N O T I C E

NASA

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Space Administration

NOV 0 6 1980

JSC-16956

Lyndon B. Johnson Space Center
Houston, Texas 77058

E82-10133

NASA-CR-161051

EARTH OBSERVATIONS DIVISION

SPACE AND LIFE SCIENCES DIRECTORATE

SONORA EXPLORATORY STUDY FOR THE DETECTION OF WHEAT-LEAF RUST

(E82-10133) SONORA EXPLORATORY STUDY FOR THE DETECTION OF WHEAT-LEAF RUST (Lockheed Engineering and Management) 43 p HC A03/MF A01 CSCL 02C

N82-21661

Unclas
G3/43 00133

Prepared By

Lockheed Engineering and Management Services Company, Inc.
Houston, Texas

Contract NAS 9-15800

November 1980

LEMSCO-15604

1. Report No. JSC-16956	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Sonora Exploratory Study for the Detection of Wheat-Leaf Rust		5. Report Date November 1980
		6. Performing Organization Code
7. Author(s) R. W. Payne, Lockheed Engineering and Management Services Company, Inc.		8. Performing Organization Report No. LEMSCO-15604
9. Performing Organization Name and Address Lockheed Engineering and Management Services Company, Inc. 1830 NASA Road 1 Houston, Texas 77058		10. Work Unit No.
		11. Contract or Grant No. NAS 9-15800
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, Texas 77058 (Technical Monitor: R. A. Wright)		13. Type of Report and Period Covered Technical Report
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The study which is the subject of this report was conducted to explore the applicability of Landsat remote sensing technology to the detection of a wheat-leaf-rust epidemic in Sonora, Mexico, during 1977. Landsat data acquired during crop years 1975-76 and 1976-77 were clustered, classified, and analyzed in order to detect agricultural changes. The results indicate the presence of wheat-leaf rust during both crop years, with 1977 being the most severely affected. Additional analyses show a significant increase in fallowing during 1977, as well as a substantial decrease in reservoir levels in the Sonora agricultural region. Conclusions and recommendations resulting from the data processing and analyses are also provided in the report.

17. Key Words (Suggested by Author(s)) CIMMYT, ISOCLS clustering, Landsat, Leaf rust, Mexico, Remote Sensing, Wheat	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	43	

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA — JSC

JSC-16956

SONORA EXPLORATORY STUDY FOR THE DETECTION OF WHEAT-LEAF RUST

Job Order 86-902

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HOUSTON, TEXAS

November 1980

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PREFACE

The study which is the subject of this document was conducted in support of the Space and Life Sciences Directorate at the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center. Under Contract NAS 9-15800, personnel of Lockheed Engineering and Management Services Company, Inc., performed the tasks which contributed to the completion of this research.

The following scientists and other personnel assisted in conducting the research and compiling this report. L. R. Hall and R. E. Hinkle of Lockheed Engineering and Management Services Company, Inc., provided assistance in the data-processing phases. R. B. MacDonald of the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, provided technical consultation and reviews.

Lockheed provided, without cost, its Remote Sensing Applications Laboratory, located in Houston, for data processing.

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ABBREVIATIONS

CCT	computer-compatible tape
CIMMYT	International Center for the Improvement of Maize and Wheat
CRT	cathode-ray tube
EROS	Earth Resources Observation Systems
ISOCLS	Iterative Self-Organizing Clustering System
MSS	multispectral scanner
pixel	picture element
RSAL	Remote Sensing Applications Laboratory
USDA	U.S. Department of Agriculture

1. SUMMARY

The study which is the subject of this report was conducted to explore the applicability of Landsat remote sensing technology to the detection of wheat-leaf rust in Sonora, Mexico. As a result of this study, further discussions with scientists of the International Center for the Improvement of Maize and Wheat (CIMMYT) regarding this problem should prove productive.

Sonora is Mexico's largest wheat-producing state; and its wheat region, which is located near Ciudad Obregón, is often referred to as the "Valley of Wheat." Landsat data covering the Valley of Wheat during crop years 1975-76 and 1976-77 were processed and clustered, hardcopy maps were produced, and a limited data analysis study was conducted in order to identify stressed wheat. Crop year 1976-77 was severely affected by an epidemic of wheat-leaf rust, and it was believed that optimal detection of the affected wheat was during the 1977 jointing stage (March time frame).

Landsat data acquired during March 1976 and March 1977 were processed, clustered, and initially analyzed using Lockheed's Remote Sensing Applications Laboratory (RSAL). The Landsat multispectral scanner (MSS) data and the RSAL cluster and classification results were converted into hardcopy color maps. These map products were further analyzed using additional Landsat imagery and cluster results (cluster means) obtained during the data-processing phases.

Analysis of the 1977 Landsat processing results (image maps, cluster maps, and cluster means) indicated the presence of potentially stressed vegetation (i.e., rust-infected wheat). Clusters containing stressed vegetation account for 45.6 percent of all vegetation classified as wheat using the 1977 data. This was significantly greater than the 13.2 percent classified using the 1976 data. The greatest concentration of wheat classified as being stressed with wheat-leaf rust using the 1977 data was centered near Huatabampo, Sonora, which was the early center of the epidemic of wheat-leaf rust.

Analysis revealed a significant increase in fallow fields in the Sonora agricultural region from March 1976 to March 1977. Fallow fields increased from approximately 2 percent of the cropland in 1976 to approximately 25 percent in 1977. Analysis of the data also indicated a reduction in wheat area of 52 461 hectares (129 635 acres) between 1976 and 1977.

Landsat full-frame analysis revealed that the two major reservoirs serving the Valley of Wheat were extremely low in 1977 when compared to water levels detected in 1973 Landsat imagery. Based on this information, it was hypothesized that the reduction in reservoir irrigation waters and the issues of land tenure disrupted the wheat and summer crop (cotton and soybean) plantings for the 1976-77 crop cycle, resulting in an increase of fallow (unplanted) fields of 52 461 hectares (129 635 acres). A literature search of the U.S. Department of Agriculture (USDA) Foreign Agriculture periodicals for the years 1975-80 provided information to substantiate these conclusions (refs. 1-3).

If follow-on studies are to be conducted, it is recommended that (1) additional Landsat data covering the 1975-76 and 1976-77 growing cycles be collected, (2) improved crop calendars be obtained, (3) some of the newly developed classification techniques be utilized, and (4) Sonora ground-observations data collected by CIMMYT personnel be obtained for additional analysis.

2. INTRODUCTION AND OBJECTIVES

The wheat-growing region in the State of Sonora, Mexico, was severely affected by an epidemic of wheat-leaf rust during crop year 1976-77. The wheat-leaf rust, which is caused by a fungus (*Puccinia recondita*), significantly reduced the state's wheat production.

Sonora is Mexico's largest wheat-producing state; and its wheat region, which is located near Ciudad Obregón, is often referred to as the "Valley of Wheat."

CIMMYT informed the National Aeronautics and Space Administration (NASA), Lyndon B. Johnson Space Center (JSC), that the early center of the wheat-leaf-rust epidemic was at Huatabampo, Sonora, in February 1977. This town is situated to the southeast of Ciudad Obregón in the Valley of Wheat. The wheat-leaf rust then spread from Huatabampo into the Ciudad Obregón area. By March when wheat was in the jointing stage, the wheat-leaf rust had affected almost all areas in the valley. During the March time frame, the rust was clearly visible and had reached a maximum in terms of external plant appearance.

Apart from the problem of wheat-leaf rust, it was believed that issues of land tenure (property ownership) in Sonora had impacted the 1976-77 crop production cycle. Large commercial farms were occupied by farm laborers during 1976; and late in 1976, the Mexican Government declared that ownership of nearly 100 000 hectares (247 105 acres) in Sonora was illegal. The property rights against some of this land remain in dispute, and the resolution of the issue is contingent upon the decision of the Mexican Supreme Court.

An additional and important factor that affected crop production in Sonora was a drought which began in 1975. Image analysis revealed that the water levels in local reservoirs were extremely low in 1977 when compared to the 1973 levels. Information from the USDA Foreign Agriculture periodicals showed that reduced reservoir levels impacted crop plantings in the 1976-77 crop year.

In response to CIMMYT's interest in the application of remotely sensed Landsat data to agricultural problems, the NASA/JSC Space and Life Sciences Directorate initiated a project to explore the use of recently developed aerospace remote sensing technology to the specific problem of detecting wheat-leaf rust.

The objective of the project was to explore the applicability of machine-classified Landsat data to the detection of wheat-leaf rust. The specific objectives of the study were as follows:

a. To cluster and classify Landsat data acquired over Sonora during March 1977 and March 1976

b. To produce hardcopy products from the Landsat MSS data (Landsat image map) and the classified data (cluster map)

c. To perform a limited comparative analysis of the Landsat image maps and cluster maps

3. SONORA STUDY AREA

The Sonora exploratory study site was limited to an area of approximately 7770 square kilometers (3000 square miles) in the Valley of Wheat near Ciudad Obregón, Sonora (fig. 3-1). This represents approximately 9C percent of the agricultural land in the Valley of Wheat. The remaining 10 percent of the agricultural land is located within an adjacent Landsat footprint (37-41). A computer-compatible tape (CCT) set for this footprint was on order from the Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, but was unavailable at the time data processing and analysis were conducted.

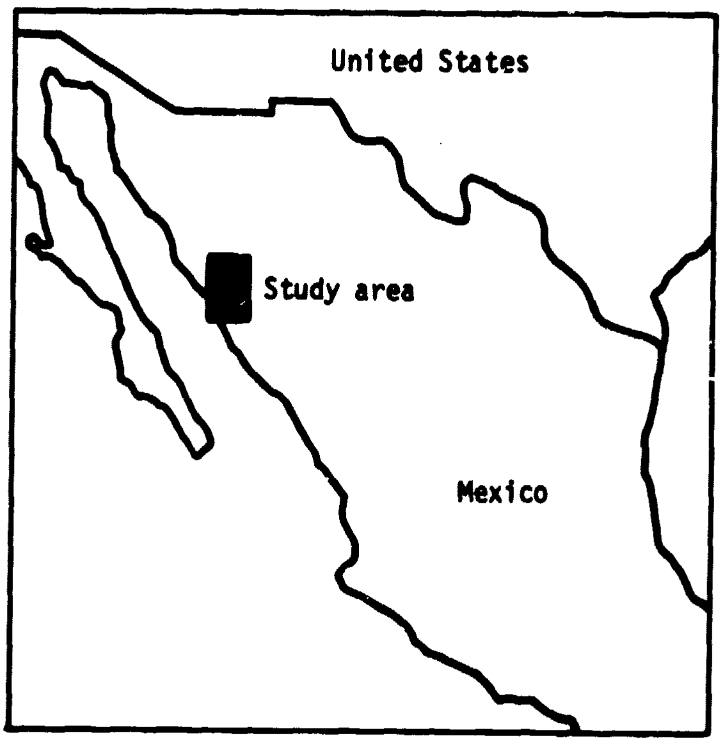

Figure 3-1.- Sonora, Mexico, study area location.

4. SONORA AGRICULTURAL REGION

The Sonora agricultural region is based, largely, upon an irrigated multiple-cropping system which produces a variety of fields crops (e.g., wheat, soybeans, and cotton), vegetables, and fruits.

Sonora is the largest wheat-producing state in Mexico. The majority of Sonora's wheat and other agricultural crops are grown on the southern coastal plain. The northern extent of the agricultural region is near Hermosillo and ranges south along the Gulf of California to the State of Sinaloa.

The coastal plain, which is generally warm and dry, is in year-round production of irrigated crops such as wheat and soybeans. Yields per planted unit rank among the highest in the world. Wheat has typically been produced by the more progressive farmers during the cool, dry winter months when water for irrigation is available (ref. 4). The source of water is runoff from the coastal Sierria Madre highlands during the July-October time period. The water is stored in large reservoirs near Ciudad Obregón.

The study site selected for this demonstration of Landsat remote sensing technology is situated near Ciudad Obregón. This area represents Mexico's major wheat region and is often referred to as the Valley of Wheat.

The principal crops grown in Sonora are wheat, soybeans, safflower, cotton, sorghum, sesame, alfalfa, and flax. Summer crops such as cotton and soybeans are doubled-cropped with wheat.

Cotton and soybean production in Sonora has varied greatly because of world cotton prices and government price supports. When cotton prices are depressed, the farmers have turned to soybeans. In 1977, the cotton area was supposed to increase in response to (1) higher world prices and (2) an expected decrease in soybean plantings because of reduced irrigation waters. Cotton can replace soybeans since its water requirements are less, thus requiring less irrigation.

5. WHEAT-LEAF RUST

Wheat-leaf rust is caused by a fungus (*Puccinia recondita*) which is found all over the world (ref. 5). The fungus attacks leaf blades and sheaths, resulting in orange or orange-brown pustules on the green leaves. At times, the fungus also affects the stem, glumes, and awns. The fungus depletes the plant's water and nutrients needed for development of the kernel. As a consequence, the plant transpires water at an accelerated rate, resulting in stress.

The red-spore stage, which is responsible for the plant damage, will result in fewer and lighter kernels. Yield losses from wheat-leaf rust may be 30 percent, but losses up to 94 percent have been reported for susceptible wheat varieties.

NASA/JSC was informed by CIMMYT that the use of March Landsat acquisitions would probably be most suitable for detecting rust-infected wheat.[1]

[1]Personal communication to R. B. MacDonald, NASA/JSC, from R. Glenn Anderson, director of the Wheat Program for CIMMYT, dated July 5, 1979.

6. DATA SET

The Landsat digital data used in the exploratory study consisted of data from 1976 and 1977. Eight CCT sets which cover four Landsat footprints were ordered for both 1976 and 1977. The EROS Data Center scene numbers and the acquisition dates for these data are as follows:

Landsat scene identification	Acquisition date	Landsat footprint
8532516444500	3/09/76	37-41
8242017021500	3/17/76	36-41
8278116555500	3/13/77	37-41
8278016501500	3/12/77	36-41
8292516483500	8/04/77	37-41
8292416425500	8/03/77	37-41
8539716395500	5/20/76	37-41
8260016570500	9/13/76	36-41

The March 17, 1976, and March 12, 1977, Landsat scenes were selected for computer-assisted clustering and classification. The remainder of the CCT's, along with five full-frame color composites from 1977 and a black-and-white band 5 image from 1976, were used to identify general land uses, wheat, and other agricultural crops.

The EROS Data Center scene numbers and the acquisition dates for the full-frame color composites are as follows:

Landsat scene identification	Acquisition date	Landsat footprint
8274516572500	2/05/77	37-41
8276216510500	2/22/77	36-41
8278016501500	3/12/77	36-41
8278116555500	3/13/77	37-41
8292516483500	8/04/77	37-41

In addition, the 1976 black-and-white image, dated September 13, along with the March 17, 1976, color Landsat image map, was used to identify specific agricultural crops (e.g., wheat). The EROS Data Center scene number for the 1976 black-and-white image is 8260016570500 (Landsat footprint 36-41).

Multitemporal coverage of the entire study area was available only for the sidelap area between the footprints 36-41 and 37-41. As a result, postharvest data were not available for the eastern portions of the study area. The effects from this are discussed in section 10, Data Analysis Results.

7. TECHNICAL APPROACH

The technical processing and analysis methodologies for this study are described in this section. A generalized flow diagram for the data processing and analysis functions is shown in figure 7-1.

7.1 REMOTE SENSING APPLICATIONS LABORATORY

The data-processing system used to cluster and classify the Landsat MSS data was the Lockheed RSAL. The system is a user-oriented digital image-processing system consisting of the Digital Equipment Corporation PDP 11/70 central processing unit, RP06 disk pack subsystem, TU45 magnetic tape subsystem, LA36 Decwriter II, CR11 card reader, VT52 cathode-ray tube (CRT) terminal, Model 4012 graphics terminal; a Floating Point Systems, Inc., AP-1208 array processor; and a COMTAL Corporation Vision One interactive image analysis system.

7.2 DATA PROCESSING

The image analysis and computer-aided classification techniques utilized to produce the digital Landsat image maps and cluster maps are described in the following sections.

7.2.1 INITIAL IMAGE ANALYSIS

The Landsat full-frame imagery of Sonora for 1973, which was available at the NASA/JSC Earth Observations Division, was analyzed in order to make a final selection of the exploratory study area. Analysis of the data revealed that the Valley of Wheat near Ciudad Obregón was covered in its entirety by two adjacent full frames (Landsat footprints 36-41 and 37-41). However, data availability constraints resulted in the selection of only Landsat data covering footprint 36-41 for the computer-aided clustering and classification process.

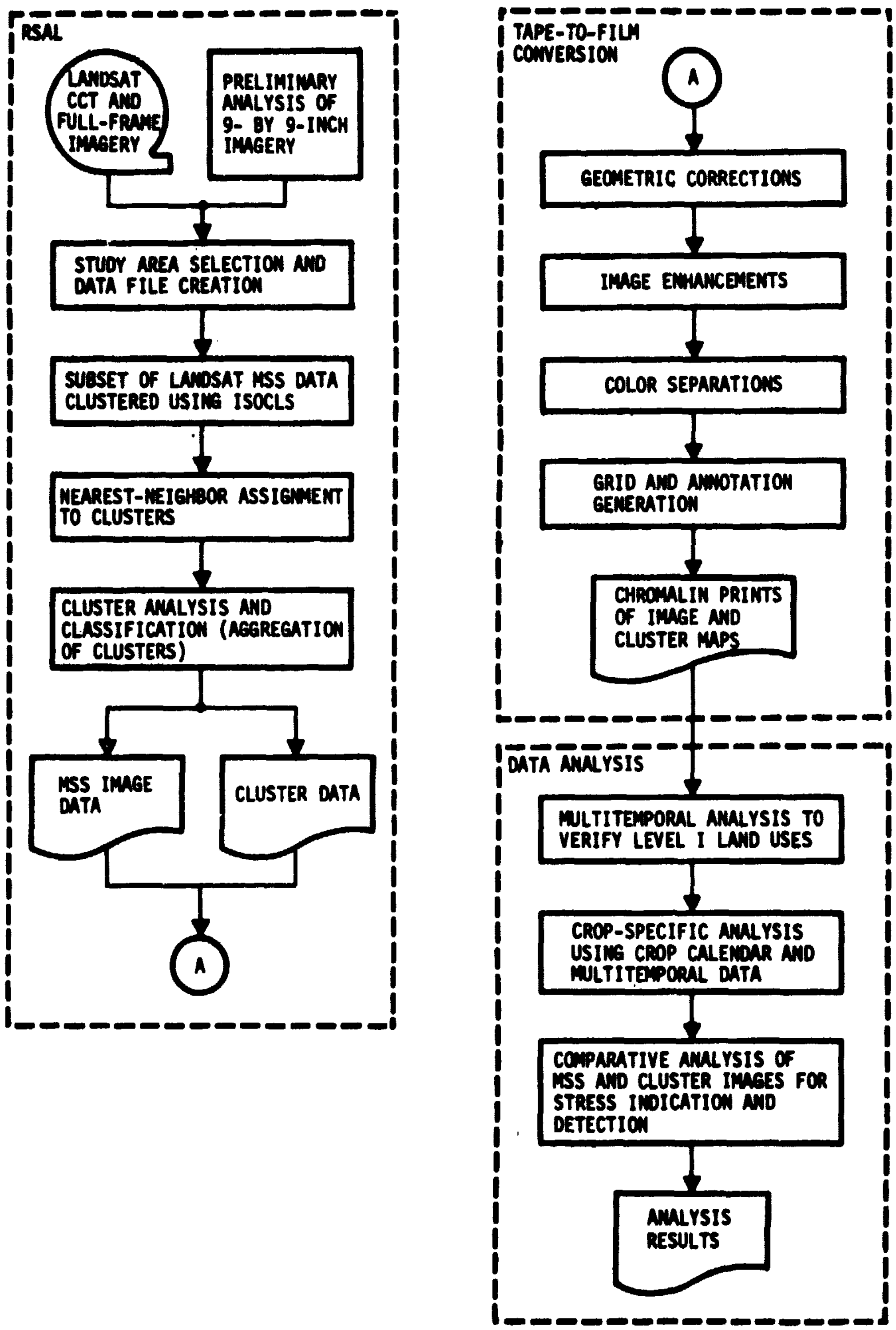

Figure 7-1.- Generalized technical processing and analysis flow.

7.2.2 COMPUTER-ASSISTED CLASSIFICATION

7.2.2.1 Data File Creation

The Landsat CCT sets were loaded, sampled, and displayed on the RSAL digital image display system. Data files were created from areas of approximately 1600 columns by 1600 scan lines from the March 12, 1977, and March 17, 1976, CCT's. These data were then used for detailed image analyses and for clustering and classification. This resulted in an image size of approximately 25 by 22 inches when displayed at a scale of 1:250 000 (the scale specified by the contract job order).

7.2.2.2 Clustering

For more efficient processing, the data sets were reduced by sampling the files for each Landsat subscene (March 1977 and March 1976). The data were clustered using the Iterative Self-Organizing Clustering System (ISOCLS) program. The RSAL ISOCLS algorithm included modifications to the original algorithm to reflect new requirements from a variety of users.

An initial unsupervised clustering of the 1976 data was conducted using an established maximum of 15 clusters; however, analysis of the results indicated that too many classes of land use were contained in each cluster. The clustering parameters were then set to generate a maximum of 60 clusters for each Landsat subscene using the unsupervised mode. Clustering of the March 12, 1977, data resulted in 43 clusters; the March 17, 1976, data clustered into 44 clusters.

Following the clustering of the two sampled subscene data files, the picture elements (pixels) which were not sampled and clustered were then assigned to the appropriate cluster via the nearest-neighbor criterion. The Landsat MSS image data and cluster results were then written into the local Universal format, which is compatible with the digital tape-to-film conversion system.

7.2.2.3 Manual Classification Technique

The clustering results for each crop year, 1976 and 1977, were analyzed using the RSAL image analysis station. Each cluster was merged (overlaid) onto the Landsat MSS color-composite image, and the land use or land uses contained within the clusters were determined. This procedure was used to analyze each cluster for both 1976 and 1977.

Clusters containing similar land uses were noted, and lists of the 1976 and 1977 clusters which should be aggregated and coded under a single category (e.g., water, woodland, grassland, and barren) were transmitted to Seiscom Delta Inc. (Houston) for conversion into color-coded cluster maps (see tables 7-1 and 7-2).

Agricultural (cropland) land uses, especially those having a vegetative cover, were coded separately. The data analysis was to concentrate on detection of rust-infected wheat, and any cropland cluster was a candidate for containing the stressed wheat. Consequently, cropland clusters were coded after the products were generated.

TABLE 7-1.- CLUSTER AGGREGATIONS FOR 1976 DATA

Cluster map number	Cluster name	Original cluster numbers
Noncropland clusters		
1	Water and shadows	8, 12, 29, 32, 39, 46
2	Barren land and urban	1, 9, 16, 19, 23, 25, 27, 35
3	Woodland	4, 14, 20
4	Desert shrub and fallow	10, 31
5	Grassland	5, 13, 30, 34, 37, 38
6	Roads and border pixels	2, 17, 21, 22, 26, 33, 36, 41, 42, 45, 47
Cropland clusters		
7	Wheat	3
8	Wheat	6
9	Wheat	7
10	Wheat and alfalfa	11
11	Wheat	15
12	Wheat and alfalfa	18
13	Wheat	24
14	Wheat borders and roads[a]	28
15	Wheat	40
16	Wheat	43
17	Wheat borders	44

[a]Cropland and noncropland spectral confusion.

TABLE 7-2.- CLUSTER AGGREGATIONS FOR 1977 DATA

Cluster map number	Cluster name	Original cluster numbers
Noncropland clusters		
1	Water and shadows	4, 8, 12, 41
2	Barren land	1, 5, 24, 29, 36, 39
3	Woodland	6, 34
4	Desert shrub and fallow	10, 22, 33
5	Grassland and fallow	9, 18, 23, 31
6	Roads, border pixels, and streams	20, 21, 27, 32, 35, 37, 38, 44
Cropland clusters		
7	Fallow, grassland, and shrub[a]	2, 13, 14, 26, 28
8	Wheat	3
9	Fallow and residue	5
10	Wheat	7
11	Alfalfa and wheat	11
12	Alfalfa	16
13	Wheat	19
14	Cropland borders	25
15	Wheat and alfalfa	30
16	Wheat and unknown spring crop (late wheat)	40
17	Cropland borders	42
18	Wheat and alfalfa	43

[a]Cropland and noncropland spectral confusion.

8. OUTPUT PRODUCTS

A description of the map products and the techniques used to generate the final products are presented in this section. In addition, the output from the RSAL processing is discussed.

The Sonora Landsat digital data, both MSS and cluster, were converted from the digital tape format into final map products by Seiscom Delta Inc. A functional flow of the Seiscom tape-to-film conversion system is shown in figure 8-1.[2]

8.1 LANDSAT IMAGE MAP

The Landsat image maps for 1976 and 1977 were generated using MSS bands 4 (visible green), 5 (visible red), and 6 (near infrared). Bands 4, 5, and 6 were assigned blue, green, and red, respectively, in order to simulate false-color-infrared imagery.

Band 7, which is normally used to produce color composites, exhibited excessive data dropouts when viewed on the RSAL CRT terminal. Band 6 did not have data dropouts; therefore, it was selected over band 7.

Five copies each of the Landsat image maps for 1976 and 1977 were produced at the scale of 1:250 000 (with a true-north orientation of the image). The requirements of the contract job order were exceeded by providing the following additional map annotations: bar scale, latitude-longitude grid, locator map, and north arrow.

Seiscom converted the data from Universal format to integer format and applied geometric corrections (pixel deskewing and pixel squaring) to each Landsat subscene image file. Because of orbital track and satellite attitude differences between the 1976 and 1977 full frames, the geographic positions of many ground features were significantly different with respect to the latitude-longitude

[2]Tape-to-Film Conversion System, personal communication with Brian T. Fine, marketing manager, Seiscom Delta Inc.

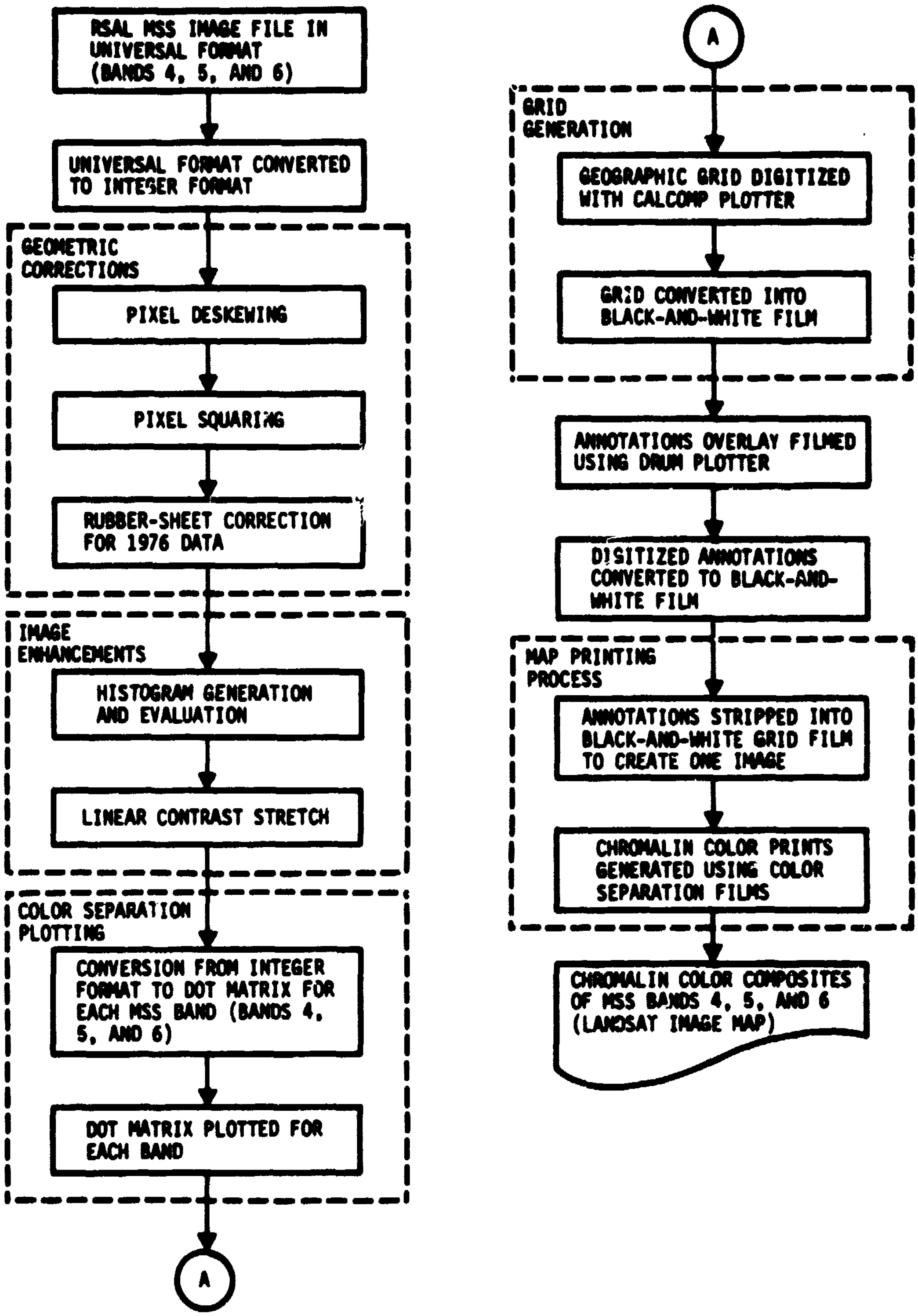

Figure 8-1.- Detailed color composite tape-to-film conversion flow.

grid. Lockheed requested that Seiscom apply a rubber-sheet correction to the 1976 data in order to provide a better fit between the two Landsat images and the grid.

Spectral image enhancements, which include histogram evaluations and linear contrast stretching, were applied in order to optimize the vegetation signatures.

The enhanced integer format data were converted into a dot matrix and filmed using a laser drum plotter. Color separations for each spectral band were produced for the 1976 and 1977 Landsat images.

The latitude-longitude grid was generated with a Calcomp plotter and converted into a black-and-white separation (with the grid lines displayed in black). The map annotations (e.g., name, date, bands, and north arrow) were filmed using the drum plotter and spliced into the grid overlay separation. This formed a single black-and-white separation which was added to the color separations to produce the final Landsat image map.

8.2 CLUSTER MAP

The clustered data were converted from the digital format into cluster maps using a procedure similar to that used to generate the Landsat image maps. The primary difference in the production of the cluster maps is that the clusters are contained in a single band (i.e., each cluster is assigned to a digital value ranging from 0 to 256); therefore, each cluster corresponds to a film density with a unique color assigned to each density level.

The cluster maps were scaled to the Landsat image maps and given the same annotations with one exception; i.e., the cluster maps have color-coded chips along the right margin which correspond to the data clusters displayed on the map.

Five copies each of the two cluster maps (1976 and 1977) were generated.

8.3 CLUSTERING TABULATIONS

In addition to producing the required map products, tabulations of the clustering results (mean, standard deviations, distance between clusters, cluster populations, and clustering results after each ISOCLS iteration) were generated using the Lockheed RSAL.

9. DATA ANALYSIS TECHNIQUES

Multitemporal image analysis techniques were utilized to identify the land uses. The Landsat full-frame imagery available for analysis is presented in section 6, Data Set. Historical crop calendars of state-level planting and harvesting seasons (ref. 6) were used to identify specific crops or crop classes (i.e., summer crops). The study area is located in southern Sonora near the border of the State of Sinaloa; consequently, an interpolative crop calendar was developed for this transition area between the two states. The Sonora crop calendars are shown in figure 9-1.

Analysis constraints included the lack of detailed historical crop calendars, insufficient Landsat data (i.e., no wheat planting or harvesting data), and no ground-observations data from previous years.

Cluster analysis of the 1976 and 1977 cluster maps was conducted using (1) the comparative image analysis technique, whereby each cluster was compared to the corresponding areas in the 1:250 000 Landsat image map and the Landsat full-frame imagery, and (2) results from an evaluation of each Landsat spectral band cluster means, standard deviations for each band, and distances between clusters.

The imagery and cluster means were analyzed with the expectation that jointed rust-infected wheat, if detectable, would exhibit a stressed signature. Stressed vegetation usually has a less vigorous signature in the near-infrared region than does healthy vegetation.

A plot of spring wheat during the jointing and ripening stages is shown in figure 9-2. The figure illustrates that stressed wheat, which in this case is ripe (senescence) wheat, can be expected to have reduced reflectance and emittance in the near-infrared bands (bands 6 and 7).

Therefore, analysis for the identification of stressed wheat was conducted with the premise that a reduced color-infrared response or low cluster mean

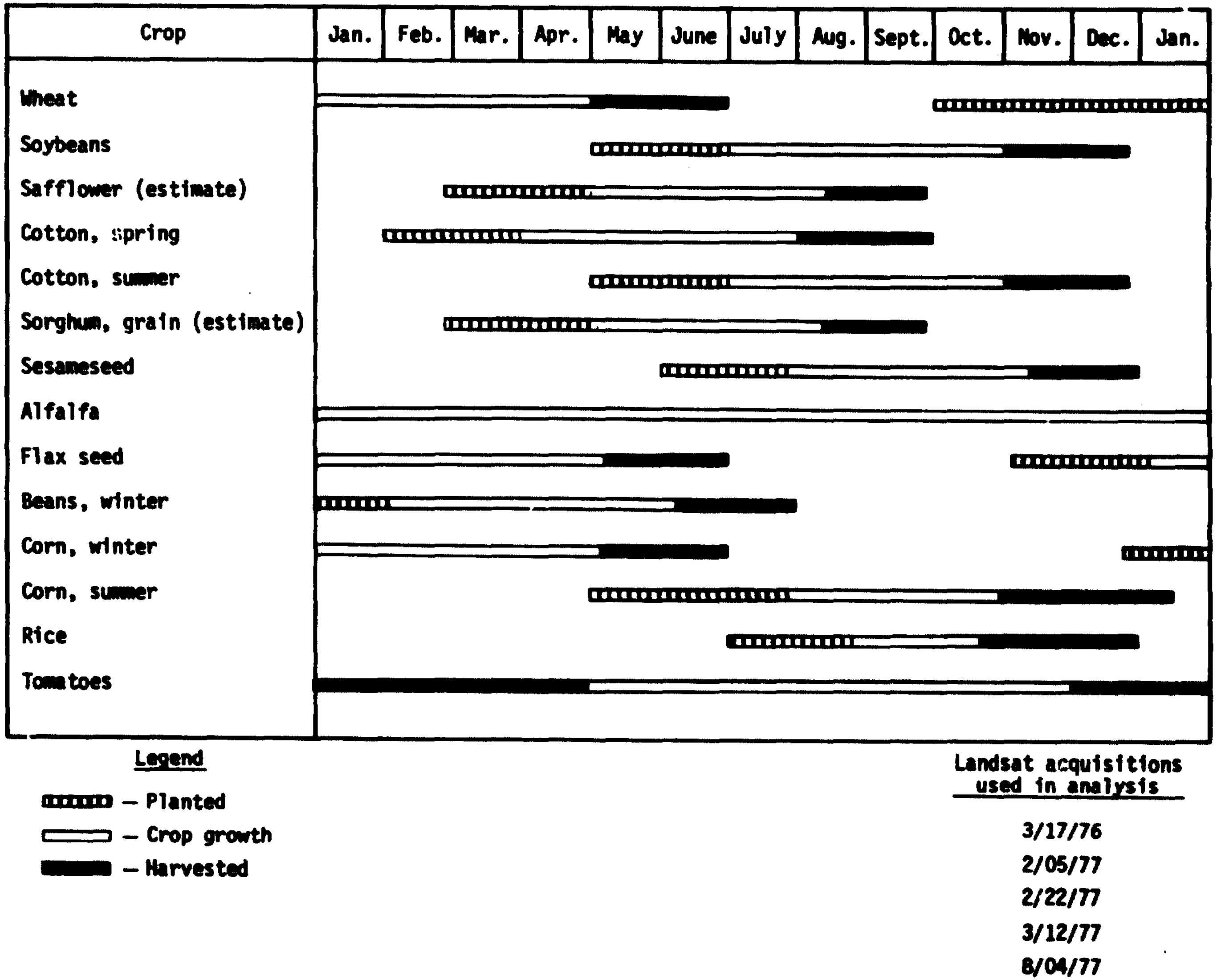

Figure 9-1.- Historical crop calendars for Sonora.

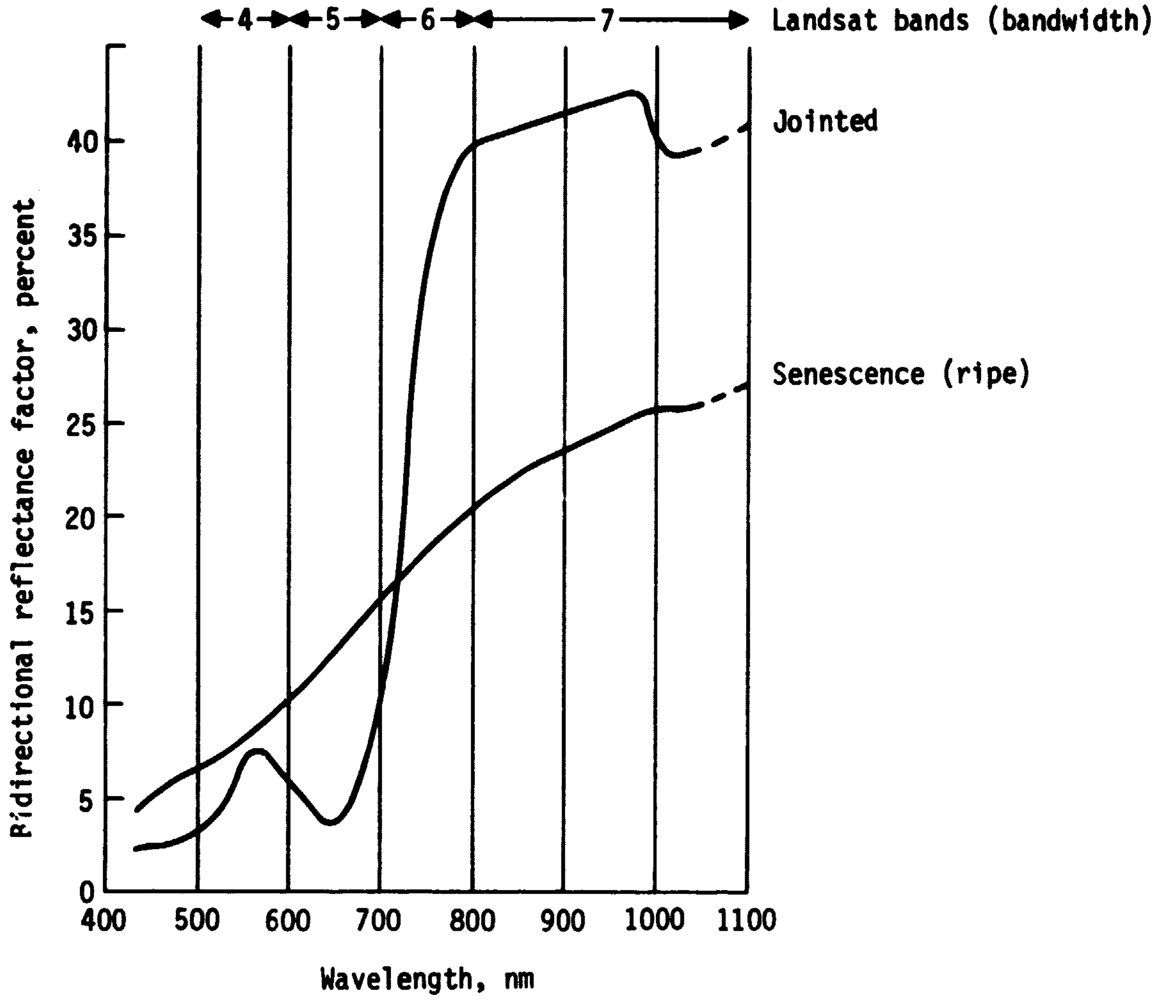

Figure 9-2.- Reflectance of spring wheat at different maturity stages for Williams County, South Dakota, in 1975.

for bands 6 and 7 during the jointing stage would be an indication of rust-infected wheat. Reduced color-infrared response in this context can be roughly equated to the lower response exhibited by the ripened spring wheat shown in figure 9-2.

10. DATA ANALYSIS RESULTS

The imagery and cluster analysis results are presented in this section, along with observations regarding the spectral data behavior, agricultural cropping practices, and additional factors which may have affected cropping practices in 1976 and 1977.

10.1 IDENTIFICATION OF CROPS

The crop identification methodology (decision logic) is presented in this section. The methodology for 1977 is discussed first, followed by a discussion of the 1976 crop identification techniques.

10.1.1 ANALYSIS OF 1977 DATA

Agricultural fields (clusters) containing a vegetative cover in February and March with an absence of a vegetative cover (postharvest) in August were identified as wheat. For a comparison of crop calendars and acquisitions, see figure 9-1. Some agricultural fields contained a ground cover in February, March, and August and are potentially either wheat double-cropped with a summer crop or alfalfa (permanent vegetative cover). The uncertainty regarding the label for these fields is due to the unavailability of Landsat data for the May-June time frame when wheat is usually harvested; therefore, the clusters with ground-cover signatures on all three acquisitions could be labeled as either of the above. However, it is believed that these fields are most likely alfalfa since it is a significant crop in Sonora (20 000 hectares, 49 421 acres, in 1975).

One cluster contained fields which were nonvegetated in February, were vegetated in March, and were again nonvegetated in August. These fields were labeled as a spring crop (potentially either wheat, safflower, or sorghum).

Fields without a vegetative cover on all three acquisitions were labeled as fallow, although the possibility exists that a summer crop may have been sown following the wheat harvest in May or June and harvested prior to the August acquisition.

It should be noted that a single acquisition (March 12) was clustered and classified; therefore, clusters are mixed (i.e., contain more than one crop), as indicated in tables 7-1 and 7-2.

10.1.2 ANALYSIS OF 1976 DATA

The available Landsat acquisitions for 1976 which were used in the analysis were acquired on March 9, March 17, and September 13. The March 17 acquisition was used for the clustering and classification. A field with a vegetative cover during March and an absence of a ground cover in September was interpreted to be wheat, since it is the predominant crop.

Clusters which contained fields labeled as alfalfa using the 1977 data were also labeled as alfalfa (wheat plus alfalfa) using the 1976 data. (Alfalfa is a perennial crop and may remain in the same field as long as 7 years.) As indicated above, this resulted in mixed clusters of wheat and alfalfa. Again, it should be noted that the alfalfa interpretation may be in error, but it is believed that this is the most likely label. The September 13 acquisition (black-and-white full-frame image) was somewhat useful in determining if a ground cover was still present in September.

10.2 IDENTIFICATION OF WHEAT-LEAF RUST

The image analysis criterion for identifying stressed vegetation is the low color-infrared response. Both the 1976 and 1977 imagery exhibited signatures which it is believed fit this criterion. These less-than-vigorous (stressed) color-infrared signatures are dark reddish brown and light red in color.

Two 1976 wheat clusters (8 and 13) and three 1977 wheat clusters (10, 13, and 16) have been interpreted as containing stressed signatures. The 1977 stressed clusters probably contain the rust-infected wheat. The 1976 stressed clusters may be due to either wheat-leaf rust, a disease similar to leaf rust, or healthy crops with reduced infrared reflectance and emittance characteristics.

Wheat cluster means for each 1976 and 1977 Landsat MSS band were analyzed, and the results are shown in figures 10-1 and 10-2.[3] It should be noted that the clusters identified as containing the stressed-wheat signatures have the lowest cluster means in the near-infrared bands (6 and 7). Also, it is interesting to note that the threshold for image interpreted vigorous (healthy) wheat is at approximately digital value 50 or less in band 7 for both crop years. The cluster means for noncropland are shown in figure 10-3 for comparison purposes.

The clusters identified as containing stressed vegetation (potentially rust-infected wheat) in 1977 account for 45.6 percent of the total clusters identified as wheat (or predominately wheat). For 1976, the stressed clusters account for a significantly lower proportion (only 13.2 percent) of the total wheat clusters. (Tables 10-1 and 10-2 contain the wheat cluster populations used to calculate these proportions.)

The greatest concentration of wheat classified as being stressed with wheat-leaf rust using the 1977 data was centered near Huatabampo, Sonora, which was the early center of the epidemic of wheat-leaf rust.

10.3 INCREASE IN FALLOW FIELDS

A significant increase in the number of fallow fields from 1976 to 1977 was observed. In March 1976, approximately 2 percent of the cropland was in fallow; however, in March 1977, approximately 25 percent of the cropland was in fallow.

10.4 REDUCTION IN PLANTED WHEAT AREA

The area classified as wheat (including potential alfalfa area) in 1976 within the study area was 208 714 hectares (515 745 acres). The area sown to wheat in 1977 was 156 253 hectares (386 110 acres), a reduction of 52 461 hectares (129 635 acres). Again, the wheat area includes potential alfalfa confusion area.

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[3] The digital values for band 7 (near infrared) were doubled in order to compensate for data compression which occurs during Landsat telemetry.

TABLE 10-1.- WHEAT CLUSTER POPULATIONS FOR 1976 DATA

Cluster	Crop	Total pixels in each cluster	Pixels in stress clusters
7	Wheat	6 525	
8	Wheat	22 146	22 146
9	Wheat	12 429	
10	Wheat and alfalfa	114 800	
11	Wheat	66 054	
12	Wheat and alfalfa	84 140	
13	Wheat and a summer crop	40 402	40 402
14	Wheat, roads, and wheat borders	17 880	
15	Wheat	36 355	
16	Wheat	45 746	
17	Wheat and wheat borders	26 693	
Total pixels		[a]473 170	[b]62 548

[a]Represents 208 714 hectares (515 745 acres).
[b]Represents 27 590 hectares (68 177 acres).

TABLE 10-2.- WHEAT CLUSTER POPULATIONS FOR 1977 DATA

Cluster	Crop	Total pixels in each cluster	Pixels in stress clusters
8	Wheat	10 714	
10	Wheat	43 180	43 180
11	Alfalfa and wheat	80 150	
13	Wheat	75 356	75 356
14	Borders with crop	18	
15	Wheat and alfalfa	65 185	
16	Wheat and a spring crop	42 994	42 994
17	Borders with crop	49	
18	Wheat and alfalfa	36 583	
Total pixels		[a]354 229	[b]161 530

[a]Represents 156 253 hectares (386 110 acres).

[b]Represents 71 252 hectares (176 068 acres).

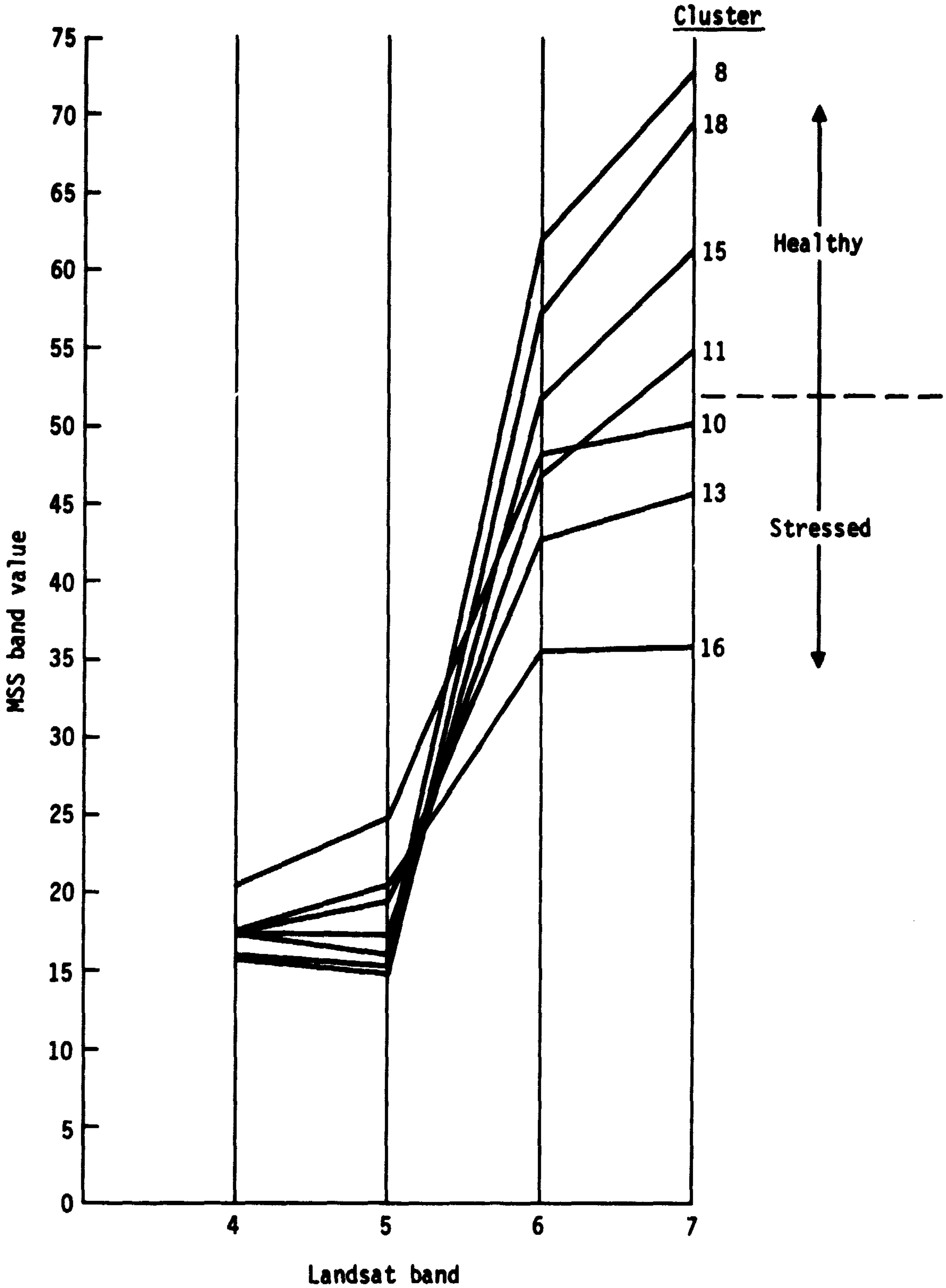

Figure 10-1.- Plot of 1977 wheat cluster means.

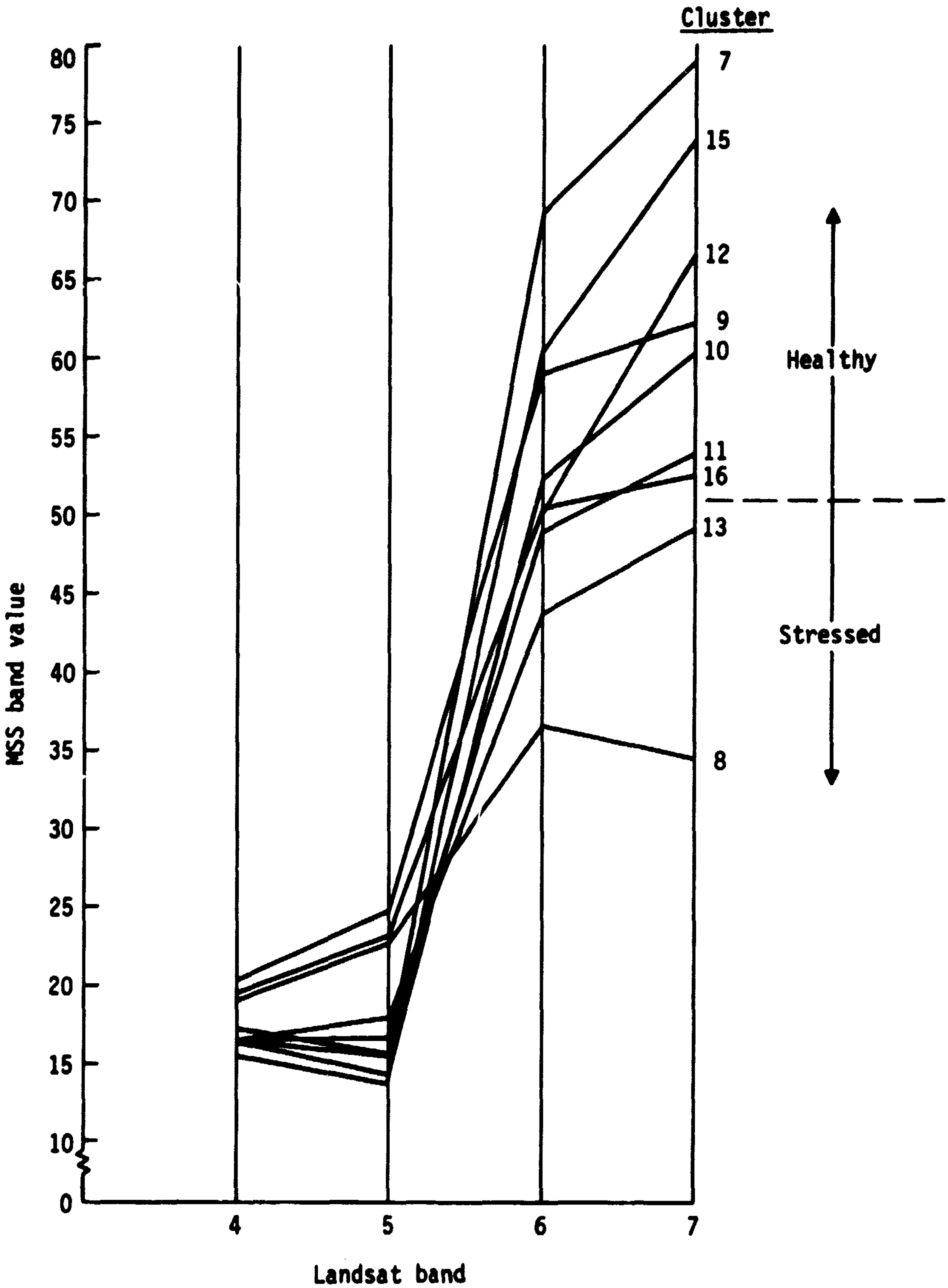

Figure 10-2.- Plot of 1976 wheat cluster means.

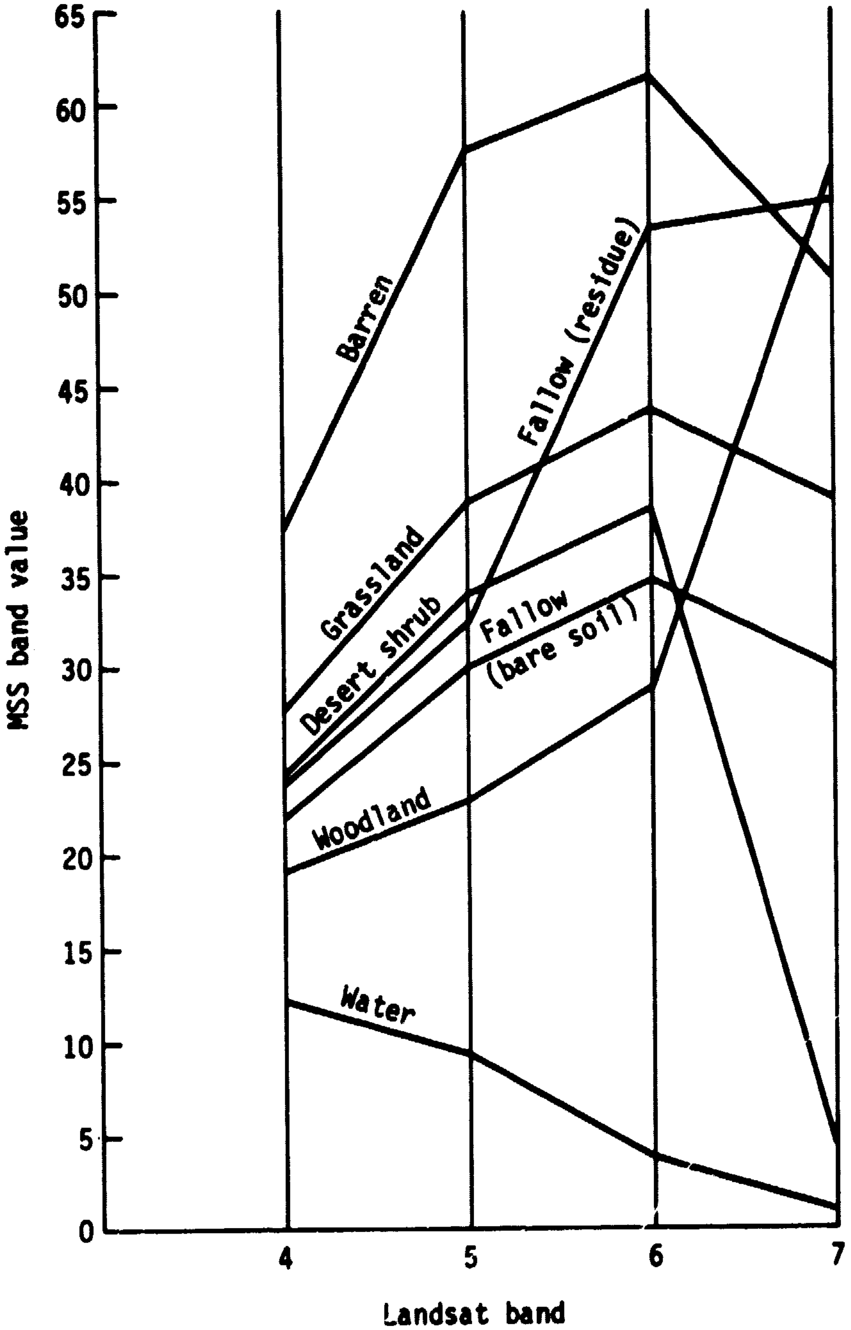

Figure 10-3.- Plot of 1977 noncropland cluster means.

10.5 REDUCTION IN RESERVOIR LEVELS

Analysis of Landsat full-frame imagery acquired during late 1976 and 1977 indicates reduced water levels in the reservoirs which provide irrigation water to the Valley of Wheat. The water levels in late 1977, especially, are significantly lower than the levels detectable in the 1973 Landsat imagery. The affected reservoirs are the Presa Alvara Obreyón, north of Ciudad Obregón, and Presa Macuzari, east of the Valley of Wheat.

11. CONCLUSIONS

Analysis of the 1977 Landsat data indicates that a significant proportion of the identified wheat is stressed (potentially rust-infected wheat). Additionally, a significant increase in fallow fields from 1976 to 1977 was detected. Initially, it was concluded that the fallow fields represented unplanted cropland. It was believed that this resulted from planting disruptions due to land occupation by the farm workers or that it was due to a shortage of reservoir irrigation waters. The net effect from the increased fallow fields is a reduction in harvested wheat area of 52 461 hectares (129 635 acres). Subsequent to the initial interpretation, a literature search of the USDA Foreign Agriculture periodicals for the years 1975-80 was conducted. Information from these periodicals has substantiated the conclusion regarding the effects from the Mexican land reformation action. It also substantiated the conclusion that the reduction in 1977 planted area was due, partially, to a lack of irrigation waters (low reservoir levels).

Ground observations will be required to substantiate these analyses and conjectures. The possibility exists that wheat-leaf rust is not Landsat detectable and that the clusters identified as containing stressed signatures represent different varieties of wheat or perhaps even nonwheat crops.

Analysis of the data was constrained by insufficient Landsat data for fall 1976 and summer 1977, incomplete historical crop calendars, and an absence of ground observations.

12. RECOMMENDATIONS

It is recommended that, if follow-on exploratory studies are conducted, a subset of the current study area be processed using more advanced classification techniques. This would permit clustering and analysis of multitemporal data, as opposed to the single-acquisition clustering used in this study. It is also recommended that NASA/JSC acquire additional Landsat CCT data for the 1975-76 and 1976-77 growing cycles. The Sonora ground-observations data collected by CIMMYT and improved crop calendars should also be acquired prior to performing follow-on studies.

13. REFERENCES

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