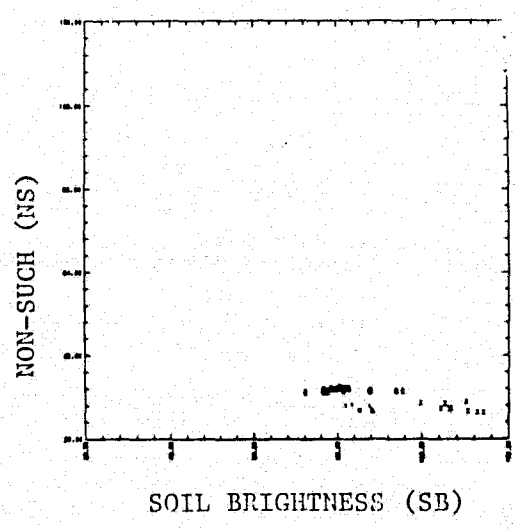
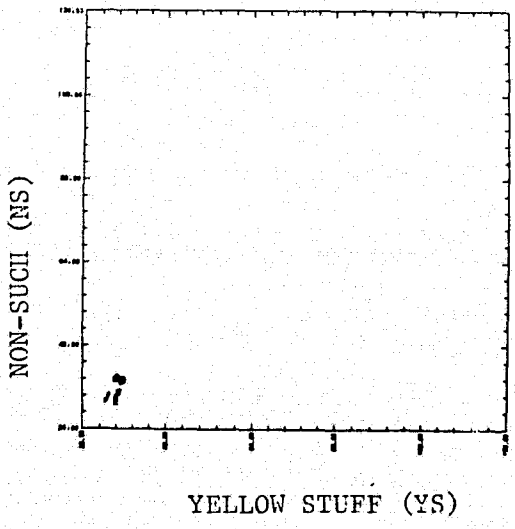
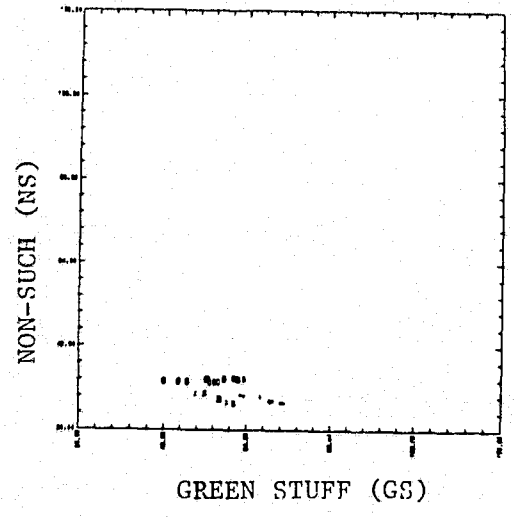
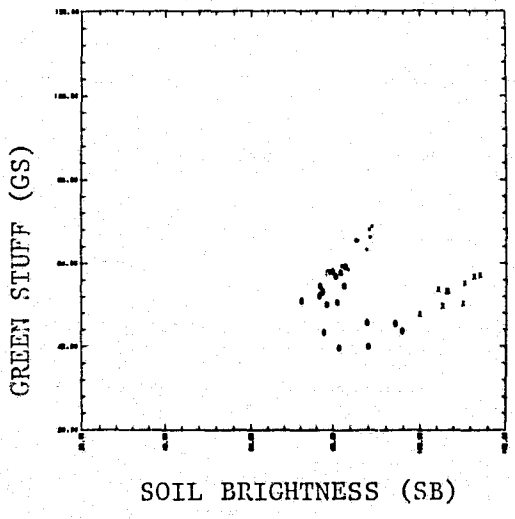
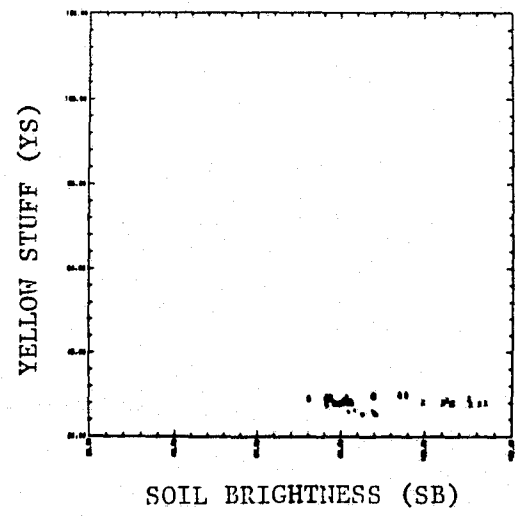
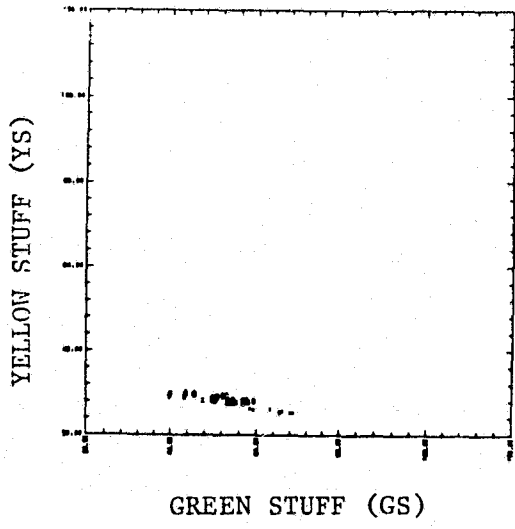


FIGURE 30. Scatter Plots of Model Generated LANDSAT Counts (Transformed) (O=March, \$=April, .=May, X=June)

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 tasselled 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 variable 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 influential 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

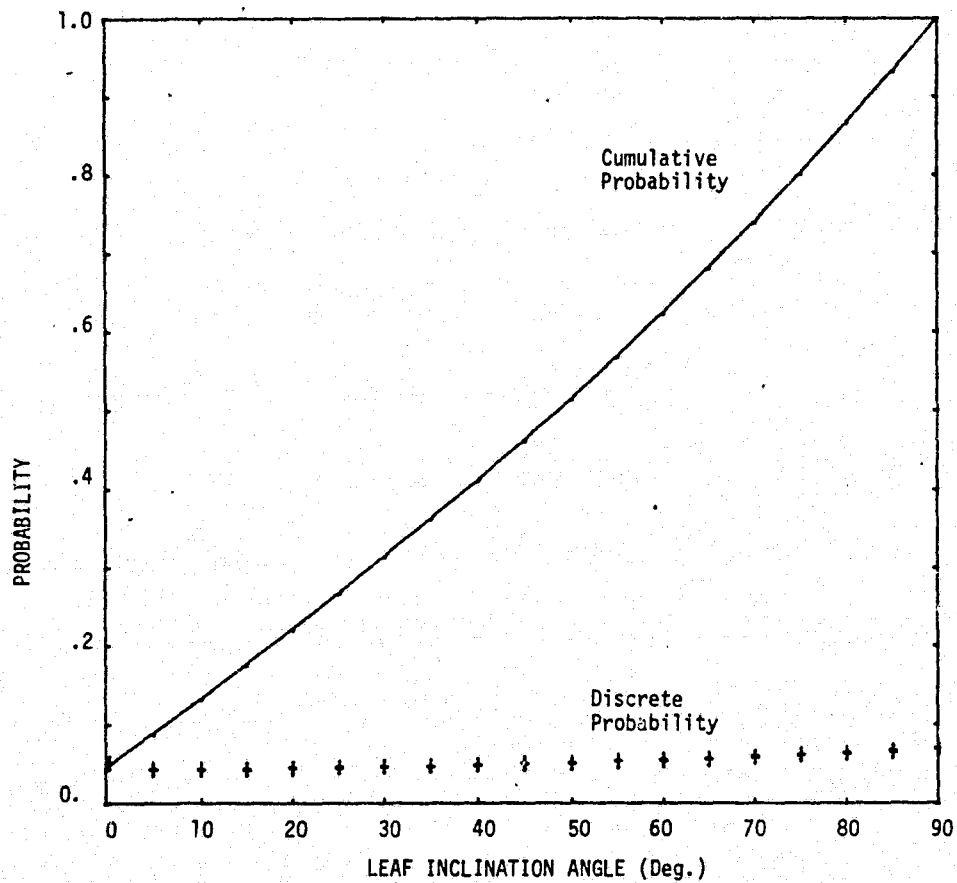
FIELD DATA SET PRESENTATION

A. MARCH 13, 1976 TILLERING STAGE FIELD 107

Crop Type: Eagle Wheat Weeds: 0%
 Height: 7-10 cm Soil: Dry
 Chlorotic: 0% 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

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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

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DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE=	BAND1	BAND2	BAND3	BAND4
031476	0920	WHEAT CSII	107.1	ON ROW		.130	.148	.248	.321
031476	0921	WHEAT CSII	107.1	OFF ROW		.063	.147	.250	.350
031476	0922	WHEAT CSII	107.1	ON ROW		.267	.235	.375	.400
031476	0923	WHEAT CSII	107.1	OFF ROW		.200	.188	.286	.294
031476	1251	WHEAT CSII	107.1	OFF ROW		.142	.157	.253	.304
031476	1252	WHEAT CSII	107.1	ON ROW		.133	.154	.249	.280
031476	1330	WHEAT CSII	107.1	ON ROW		.078	.135	.214	.294
031476	1340	WHEAT CSII	107.1	OFF ROW		.104	.142	.209	.279
031476	1455	WHEAT CSII	107.1	ON ROW		.107	.132	.214	.277
031476	1457	WHEAT CSII	107.1	OFF ROW		.091	.140	.231	.277
031476	1522	WHEAT CSII	107.1	ON ROW		.145	.156	.259	.297
031476	1534	WHEAT CSII	107.1	OFF ROW		.450	.166	.259	.311
031476	1253	WHEAT CSII	DIF P	PERCENT		.089	.066	.060	.071
031476	0926	WHEAT CSII	DIF	PERCENT		.417	.300	.320	.276
031476	1341	WHEAT CSII	DIF	PERCENT		.104	.090	.073	.076
031476	1458	WHEAT CSII	DIF	PERCENT		.137	.149	.150	.160
031476	1342	WHEAT CSII	107.1	SOIL		.113	.161	.218	.271
031476	0928	WHEAT CSII	107.1	SOIL		.174	.154	.211	.227
031476	1254	WHEAT CSII	107.1	SOIL		.120	.150	.207	.241
031476	1430	WHEAT CSII	TRANS	GREEN		.034	.027	.323	.455
031476	1430	WHEAT CSII	TRANS	GREEN		.000	.000	.265	.392
031476	0931	WHEAT CSII	107.2	ON ROW		.182	.333	.227	.240
031476	0932	WHEAT CSII	107.2	OFF ROW		.143	.213	.214	.250
031476	0934	WHEAT CSII	DIF	PERCENT		.313	.323	.250	.225
031476	1304	WHEAT CSII	107.2	ON ROW		.190	.223	.274	.296
031476	1305	WHEAT CSII	107.2	OFF ROW		.142	.192	.233	.278
031476	1348	WHEAT CSII	107.2	ON ROW		.128	.185	.252	.309
031476	1349	WHEAT CSII	107.2	ON ROW		.142	.193	.262	.301
031476	1350	WHEAT CSII	107.2	OFF ROW		.155	.103	.271	.300
031476	1501	WHEAT CSII	107.2	ON ROW		.121	.176	.244	.275
031476	1502	WHEAT CSII	107.2	OFF ROW		.144	.189	.250	.283
031476	1540	WHEAT CSII	107.2	ON ROW		.195	.224	.300	.330
031476	1541	WHEAT CSII	107.2	OFF ROW		.189	.224	.294	.325
031476	0934	WHEAT CSII	DIF	PERCENT		.313	.323	.250	.225
031476	1306	WHEAT CSII	DIF	PERCENT		.108	.088	.076	.068
031476	1351	WHEAT CSII	DIF	PERCENT		.120	.105	.086	.100
031476	1543	WHEAT CSII	DIF	PERCENT		.176	.134	.124	.107
031476	1352	WHEAT CSII	107.2	SOIL		.147	.189	.243	.268
031476	0935	WHEAT CSII	107.2	SOIL		.188	.258	.281	.325
031476	1308	WHEAT CSII	107.2	SOIL		.159	.192	.269	.278
031476	0940	WHEAT CSII	107.3	ON ROW		.133	.188	.250	.278
031476	0941	WHEAT CSII	107.3	OFF ROW		.172	.176	.233	.243
031476	0943	WHEAT CSII	DIF	PERCENT		.444	.364	.370	.332
031476	1315	WHEAT CSII	107.3	ON ROW		.105	.141	.199	.246
031476	1316	WHEAT CSII	107.3	OFF ROW		.100	.131	.208	.249
031476	1357	WHEAT CSII	107.3	ON ROW		.114	.148	.215	.260
031476	1358	WHEAT CSII	107.3	OFF ROW		.124	.144	.206	.253
031476	1506	WHEAT CSII	107.3	OFF ROW		.099	.136	.167	.245
031476	1507	WHEAT CSII	107.3	ON ROW		.116	.136	.206	.232
031476	1547	WHEAT CSII	107.3	ON ROW		.152	.191	.267	.319
031476	1548	WHEAT CSII	107.3	OFF ROW		.166	.191	.274	.303
031476	1401	WHEAT CSII	107.3	SOIL		.143	.189	.225	.267
031476	0942	WHEAT CSII	107.3	SOIL		.185	.182	.259	.273
031476	1320	WHEAT CSII	107.3	SOIL		.122	.179	.226	.253
031476	1310	WHEAT CSII	DIF	PERCENT		.096	.076	.068	.070
031476	1400	WHEAT CSII	DIF	PERCENT		.124	.115	.105	.110
031476	1540	WHEAT CSII	DIF	PERCENT		.185	.144	.130	.110
031476	0946	WHEAT CSII	107.4	ON ROW		.107	.086	.227	.294
031476	0948	WHEAT CSII	107.4	OFF ROW		.143	.118	.231	.294
031476	0950	WHEAT CSII	DIF	PERCENT		.357	.294	.260	.118
031476	1321	WHEAT CSII	107.4	ON ROW		.062	.074	.192	.241
031476	1322	WHEAT CSII	107.4	OFF ROW		.066	.077	.164	.234
031476	1405	WHEAT CSII	107.4	ON ROW		.061	.070	.201	.251
031476	1406	WHEAT CSII	107.4	OFF ROW		.065	.077	.177	.234

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	0940	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	UIF	PERCENT	.185	.142	.128	.117

B. APRIL 17, 1976

BOOTING STAGE

FIELD 107

Crop Type: Eagle Wheat

Weeds: 0%

Height: 30-35 cm

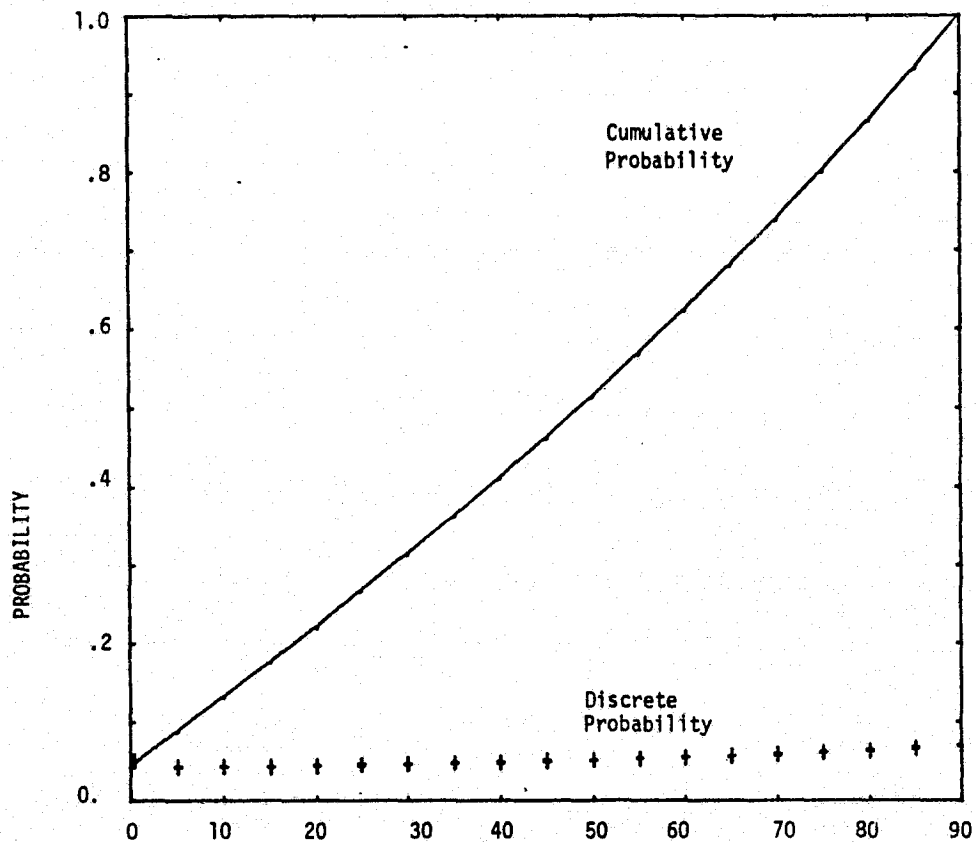
Soil: Wet

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

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		LEAF INCLINATION ANGLE (Deg.)								
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

ORIGINAL PAGE
OF 3000 ORIGINALS

DATE	TIME	CPOP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE=	BAND1	BAND2	BAND3	BAND4
041876	1043	WHEAT CSII	107.4	OFF ROW		.052	.053	.227	.316
041876	1044	WHEAT CSII	107.4	ON ROW		.043	.038	.214	.301
041876	1046	WHEAT CSII	107.4	SOIL		.051	.176	.205	.245
041876	1045	WHEAT CSII	DIF	PERCENT		.095	.062	.068	.071
041876	1135	WHEAT CSII	107.4	OFF ROW		.058	.043	.250	.035
041876	1135	WHEAT CSII	107.4	ON ROW		.046	.034	.246	.343
041876	1138	WHEAT CSII	107.4	OFF ROW		.053	.039	.258	.378
041876	1140	WHEAT CSII	107.4	ON ROW		.045	.039	.238	.338
041876	1136	WHEAT CSII	DIF	PERCENT		.104	.077	.074	.083
041876	1211	WHEAT CSII	107.4	OFF ROW		.052	.040	.252	.384
041876	1213	WHEAT CSII	107.4	ON ROW		.045	.040	.237	.346
041876	1214	WHEAT CSII	107.4	OFF ROW		.052	.041	.256	.350
041876	1215	WHEAT CSII	107.4	ON ROW		.048	.041	.238	.345
041876	1214	WHEAT CSII	DIF	PERCENT		.159	.145	.141	.145
041876	1214	WHEAT CSII	107.4	SOIL		.162	.212	.231	.295
041876	1343	WHEAT CSII	107.4	OFF ROW		.053	.039	.231	.427
041876	1342	WHEAT CSII	107.4	ON ROW		.049	.039	.257	.351
041876	1345	WHEAT CSII	107.4	OFF ROW		.056	.042	.268	.377
041876	1345	WHEAT CSII	107.4	ON ROW		.048	.042	.248	.343
041876	1343	WHEAT CSII	DIF	PERCENT		.139	.117	.116	.126
041876	1344	WHEAT CSII	107.4	SOIL		.167	.176	.248	.262
041876	1036	WHEAT CSII	107.3	OFF ROW		.067	.070	.186	.284
041876	1035	WHEAT CSII	107.3	ON ROW		.063	.067	.217	.302
041876	1036	WHEAT CSII	DIF	PERCENT		.167	.232	.283	.344
041876	1123	WHEAT CSII	107.3	OFF ROW		.097	.061	.066	.067
041876	1125	WHEAT CSII	107.3	ON ROW		.073	.077	.188	.282
041876	1126	WHEAT CSII	107.3	OFF ROW		.069	.014	.204	.279
041876	1131	WHEAT CSII	107.3	ON ROW		.073	.083	.192	.275
041876	1125	WHEAT CSII	DIF	PERCENT		.070	.075	.167	.294
041876	1205	WHEAT CSII	107.3	OFF ROW		.108	.086	.094	.104
041876	1205	WHEAT CSII	107	ON ROW		.075	.126	.179	.296
041876	1207	WHEAT CSII	107	OFF ROW		.068	.122	.194	.315
041876	1207	WHEAT CSII	107	ON ROW		.075	.126	.190	.318
041876	1206	WHEAT CSII	DIF	PERCENT		.075	.130	.201	.321
041876	1207	WHEAT CSII	107	SOIL		.167	.197	.192	.145
041876	1209	WHEAT CSII	107.3	OFF ROW		.073	.143	.136	.213
041876	1209	WHEAT CSII	107.3	ON ROW		.092	.104	.222	.323
041876	1233	WHEAT CSII	107.3	OFF ROW		.069	.033	.206	.295
041876	1233	WHEAT CSII	107.3	ON ROW		.088	.089	.218	.281
041876	1233	WHEAT CSII	DIF	PERCENT		.069	.080	.206	.288
041876	1232	WHEAT CSII	107.3	SOIL		.119	.098	.095	.103
041876	1021	WHEAT CSII	107.3	OFF ROW		.223	.278	.346	.394
041876	1022	WHEAT CSII	107	ON ROW		.166	.202	.050	.368
041876	1025	WHEAT CSII	107	SOIL		.162	.202	.312	.364
041876	1024	WHEAT CSII	DIF	PERCENT		.227	.279	.349	.393
041876	1114	WHEAT CSII	107.2	OFF ROW		.122	.073	.073	.075
041876	1114	WHEAT CSII	107	ON ROW		.171	.211	.345	.386
041876	1120	WHEAT CSII	107	OFF ROW		.175	.205	.318	.380
041876	1120	WHEAT CSII	107	ON ROW		.172	.211	.324	.356
041876	1115	WHEAT CSII	DIF	PERCENT		.169	.202	.324	.347
041876	1158	WHEAT CSII	107.2	OFF ROW		.145	.128	.132	.140
041876	1158	WHEAT CSII	107.2	ON ROW		.174	.186	.318	.387
041876	1200	WHEAT CSII	107.2	OFF ROW		.178	.184	.326	.381
041876	1200	WHEAT CSII	107.2	ON ROW		.173	.214	.316	.383
041876	1159	WHEAT CSII	DIF	PERCENT		.177	.208	.323	.375
041876	1159	WHEAT CSII	107.2	SOIL		.130	.107	.099	.103
041876	1201	WHEAT CSII	107.2	OFF ROW		.235	.280	.354	.395
041876	1201	WHEAT CSII	107.2	ON ROW		.127	.212	.318	.389
041876	1204	WHEAT CSII	107.2	OFF ROW		.172	.206	.325	.383
041876	1204	WHEAT CSII	107.2	ON ROW		.173	.204	.323	.394
041876	1203	WHEAT CSII	DIF	PERCENT		.173	.204	.327	.378
041876	1203	WHEAT CSII	107.2	SOIL		.109	.084	.084	.092
041876	1212	WHEAT CSII	107.2	OFF ROW		.244	.305	.359	.403
041876	1212	WHEAT CSII	107.2	ON ROW		.076	.054	.313	.540

041876	1415	WHEAT CSU	107.2	GREEN 2	.080	.070	.348	.525
041876	1221	WHEAT CSU	107.2	GREEN 1	.415	.384	.652	.722
041876	1001	WHEAT CSU	107.1	OFF ROW	.038	.023	.260	.375
041876	1107	WHEAT CSU	107.1	OFF ROW	.044	.035	.184	.364
041876	1003	WHEAT CSU	107.1	ON ROW	.042	.030	.240	.360
041876	1107	WHEAT CSU	107.1	ON ROW	.040	.024	.172	.336
041876	1007	WHEAT CSU	107.1	SOIL	.104	.129	.165	.199
041876	1005	WHEAT CSU	DIFF	PERCENT	.104	.068	.080	.078
041876	1108	WHEAT CSU	DIFF	PERCENT	.096	.058	.049	.076
041876	1147	WHEAT CSU	107.1	OFF POW	.051	.037	.273	.381
041876	1220	WHEAT CSU	107.1	OFF POW	.046	.034	.262	.362
041876	1148	WHEAT CSU	107.1	ON POW	.043	.032	.231	.323
041876	1227	WHEAT CSU	107.1	ON POW	.046	.031	.230	.325
041876	1154	WHEAT CSU	107.1	OFF POW	.046	.036	.260	.355
041876	1227	WHEAT CSU	107.1	OFF POW	.046	.031	.267	.379
041876	1155	WHEAT CSU	107.1	ON ROW	.041	.030	.224	.319
041876	1228	WHEAT CSU	107.1	ON ROW	.035	.028	.237	.333
041876	1149	WHEAT CSU	DIFF	PERCENT	.123	.111	.114	.128
041876	1222	WHEAT CSU	DIFF	PERCENT	.146	.126	.131	.141
041876	1154	WHEAT CSU	107.1	SOIL	.094	.107	.189	.190
041876	1222	WHEAT CSU	107.1	SOIL	.096	.115	.157	.184

C. MAY 16, 1976

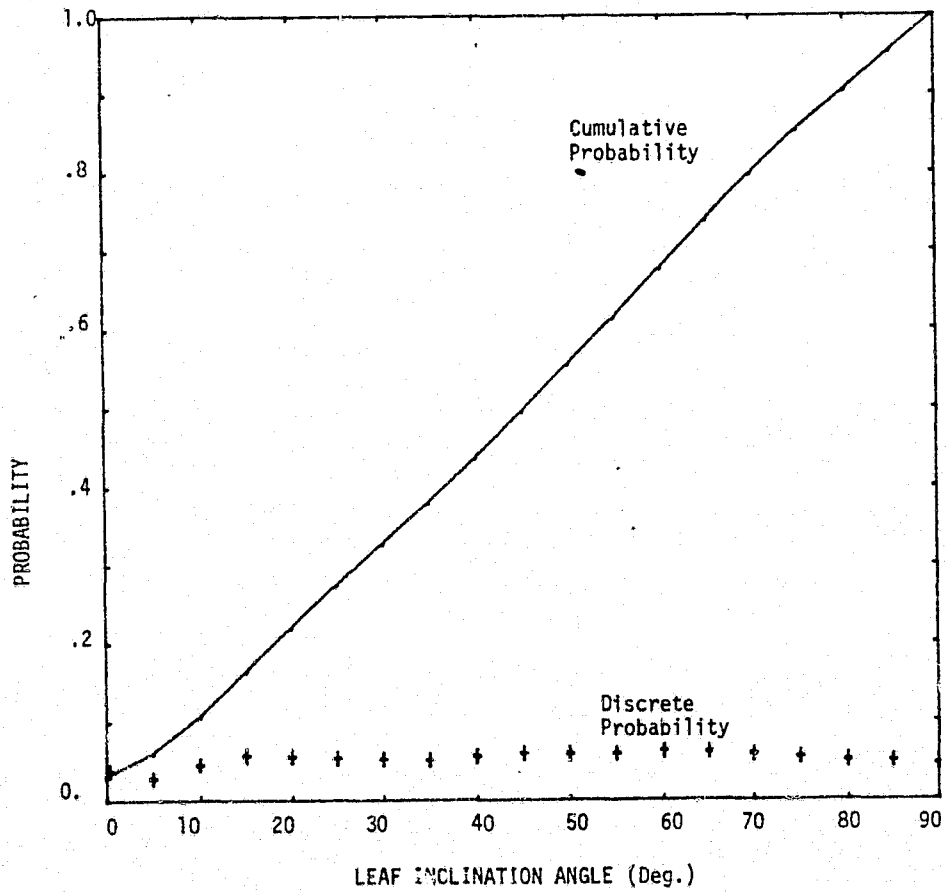
HEADED

FIELD 107

Crop Type: Eagle Wheat Weeds: --
 Height: 74-79 cm Soil: --
 Chlorotic: 0% Wind: --

	<u>PLOT 1</u>	<u>PLOT 2</u>	<u>PLOT 3</u>	<u>PLOT 4</u>
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

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LEAF INCLINATION ANGLE (Deg.)	
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

D. JUNE 13, 1976

RIPENING

FIELD 107

Crop Type: Eagle Wheat

Weeds: 5-10%

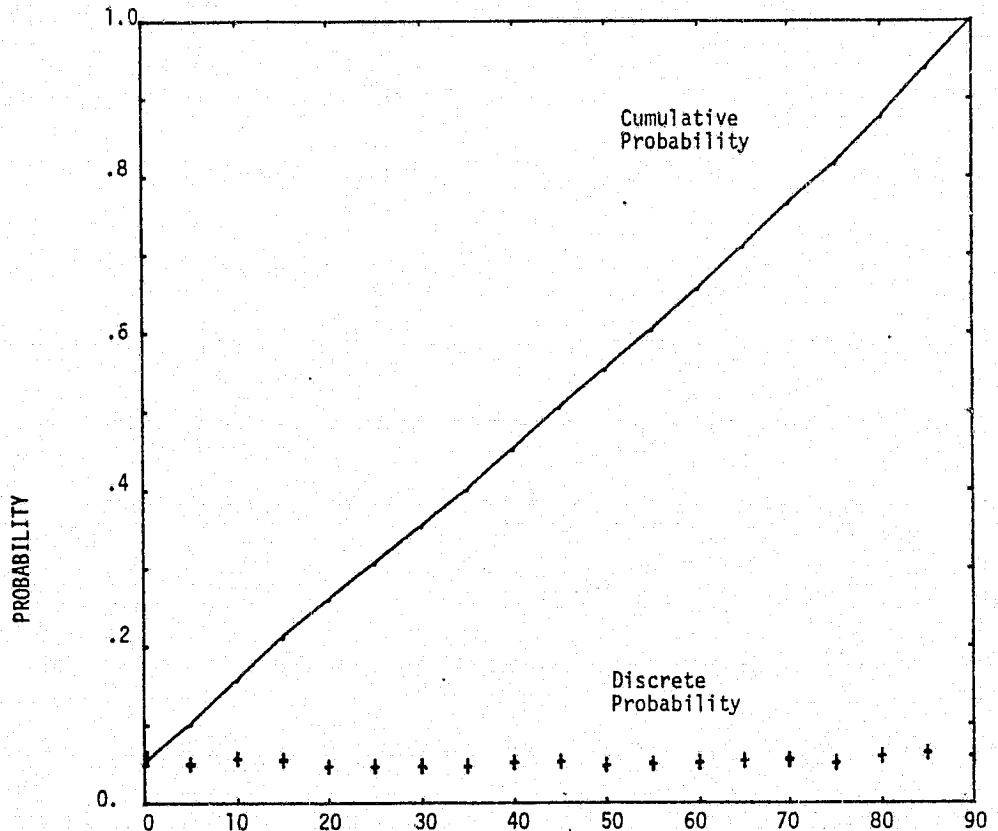
Height: 65-70 cm

Soil: Dry

Chlorotic: 24%

Wind: W

	<u>PLOT 1</u>	<u>PLOT 2</u>	<u>PLOT 3</u>	<u>PLOT 4</u>
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



		LEAF INCLINATION ANGLE (Deg.)							
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 LOCATTON	PLOT NUMFR	ORIENTATION	REFLECTANCE=	BAND1	BAND2	BAND3	BAND4
061276	1145	WHEAT CSII	107.4	ON ROW	.064	.105	.140	.323	
061276	1146	WHEAT CSII	107.4	OFF ROW	.380	.063	.217	.286	
061276	1147	WHEAT CSII	107.4	OFF ROW	.104	.137	.230	.277	
061276	1148	WHEAT CSII	DIF	PERCENT	.072	.048	.057	.068	
061276	1248	WHEAT CSII	107.4	ON ROW	.090	.125	.240	.350	
061276	1247	WHEAT CSII	107.4	OFF ROW	.086	.096	.259	.260	
061276	1247	WHEAT CSII	107.4	OFF ROW	.093	.105	.213	.251	
061276	1248	WHEAT CSII	107.4	ON ROW	.086	.108	.213	.294	
061276	1250	WHEAT CSII	DIF	PERCENT	.071	.050	.061	.071	
061276	1341	WHEAT CSII	107.4	ON ROW	.102	.118	.258	.291	
061276	1242	WHEAT CSII	107.4	OFF ROW	.084	.107	.206	.257	
061276	1343	WHEAT CSII	107.4	OFF ORW	.087	.098	.176	.266	
061276	1344	WHEAT CSII	107.4	ON ORW	.098	.112	.230	.314	
061276	1345	WHEAT CSII	DIF	PERCENT	.069	.046	.052	.067	
061276	141	WHEAT CSII	107.4	SOIL	.161	.194	.238	.283	
061276	1801	WHEAT CSII	107.4	ON ROW	.096	.130	.250	.390	
061276	1802	WHEAT CSII	107.4	OFF ORW	.072	.068	.242	.259	
061276	1803	WHEAT CSII	107.4	OFF ROW	.128	.105	.359	.310	
061276	1803	WHEAT CSII	107.4	ON ROW	.072	.111	.195	.368	
061276	1804	WHEAT CSII	DIF	PERCENT	.112	.074	.078	.092	
061276	1251	WHEAT CSII	107.4	SOIL	.164	.192	.240	.277	
061276		WHEAT CSII	TRANS	GREEN1	.053	.032	.383	.555	
061276		WHEAT CSII	TRANS	GREEN2	.147	.141	.428	.513	
061276		WHEAT CSII	TRANS	GREEN3	.248	.287	.504	.561	
061276		WHEAT CSII	TRANS	GREEN4	.256	.322	.493	.549	
061276		WHEAT CSII	TRANS	GREEN5	.138	.249	.373	.427	
061276	1126	WHEAT CSII	107.3	ON ROW	.116	.144	.245	.300	
061276	1127	WHEAT CSII	107.3	OFF ROW	.108	.148	.224	.284	
061276	1128	WHEAT CSII	107.3	OFF ROW	.116	.164	.215	.290	
061276	1129	WHEAT CSII	107.3	ON ROW	.116	.138	.249	.287	
061276	1130	WHEAT CSII	DIF	PERCENT	.079	.054	.059	.066	
061276	1237	WHEAT CSII	107.3	ON ROW	.152	.152	.293	.330	
061276	1236	WHEAT CSII	107.3	OFF ROW	.114	.144	.208	.270	
061276	1238	WHEAT CSII	107.3	OFF ROW	.121	.167	.239	.301	
061276	1239	WHEAT CSII	107.3	ON ROW	.121	.161	.251	.328	
061276	1240	WHEAT CSII	DIF	PERCENT	.072	.056	.058	.070	
061276	1330	WHEAT CSII	107.3	ON ROW	.135	.160	.207	.296	
061276	1331	WHEAT CSII	107.3	OFF ROW	.127	.160	.222	.271	
061276	1332	WHEAT CSII	107.3	OFF ROW	.130	.165	.237	.291	
061276	1333	WHEAT CSII	107.3	ON ROW	.142	.174	.270	.319	
061276	1334	WHEAT CSII	DIF	PERCENT	.069	.054	.063	.072	
061276	1331	WHEAT CSII	107.3	SOIL	.149	.190	.245	.293	
061276	1854	WHEAT CSII	107.3	ON ROW	.117	.164	.229	.330	
061276	1853	WHEAT CSII	107.3	OFF ROW	.146	.147	.271	.288	
061276	1854	WHEAT CSII	107.3	OFF ROW	.117	.136	.236	.287	
061276	1855	WHEAT CSII	107.3	ON ROW	.117	.124	.243	.282	
061276	1856	WHEAT CSII	DIF	PERCENT	.102	.073	.079	.090	
061276	1240	WHEAT CSII	107.3	SOIL	.167	.202	.266	.310	
061276	1025	WHEAT CSII	107.2	ON ROW	.141	.188	.314	.397	
061276	1024	WHEAT CSII	107.2	OFF ROW	.157	.188	.320	.366	
061276	1025	WHEAT CSII	107.2	OFF ROW	.172	.224	.314	.397	
061276	1028	WHEAT CSII	DIF	PERCENT	.096	.060	.062	.066	
061276	1227	WHEAT CSII	107.2	ON ROW	.149	.180	.298	.362	
061276	1226	WHEAT CSII	107.2	OFF ROW	.156	.218	.298	.367	
061276	1229	WHEAT CSII	107.2	OFF ROW	.130	.177	.257	.324	
061276	1228	WHEAT CSII	107.2	ON ROW	.156	.171	.333	.373	
061276	1231	WHEAT CSII	DIF	PERCENT	.071	.050	.054	.061	
061276	1321	WHEAT CSII	107.2	ON ROW	.171	.181	.340	.380	
061276	1322	WHEAT CSII	107.2	OFF ROW	.164	.221	.302	.374	
061276	1323	WHEAT CSII	107.2	OFF ROW	.142	.186	.250	.310	
061276	1323	WHEAT CSII	107.2	OFF ROW	.145	.166	.244	.340	
061276	1325	WHEAT CSII	DIF	PERCENT	.069	.052	.060	.072	
061276	1329	WHEAT CSII	107.2	SOIL	.167	.192	.299	.354	
061276	1742	WHEAT CSII	107.2	ON ROW	.129	.174	.246	.390	

061271	1742	WHEAT	CSII	107.2	OFF ROW	174	197	351	367
061272	1745	WHEAT	CSII	107.2	ON ROW	143	163	300	362
061273	1747	WHEAT	CSII	107.2	PERCENT	120	179	343	463
061274	1749	WHEAT	CSII	107.2	SOIL	114	245	079	090
061275	0045	WHEAT	CSII	107.2	ON ROW	155	154	267	333
061276	0047	WHEAT	CSII	107.2	OFF ROW	155	130	237	267
061277	0045	WHEAT	CSII	107.2	PERCENT	147	182	249	302
061278	0048	WHEAT	CSII	107.2	ON ROW	118	075	071	076
061279	1211	WHEAT	CSII	107.1	OFF ROW	107	137	275	328
061280	1212	WHEAT	CSII	107.1	ON ROW	107	146	208	284
061281	1214	WHEAT	CSII	107.1	PERCENT	084	119	196	244
061282	1215	WHEAT	CSII	107.1	ON ROW	103	149	227	299
061283	1216	WHEAT	CSII	107.1	PERCENT	103	054	055	062
061284	1311	WHEAT	CSII	107.1	ON ROW	127	150	259	319
061285	1312	WHEAT	CSII	107.1	OFF ROW	116	157	207	275
061286	1313	WHEAT	CSII	107.1	ON ROW	102	134	226	275
061287	1315	WHEAT	CSII	107.1	ON ROW	120	160	248	307
061288	1315	WHEAT	CSII	107.1	PERCENT	073	057	060	067
061289	0656	WHEAT	CSII	107.1	SOIL	088	182	225	271
061290	1730	WHEAT	CSII	107.1	ON ROW	106	197	232	244
061291	1731	WHEAT	CSII	107.1	OFF ROW	113	126	220	271
061292	1732	WHEAT	CSII	107.1	ON ROW	088	117	238	312
061293	1733	WHEAT	CSII	107.1	PERCENT	100	126	226	312
061294	1217	WHEAT	CSII	107.1	SOIL	105	085	073	089

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061 276	1745	WHEAT	CSII	107.2	OFF ROW	.164	.197	.321	.367
061 276	1745	WHEAT	CSII	107.2	OFF ROW	.143	.163	.300	.362
061 276	1745	WHEAT	CSII	107.2	ON ROW	.129	.197	.343	.463
061 276	1746	WHEAT	CSII	DIF	PFRCENT	.114	.079	.079	.090
061 276	1746	WHEAT	CSII	107.2	SOIL	.193	.245	.326	.367
061 276	0045	WHEAT	CSII	107.1	ON ROW	.155	.154	.261	.332
061 276	0047	WHEAT	CSII	107.1	OFF ROW	.155	.130	.237	.267
061 276	0045	WHEAT	CSII	107.1	SOIL	.207	.182	.249	.302
061 276	0048	WHEAT	CSII	DIF	PFRCENT	.147	.075	.071	.076
061 276	1211	WHEAT	CSII	107.1	ON ROW	.118	.137	.275	.328
061 276	1212	WHEAT	CSII	107.1	OFF ROW	.107	.146	.208	.284
061 276	1214	WHEAT	CSII	107.1	OFF ROW	.084	.119	.196	.246
061 276	1215	WHEAT	CSII	107.1	ON ROW	.103	.149	.227	.299
061 276	1215	WHEAT	CSII	DIF	PFRCENT	.073	.054	.055	.062
061 276	1211	WHEAT	CSII	107.1	ON ROW	.127	.160	.259	.319
061 276	1212	WHEAT	CSII	107.1	OFF ROW	.116	.157	.207	.277
061 276	1214	WHEAT	CSII	107.1	OFF ROW	.102	.134	.206	.275
061 276	1215	WHEAT	CSII	107.1	ON ROW	.120	.160	.248	.300
061 276	1215	WHEAT	CSII	DIF	PFRCENT	.073	.057	.050	.067
061 276	0045	WHEAT	CSII	107.1	SOIL	.198	.182	.225	.271
061 276	1730	WHEAT	CSII	107.1	ON ROW	.106	.107	.232	.240
061 276	1731	WHEAT	CSII	107.1	OFF ROW	.113	.126	.220	.244
061 276	1732	WHEAT	CSII	107.1	OFF ROW	.088	.117	.238	.271
061 276	1732	WHEAT	CSII	107.1	ON ROW	.100	.126	.226	.312
061 276	1734	WHEAT	CSII	DIF	PFRCENT	.106	.078	.073	.081
061 276	1217	WHEAT	CSII	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)
5      THIS PROGRAM COMPUTES TASSELED CAP TRANSFORMATION FOR LANDSAT
      DATA VECTORS
      DIMENSION X(4), U(4), R(4,4), RT(4,4), O(4), RADMAX(4), BW(4), CNTMAX(4),
      Z XCNTS(4)
10     DATA (RADMAX(I), I=1,4) / 2.46, 2.00, 1.76, 1.60 /
      DATA (CNTMAX(I), I=1,4) / 3*(127.), 63. /
      DATA (BW(I), I=1,4) / 3*(.1), .3 /
      READ SWITCH -- C = PUNCH COUNTS, TC = PUNCH TRANSFORMED COUNTS
15     READ(5,5) SW
      5 FORMAT(A2)
      READ THE TRANSFORMATION MATRIX, R, AND COMPUTE ITS TRANSPOSE, RT,
20     AND READ THE OFFSET VECTOR, O
      DO 20 J=1,4
      READ(5,10) (R(I,J), I=1,4)
      10 FORMAT(4F10.6)
      DO 20 I=1,4
25     RT(J,I) = R(I,J)
      READ(5,10) (O(I), I=1,4)
      PRINT HEADINGS AND CONSTANT MATRICES
30     WRITE(6,30)
      30 FORMAT(1H1,35X,52HTASSELED CAP TRANSFORMATION FOR LANDSAT DATA VEC
      X(ORS/))
      WRITE(6,35)
35     FORMAT(19H0TRANSFORM MATRIX =)
      DO 45 I=1,4
      WRITE(6,40) (R(I,J), J=1,4)
      40 FORMAT(1H *(F10.5))
      45 CONTINUE
      WRITE(6,50)
40     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)
45     FORMAT(/16H OFFSET VECTOR =)
      WRITE(6,40) (O(I), I=1,4)
      READ THE LANDSAT MSS SIGNAL VECTOR, X, CONVERT IT TO COUNTS, XCNTS,
50     AND COMPUTE THE TRANSFORMED VECTOR, U
      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)

```

```
60      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)
65      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.2MC) GO TO 350
70      WRITE(7,300) (XCNTS(I),I=1,4),SW,CID
300     FORMAT(*4(F10.5),25X,A2,3X,A10)
350     IF (SW.EQ.2MC) GO TO 450
      WRITE(7,400) (U(I),I=1,4),SW,CID
400     FORMAT(*4(F10.5),25X,A2,3X,A10)
75      450 CONTINUE
      GO TO 77
      C
999 STOP
END
```

B. PROGRAM SCATPLT

```

PROGRAM SCATPLT(INPUT,OUTPUT,FILMPH,TAPES=INPUT,TAPE6=OUTPUT,
*TAPE7=FILMPH,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)
10 IDFS = DATA DESCRIPTION
READ(5,10)LAB,NPLOT,NCOLS,((MA(I,J),J=1,2),I=1,10),IDES
11 FORMAT(A10,2I5,20I1,3A10)
C READ MINIMUM AND MAXIMUM DATA VALUES FOR PLOTTING
12 READ(5,12)XMIN,XMAX,YMIN,YMAX
13 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
20 READ(5,20)NPTS,ICHA
IF(EOF(5))55,22
21 FORMAT(I5,A1)
22 KK=JJ+1 S 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)=ICHA
WRITE(6,26)LSYMB(I,1),(DATA(I,K),K=1,NCOLS)
26 FORMAT(1H ,A1,5X,4F10,3)
50 CONTINUE
JJ=JJ+NPTS
35 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,A10,13,4H VS ,I3)
WRITE(7,70)
45 FORMAT(1H ,1X,6HSYMBOL,4X,1HX,6X,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 PFFML(5,5,5,5)
55 CALL FWSIPT(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
60 CALL FRAMF
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	-.28472	-.82943	.22303		
.63248	-.55149	.52244	.01170		
.58572	.59453	-.03899	-.52450		
.26414	-.79070	.19386	.80982		
TRANSPOSE OF TRANSFORM MATRIX =					
.43259	.63248	.58572	.26414		
-.28472	-.55149	.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	31.60094	32.46421	
LANDSAT VECTOR =	4.41310	4.53920	5.52260	4.58530	MAR 1 1500
VECTOR IN COUNTS =	22.59934	28.82392	39.85059	18.83960	
TRANSFORMED VECTOR =	88.32415	42.38997	30.41267	31.73263	
LANDSAT VECTOR =	5.75890	5.13920	6.35530	5.02040	MAR 1 1930
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	4.74040	MAR 2 1300
VECTOR IN COUNTS =	32.66000	40.81018	45.02366	19.50151	
TRANSFORMED VECTOR =	103.46207	36.18526	28.25678	31.43984	
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	39.13443	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	17.79161	
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 =	23.19544	28.30512	35.85309	16.92248	
TRANSFORMED VECTOR =	85.49202	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 =	25.55692	30.03486	37.85177	17.51701	
TRANSFORMED VECTOR =	88.86232	38.99654	28.38917	32.39043	
LANDSAT VECTOR =	4.67530	4.45750	4.69250	3.97400	MAR 3 1500
VECTOR IN COUNTS =	23.94206	28.30212	33.84055	16.32796	
TRANSFORMED VECTOR =	84.40501	37.40891	28.77458	33.13376	
LANDSAT VECTOR =	6.17110	5.96920	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	22.44050	40.51733	19.96497	
TRANSFORMED VECTOR =	86.85616	45.80204	24.04625	33.08646	
LANDSAT VECTOR =	3.39300	2.83050	4.48540	3.94190	MAR 4 1325
VECTOR IN COUNTS =	17.40195	17.97367	32.30624	16.19667	
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	28.58557	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 =	74.24463	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 =	72.31960	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	46.48551	26.92017	
TRANSFORMED VECTOR =	80.29000	62.15744	28.43622	33.02790	
LANDSAT VECTOR =	2.95130	1.70980	6.49120	6.10670	APR 1 1220
VECTOR IN COUNTS =	15.11351	10.85723	46.83991	25.08852	
TRANSFORMED VECTOR =	79.46674	61.91252	28.17402	31.24745	
LANDSAT VECTOR =	6.95370	6.78540	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 =	38.25440	41.42422	59.63949	27.34296	
TRANSFORMED VECTOR =	116.03733	47.38923	26.54654	31.43245	
LANDSAT VECTOR =	6.80800	6.78590	8.31450	6.72360	APR 2 1300
VECTOR IN COUNTS =	33.83935	43.09046	59.99669	27.62523	
TRANSFORMED VECTOR =	116.33027	47.50516	29.46076	30.45455	
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	33.09977	

LANDSAT VECTOR =	3.31050	3.02530	4.99720	4.46030	APR 3 1130
VECTOR IN COUNTS =	19.51376	19.21065	36.06008	20.38076	
TRANSFORMED VECTOR =	17.04607	47.16995	28.39501	34.16789	
LANDSAT VECTOR =	3.37220	4.43530	5.07000	5.47290	APR 3 1205
VECTOR IN COUNTS =	19.82941	28.16416	36.58879	22.48848	
TRANSFORMED VECTOR =	85.70155	43.37736	33.14960	35.77115	
LANDSAT VECTOR =	4.08790	3.36980	5.60860	5.19940	APR 3 1330
VECTOR IN COUNTS =	20.93400	21.37823	40.47115	21.36275	
TRANSFORMED VECTOR =	83.93710	48.65579	28.37941	32.99214	
LANDSAT VECTOR =	3.10440	2.13790	5.80450	5.40450	APR 4 1045
VECTOR IN COUNTS =	15.89753	13.57566	41.89474	22.20565	
TRANSFORMED VECTOR =	77.36137	55.77215	28.57824	31.71833	
LANDSAT VECTOR =	3.19630	1.93800	6.40670	6.14090	APR 4 1140
VECTOR IN COUNTS =	16.36815	12.30630	46.66312	25.22945	
TRANSFORMED VECTOR =	80.85965	60.67783	27.92405	31.75108	
LANDSAT VECTOR =	3.13500	1.99510	6.41750	6.24330	APR 4 1215
VECTOR IN COUNTS =	16.05423	12.66888	46.30892	25.65182	
TRANSFORMED VECTOR =	60.85723	60.57985	28.47015	32.21319	
LANDSAT VECTOR =	3.22700	1.99510	6.85930	6.10520	APR 4 1345
VECTOR IN COUNTS =	16.52536	12.66828	49.49909	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	32.59182	
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 =	44.18220	69.85243	28.04980	36.93959	
LANDSAT VECTOR =	4.10570	2.80040	7.82530	7.00730	MAY 1 1245
VECTOR IN COUNTS =	21.02516	17.78254	56.47026	23.79086	
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	51.93743	32.84245	
TRANSFORMED VECTOR =	96.26209	59.12033	29.46434	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	8.04350	7.31040	MAY 2 1050
VECTOR IN COUNTS =	27.87906	27.88031	58.04189	30.02621	
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	55.83241	26.64925	31.74524	
LANDSAT VECTOR =	4.42800	3.49880	8.12540	7.93640	MAY 3 0955
VECTOR IN COUNTS =	25.23613	22.21738	56.63215	32.80625	
TRANSFORMED VECTOR =	49.42386	63.35524	26.71101	33.54261	

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LANDSAT VECTOR =	4.31080	3.08500	7.52650	7.70070	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	20.49128	49.80204	26.22498	
TRANSFORMED VECTOR =	89.94405	57.27117	28.65227	31.96616	
LANDSAT VECTOR =	2.94800	1.75640	6.03450	6.79960	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	12.19580	47.45326	27.85737	
TRANSFORMED VECTOR =	91.89770	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	28.92192	32.55301	
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	21.97641	32.47398	
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	21.89031	
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	45.57822	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	

LANDSAT VECTOR =	6.34650	6.05050	7.36350	6.10440	JUN 3 1235
VECTOR IN COUNTS =	32.50022	38.42131	53.13435	25.00112	
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	26.91638	46.09368	23.64431	
TRANSFORMED VECTOR =	42.85944	49.00616	28.52869	32.75573	
LANDSAT VECTOR =	4.99630	4.50150	6.88850	5.75470	JUN 4 1250
VECTOR IN COUNTS =	25.98589	28.58452	49.70679	23.64431	
TRANSFORMED VECTOR =	46.50675	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	6.59050	JUN 4 1800
VECTOR IN COUNTS =	25.12974	27.54185	35.90082	27.07836	
TRANSFORMED VECTOR =	100.45272	55.78999	27.78368	30.72710	

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B. MODEL DATA TRANSFORMATIONS

TASSELED CAP TRANSFORMATION FOR LANDSAT DATA VECTORS

TRANSFORM MATRIX =			
.43758	-.28972	-.82943	.22303
.63748	-.56149	.52244	.01170
.58572	.59953	-.03899	-.52450
.26414	.49070	.19386	.80982

TRANSPOSE OF TRANSFORM MATRIX =			
.43258	.63748	.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	5.31440	4.61740	MAP L1 S1
VECTOR IN COUNTS =	22.89738	28.47248	38.35111	18.97231	
TRANSFORMED VECTOR =	87.39138	41.66391	70.05918	32.68940	
LANDSAT VECTOR =	4.99650	5.22120	5.91860	5.11720	MAP 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	MAP L1 S3
VECTOR IN COUNTS =	27.68651	36.28136	50.21118	25.27361	
TRANSFORMED VECTOR =	103.00928	46.09367	70.93258	32.73056	
LANDSAT VECTOR =	3.91910	3.72380	5.33790	4.79480	MAP L2 S1
VECTOR IN COUNTS =	20.06958	23.64613	38.51780	19.70037	
TRANSFORMED VECTOR =	83.40171	45.65610	30.02467	32.50365	
LANDSAT VECTOR =	4.61700	4.62490	4.44800	5.82770	MAP L2 S2
VECTOR IN COUNTS =	23.64351	29.34271	46.52818	23.94425	
TRANSFORMED VECTOR =	94.36351	48.30417	30.54687	32.60382	
LANDSAT VECTOR =	5.17210	5.35780	7.00490	6.26450	MAP L2 S3
VECTOR IN COUNTS =	26.49616	34.02203	50.54672	25.73892	
TRANSFORMED VECTOR =	101.38054	49.14976	30.82499	32.63741	
LANDSAT VECTOR =	2.96540	2.34490	5.56880	5.35920	MAP L3 S1
VECTOR IN COUNTS =	15.18572	14.89011	40.18395	22.01973	
TRANSFORMED VECTOR =	77.33958	54.12887	29.88567	32.31662	
LANDSAT VECTOR =	3.25370	2.72250	6.05430	5.82770	MAP L3 S2
VECTOR IN COUNTS =	16.66209	17.28787	41.68728	23.94425	
TRANSFORMED VECTOR =	82.05507	55.39832	30.15030	32.39467	
LANDSAT VECTOR =	3.28250	2.72250	6.21630	6.02180	MAP 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 =	3.81040	3.05400	5.97600	5.78090	APP L1 S1
VECTOR IN COUNTS =	19.51396	19.39290	43.12227	23.75106	
TRANSFORMED VECTOR =	84.23839	52.95598	29.86938	33.19627	
LANDSAT VECTOR =	3.93380	3.29360	6.24580	6.05490	APP L1 S2
VECTOR IN COUNTS =	20.14486	20.85786	45.06912	24.87774	
TRANSFORMED VECTOR =	86.87111	53.67346	29.25012	33.24460	
LANDSAT VECTOR =	3.87220	3.05400	6.73690	6.68920	APP L1 S3
VECTOR IN COUNTS =	19.82941	19.39290	48.61286	27.48420	
TRANSFORMED VECTOR =	88.57665	57.98782	29.11721	33.40914	

LANDSAT VECTOR =	3.44170	2.36550	6.24580	6.19190	APR L2 S1
VECTOR IN COUNTS =	17.62433	15.02727	49.04912	25.44043	
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	51.20974	28.75388	
TRANSFORMED VECTOR =	87.73845	61.31985	28.88467	33.32408	
LANDSAT VECTOR =	3.59530	2.52540	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	2.36450	6.83520	6.84380	APP L3 S1
VECTOR IN COUNTS =	17.93326	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	APP L3 S2
VECTOR IN COUNTS =	17.46762	14.48308	42.43535	27.83682	
TRANSFORMED VECTOR =	84.43977	61.49791	28.58632	33.20373	
LANDSAT VECTOR =	3.68750	2.59540	7.20430	7.27390	APR L3 S3
VECTOR IN COUNTS =	18.83357	16.48079	51.98557	29.88378	
TRANSFORMED VECTOR =	88.93492	63.04789	28.71398	33.33847	
LANDSAT VECTOR =	3.76430	2.29370	7.49930	6.25080	MAY L1 S1
VECTOR IN COUNTS =	19.27686	14.56499	54.11427	25.68140	
TRANSFORMED VECTOR =	88.03015	63.27472	24.48921	28.88411	
LANDSAT VECTOR =	3.90070	2.57850	7.52650	6.30720	MAY L1 S2
VECTOR IN COUNTS =	19.97533	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	28.60782	
LANDSAT VECTOR =	3.73020	1.97750	8.45250	6.95080	MAY L2 S1
VECTOR IN COUNTS =	19.10223	12.55712	50.99247	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	27.67267	
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	6.95080	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	8.13520	7.53790	MAY L3 S2
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 S3
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	6.20180	JUN L1 S1
VECTOR IN COUNTS =	29.39999	35.69462	57.37586	25.48008	
TRANSFORMED VECTOR =	107.63047	50.32384	28.96555	29.51534	

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 S2
VECTOR IN COUNTS =	32.86585	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	29.67771	29.11597	
LANDSAT VECTOR =	5.77660	5.48720	9.04570	6.99940	JUN L2 S2
VECTOR IN COUNTS =	29.50178	34.85642	65.27295	28.75840	
TRANSFORMED VECTOR =	112.67032	57.08545	29.70448	28.05891	
LANDSAT VECTOR =	6.27520	5.92450	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	6.21500	10.31330	7.87700	JUN L3 S2
VECTOR IN COUNTS =	33.04863	39.47160	74.41984	32.36420	
TRANSFORMED VECTOR =	123.39906	60.74353	28.58247	27.00863	
LANDSAT VECTOR =	6.34650	6.08170	10.14400	7.75990	JUN L3 S2
VECTOR IN COUNTS =	32.50022	38.63149	73.19818	31.88307	
TRANSFORMED VECTOR =	121.79783	60.40305	28.55283	27.12761	