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A COMPARISON OF SIMULATED THEMATIC MAPPER DATA AND MULTISPECTRAL SCANNER DATA FOR KINGSBURY COUNTY, SOUTH DAKOTA

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ABSTRACT

Single date and multidate landsat MSS and Thematic Mapper (TM) data were simulated utilizing helicopter spectrometer data from 5 years of commercial field data and actual field boundaries and land use from a 5-by-6 nm sample segment in Kingsbury Co., South Dakota. Single date simulations for MSS and TM clusters using "CLASSY" showed a decrease in mixed pixels on the borders of fields with TM, but an increase in the number of TM clusters for cover types which have significant within-field variability.

I. INTRODUCTION

The Landsat-D Earth-observing satellite is scheduled to be launched in mid-1982 into a sun-synchronous orbit at a nominal altitude of 705 kilometers with a 16-day repetitive cycle. The principal observing instruments on Landsat-D will be the Thematic Mapper (TM) and the multispectral scanner (MSS). The TM will have considerably greater spatial, spectral, and radiometric resolution than the multispectral scanner. The TM will have seven spectral bands that are 0.45 to 0.52, 0.52 to 0.60, 0.63 to 0.69, 0.76 to 0.90, 1.55 to 1.75, 2.08 to 2.35, and 10.5 to 12.5 micrometers, with an instantaneous field of view at a nadir of 30 meters (except for the thermal band with a field of view of 120 meters) compared to 80 meters for the MSS. In addition, the TM will have 256 quantitizing levels whereas the MSS has 64. Table 1 describes some other performance characteristics of the TM (ref. 1).

Table 1. Radiometer Characteristics for the Thematic Mapper

Band	Spectral width μm	Dynamic range, mW/cm^2 sr	Low level input, mW/cm^2 sr	Solar irradiance, mW/cm^2 sr	Gain counts, mW/cm^2 sr	Basic primary rationale for vegetation
1	0.45-0.52	0-1.00	0.28	4.63	354.2	Sensitivity to chlorophyll and carotinoid absorption.
2	0.52-0.60	0.233	0.24	4.85	122.0	Slight sensitivity to chlorophyll, plus green reflectance characteristics.
3	0.63-0.69	0-1.35	0.13	3.07	209.0	Sensitivity to chlorophyll absorption.
4	0.76-0.90	0-3.00	0.16	4.69	89.8	Sensitivity to vegetational density or biomass.
5	1.55-1.75	0-0.60	0.08	1.30	490.4	Sensitivity to absorption by plant leaves and snow cloud reflectance differences.
6	2.08-2.35	0-0.43	0.05	0.74	671.1	Sensitivity to absorption by water in plant leaves and hydroxyl ions in minerals.
7	10.40-12.50	260-320 K	300 K	0.5 K (NeΔT)	0.5 K	Scene equivalent blackbody temperature.

During the Large Area Crop Inventory Experiment (LACIE) project, it was found that the mixed pixels of Landsat MSS data on the borders of the fields and the missing of key acquisitions due to cloud cover caused most of the errors in estimating the wheat acreage in the United States (ref. 2). Simulation of MSS and TM data from known distributions enables these error sources to be examined and enables the proper utilization of ground level field research data for understanding the interplay of signal and noise from the ground, atmosphere, and sensor. With this purpose in mind, a simulation capability was implemented which could generate a multitemporal data set of simulated TM and MSS data based on aperiodic multisite helicopter spectrometer data. This capability uses the Badhwar profile (ref. 3) to fit the band integrated reflectances for each field and utilizes actual field boundary polygons as a base to paint the TM and MSS pixels by using standard Monte Carlo techniques. Actual field planting dates are used to initialize the Badhwar profile and both random and clustered within-field variance may be simulated together with various atmospheric and viewing conditions. At the present time the instrument modulation transfer function and the thermal band are not included in the model.

II. THEMATIC MAPPER SCENE DEFINITION

An agricultural segment in Kingsbury County, South Dakota, was selected as the scene to simulate a TM product. This segment is characterized by 19 categories of land use (see Table 2), a large variety of field sizes and shapes, as well as some areas of water. In addition, good Landsat acquisitions that were taken in 1978 over this site are available for comparison.

Table 2. Land use proportions of Kingsbury, South Dakota, segment as determined from ground truth map

Land use	Proportion, %
Alfalfa	4.8
Corn	23.7
Spring wheat	8.9
Barley	2.5
Flax	3.8
Oats	9.1
Grass	7.3
Pasture	3.4
Land not inventoried	16.2
Water	4.8
Nonagriculture (undeveloped land)	2.5
Idle stubble	7.8

During the accuracy assessment validation phase of the LACIE for the prediction of small grains within a 5-by-6-nautical-mile segment, a ground truth map of the segment was prepared. This ground truth map defined the use of all land use areas greater than 1 acre within the segment boundaries. The preparation of the map was the result of an extensive inventory by a designated USDA enumerator who recorded each land use category and land use boundary on an overlay on a current year High Altitude aerial photograph.

This overlay was the basis for delineation and digitization of the scene in such a manner that the borders and vertices of the land-use area were defined by a polygon in Landsat MSS line number and column coordinates. The entire area was subdivided into areas designated as ground truth subpixels. The size of the subpixels was established in such a manner that a 2-by-3 set of subpixels (i.e., three lines of two subpixels) was equivalent to a Landsat pixel. Thus, the land use within the segment is defined by 351 lines of 392 subpixels in a line. This is equivalent to subpixel centers being 28.4 meters apart in a line and lines being 26.4 meters apart. A similar area would be covered by the TM with 308 lines and 380 pixels in a line (29.3 meters apart in a line, and lines 30 meters apart at nadir). Even though the resolution of the digitized ground truth map is slightly better than that of the TM, it is considered a good base to simulate a TM scene.

The simulation was done for both MSS and TM for July 16 (day 197 of the year), a time in which most spring grain crops have passed heading (fig. 1). A multitemporal simulation was done for MSS for June 4, June 21, July 8, and July 25 for the same segment (fig. 2).

III. ANALYSIS OF DATA

The basic data used in the present simulation were acquired using a helicopter-mounted Field Spectrometer System (FSS) over Finney County, Kansas; Williams County, North Dakota; and Hand County, South Dakota. The FSS has a 22-meter field of view of the ground from 200 meters above the ground, a spectral resolution of 20 angstroms from 0.4 to 1.1 micrometers and a resolution of 50 angstroms from 1.1 to 1.4 micrometers. The basic measurements are the bidirectional reflectance values throughout the growing season for each of approximately 80 fields per segment per crop year.

A complete description of the data sources, crop conditions, and instruments is given by Bauer et al. (ref. 4). Reference 5 gives details of the crop type, the geographic location of the fields, and selected agronomic information used in this simulation.

The field measurement data from the FSS were not available for all the land use categories present in the Kingsbury site. Hence, some other methods were developed to simulate the data for the missing ground cover types. In reference 5 the authors discuss the approximations made to simulate the missing spectral data. These data are integrated over the reflective TM bands using the TM spectral response functions. (The thermal band was not studied.) However, because of a current calibration uncertainty of the FSS in the wavelength region of 0.67 to 0.70 micrometer the TM-3 band was integrated only from 0.63 to 0.67 micrometer.

In terms of percent reflectance, the FSS response is calibrated against a spectrally flat canvas panel at the end of each flight leg (which is referenced to a Barium sulphate panel). When integrated to TM bands, the response is in percent reflectance, which must be converted to TM counts for use in the simulation. The reflectance values are first converted into radiance using the solar irradiance values obtained from Thekaekara et al. (ref. 6) and integrating over the TM bands. These irradiance values are given in column 5 in Table 1. Using the preflight minimum (r_{min}) and maximum (r_{max}) radiance sensitivity of each band, a gain $G = 255/(r_{max}-r_{min})$ is computed and given in column 6 of Table 1. Using the percentage reflectance, solar irradiance, and gain factors, the TM count values are generated and used in the simulation. These values result in a scene simulation with no atmosphere and the Sun at a 0° zenith angle.

IV. THEMATIC MAPPER SCENE GENERATION

The actual generation of the simulated image was basically a process of painting the scene according to the digitized ground truth image discussed in section II with the spectral values of the corresponding crop obtained from the FSS data discussed in section III.

The FSS spectral data were converted into a cumulative frequency distribution for each field of each crop, for each observation date, and in each of the TM bands. The data from several geographic locations and dates were appropriately combined to produce a collection of distributions to represent a collection of crops and fields. Using a uniform random number generator and the cumulative distributions, a spectral response to a pixel was estimated based on the probability of that response for the crop indicated to exist at that pixel by the digitized ground truth. The initial simulation (fig. 1) was done for a single date and used a single distribution for each crop at a specified day of the year. Later simulations fit the Badhwar temporal profile (Incomplete Gamma Function) to the spectral data as a function of day of year for each crop class. Between field variance was modeled by using an offset of the planting date of each field. Planting date was also used in parameterizing the within field variability for each crop class.

This method would produce a scene depicting only the within field variation. All fields of the same type would show the same overall variation with no spatial correlation to the variation within a specific field. An attempt was made to overcome the limitations by using an objective analysis program to overlay a mask of coherent areas of variation in the scene. Results of inducing this variability within the fields can be seen in Figure 1.

This procedure was done for each of the pixels in the segment and produced a scene of 392 pixels by 351 pixels (compared to the actual TM scene of 370 pixels by 309 pixels). The spectral values are converted into actual TM counts using the procedure discussed in section III, and a table of these counts is used to create an image.

V. EXAMPLES OF THE THEMATIC MAPPER SIMULATED PRODUCT

The data comprising the simulated image were written to computer-compatible magnetic tape. One method of viewing the simulated image was to process the tape on a General Electric Image-100 (I-100) system with a matrix Polaroid camera for permanent copies. The I-100 system is capable of reading any five of the six bands at one time. The three color guns can be assigned to any set of three of the five channels, and the image can be viewed on a cathode-ray tube (CRT). The matrix camera picture images in figures 1 and 2 were generated with TM channels 2, 3, and 4 assigned to the blue, green, and red (BGR) guns, respectively.

The simulated TM imagery does not mix the pixel values at the field borders. Research is now underway to perform this function.

In section II, the six TM subpixels comprising a Landsat pixel are discussed. When the spectral values of these six subpixels are averaged in each channel, a simulated Landsat image will be shown illustrating the mixing of pixels at the field boundaries as they begin to have the appearance of the pixels in the upper left portion of the Landsat image.

Since the spectral data were acquired from a helicopter-borne filter wheel spectrometer, the data are not quite representative of data that would be taken on satellites orbiting the Earth above the atmosphere. Atmospheric simulation programs have been devised using the Dave model (ref. 7) to add such a correction to this FSS spectral data.

A ground truth map of the quarter image is provided in figure 3. The 12 categories of crops of other land use are listed with their alphabetic code. The TM channels 2, 3, and 4 are near the Landsat channels 1, 2, and 4, which are used in the generation of the production film converter (PFC) product 1, an analyst tool used in the LACIE project. It is quite noticeable that the boundaries of the simulated data are much better defined for the TM image than for the MSS image (which has many more mixed pixels.)

Preliminary cluster results on MSS and TM were obtained for the July 16 single date simulation using the CLASSY algorithm. The results for a selected region is shown in figures 4 and 5 and the number of clusters obtained is shown in Table 3. From these preliminary results it is evident that the TM clusters are more pure and the fields and boundaries are much more distinct (fewer mixed pixels on the boundaries). However, when significant variability exists in a category (e.g., pasture), it is much more evident in the TM data. This may cause decreased classification performance for some ground cover types using TM unless the additional band and greater radiometric resolution make up for the difference. Small fields of homogenous cover should have classification performance increases which are significant.

Table 3. Clustering of simulated MSS and TM using CLASSY

Crop	# Clusters MSS	# Clusters TM
Rye	1	1
Barley	1	2
Wheat	1	1
Oats	2	1
Alfalfa	3	2
Corn	3	4
Pasture	4	6
Trees	2	1
Sorghum	1	2
Water	1	1

VI. REFERENCES

1. Salomonson, V.V., et al.: An Overview of Progress in the Design and Implementation of Landsat-D Systems. IEEE Transactions on Geoscience and Remote Sensing, vol. GE-18, no. 2, April 1980.

2. MacDonald, R.B.: Proceedings of the LACIE Symposium, JSC-16015, 1978.

3. Badhwar, G.D.: Crop Emergence Date Determination from Spectral Data, Photogrammetric Engineering and Remote Sensing, vol. 46, no. 3, pp. 369-377, March 1980.

4. Bauer, M.E., et al.: Agricultural Scene Understanding and Supporting Field Research. Final Report, Contract NAS9-15466, Laboratory for Applications of Remote Sensing, Purdue Univ. (West Lafay Lafayette, Ind.), 1979.

5. Badhwar, G.D., K.E. Henderson, W.R. Johnson, and M.L. Sestak: Six Channel Thematic Mapper Simulation, SR-L1-04098, JSC-17139, 1981.

6. Thekaekara, M.P., et al.: The Solar Constant and the Solar Spectrum Measured from a Research Aircraft. NASA Technical Report R-351, Goddard Space Flight Center (Greenbelt, Md.), 1974.

7. Dave, J.V.: Extensive Data Sets of the Diffuse Radiation in Realistic Atmospheric Models with Aerosols and Common Absorbing Gases. Solar Energy, vol. 21, pp. 361-369, 1978.

Figure 1. Simulated thematic mapper (TM) scene of spring wheat segment; blue, green, and red = channels TM-2, -3, and -4.

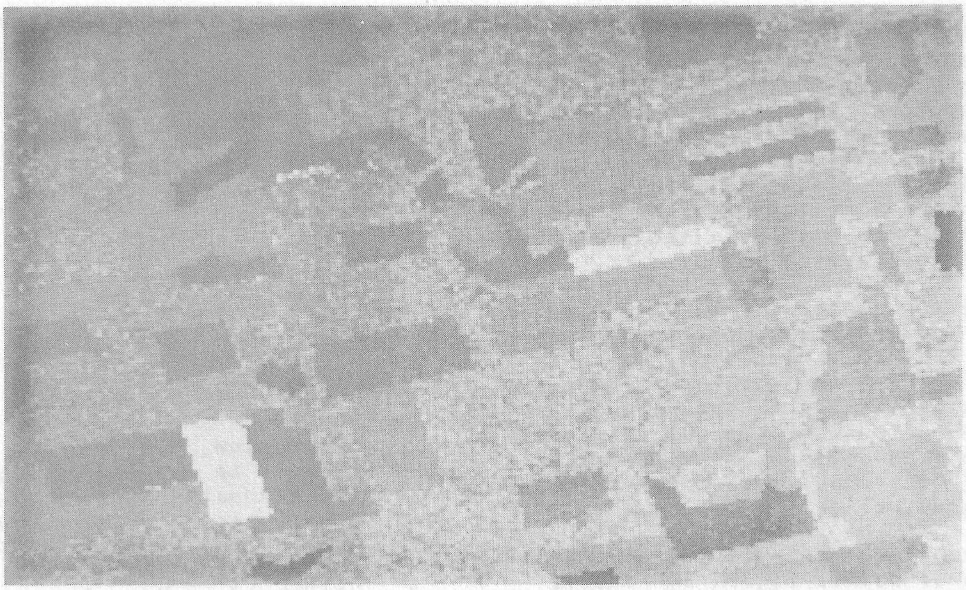


Figure 1 (concluded). Simulated MSS scene of spring wheat segment with Landsat resolution; blue, green, and red = channels TM-2, -3, and -4.

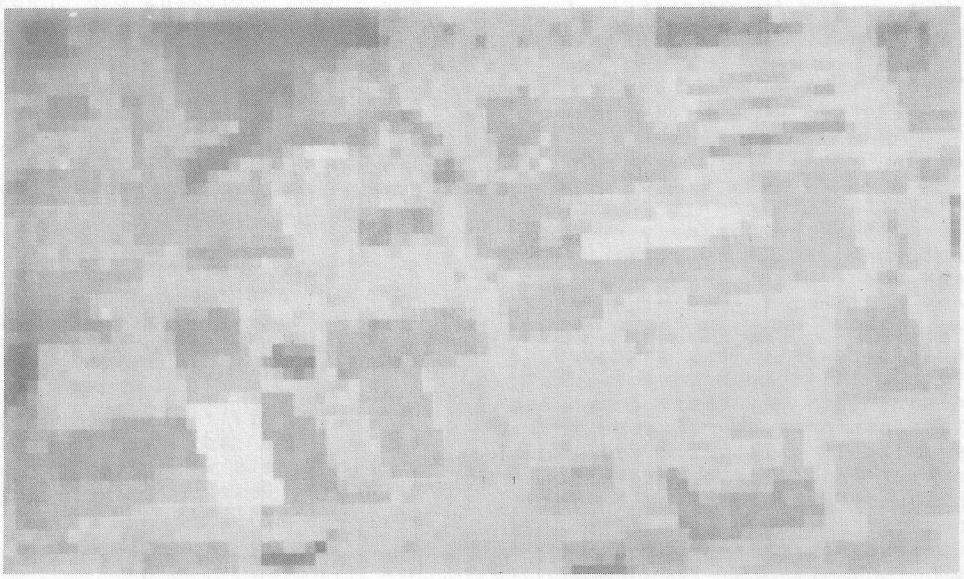


Figure 2. Simulated Landsat MSS Data* Kingsbury, South Dakota.

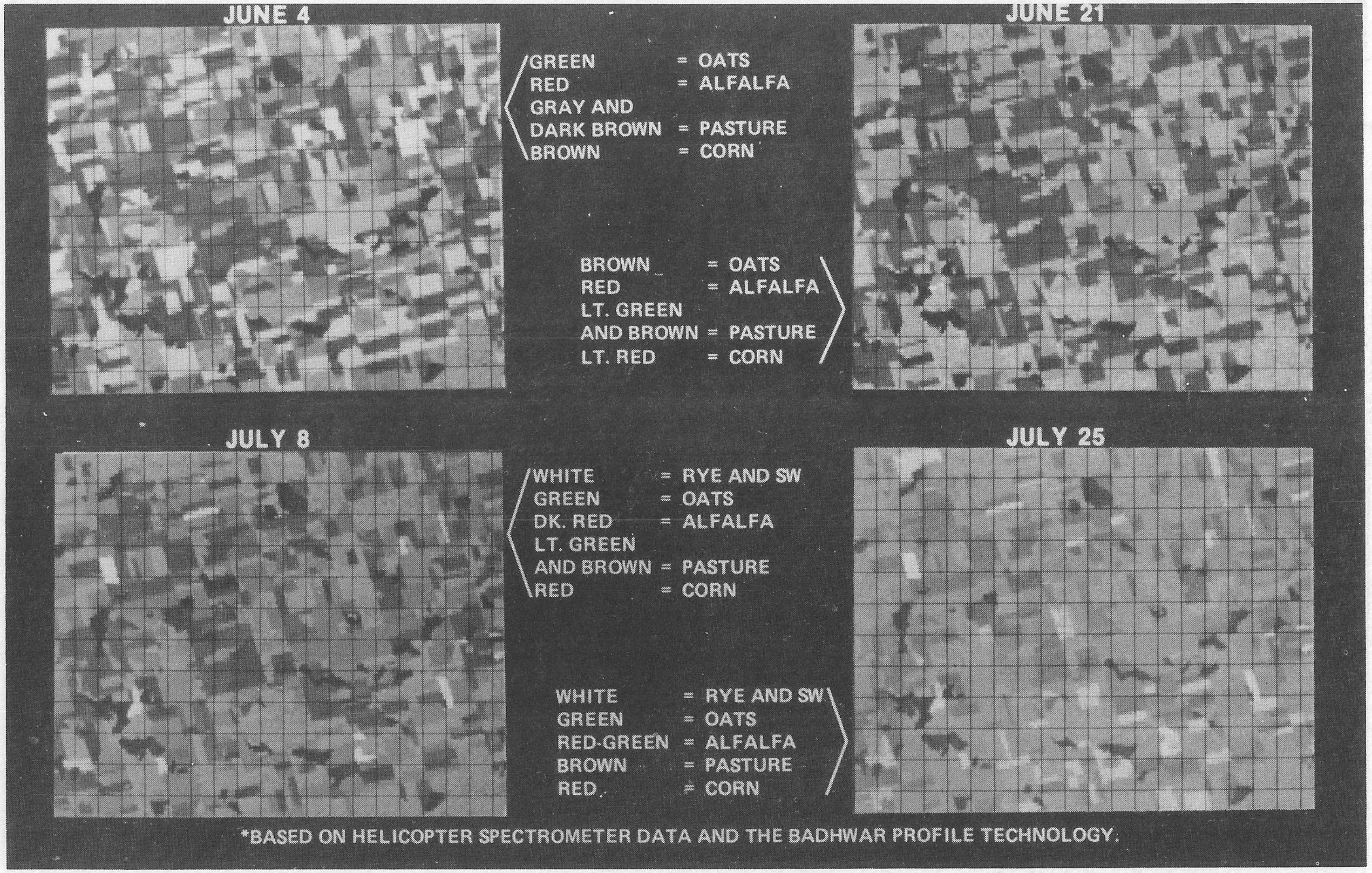
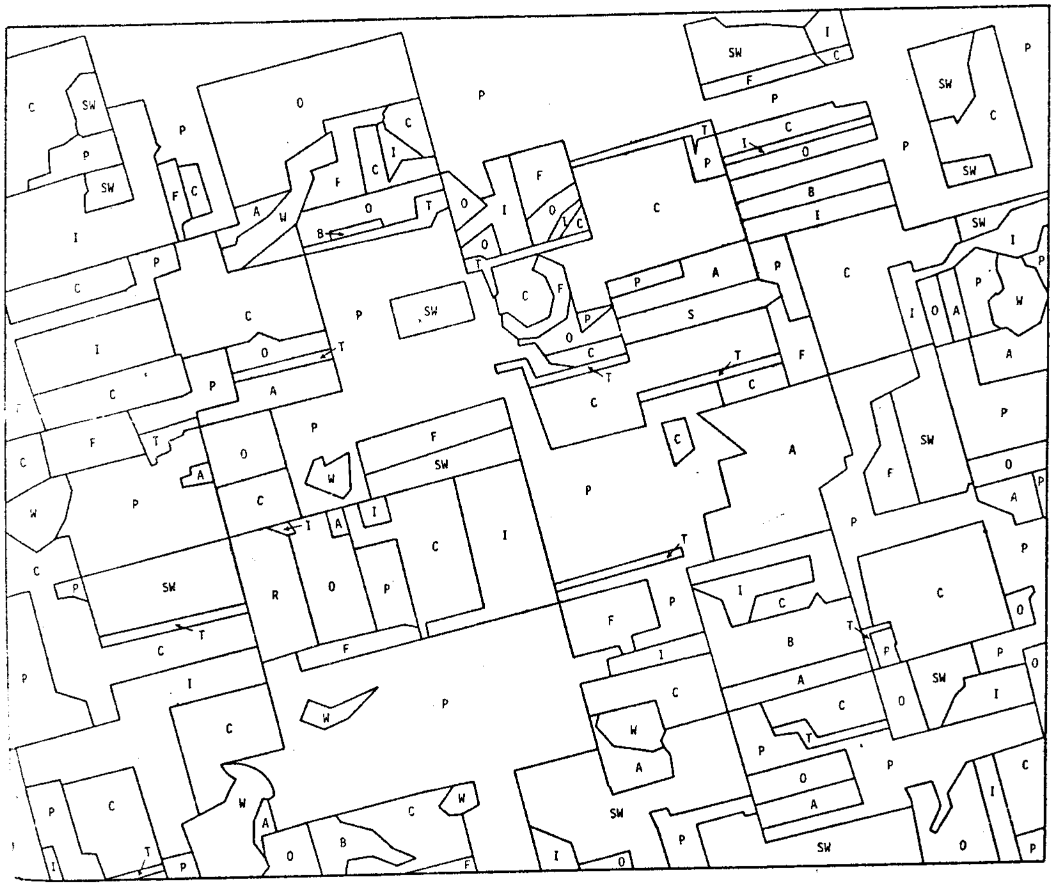


Figure 3. Ground truth map of simulated TM scene of one-quarter segment.



Legend

A Alfalfa
B Barley
C Corn
F Flax
I Idle fallow
O Oats
Pasture, grass, hay
P Noninventory, homestead
Nonagriculture
R Rye
S Sorghum
SW Spring wheat
T Trees
W Water

Figure 4. CLASSY cluster results for MSS of a selected area from Figure 1.

```
=======MMM=====@======<<<==
M=@==@===@=====<<<<<XXXXX@M
M====@===<<<<<XX<<XXXXXXX<M
@=M@@<<XXXXX<XXXXXXXXXXXX<=
AM===KXXX<XXXXXXXX<<XXXXX<K
+=====<XXXXXXXXXXXXXX<%VVVK
+A====<XXXXXXXXXX*H%%%$VVV:
+A=@@@=XXXXXXXX/AAHHVV$$*V:
+A<KKK=<XXXXXAASSSHH%:*++$*
++<H:V=<X<<XXASS//HH%VV+*VV
++$H%VK@XX<XX/SS<HHH%VK%%%X
++$H%VK=****-AS/HH<<XXXXX*/
+++<KKK==--XASS/XX<<XX<XX<%
/++*=KK*//ASSA/XX*/>>>>/%//
$AAKVVV/ASSA/--/*>////A====
==M=V::OSS/****KM=M@=M===M=
```

Legend for MSS clusters

<X	=	oats
M@	=	pasture
*-/	=	alfalfa
S	=	water
O:V	=	corn
$+	=	idle
/%>	=	trees (borders)
>	=	rye and sorghum
<HA	=	flax

Figure 5. CLASSY cluster results for TM of a selected area from Figure 1. (Same area on Figure 4.)

```
VKKK:KKKKVKV$///$$VK::KSVKV$K:K$K$SVKS$VKVSSKKVVKVKKV:VVS
KSVK:KSKVKSK///////VVKKVKK$VKKK$SKKKKKKKK$KVSKK@KV:KVKK$V
:VKV:V$KKKV$$//$///KKVV:KKKKSKK$KVKKKK:KKVK@@@@KVKKKSK$V
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KKKK=V>%<>%%>-          EEEEEEE$:VMMMMMMMKSS:SK$KV::VV=//=
KK:S//%%>% % >/          EEEEHEHEMMMMMK::KKK$KSSK$/=SKVK/$//
K$=//KK>%%>%>--        =EEEEEE==-/:/KVVVKK:/:K$K$K//==:SKSV/
```

Legend for TM clusters

@	=	oats
0	=	flax
blank	=	water
HE	=	alfalfa
=K:VK$/	=	pasture
+AH	=	idle
<%>	=	corn

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Keith E. Henderson, born 1939 in Yuma, Colorado. After graduating from local high school, attended Colorado State University (B.S.-1961 and M.S.-1963 in Agronomy) and University of Arizona (Ph.D.-1969 in Crop Science). Dr. Henderson has gained a broad experience in crop production and agricultural resource development through employment with Great Western Sugar Co. of Denver, Colorado (1969-1971), Ford Foundation (Saudi Arabia Agricultural Development Program (1971-1976) and the National Aeronautics and Space Administration LACIE and AgRISTARS programs (1976-present). Current work is with the AgRISTARS Supporting Research Project in the Earth Resources Research Division of NASA Johnson Space Center.

William R. Johnson received the B.S. degree in Mathematics and Meteorology from the University of Chicago in 1946, and the M.S. degree from Florida State University in 1961. He has had experience in meteorology and in the use of Landsat data in crop inventorying applications. He is currently employed by Lockheed Engineering and Management Services Company in Houston, Texas, where he has performed studies of atmospheric aerosols on remotely sensed spectral data.

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Jess G. Carnes received the B.A. degree from Trinity University in 1966, and the Ph.D. degree in Physics from Rice University in 1971. Since 1971, he has been employed by Lockheed Engineering and Management Services Co. in Houston, Texas. From 1971 to 1974, he investigated the electrical and magnetic properties of returned lunar rock samples. From 1974 to 1977, he performed balloon-borne measurements of ozone in the stratosphere. Since 1977, he has been involved in the development and evaluation of remote sensing techniques for using Landsat data to inventory crops.

David E. Pitts was born in 1939 in Oklahoma City, Oklahoma. He attended the University of Oklahoma majoring in Engineering Physics (B.S.-1961, M.S.-1964). He joined the NASA Johnson Space Center in 1963 to design atmospheric density models of the planets for heatshield design for Gemini, Apollo, Skylab, and advanced manned planetary missions. He returned to the University of Oklahoma on a Sabbatical to complete a Doctorate of Engineering in Meteorology (1971). He has participated in the design and conduct of remote sensing experiment programs at NASA such as: Apollo 9, Skylab EREP, Landsat, LACIE, and various aircraft experiments. His current assignment is as the Head of the Radiation Characterization Section which is conducting research into remote sensing of crop identification, condition, and crop stage as part of the Supporting Research Project of AgRISTARS.