Progress Report - NASA Grant NAG13-38
December 15, 1996 - September 30, 1997

Overview:
The PI directed attention toward recruiting graduate students and establishing the proper baselines for the intended research. Five graduate students (2 Masters and 3 Ph.D.) are supported in part for their research work from this grant. Three have initiated their research by submitting research plans and the others will initiate their plans during the next funding period. The PI was on a Sabbatical Leave (October 1, 1996 to March 31, 1997) with Space Imaging Inc., Thornton, Colorado during the first part of this reporting period. Five publications have been accomplished during the current phase of the grant.

Objectives:

Objective 1
The primary agricultural objective of this research is to determine what soil and crop information can be verified from remotely sensed images during the growing season. Specifically:
   A. Elements of crop stress due to drought, weeds, disease and nutrient deficiencies will be documented with ground truth over specific agricultural sites.
   B. Use of remote sensing with GPS and GIS technologies for providing a safer and environmentally friendly application of fertilizers and chemicals will be documented.

Accomplishments
We succeeded in obtaining a HYDICE sensor flight and three Positive Systems flights over the Purdue Agronomy Research Center and the Davis Agronomy Research Center during this growing season. The HYDICE flight was obtained on August 7 under partly cloudy conditions while the Positive Systems flights were on August 8, September 5 and 26 under clear weather conditions. The data is being analyzed and prepared for presentation at the American Society of Agronomy meetings in October, 1997.

We have been cooperating with the National Agricultural Statistics Service, USDA who have obtained detailed yield data from one of the bulk Corn and one of the bulk soybean fields on the Davis Farm. We will share the remotely sensed data with them in exchange for the yield data obtained through ground test plots and from yield monitor data. Patrick Willis, MS student will be using this data as part of his thesis research.

We obtained data over one of the neighboring corn fields and saw some "circle-type of patterns within the corn. It was discovered to be Canada Thistle which is found in patches of 10-20 feet diameter across the field. Areas with the thistle greatly reduce the size of the corn by about 70%. Initial classification results show that one can map the Canada thistle patches across the entire field.

Bruce Erikson, Ph.D. graduate student has been simulating hail damage on corn plants at the Purdue Agronomy Research Center. He has used a "hailing" machine using ice as well as a "weed eater" to simulate hail damage. He has also accomplished stand reduction in corn from 0, 25, 50 and 75% reduction to determine the effectiveness of using remotely sensed scanner data to measure this reduction. Visual inspection of his plots in the preliminary data shows that one can see differences between the different treatments.

Objective 2
The primary natural resource objective will be to determine uses of vegetative categories of remotely sensed data for biodiversity, wildlife habitat, soil categories and carbon change relationships.

Accomplishments
Copies of sensor data obtained over the forest plots located at the Davis Research Center were provided to Dr. Guofan Shao, Purdue Department of Forestry and Natural Resources, who has been obtaining detailed site data of individual trees within the different tracks. The resolution of the data was 1 meter and 0.8 meters for the Positive Systems and the HYDICE data respectively. Dr. Shao is planning to develop a Masters Degree thesis for one of his students with the use of this data.

Data from the sensor flights are being utilized as part of a graduate level Agronomy course AGRY 545, "Remote Sensing of Natural Resources" for which the PI has major responsibilities. Students are using the data as part of their laboratory exercises to learn about the use of hyperspectral data. Additionally, Dr. David Landgrebe, School of Electrical and Computer Engineering is using the data in the laboratory portion of his course, E&CE 577, "Engineering Aspects of Remote Sensing".

Objective 3
Technology transfer functions such as the use that farmers, agricultural business, industry and organizations would make of the data/information in active management decisions will be documented.

Accomplishments
The following participation and/or presentations were given by the PI during this phase of the grant:

Jan. 10, "High Tech Agriculture," Westminster Rotary Club, Westminster, CO.

Jan 11, "Application of Remote Sensing to Precision Farming," CSU Ag Ext. Meeting, Colorado State University, Ft. Collins, CO

Jan 29, Session Chair and Organizer for Session A-8 Mission to Planet Earth: National and International Partnerships, Space Technology & Applications International Forum (STAIF-97), Albuquerque, NM.

Jan 29, Baumgardner, M.F., C.J. Johannsen, E. Dobos, L. Biehl, B Worstel, C.W. Ahn, I. Bayramin and T. Helt, "Providing soil spatial information for long term environmental monitoring and MTPE research projects," Mission to Planet Earth: National and International Partnerships, Space Technology & Applications International Forum (STAIF-97), Albuquerque, NM.

Jan 30, Organizer for Session A-9 Projects/Programs Relating to Mission to Planet Earth, Space Technology & Applications International Forum (STAIF-97), Albuquerque, NM.

Jan 30, C.J. Johannsen, A. Falconer, W. Wigton, "Information Requirements for Agriculture: The Next Decade," Projects/Programs Relating to MTPE, Space Technology & Applications International Forum (STAIF-97), Albuquerque, NM.

Jan 30, Presented a paper for: Gary Petersen, Egide Nizeyimana, Eric Warner and X Shi, "An Assessment of Soil Productivity Loss Caused by Expanding Urban Land Use Using Remote Sensing and Soil Productivity Models," Projects/Programs Relating to MTPE, Space Technology & Applications International Forum (STAIF-97), Albuquerque, NM.

Feb 13, "Precision Farming - Will Remote Sensing Make a Contribution," Soil & Crop Seminar, Colorado State University, Ft. Collins, CO.

Feb 17, "Remote Sensing Advances for Precision Agriculture," Forest Sciences Seminar, Colorado State University, Ft. Collins, CO.

Mar 6, "Using Remote Sensing in Precision Farming" Colorado Space Consortium, University of Colorado, Boulder, CO.

Mar 11, "Precision Agriculture," Northglenn/Thornton Rotary Club, Northglenn, CO.

Mar 12, "Precision Agriculture at Purdue University: Present Programs and Future Directions", College of Agriculture and Life Sciences Seminar, University of Wisconsin, Madison, WI

May 19, Introduction of Keynote Speaker, Dr. Allan Falconer at UGISA/IKO GIS Conference, Indianapolis, IN.

May 1 Invited Lecturer, "Advances in Remote Sensing for Site Specific Farming," ABE 491S, Site Specific Agriculture, Purdue University.

May 15, "Precision Farming - Agriculture in the Space Age," Lafayette Kiwanis Club, West Lafayette, IN.

June 26, "Advances in Remote Sensing for Agriculture," Pulaski County Agriculture Tour, Winamac, IN.

June 26, "Precision Farming," Argentina Agronomist Tour, Purdue Agronomy Research Center.

July 2, "Remote Sensing Applications for Precision Agriculture," Henry County Ag Alumni Chapter, Lewisville, IN.

July 8, "Earth Remote Sensing" USRA User's Conference, Johnson Space Center, Houston, TX

Aug 5, Participant in "Ag Technology Leadership Forum," Ag Education & Consulting, University of Illinois, Champaign, IL

Aug 6, Panel participant in "The Future of Ag Industries in Precision Farming," Information Agriculture Conference Champaign, IL

Aug 7, C.J. Johannsen and P.G. Carter, "Who's Who in Commercial Satellite Remote Sensing: A Status Check," Information Ag Conference, Champaign, IL. (2 presentations, Concurrent Sessions)

Aug 7, J.H. Arvik and C.J. Johannsen, "Where are We and How did We Get Here," Information Ag Conference, Champaign, IL. (2 presentations, Concurrent Sessions).

Aug 22, Participant in discussions on Ag Advances in Remote Sensing, NASA/Ag Scientists Meeting, Washington, DC.

Sep 17, Session Chair for Social Sciences and Satellites Workshop, Consortium for International Earth Science Information Network (CIESIN), Washington, DC.

The following papers were written and published during this phase of the grant (copies are appended to the report):

Johannsen, C.J., A. Falconer, and W. Wigton, "Information Requirements for Agriculture: The Next Decade," Projects/Programs Relating to MTPE, Space Technology & Applications International Forum (STAIF-97), Part One: 221-224, Albuquerque, NM, January, 1997.

Berglund, J.A. and C.J. Johannsen, "Change Detection in a Broccoli Field through Cluster Analysis of Multispectral Imagery," Space Imaging EOSAT Technical Note No. 97-013, 16 pp., April 8, 1997.

Johannsen, C.J., J.H. Arvik, and J.A. Berglund. "Information Requirements for Precision Farming: The Next Decade," American Technology No. 1: 18-21, 1997.

Johannsen, C.J. "Glossary of Terms for Precision Farming," Modern Agriculture, Issue 1, pp. 44-46 January/February, 1997 (re-published on pp. 44-46 April/May, 1997, June/July, 1997 issues). Also listed on Ag Electronics Association's website located at: http://www.agelectronicsassn.org/

Johannsen, C.J. and P. G. Carter. "Who's Who in Commercial Satellite Remote Sensing: A Status Check," Presented at InfoAg Conference, August 7, 1997 and published at URL: http://dynamo.ecn.purdue.edu/~biehl/LARS/

The PI provided assistance to the following persons with articles and was quoted in their articles:

Tom Bechman, Associate Editor, "Eyes in the Sky," Wallaces Farmer magazine, January, 1997

Ron Brunoehler, Editor, "Remote Sensing is Ready to Fly," pp. 18a-18c, Soybean Digest, April, 1997.

Ron Brunoehler, Editor, "Aerial Imagery is Progressing Fast," p18c, Soybean Digest, April, 1997.

Linda Turner, Writer, Space Imaging EOSAT, "Benefits of Remote Sensing to Agriculture," SIE Homepage: WWW.spaceimage.com/

Micola Giacchetti, "A Sixth Sense," Farm Chemicals, July, 1997.

Robert F. Pelzmann, Jr, "Using Imagery in Field Management," Modern Agriculture, Vol 1, Issue 2:17-18, April/May, 1997.

Don Kelso, "Annual County Ag Field Tour focuses on high yields, remote sensing," Pulaski County Journal, Page 8, July 9, 1997.

Pat Shipman, "Satellites Launch New World for Farmers of the Future," FarmWeek, Page 5, Aug 18, 1997.

The PI provided remote sensing and precision farming background information to the following people:

- Bob Ebisch, Writer, Delta Airlines.
- Jeff Coles, Wall Street Journal
- Jenna Carrier, CNN
- Greg Horeman, Editor, Farm Journal

Submitted by:

Chris J. Johannsen

Purdue University

October 20, 1997

Change Detection in a Broccoli Field through Cluster Analysis of Multispectral Imagery

Technical Note No. 97-013

<u>Judith Berglund</u>
<u>Dr. Chris J. Johannsen</u> [1,2]

Abstract

The purpose of this study was to determine if and when changes and anomalies in a field could be detected through the use of clustering techniques. The preliminary results of this study suggest that changes in biomass, cultivation activities, irrigation patterns, drainage patterns, changing moisture conditions, and anomalies such as areas containing mildew can be detected and monitored through the use of clustering. It also appears that clustering has the potential to detect anomalies before these problems can be observed and treated by individuals who are scouting the fields. Early detection of these adverse conditions could help the client to better manage their crops and maximize yield.

Objective:

The purpose of this study was to determine if and when changes and anomalies in a field could be detected through the use of clustering techniques. An anomaly can be defined as anything that is out of the ordinary that could adversely affect the yield of the crop. Our goal was to notify the client of the exact location of anomalies as rapidly as possible, so that farm managers can identify what is causing the anomaly and take any required action to minimize any reduction in yield quality or quantity. The patterns produced by irrigation techniques, cultivation/tillage practices, soil type, drainage patterns, differences in planting date, differences in crop type and harvesting practices, as well as tractors, harvesters, water canisters and power poles should be identified and initially ruled out as anomalies because they are normal and known occurrences in a field. However, it is possible that some of these items, such as drainage patterns and irrigation techniques, over time may adversely affect the yield of the crop, and this should be brought to the attention of the client.

We encountered a lack of ground truth during this study. The only information available to us was the crop type for the fields. We had no information as to the date of planting, the date of harvesting, the irrigation, cultivation or fertilization schedule, the soil types within the field, or the history of the field including previous crops or areas that tend to have re-occurring negative impacts on production.

The field chosen for the majority of this study was a field of broccoli located in Block 8 of the Lanini Ranch, in Gonzales Hot Area #2 (shown in a Landsat image in Figure 1). This field is near Salinas, CA and is approximately 16 acres in size. The dates of imagery collection, August 26 to November 5, 1996, cover a significant portion of the growing season for this crop. An anomalous area in this particular field was located during the first 24 hour turnaround (10/28/96) and identified by the client as mildew. The client also stated that they had sprayed to treat the mildew a few days earlier on 10/25/96. This field with one known anomaly seemed to be an ideal candidate for assessing earlier detection of mildew as well as other anomalies.

Background on Broccoli Production in California:

California produces approximately 90 percent of the broccoli grown in the United States. The study field is located in Monterey County which produces 50% of the broccoli in California, making it the leading county in the state in broccoli production.

Broccoli is a cool season vegetable. Planting begins in mid-July and continues through January; however, the majority of the planting ends in October. Overall in California, the major harvest

period is from mid-October through December with lesser acreage being harvested through April. Regarding planting techniques, nearly all fields are direct seeded. Usually it is grown in double rows on raised beds, 38- to 42-inches wide. Spacing between seedlings is 12 to 14 inches. Occasionally broccoli is planted in single rows on 30-inch beds. Within a row, plant spacing is typically 5 to 6 inches apart. A typical broccoli planting is approximately 50,000 plants per acre with a typical growing season ranging from 70 days to 140 days. It grows best on well-drained soils; however, it may be grown on a wide range of soil textures.

Regarding irrigation techniques, broccoli is irrigated in a variety of ways. Sprinkler or furrow irrigation can be used from stand establishment through harvest. Many growers use sprinkler irrigation to germinate the seed and then switch to furrow irrigation for the remainder of the season once emergence has occurred. Amount and frequency of sprinkler or furrow irrigation varies widely depending on crop production area, broccoli maturity class, weather conditions (primarily temperature and humidity), and soil type.

Regarding weeds and diseases, nearly all fields are treated with preplant and/or preemergence herbicides coupled with mechanical cultivation. Downy mildew (peronospora parasitica) is a common fungal disease in broccoli causing leaf spots. Though symptoms are obvious in the field, economic loss is usually slight from foliar damage unless young seedlings are severely attacked or the disease goes systemic within mature heads. Some growers never apply a fungicide for this disease, while others almost always do as an insurance factor. Additional information regarding broccoli production in California can be found on the University of California at Davis website (http://vrichome.ucdavis.edu/vrichome/html/selectnewcrop.broccoli.htm).

Background on the Clustering Algorithm and Technique:

In general, clustering implies grouping spectrally similar pixels together. A pixel is determined to be similar based on simple distance measures in multispectral space. The software package used in this study to perform the cluster analysis was MultiSpec, Version 2.15.95, developed at Purdue University by David Landgrebe and Larry Biehl, and written by Larry Biehl (http://dynamo.ecn.purdue.edu/~biehl/MultiSpec). This software package uses the Euclidean distance similarity measure. Each pixel in the selected image classification area is compared to the remaining cluster centers using the Euclidean distance. The pixel is assigned to the nearest cluster unless it is determined to be too far away which occurs when the Euclidean distance squared is more than "number of channels * classification threshold squared" (Introduction to MultiSpec, p. 55).

The MultiSpec software allows the user to run one of two clustering algorithms, a simple one-pass cluster algorithm or an ISODATA type iterative algorithm. In this study, the isodata algorithm (also called the migrating means technique) was used. It is based upon estimating some reasonable assignment of the pixel vectors into candidate clusters and then moving them from one cluster to another in such a way that the sum of squared error (SSE) measure is reduced. The SSE measure computes the cumulative distance of each pattern from its cluster center for each cluster individually, and then sums these measures over all the clusters. If it is small, the distances from patterns to cluster means are all small and the clustering would be regarded favorably (Remote Sensing Digital Image Analysis, Second Edition (1993), by John A. Richards, pp. 230-231).

When the isodata algorithm is selected in MultiSpec, the user is allowed to specify the image area to be used for clustering, the classification threshold, the number of initial clusters desired, the convergence percent (default is 98.0 %), the minimum number of pixels that are needed for a "usable" cluster, and one of four options for locating the initial cluster centers (along first covariance eigenvector, along first correlation eigenvector, within eigenvector volume, and use one-pass cluster centers). The first three of these options for locating the initial cluster centers cause calculation of the principal components of the data set, either based upon the covariance matrix of the data (option 1) or the correlation matrix (options 2 and 3). For options 1 and 2, the

desired number of initial clusters are placed equally spaced along the first principal component. For option 3, the points are scattered over the volume defined by the first three principal components. For option 4, the one-pass clustering algorithm is run first, then the cluster centers determined by it are used to initiate the isodata clustering (Introduction to MultiSpec, p. 56).

After determining the initial cluster centers, the algorithm examines the location of each pixel in the segment of the image to be clustered and then associates each pixel with the cluster center the smallest Euclidean distance from it. After all pixels have been so assigned, one complete iteration is done and a test for stopping is carried out, as follows. If during that iteration at least the convergence percent of the pixels did not change the cluster center to which they were associated during the previous iteration, the clustering is declared complete. If not, the mean values of all clusters are calculated. These become the new cluster centers, and the clustering process is repeated through another iteration. When the convergence percent has been met, the clustering stops and each cluster is examined to determine if it contains at least the minimum number of pixels needed for a usable cluster (as specified earlier by the user). If it does not, then that cluster center is not listed. The image is then classified based on these clusters (Introduction to MultiSpec, 1995, p. 56. The isodata algorithm implemented here is similar to that originally described by Ball and Hall (1965). It is also described in Remote Sensing Digital Image Analysis, Second Edition (1993), by John A. Richards pp. 231-233.)
In this study, the user specified parameters are as follows:

- The images used in the clustering algorithm were solar and radiometrically corrected images of the broccoli field itself. Roads forming the boundary of the field and surrounding fields were clipped from the image to allow for the maximum variability within the field when displayed.
- A classification threshold of 5 was chosen because it seemed to show the most variability without yielding overwhelming results. As shown in Figure 2, the difference between a classification threshold of 4 and 5 is minimal when varying the threshold. We noted that a threshold of 6 would not give additional valuable information.
- The number of initial clusters was allowed to vary until a final number of 7 to 9 (optimum of 8) clusters was achieved. An optimum number of 8 clusters was chosen because visually, it showed a reasonable amount of variability without overwhelming the interpretation of the clustered image with "noise" or distracting the viewer from the most significant patterns. Figure 3 illustrates this point in that with 8 clusters, we could interpret the watering pattern of the sprinkler irrigation as well as assess the impact of mildew and drainage patterns.
- The default of 98.0% convergence was maintained, and a minimum cluster size of 3 pixels was specified.
- We chose option 3, "within eigenvector volume," as the method by which to locate the initial cluster centers. With this option, the initial cluster means are scattered over the volume/data defined by the first three principal components which serves to enhance convergence and to avoid anomalous cluster generation when dealing with unusual datasets.

Results of the Cluster Analysis:

The images in Figure 4 were clipped from individual tiles from the 20 flights over the study area illustrates that a sequence of color infrared (IR) images hold a great deal of information even though they had not been solar corrected. To better view the maximum variability within the field, solar and radiometrically corrected images were created (Figure 5). More detail and variability can be observed in Figure 5 but one can also see artifacts of the imagery in these field specific images, such as the solar reflection variation in the image for F19 (where 2 images with different solar reflections were mosaicked together)and a vignetting effect in F20. These artifacts do not appear to have affected the clustering results. A summary view of the field specific clustering analysis is shown in Figure 6 where one can observe and monitor increasing biomass, cultivation activities, irrigation practices, drainage patterns, soil moisture changes across the field, and observe the impact of anomalies such as mildew areas.

Increasing biomass:

In the first three images, F1 to F3, (Figure 4), the individual plants are probably not large enough to be detected by the sensors. At F4, the image shows a hint of red, indicating vegetative growth can be measured by the sensor. By F11, the field is mostly red. And by F18, the field is most likely covered with big leafy broccoli plants (bright red indicating lots of chlorophyll in the leaves) which are mature and ready to produce broccoli heads.

Another pattern detected by the clustering, which is also obvious in the color IR field specific images in Figure 5, is the difference between the left 2/5ths and the right 3/5ths of the field. For example, in the color IR field specific images for F8, F11, F12, and possibly F15, one can see that the left 2/5ths of the field are brighter red in color than the remainder of the field. In the clustered images in Figure 6 for F8, F11, F12, F15, F17, F18, and F19, one can see and quantify that the left side of the field is assigned a different cluster than the majority of the right side. By F20, this difference is no longer apparent in the clustered image. It is difficult to state what caused this difference in the absence of ground truth. However, it appears that something affected biomass during the first few weeks of growth and this would likely be of interest to the farm manager.

Cultivation Activities:

In Figure 7, we accumulated some of the cultivation practices that impacted our analysis. One can observe that the grower has begun cultivation of the first couple rows of the field (near the top of this image) for weed control. In F4, the farmer has cultivated over half of this field. In F5, a few more rows have been cultivated. By F6, the farmer has completely tilled the field. In these images, as well as in the field specific image of F5, the uncultivated area (left side of this image) is lighter in color than the cultivated areas. The lighter color indicates a lower moisture content since the soil surface is drier. Cultivation activities bring the moist soil to the surface, resulting in a higher moisture content which shows up as a darker color on the color IR imagery. Cluster analysis also reveals these patterns. For example, the resulting image from the cluster analysis for F5 displays the uncultivated (drier) area as yellow in color, and the cultivated (and more moist) area as primarily fuchsia or pink color.

Irrigation, Drainage Patterns, Changes in Moisture Content, and Mildew:

In Figure 8, one can observe the dark rounded edges that extend into the roads bordering the fields (at the end of the rows), that the grower is using sprinkler irrigation techniques. The dark area corresponds to the recently watered area (high moisture content). Once these rows have been irrigated, the grower may move the sprinkler system (field-length pipes with sprinkler heads attached) to water the rows that have not been irrigated. Prior to the collection of F8 image, the farmer apparently moved the sprinkler to irrigate the remaining rows. In F8 the field is beginning to dry, but some rows are darker than others and these differ slightly from those in F7, thus substantiating the idea that the farmer moved the sprinkler pipes. This pattern can be detected through cluster analysis, as shown in the resulting clustered image for F8 (lower right corner of Figure 8). The "stripes" visible on the color IR image which correspond to the drier areas between the irrigated sets of rows are very striking on the clustered image assigned to a purple-blue color. The variability (shown as horizontal banding of the clusters) in the remainder of the field is believed to be due to gravity drainage or changes in soil moisture toward the top of the field, with the yellow area being the most moist.

This end of the field appears to be darker in color (indicating higher moisture content) in the entire sequence of color IR imagery (Figures 4 and 5) and in the clustered images (Figure 6). In the clustered image for F5, this area is light blue. In F8, it is yellow. By image F11, the area with the most moisture is becoming more sharply defined and is represented by light blue and kelly green clusters. One can easily track this pattern from image to image through to F20. Space Imaging identified this pattern as being an anomaly during its first 24 hour turnaround (10/28/96, or F18) and notified the client. The client reported that this area of the field contained mildew. In fact, the

majority of the field was affected by mildew, but this area was more intensely affected causing leaves to be more yellow in color. The client also reported that they had identified and sprayed this area on 10/25/96 to treat the mildew. The clusters corresponding to the mildewed areas are visible on images as early as F11 (9/30/96), nearly a month before it was detected and sprayed by the client (Figure 9).

Conclusions/Future Work:

Interpretation of the imagery was made based on the limited ground truth available at the time of the study and upon our knowledge of crop growth. Figure 10 indicates that the clustering routine is tracking the features in the field and assigning clusters relatively well.

The preliminary results of this study suggest that changes in biomass, cultivation activities, irrigation patterns, drainage patterns, changing moisture conditions, and anomalies such as areas containing mildew can be detected and monitored through the use of clustering. It also appears that clustering has the potential to detect anomalies, such as mildewed areas or adverse conditions in the field that could lead to crop stress and ultimately damage, before these problems can be observed and treated by individuals who are scouting the fields. Early detection of these adverse conditions could help the client to better manage their crops and maximize yield. The next step in this research would be to obtain more complete ground truth for a variety of crops, apply the clustering routine to this variety of imagery and determine if one can automate the function.

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[1] Chris J. Johannsen is Professor of Agronomy & Director of LARS at Purdue University and is a Visiting Chief Scientist and Judith Berglund is an M.A. Aspirant, University of Texas at Austin and an Intern at Space Imaging Inc., 9351 Grant St., Suite 500, Thornton, CO 80229.
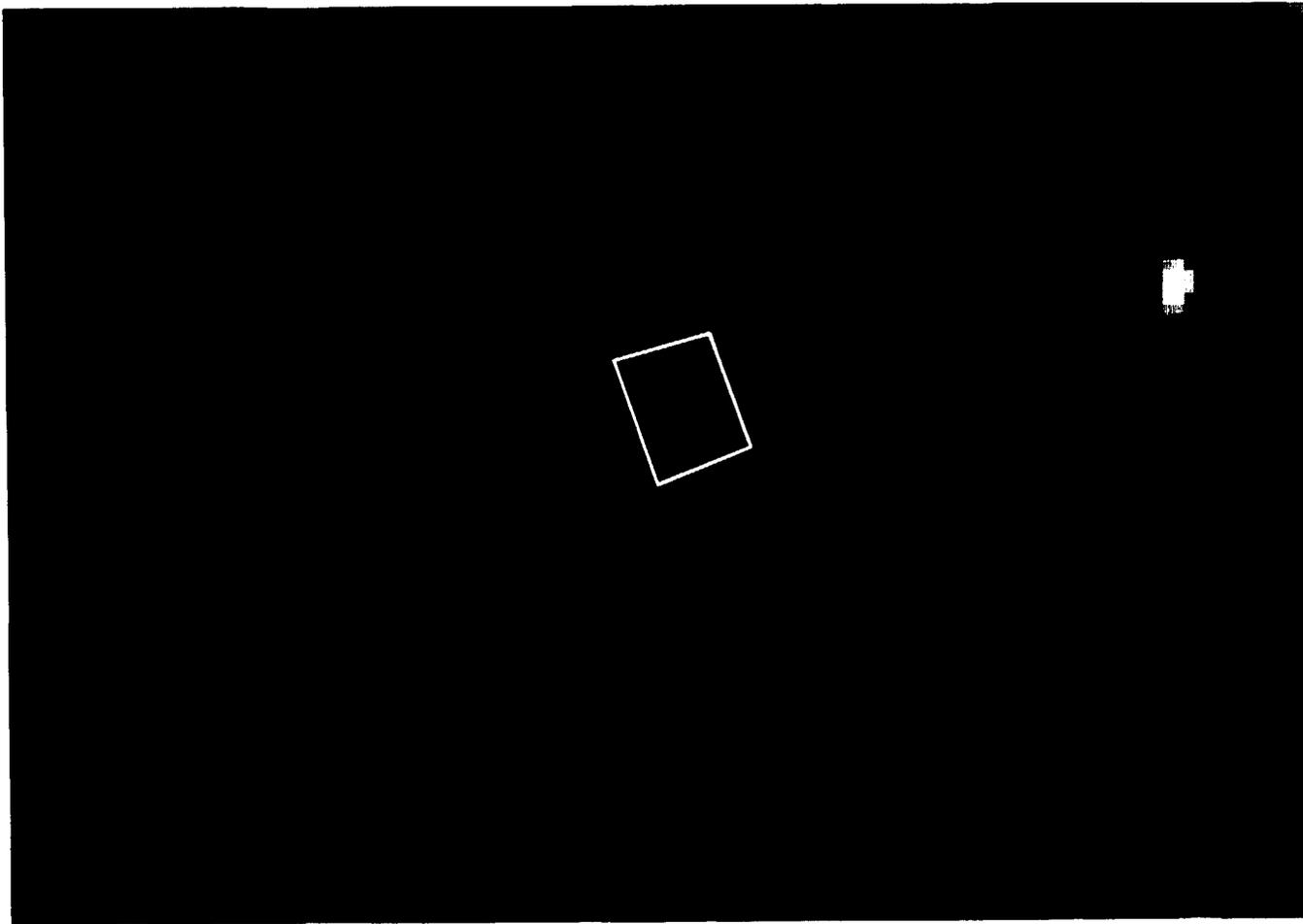
Figure 1. Landsat TM image obtained on October 14, 1996 in comparison to SIE aerial 1 Meter data obtained on October 15, 1996 of Salinas, CA ag data set. The outlined area, Block 8 of the Lanini Ranch, is the study site.
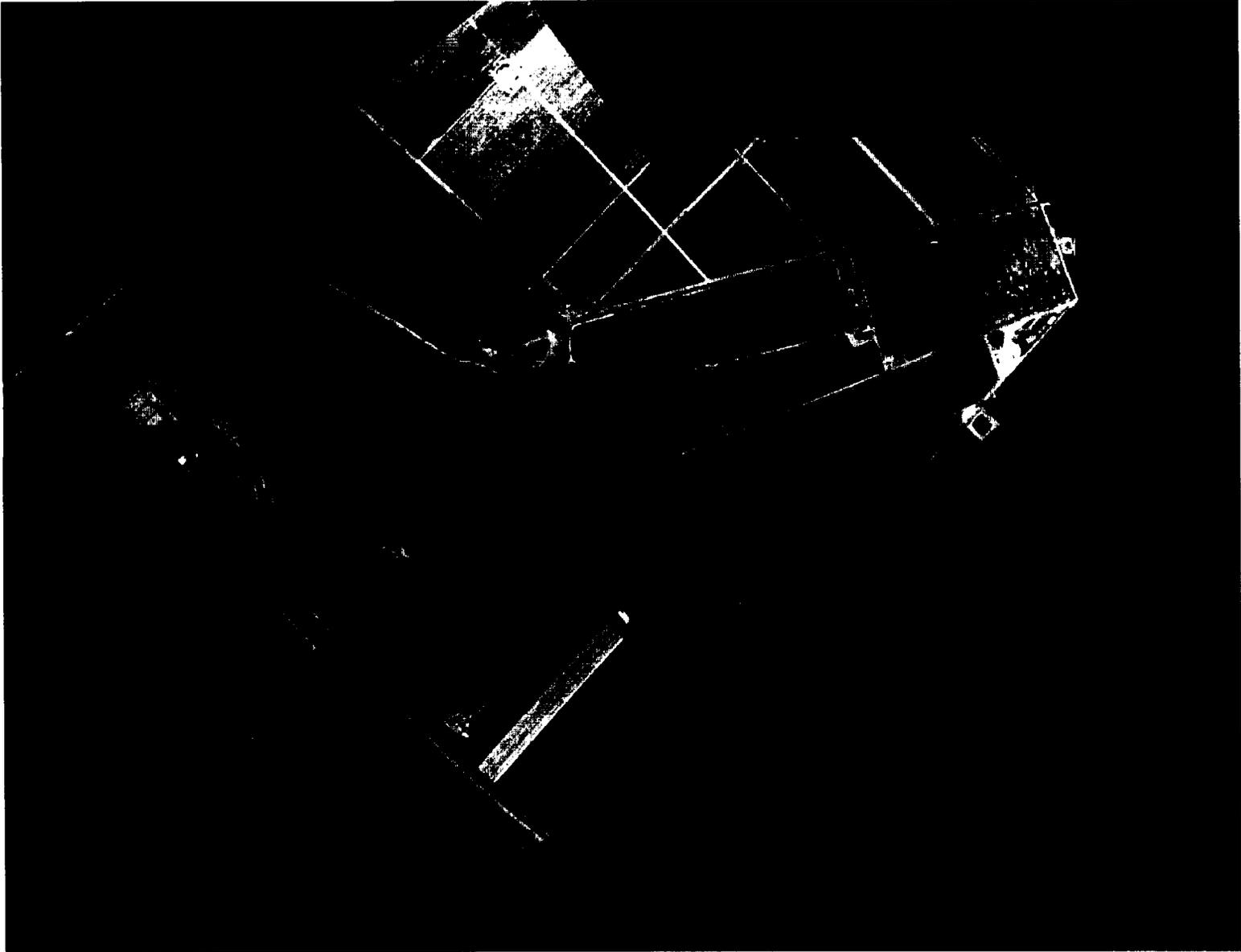
Figure 1 Continued.

Subset of F2, Color IR

6 clusters, CT = 4
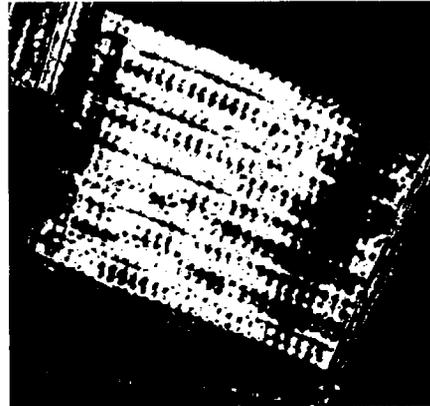
6 clusters, CT = 5
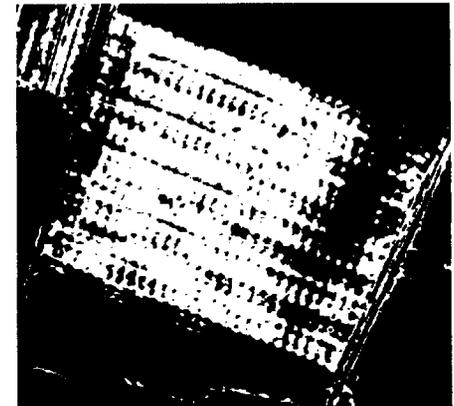
Notice that each of the above images contain 6 clusters and each of the below images contain 8 clusters. Keeping the number of clusters constant and varying the classification threshold (CT) entered in the ISODATA algorithm yields different results.

8 clusters, CT = 2
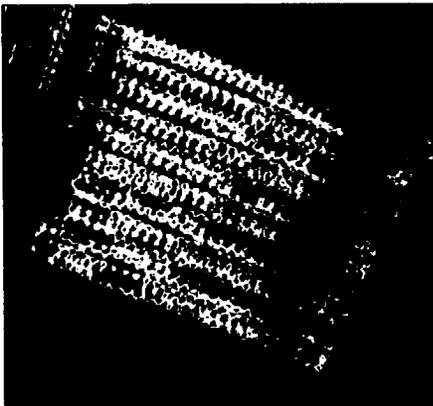
8 clusters, CT = 3
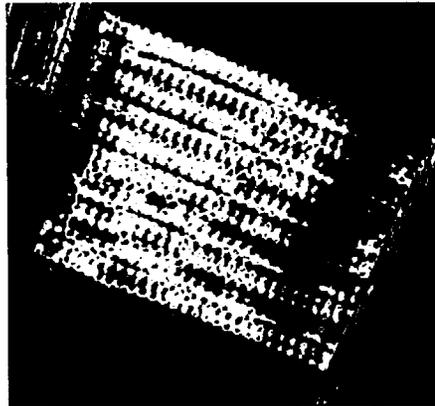
8 clusters, CT = 4
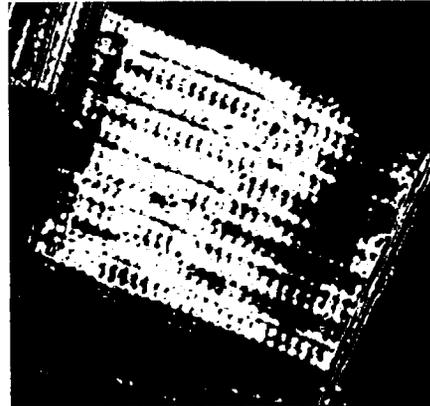
8 clusters, CT = 5
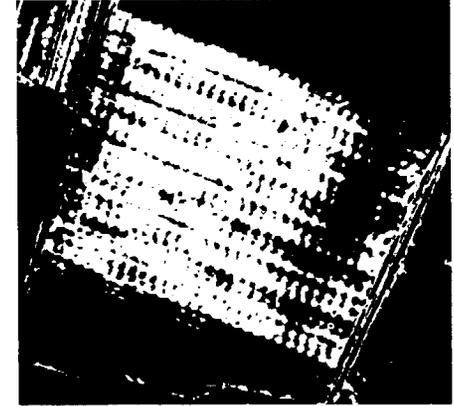
Figure 2. Varying the classification threshold (CT) provided slightly different results. Optimal CT appeared to be 5 for results that compared visually similar to CIR images.

F 18   10/28/96

3 Clusters

5 Clusters

6 Clusters

7 Clusters
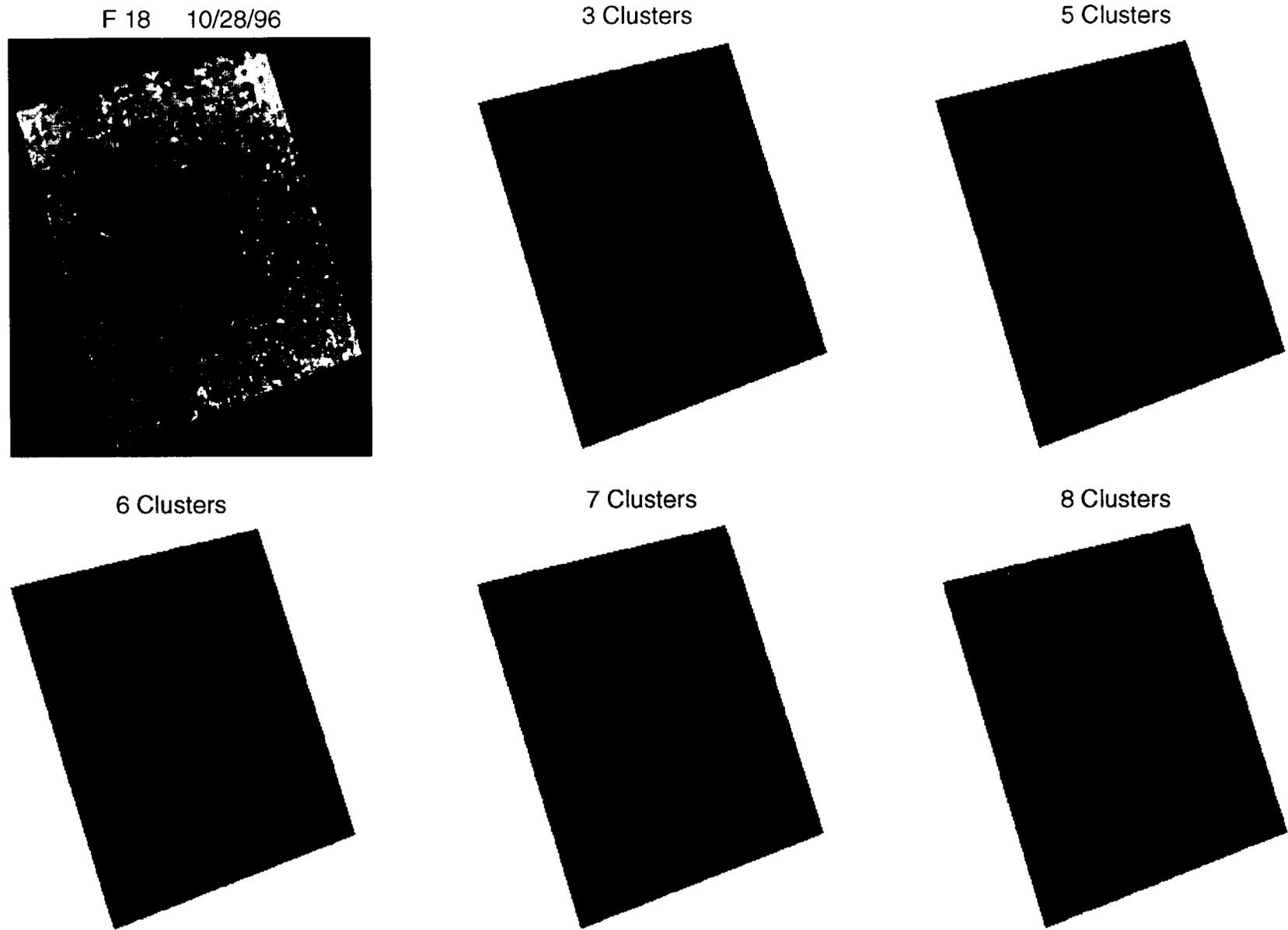
8 Clusters

Figure 3. Varying the number of clusters for the October 28, 1996 image to determine the optimum number of clusters.

F 1   8/26/96   F 2   8/29/96   upside down   F 3   9/3/96   F 4   9/5/96

F 5   9/9/96   F 6   9/12/96   F 7   9/16/96   F 8   9/19/96

F 9   9/24/96   upside down   F 10   9/26/96   F 11   9/30/96   F 12   10/3/96   upside down

Figure 4. Aerial color infrared images for each of the 20 flight dates. The images have not been corrected for solar differences.

F 13   10/7/96   F 14   10/11/96   F 15   10/14/96   F 16   10/18/96
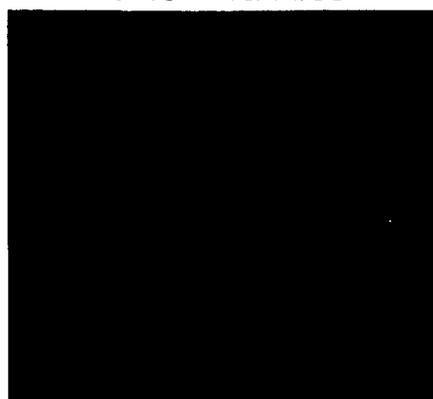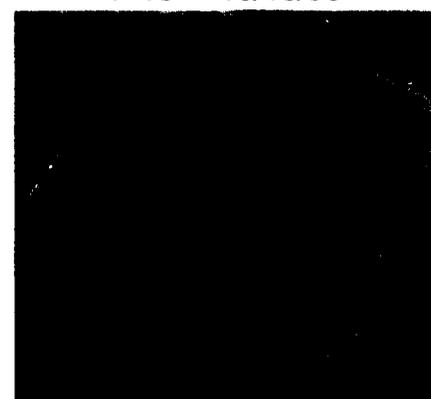
F 17   10/21/96   F 18   10/28/96   F 19   10/31/96   F 20   11/5/96
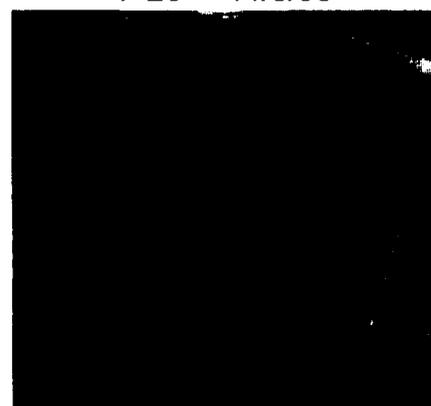
Figure 4. Continued.

F 5 9/9/96
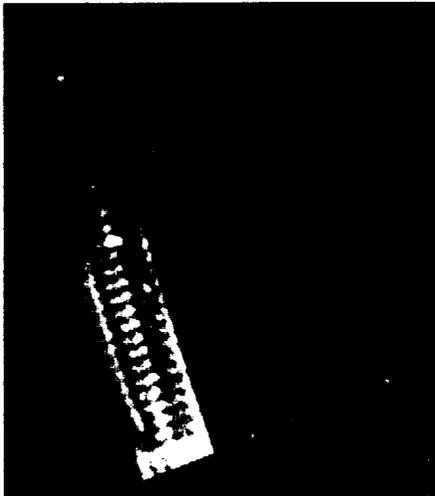
F 8 9/19/96
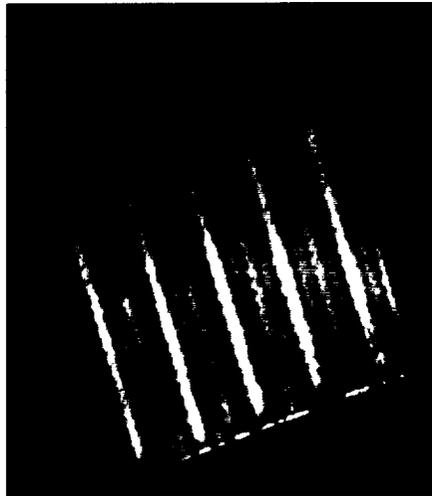
F 11 9/30/96

F 12 10/3/96
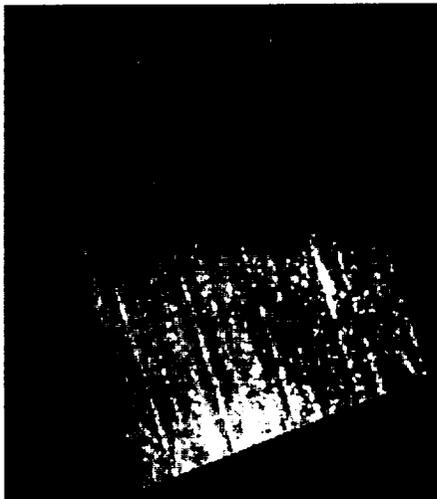
F 15 10/14/96
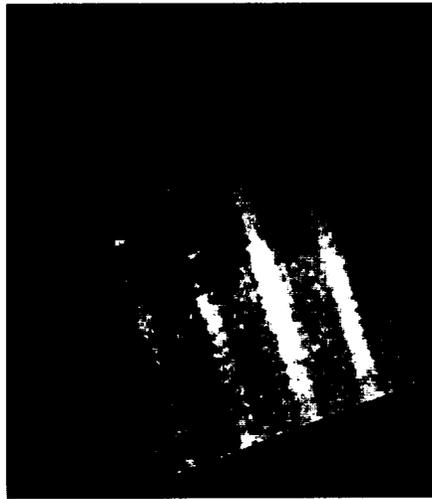
F 17 10/21/96
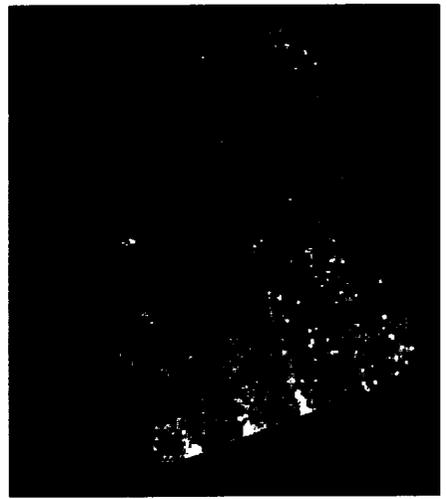
F 18 10/28/96
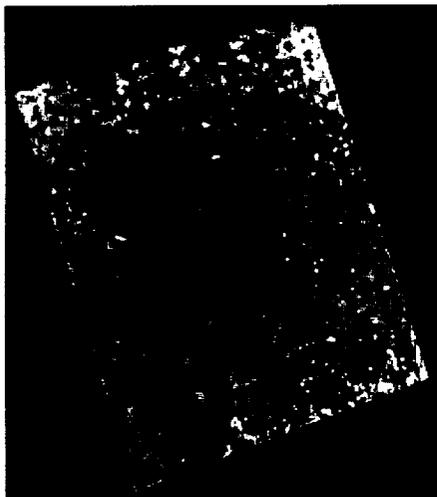
F 19 10/31/96
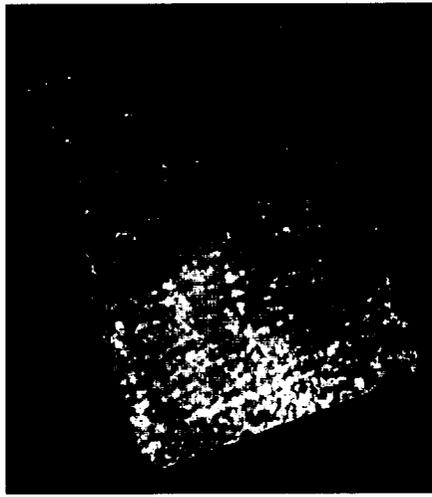
F 20 11/5/96
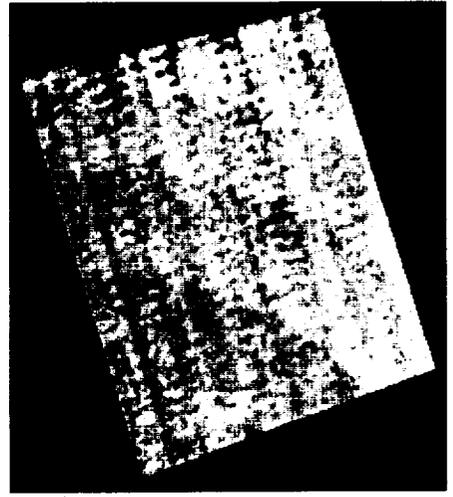
Figure 5. Solar and radiometrically corrected images from selected fight dates
to demonstrate the field specific histogram stretch processing.
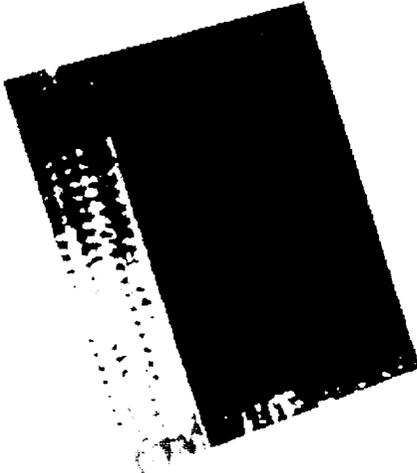
F 5   9/9/96   8 Clusters F 8   9/19/96   7 Clusters F 11   9/30/96   8 Clusters
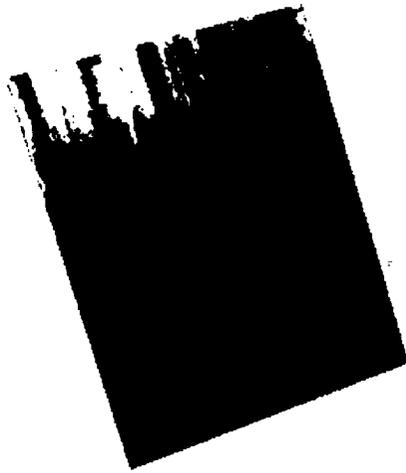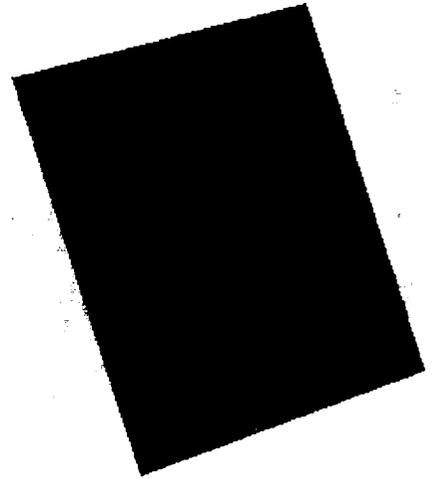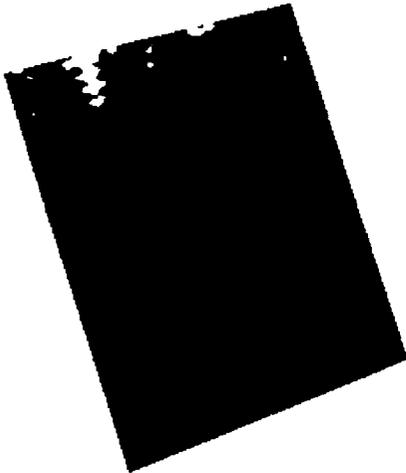
F 12   10/3/96   7 Clusters F 15   10/14/96   8 Clusters F 17   10/21/96   8 Clusters
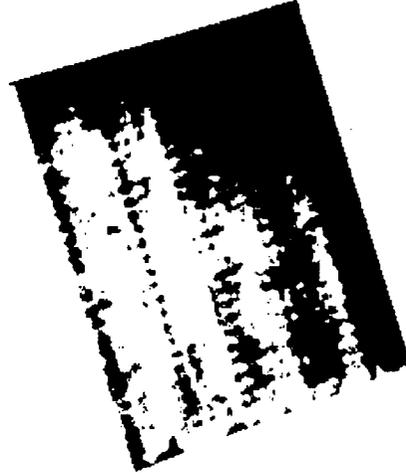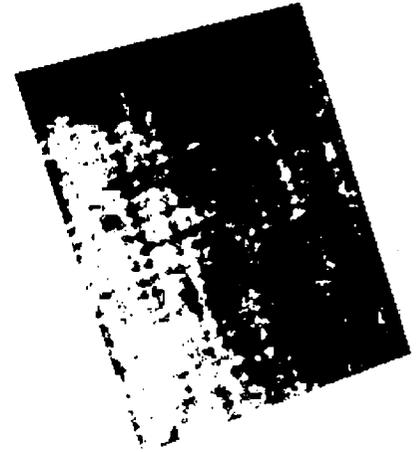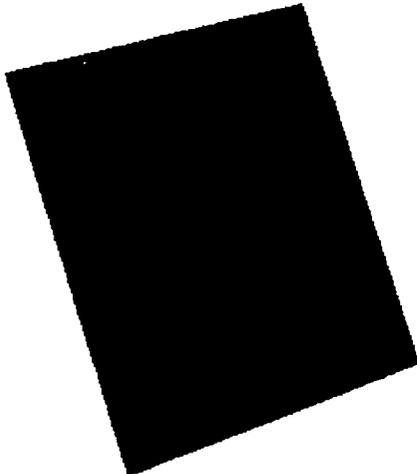
F 18   10/28/96   8 Clusters F 19   10/31/96   9 Clusters F 20   11/5/96   8 Clusters
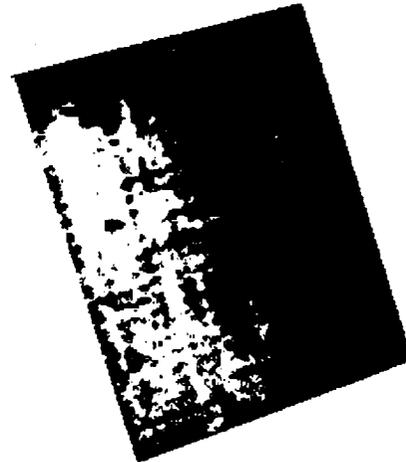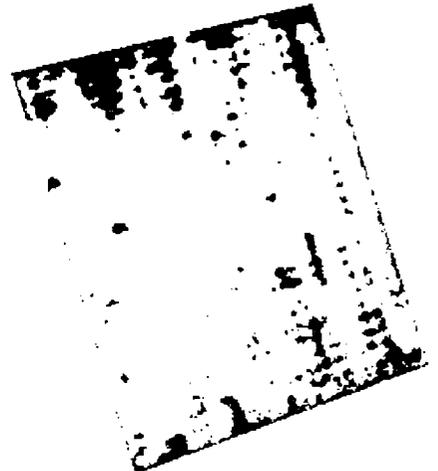
Figure 6. Field specific cluster analysis using ISODATA algorithm within the Eigenvector volume initialization option of the MutiSpec software.

F 3   9/3/96

F 4   9/5/96

F 5   9/9/96

F 6   9/12/96

F 5   9/9/96
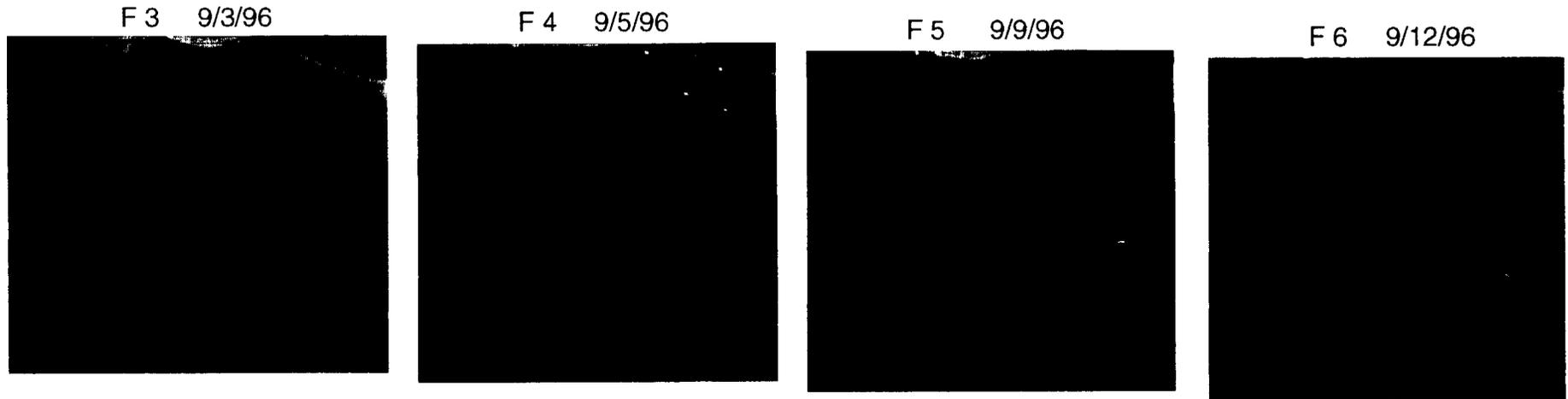
8 Clusters

Cultivation activities can be observed in the above sequence of color IR images. This activity can also be detected through cluster analysis, as shown on the far right. The yellow color corresponds to the area of the field that has not yet been cultivated. In the field specific image (to the right), the uncultivated area shows up as being lighter in color than the cultivated areas. The lighter color indicates a lower moisture content. Cultivation activities bring the moist soil to the surface, resulting in a darker color on the color IR image.
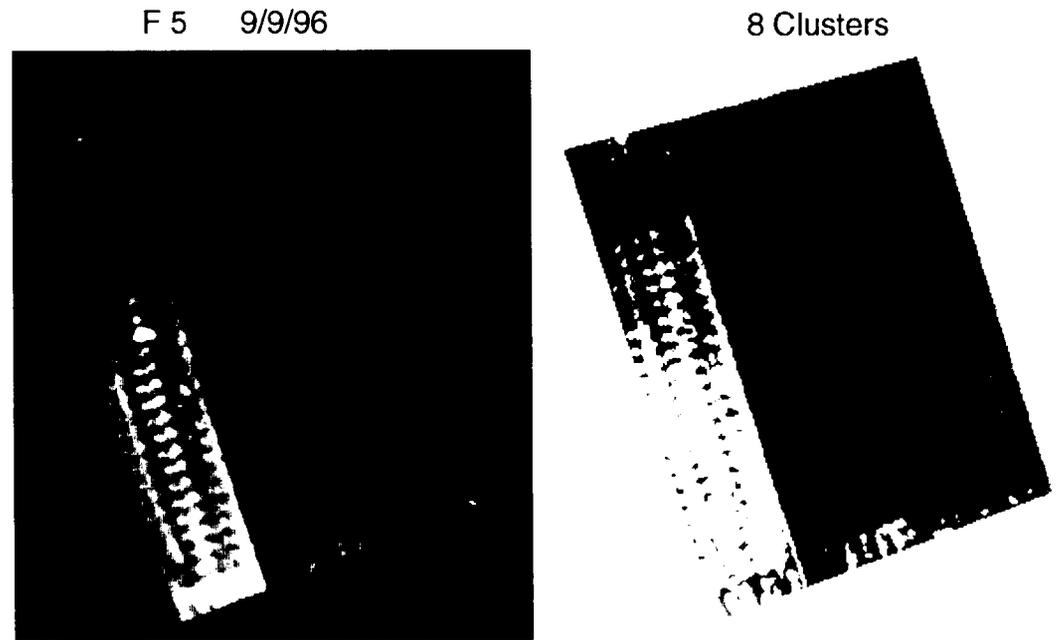
Figure 7. Cultivation activities observed in selected images.

F 7   9/16/96   F 8   9/19/96

F 8   9/19/96   7 Clusters

Irrigation and drainage patterns can be observed
in the above pair of color IR images. These
patterns can also be detected through cluster
analysis. In the image on the far lower right, the
drier area (between the irrigated sets of rows)
shows up as a purple-blue color in the lower half of
the image, and as orange and green in the upper
half. The horizontal banding is believed to be due
to gravity drainage toward the top of the field
and therefore an increase in moisture content
(with the yellow area being the most moist).
This area of the field is apparently lower in gradient
than the remainder of the field. This end of the field
appears to be darker in color (more moist) in all of
the color IR and field specific images, indicating a
chronic drainage problem which can affect the crop.
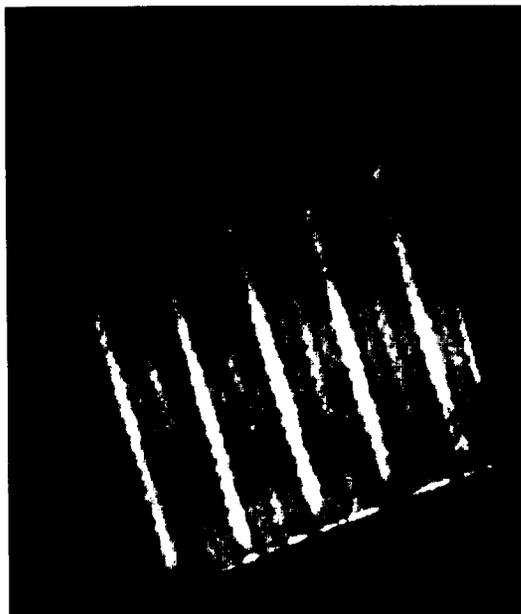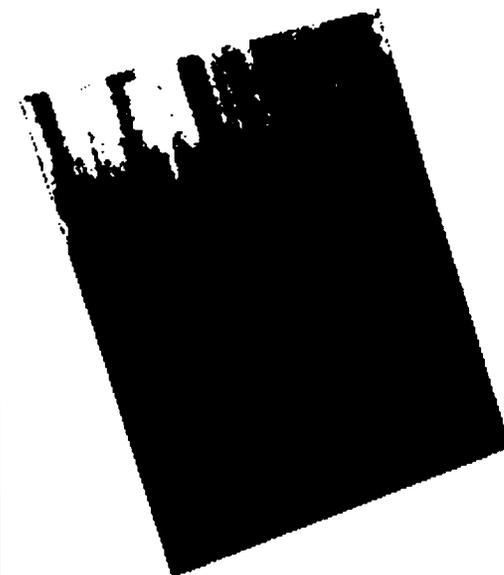
Figure 8. Irrigation and drainage patterns observed in selected images.

F 18   10/28/96   8 Clusters
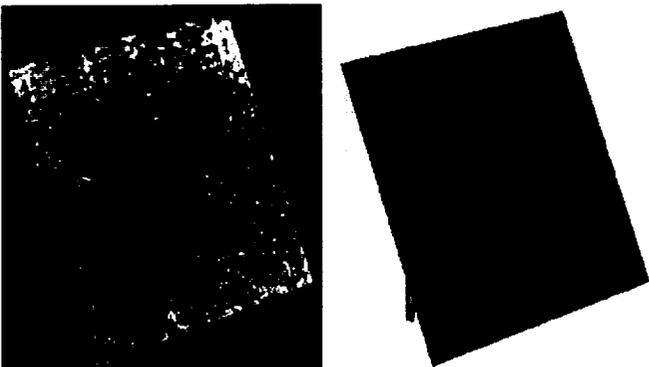
Space Imaging performed it's first 24 hour
turnaround for the client and identified the
areas indicated above as anomalies.

The client responds to our report by
saying the anomalous area was mildewed.
They had spotted this earlier and sprayed
the field to treat the mildew on 10/25/96.
The mildewed areas appear to be identified
by the cluster analysis in images as early
as Flight 11, almost a month before the
client sprayed (based on the information
available.)

F 17   10/21/96   8 Clusters
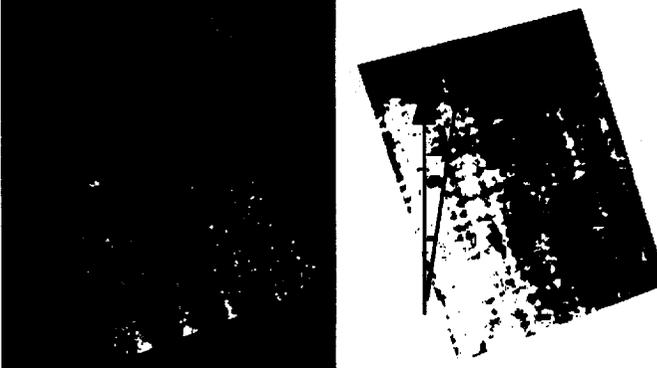
F 15   10/14/96   8 Clusters
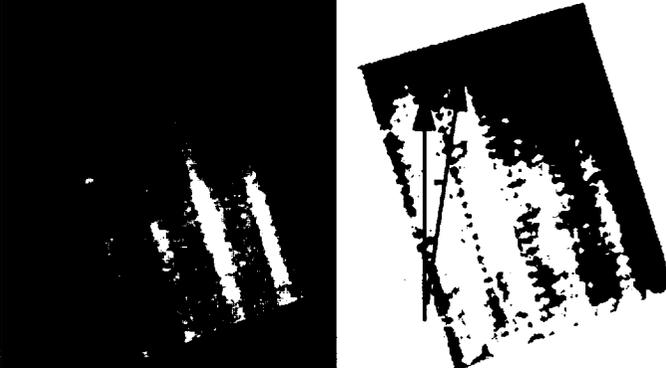
F 12   10/3/96   7 Clusters
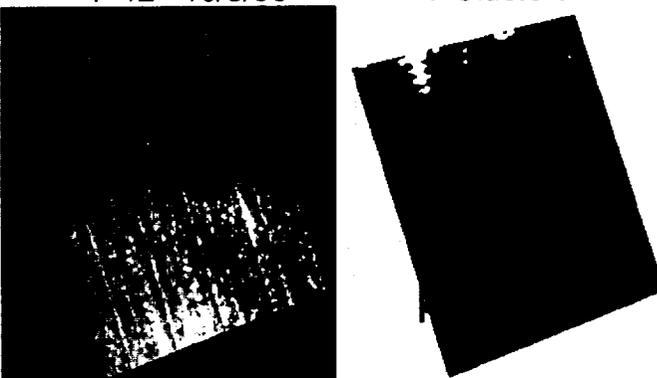
F 11   9/30/96   8 Clusters
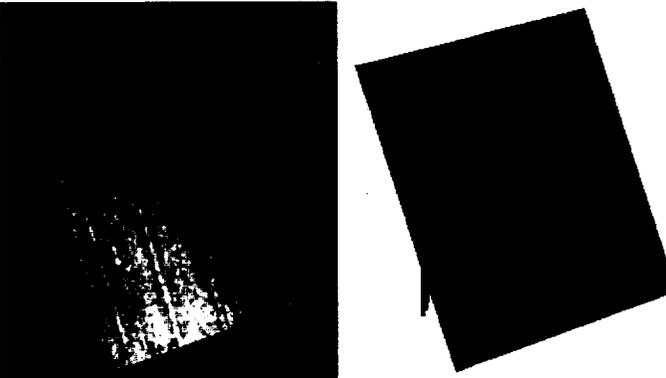
Figure 9. Distinguishing mildew in broccoli within the study site.
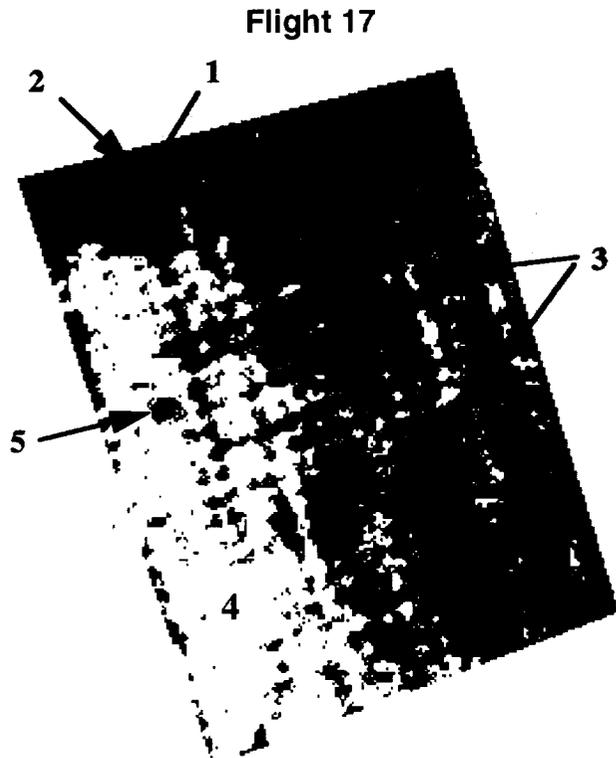
Flight 17

The chart below shows the mean spectral response for a particular feature or area of the field (labeled on the figure to the left) for flights 15, 17, and 18. This response is represented by the cluster which corresponds to that particular area. Features 1 and 2 are located within an area that is known to be mildewed. The mean spectral response for these two areas are close in value, suggesting that the clustering routine is able to distinguish anomalies. Features 3, 4, and 5 relate to presumably healthy areas of the field. As one can see by viewing the color IR images, the biomass is increasing. The crop is more mature in F17 and 18, resulting in closer values. The crop in F15 has not reached full maturity, thus accounting for the larger difference in spectral response.

(Number Corresponds to Feature on Image)

◆ Flight 15
■ Flight 17
▲ Flight 18
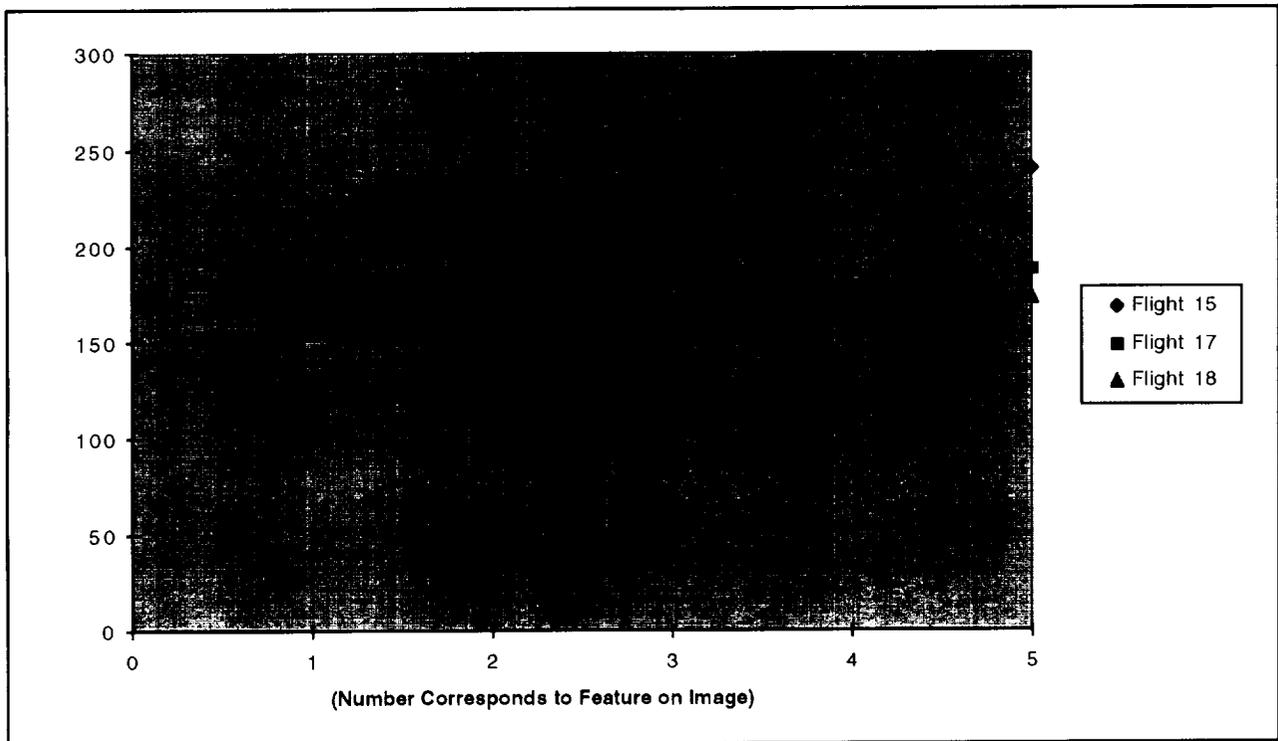
Figure 10. Relationship of cluster selection to spectral response over time.

GLOSSARY OF TERMS for Precision Farming

Aerial photography - Photos taken from airplanes to assist growers to determine variations within an area of interest such as a field.

Ag consultant - Person trained in agricultural and management sciences to provide information to land owners/managers for a fee related to the farming operation.

Ag consultant certification - There are 3 types of certification for ag consultants that are recognized in the US:
1. Certified Crop Advisor (CCA). Administered by the American Society of Agronomy. Requirements include a high school education, 4 years of experience, continuing education credits and testing.
2. Certified Professional Agronomist (CPAg). Administered by the American Society of Agronomy. Requirements include a college education, 4 years of experience, continuing education credits and testing.
3. Certified Professional Crop Consultant (CPCC). Administered by the National Alliance of Independent Crop Consultants. Requirements include a college ag degree, 4 years of experience, continuing education credits and testing.

Algorithm - A finite, ordered set of well-defined rules written as a computer program to assist in solving a specific problem.

Application - A practical use of computer software, an electronic system or a concept.

Applications package - Specialized computer programs and their associated documentation developed for practical usage. Ideally, applications packages allow a non-computer specialist to use the computer without learning complex programming languages.

Arc - A line described by an ordered sequence of points associated with vector data models. When two or more arcs are joined by a node and several arcs are linked together in a loop, they form an area or polygon.

Archive - The storage of historical records and data. When you have collected a year or two of data from your precision farming applications, you have started your own archive.

ASCII - (American Standard Code for Information Interchange). A standard coding system used to represent alphanumeric characters within a computer. ASCII files enable the transfer of some data between different computers through the use of a common set of symbols.

Aspect - Horizontal direction in which a slope faces (e.g., a SE facing slope has an aspect of 135 degrees).

Attribute - A numeric and/or text description of a spatial entity (e.g., address or owner's name for a parcel).

Attribute value - A value or property that is a characteristic of a spatial element. For example, a specific symbol or color may represent 150-160 bushels/acre which is a value assigned to that attribute.

Base map - The outline of your field with its proper coordinates is your base map. Data collected within the field by your yield monitor will be defined in location by the base map which is a binary digital map.

Baud rate - A measure which describes the speed of the transmission of single digital elements over a communications line. The number indicates how rapidly data could move through your modem or between a computer and a printer.

Benchmark -
1) Used to define how comparisons are to be made between different computer software or systems according to specific requirements.
2) In surveying, a benchmark is the elevation at a specific point.

Bit - An abbreviated term for binary digit, the smallest unit of computer data.

Block kriging - A piecewise form of kriging based on grid cells.

Buffer - An area defined by the specified length extended around a point, line, or area.

Byte - A unit of computer storage of binary data usually comprising eight bits, and equivalent to a character. You will commonly hear computer memory and storage referred to using terms such as Kilobyte (approximately one thousand bytes), Megabyte (approximately one million bytes) and Gigabyte (approximately one billion bytes).

Cartography - The art and science of the organization and communication of geographically related information such as a yield image into maps or charts. The term will refer to their construction, from data acquisition to presentation and use.

Centroid - The position at the center of a one- or two-dimensional (2D) entity such as a polygon.

Choropleth map - A thematic map such as a yield image where quantitative spatial data is depicted through the use of shading or color variations of yield ranges.

Computer aided design (CAD) - Software with the capability of performing standard engineering drawings.

Computer aided mapping (CAM) - Software with the capability of generating standard mapping functions. In contrast to GIS, it can not analyze or process a database.

Contour - A line connecting a set of points, all of which have the same value. A contour line will show elevations of the same value.

Crop scouting - Precise assessments of pest pressure and crop performance which can be tied to a specific location for better interpretation.

Cross tabulation - Comparison by location of attribute data in two or more map layers.

Customization - A procedure which produces an application or company specific interface and/or database design such as yield mapping software. For example, a customized version

of a commercial yield monitor product may include menus which allow one to add individual field numbers and other identifiers into the database.

Database - A logical collection of files managed as unit. A GIS database includes data about both the position and the attributes of geographic features.

Database management system (DBMS) - A collection of software for organizing the information in a database which might contain routines for data input, verification, storage, retrieval, and combination.

Data input - The entry of information into a computer through the use of a keyboard, digitizer, scanner, or even entering data from already existing data bases.

Data standardization - The process of achieving agreement on common data definitions, representation, and structures to which all data layers must conform.

DEM (Digital Elevation Model) - A digital representation of the elevation of locations on the land surface. A DEM is often used in reference to a set of elevation values representing the elevations at points in a rectangular grid on the Earth's surface. Some definitions expand DEM to include any digital representation of the land surface, including TIMS or digital contours.

Differential correction - correction of the GPS signal to make it more accurate. An uncorrected signal will be accurate to about 50 yards. A corrected signal can be accurate to within 1-5 feet. Correction of a signal is done from a second GPS receiver at a known fixed location. The signal is then transmitted to the tractor, combine or other equipment which corrects the proper location through differential processing. There are three common ways to transmit a correction signal from the base station to the farm implement:
1. A dedicated transmitter that is located on an existing tower, which has a range of 30-40 miles.
2. A separate, private corporation satellite to send the corrected signal, which has a range of thousands of miles.
3. Piggyback the correction signal on a commercial FM radio station frequency, which has a range of 30-40 miles.

Digitizer - A table or tablet which has the capability of digitally recording the relative position of a cursor which is moved over the area or line that you want to digitize or record.

DLG (Digital Line Graph) - A US Geological Survey digital map format used to distribute topographical maps in vector form. The digital files contain lists of the coordinate points which describe linear map features.

Edit - The process of adding, deleting, and changing data/information on a computer.

Expert system - A system designed for solving problems in a particular application area. One

can draw an inference from a stored knowledge base that was developed by recording and structuring human expertise through an individual commonly called a knowledge engineer.

Extrapolation - A method or technique to extend data or inferences from a known location to another location for which the values are not known.

Feature - A geographic component of the earth's surface that has both spatial and attribute data associated with it (e.g., field, well, waterway).

Field - 1) A set of alphanumeric characters comprising a unit of information.
2) A location in a data record in which a unit of information is stored. For example, in your database, one of your crops may contain columns of data such as location #, crop type, variety, date of planting, etc. (all of which are fields)
3) A specific location on a person's farm which may be called "Field # 10A"

Geocode - A code associated with a spatial element which describes its location. An example would be a coordinate such as longitude or latitude.

Geographic information systems (GIS) - System of computer hardware, software, and procedures designed to support the compiling, storing, retrieving, analyzing and displaying of spatially referenced data for addressing planning and management problems.

Georeference system - A coordinate system keeping track of specific points on the Earth's surface. Examples of such a system are the Universal Transverse Mercator system (UTM) and the State Plane Coordinate System.

Grid - A data structure that uses rectangular units or grid cells arranged in rows and columns to represent an area like a field.

Grid mapping - Predetermined locations in a field where soil or plant samples may be obtained for analysis. The test information can be used for assessing fertility needs and determining approximate locations for varying fertilizer and lime applications.

GPS (Global Positioning System) - A network of satellites controlled by the Defense Department that is designed to help ground-based units determine their current location in latitude and longitude coordinates. Note that the term "GPS" is frequently used incorrectly to identify Precision Farming. GPS is only one technology that is used in Precision Farming to assist you to return to an exact location to measure fertility, pests and yield.

Ground control point - An easily identifiable feature with a known location which is used to give a geographic reference to a point on a yield image.

Ground truth - The field collection of data which is used in the interpretation of information gathered from other sources such as a yield image or a remotely sensed image.

Hard disk - A large capacity, mechanical, magnetic, computer storage device which stores your programs and data.

Hardware - The various physical components of an information processing system such as a computer, view screen, plotters, and printers.

Image classification - Processing techniques which apply quantitative methods to the values in a digital yield or remotely sensed scene to group pixels with similar digital number values into feature classes or categories.

Input - An overused term that applies to the process of entering data into a computer. Also used to describe the actual data that are to be entered.

Internet - An international network comprised of many possible dispersed local and regional computer networks in which one can share information and resources. Developed originally for military and then academic use, it is now accessible through commercial on-line services to the general public.

Kriging (creeping) - An interpolation technique for obtaining statistically unbiased estimates of spatial variation of known points such as surface elevations or yield measurements utilizing a set of control points.

Layer - A logical separation of mapped information representing common data (e.g., roads, soils, yields, vegetative cover, soil tests).

Lat/lon - Refers to Latitude and Longitude which specifically describes a position on the earth. Latitude is the north to south position. Longitude is the east to west position. Precise locations are described in degree, minutes and seconds. The lat/lon of Purdue University is 86 degrees, 55 minutes, 05 seconds latitude and 40 degrees, 25 minutes, 50 seconds longitude.

Legend - A map section containing explanations of symbols, colors and/or shades that signify various elements and data values on the map. A yield map will contain a listing of yield values and the color denoting a range of yields.

LIS (Land Information System) - A system for describing data about land and its use, ownership and development. LIS refers to all aspects of handling the data such as collection, storing, checking, merging, manipulating, analyzing and displaying.

Locational reference - Referencing data collected by yield monitor, sensor or other method and relating it to a specific spatial position.

Lookup table - A reference table containing key attribute values which can be linked or related to data usually collected at a specific location. An example would be physical and chemical data relating to a soil mapping unit.

Menu - A list of options displayed by a computer data processing program, from which the user

can select an action to be initiated. These choices are usually displayed in the form of alphanumeric text but may be as icons.

Merge - To take two or more maps or data sets and combine them together into a single coherent map or database without redundant information.

Metadata - A term used to describe information about data. Metadata usually includes information on data quality, currency, lineage, ownership, and feature classification.

Mosaic - Process of assembling GIS database files for adjacent areas into a single file.

Network - 1. A group of linked computers which are able to share software, data, and various hardware devices such as printers. 2. A geometric or logical arrangement of nodes and interconnecting lines.

Noise - Random variations or error in a data set. Also an unwanted sound coming from the combine.

Output - The product of a computer process and analysis which may be displayed as a computer screen, a printed map, or tables of values.

Orthophotograph - An aerial photograph that corrects distortion caused by tilt, curvature and ground relief.

Pixel - A term used in remote sensing referring to the fundamental unit of data collection which is an abbreviation for "picture element". A pixel is represented in a remotely sensed image as a rectangular cell in an array of data values and contains a data value which represents a measurement of some real-world feature.

Point sampling - A method of grid sampling in which a sample is taken in a 10-30 foot radius at the center point of each grid location.

Polygon - An area enclosed by a line describing spatial elements, such as a similar yield range, land use or soil type.

Precision farming - Using the best available technologies to tailor soil and crop management to fit the specific conditions found within an agricultural field or tract.

Raster-to-vector conversion - A process in which one converts an image such as a yield map of grid cells into data set layers of lines and polygons.

RDBMS (Relational Database Management System) - A database management software system that organizes data into a series of records that are stored in linked tables. This provides the ability to relate different records, fields and tables, and aids data access and data transformation.

Registration - A process where one can geometrically align maps or images to allow one to have corresponding cells or features. This allows one to relate information from one image to another, or a map to an image, such as registering a yield image to a soil map to determine if soils are influencing the yield response.

Remote sensing - The act of detection and/or identification of an object, series of objects, or landscape without having the sensor in direct contact with the object.

Resolution - A way of detecting variation. In remote sensing, one has spatial resolution (the variation caused by distance separating adjacent pixels), spectral resolution (the variation from the range of spectral responses covered by a wavelength band), and temporal resolution (the variation caused by time over the same location).

Satellite constellation - A system of 24 satellites that is owned by the US Department of Defense (DoD) that can determine location to within inches. There are usually at least 4 of these satellites that are in view 24 hours a day. The DoD has intentionally introduced error into the signal that is available to civilian users allowing for an accuracy of approximately 50 yards without differential correction.

Scale - The ratio or fraction between the distance on a map, chart, or photograph and the corresponding distance on the ground. A topographic map has a scale of 1:24,000 meaning that 1 inch on the map equals 24,000 inches (2,000 feet) on the ground.

Software - The programs, procedures, algorithms (set of rules), and their associated documentation, for a computer system.

Spatial data - Data pertaining to the location, shape, and relationship among geographical features.

Thematic map - A map related to a topic, theme or subject. These maps emphasize a single topic such as yield, soil type, or land ownership.

Topologically integrated geographic encoding and referencing file (TIGER) - The nationwide digital database developed by the US Bureau of the Census. TIGER files contain street addresses and census boundaries with accompanying population statistics.

Turn-key system - A reference to hardware and/or software systems meaning that they are ready to be used immediately and are designed, provided at a cost and supported by a commercial group.

UTM (Universal Transverse Mercator) - A commonly used map projection that uses a set of transverse mercator projections for the globe which are divided into 60 zones, each covering 6 degrees longitude. Each zone has an origin of the central meridian and latitude of 0 degrees.

Variable rate technology - Instrumentation used for varying the rates of application of fertilizer, pesticides and seed as one travels across a field.

Waveband - A remote sensing term used to describe a contiguous range of wavelengths of electromagnetic energy. Visible wavelengths (seen by the human eye) which range from 400 to 700 nanometers. Near infrared (NIR) wavelengths are at 700 to 2600 nanometers.

Yield monitoring - Regular intervals where a harvested weight has been obtained along with a GPS reading. A display of the weights every 1-3 seconds is translated to bushels/acre or yield providing a yield map. Moisture of the grain is obtained at the same time.

Zoom - To enlarge or decrease the scale of an image that is being displayed. One can "zoom out" of a yield monitor image and enlarge it in a progressive scaling of the entire image or one can "zoom in" decreasing the scale.

Z-value - A commonly used reference referring to elevation values. The "z direction" refers to upward direction on a 3-D chart or diagram.

Who's Who in Commercial Satellite Remote Sensing:
A Status Check
by
Chris J. Johannsen and Paul Carter 1/, 2/, 3/

Introduction

Remote sensing technology will improve by increasing spatial, spectral and temporal resolutions starting during 1997. Commercial remote sensing is moving rapidly. This paper will present information that the authors believe to be accurate to September, 1997. Since the Russians are no longer our enemies, the aerospace companies have sought new markets for their sensors and their expertise especially since the Department of Defense is no longer their prime customer. Agriculture and many other disciplines are receiving the benefits of these events.

The current satellites in orbit are: Landsat 4 and 5, IRS-1C, IRS-1D, JERS 1, SPOT 2 and 3, ERS 1 and 2, Radarsat, and a host of NOAA satellites. All are owned and launched with government assistance or ownership and all have commercial value. Related to these satellites are companies which are marketing images, services and products.

Future satellites will be owned and launched by commercial companies in addition to governments. It is interesting to note that a strong commercial interest is mostly in the United States. Table 1 shows the satellites that are scheduled for launch during 1997-98. Many of the 1997 expected launches were delayed because of problems with launch vehicles.

Table 1. SATELLITE Launches Scheduled for 1997-98

Satellite	Launch	Resolution	Channels
Earth Watch:			
EarlyBird (USA)	9/97	3 m (P), 15 m (M)	3
QuickBird (USA)	7-8/98	0.82 m (P), 4 m (M)	4
TRW Lewis (USA)*	8/23/97	5 m (P), 30 m (M)	256,128 (384)
CTA Clark (USA)	12/97	3 m (P), 15 m (M)	3
Orbview-2/Seastar (USA)	9/97	1.1 km/4.5 km	8
Orbview-3 (USA, Saudi Arabia)	10/97	1 m (P), 8 m (M)	4
TRMM (USA-Japan)	8/97		
NOAA-K (USA)	9/97	0.5 km/1.0 km	5
IRS-1D (India)	9/97	5 m (P), 23 m (M)	4 (launched)
KitSat-3 (Korea)	97		
EROS, CST/IAI (Israel, USA)	10/97	1.5 m (P)	1
CBERS (China, Brasilia)	10/97	20 m (P), 20 m (M)	7

Space Imaging:			
IKONOS 1	12/97	1 m (P), 4 m (M)	4
IKONOS 2	98	1 m (P), 4 m (M)	4
Resurs-O1-4 (Russian)	98	160 m (M)	
IRS-P4/OceanSat-1 (India)	1-3/98	10 m, 125 m (M)	4,8
SPOT 4 (France)	1/98	10 m (P), 20 m (M)	4
RockSat (Taiwan)	4/98		
Landsat-7 (USA)	5/98	15 m (P), 30 m (M)	7
David (Israel-Germany)	6/98	5 m (P)	
EOS-AM 1 (USA, Japan)	7/98	15 m (P), 15 m (M)	14
GDE Systems (USA)	98	1 m (P)	1
Resource21 (USA, Canada)	2001**	5 m (P), 10 m (M)	3
GERS (USA)	98	5 m (P)	1
Almaz-1B (Russian)	98	2.5 m (P), 4 (M), 5.4 m, ®	3

* * * * * * * * * * * * * * * * * *

P=Panchromatic, M=Multispectral, R=Radar
* Lewis was launched but lost when thruster rockets failed to place the satellite in its proper orbit.
** originally scheduled for 1998.
Sources: Homepages of most of the companies. Also thanks to the National Land Survey, Finland (http://www.nls.fi/sat/) from which we filled in the gaps.

Aerospace Companies Relating to Ag Applications
Since the InfoAg Conference emphasizes agriculture, we derived Table 2 from Table 1 showing the expected commercial launches for 1997-98 that would impact agriculture.

Table 2. Commercial Satellite Launches Providing Data for Agriculture

Satellite	Launch	Resolution	Channels
Earth Watch:			
EarlyBird (USA)	9/97	3 m (P), 15 m (M)	3
QuickBird (USA)	7-8/98	0.82 m (P), 4 m (M)	4
TRW Lewis* (USA)	8/23/97	5 m (P), 30 m (M)	256, 128 (384)
Orbview-3 (USA, Saudi Arabia)	10/97	1 m (P), 8 m (M)	4
Space Imaging:			
IKONOS 1	12/97	1 m (P), 4 m (M)	4
IKONOS 2	98	1 m (P), 4 m (M)	4
SPOT 4 (France)	1/98	10 m (P) , 20 m (M)	4
GDE Systems (USA)	98	1 m (P), ?m (M)	1+?
Resource21** (USA, Canada)	2001	5 m (P), 10 m (M)	3
GERS (USA)	98	5 m (P), 10m (M)	4

P=Panchromatic, M=Multispectral, R=Radar

* Lewis was launched by lost when thruster rockets failed to place the satellite in its proper orbit. It was funded by government but has strong commercial interests.

** originally scheduled for 1998.

Some specific information about each company is provided in alphabetical order so that readers can contact them or follow their progress on their homepages. This information was provided directly by representatives of the companies or through their homepages.

EarthWatch Incorporated - 1900 Pike Road, Longmont, CO 80501. Telephone: (800) 496-1225, or (303) 702-5561, Fax: (303) 702-5562, E-mail: info@digitalglobe.com, and homepage: http://www.digitalglobe.com

EarthWatch is in the position to become a preeminent worldwide supplier of digital geographic information and image data, through a unique satellite system, product design, and product delivery method. They plan to be the first commercial company to build and launch high resolution commercial imaging satellites. EarthWatch has partnered themselves with many other companies to provide Digital Globe databases and distribution networks. They are looking at a broad base of customers including agriculture.

The first two of the satellites in their system are the EarlyBird and the QuickBird. EarlyBird features two sensors, 3 meter resolution panchromatic and 15 meter multispectral. It is planned for launch in late 1997. QuickBird features 0.82 meter resolution panchromatic and 3.28 meter resolution multispectral sensors and is planned for launch in late 1998.

GER - Geographic and Environmental Research Corporation - One Bennett Common, Millbrook, New York, 12545. Telephone: (914) 677-6100, Fax: (914) 677-6106. There is currently no web page.

This is the most recent company to enter the commercial satellite remote sensing arena. Their system will center around the agriculture market, making it slightly different than others in the business. Their intent is to offer agribusiness an affordable product on a rapid revisit cycle, to develop a ground system to get data and crop information to producers rapidly enough to "save" stressed crops, and promise to find new ways to deliver data and information to farmers in a more timely manner. The company plans to offer raw data and information extraction products and services.

GER plans 6-8 satellites with <10 meter panchromatic and 10 meter multispectral resolution sensor capability. This system has been dubbed GEROS (GER Earth resource Observation System) by the company, and they plan the first launch in 1998. They are currently flying agricultural fields in the Midwest with prototype sensors to gain experience with agricultural needs.

Orbimage (Orbital Sciences Corporation) - 21700 Atlantic Boulevard, Dulles, VA. 20166 Telephone: (703) 406-5436, Fax: (703) 406-5552 or e-mail info@orbimage.com, and homepage: http://www.orbimage.com.

Orbital Sciences Corporation designs, manufactures, operates, and markets a variety of space related services and products and is the parent company. Orbimage is dedicated to providing low cost, state-of-the-art, satellite-based imaging products and services to customers around the world. They plan a unique global system to collect, process, and distribute their products. Three satellites are planned over the next several years with each performing a separate task.

Orbview-1 has a resolution of 10 km and Orbview-2 of 1.1 km. Each of these are currently collecting data with a global coverage orientation. Orbview-3 is their latest satellite planned in the system. It is to have 1 meter and 2 meter resolution panchromatic, and 4 meter resolution multispectral sensors with a revisit cycle of 3 days. Latest launch date information is for fall 1997. They are stressing economic development and agriculture for a major part of their market.

Resource21 - 7257 South Tucson Way Suite 200, Englewood, CO 80112 Telephone: 303-749-2000, Fax: (303) 749-3295 There is currently no web page. Resource21 is a partnership of aerospace companies, Boeing Commercial Space Company and GDE Systems, and agribusiness companies, Agrium LTD, Farmland Industries, and ITD. They plan to specifically to emphasize production agriculture applications with a 4 satellite system and commercial aerial flights. The plan is to restart aerial flights in 1998 and to start satellite launches by the year 2001. Each satellite is to be equipped with 5 meter resolution panchromatic and 10 meter resolution multispectral sensors in 5+ bands including 3 bands visible and NIR and SWIR with a 7 day revisit cycle.

Space Imaging EOSAT - 9351 Grant Street, Suite 500, Thornton, Colorado 80229 Telephone: (303) 254-2000 or 800-425-2997, Fax: (303) 254-2215, E-mail: info@spaceimaging.com, and homepage: http://www.spaceimage.com

Space Imaging EOSAT is an experienced company with access to the marketing of products from current satellites such as Landsat, IRS-C and JERS. They are partnered with Lockheed Martin, Raytheon E-Systems, Van Der Horst Ltd, Mitsibishi, and Kodak.

The latest planned satellites, IKONOS 1 and 2 (formerly CARTERRIA 1 and 2), will have sensors for 1 meter panchromatic and 4 meter multispectral resolution and will provide 1 meter fused data from similar observations with a 3 day revisit cycle. SIE is stressing agriculture, transportation, utilities and environmental applications as their market area. Launch dates are for December 1997 and September 1998.

SPOT Image Corporation - 1897 Preston White Drive, Reston, VA 20191-4368 Telephone: (703) 715-3100, Fax: (703) 648-1813, and homepage: http://www.spot.com. SPOT, Owned by Centre National d'Etudes Spatial (CNES), the French Space Agency.

SPOT was designed by Centre National d'Etudes Spatiales, France and developed with the help from Sweden and Belgium. The system incorporates spacecraft, ground facilities for control and programming, and image production and distribution. SPOT is operating SPOT 2 and SPOT 3 at the present time and plan the launch of SPOT 4 late in 1997. SPOT 2 and 3 offer 10 meter resolution panchromatic and 20 meter resolution multispectral sensors with a flexible revisit schedule. SPOT Image Corp. markets to the US market.

SPOT has an extensive archive of images from the 10 years of collections of data. Areas that have been of particular marketing interest are land use, land cover, and special interest (deforestation, erosion, desertification, urban zones), and the impact of changes on the environment.

Summary: The status of commercial satellites for remote sensing is changing daily. One can see that there are over 20 satellites scheduled for launch during the next 16 months with 9 of them being of special interest to agriculture. There are over 50 satellites scheduled for launch during the next 10 years and that number is likely to increase as many of the commercial companies start into Phase 2 and 3 of their strategic plans. The message to agriculture and other potential users is very clear. The more satellites that are successfully launched the more data will be available and if the government doesn't interfere with the marketplace, the cheaper the cost of the data. The view from a satellite changes each time that the satellite passes over a specific area on the Earth and the type of views provided are also changing. The status is of commercial satellites is not stagnate.

October 17, 1997