NASA/CR-97- 206169

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

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INFORMATION REQUIREMENTS FOR AGRICULTURE: THE NEXT DECADE

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Abstract

International agriculture needs improved capabilities for crop production monitoring and management data. Many countries, using an area frame sample, have begun to integrate GIS and remote sensing in their national crop inventory statistics programs and as the basis for famine early warning systems. The demand for accurate digital data has been heightened by the boom in precision farming which requires analysis of data collected at 1-5 meter spatial intervals. Manipulation and interaction of such data as digital soils maps, field boundary maps, drainage maps, yield monitor images, fertilizer, seed and chemical rate applications are primary to precision farming. Interest is building in the use of remotely sensed data to compare with yield image maps to assist in management decisions. The demand for digital data at all levels will increase dramatically as data are collected for local, regional and national statistics, the management of crop production, transportation to markets, crop insurance decisions, marketing commodity futures and delivery of data to farm consultants. Users in the United States will include county extension educators, crop consultants, ag industry agronomists, farm management groups among others. In a global context the users will include development agencies, national governments, agribusiness and the investment community as well as international organizations concerned with the environmental issues related to agriculture and land use.

INTRODUCTION

Agricultural statistics as reported by national and international groups and organizations are primarily acreage and yield estimates of individual crops. Remote sensing in conjunction with Geographic Information Systems (GIS) is a good technique for identifying crops and monitoring changes in crop conditions. Statistical sample frames can be constructed using remotely sensed data by delineating the areas used for crop production. Primary sample units (PSU) can be assigned after the density of crops are known with a sampling frame. These are proven approaches used by the National Agricultural Statistical Service (NASS) of the US Department of Agriculture. Similar approaches have been used by the Foreign Agricultural Service and non-government organizations (NGOs) for estimating crop area and yield in foreign countries.

Difficulty in obtaining data in a timely and cost effective mode has curtailed the agricultural uses of remote sensing by many groups. Another important factor is that agricultural remote sensing has been oversold in the past. People were told that you could detect diseases and insects and later learned that you could not. This is rapidly changing with many organizations launching satellites and seeking agricultural groups as customers. Another factor encouraging a "second look" at remote sensing is that people are becoming familiar with yield images collected by yield monitors on harvesting equipment. They now realize that one can not do anything to change the yield for that year when viewing a yield map. However, if they could obtain a "yield map" early in the growing season by remote sensing techniques, perhaps one could make changes in their cultural practices and economically increase yield. An example would be to apply nitrogen fertilizer through their irrigation water after seeing that the crop a reduction in chlorophyll.

Precision farming is a current buzz word among agricultural circles in the USA and in Europe. The term "precision farming" means carefully tailoring soil and crop management to fit the different conditions found in each field. Precision farming is sometimes called "prescription farming," "site-specific farming" or "variable rate technology" (Johannsen 1994, 1996a, 1996b and 1996c). It has caused a focus on the use of three technologies: remote sensing, geographic information systems (GIS) and global positioning systems (GPS).

All three technologies have been used extensively in space and by defense departments around the globe. We have literally taken "agriculture into the space age". Farmers have services available that involve satellites collecting data, transmitting locational information, or providing data from a variety of sources. These technologies can be used in any agricultural locations except where restricted by the government . Farmers can analyze the available satellite information themselves, hire a land or crop consultant or they can rely on companies to do this service for them for a fee.

Some farmers have already received benefits of satellite remote sensing data. Satellite images from Landsat and SPOT have been used to distinguish crop species and locate stress conditions (Lozano-Garcia et al. 1995). The cost of obtaining the images has been the biggest deterrent in regular use of such data. A typical farm manager of 2,500 acres is not going to spend $500 to $3,500 every 2 weeks to monitor conditions in his field. Resourceful agricultural industry dealers can however, purchase digital satellite data over their trade area and spread the cost among numerous customers. Trained personnel in the use of computer analysis systems, basics of remote sensing and spectral responses of crops & soils will be a limiting factor in rapid use of these technologies.

We predict that future satellite launches, such as the TRW Small Satellite, World View Imaging, Resource21, ORBIMAGE, GER, EarthWatch and Space Imaging, will be competing for the agricultural market and lowered prices will encourage farmers to participate. The remote sensing part of precision farming will need to be proven; it has been receiving its first test through the 1995 and 1996 growing season since companies like Resource21 are providing prototype data by aircraft. They are receiving repeat customers which is a good sign.

More recently farmers have gained access to site-specific technology through Global Positioning Systems (GPS). GPS makes use of a series of military satellites that identify the location of farm equipment within a meter of an actual site in the field (Parsons et.al. 1995). The value of knowing a precise location within inches is that 1) tillage adjustments can be made as one finds various conditions while traveling across the field, 2) locations of soil samples and the laboratory results can be compared to a specific soil type and to crop yields at the end of the season, 3) fertilizer and pesticides can be prescribed to fit soil properties (clay and organic matter content) and soil conditions (relief and drainage), and 4) one can monitor and record yield data as one goes across the field.

The real value for the farmer is that he can perform more timely tillage, adjust seeding rates, perform more accurate crop protection programs, and know the yield variation within a field. These benefits will enhance the overall cost effectiveness of his crop production (Johannsen 1996b).

TILLAGE

The ability to vary the depth of tillage related to soil conditions is very important to proper seedbed preparation, control of weeds and fuel consumption and therefore cost to the farmer. Most farmers are using conservation tillage which means leaving residues on the soil surface for erosion control. The use of GPS in making equipment adjustments as one goes across the different soil types would mean higher yields and safer production at lower cost. This part of precision farming is in its infancy.

The equipment companies have announced tillage equipment with GPS and selected controls tailored to precision farming at some of the recent conferences and there will be more to come.

SEEDING

Hybrid seeds perform best when placed at spacing that allow the plants to obtain such benefits as maximum sunlight and moisture. This is best accomplished by varying the seeding rate according to the soil conditions such as texture, organic matter and available soil moisture. One would plant fewer seeds in sandy soil as compared to silt loam soils because of less available moisture. The lower seed population usually has larger heads (ears) of harvested seeds providing for a maximum yield. Since soils vary even across an individual farm field, the ability to change seeding rates as one goes across the field allows the farmer to maximize this seeding rate according to the soil conditions. A computerized soil map of a specific field on a computer fitted on the tractor along with a GPS can tell farmers where they are in the field, allowing the opportunity to adjust this seeding rate as they go across their fields.

CROP PROTECTION

The application of chemicals and fertilizers in proper proportions are of environmental and economic concern to the farmers. Environmental regulations are calling for the discontinuance of certain pesticide applications within 100 feet of a stream or waterbody or well or within 60 feet of an intermittent stream in the USA. Constraints on applying ag chemicals are also mandated in some European Countries. Using a GPS along with a digital drainage map, the farmer is able to apply pesticides in a safer manner. In fact, the spraying equipment can be preprogrammed to automatically turn off when it reaches the distance limitation or zone of the drainage feature. Additionally, farmers can preprogram the rate of pesticide or fertilizer to be applied so that only the amount needed determined by the soil condition is applied varying this rate from one area of the field to another. This saves money and allows for safer use of these materials.

HARVESTING

The proof in the use of variable rate technology (adjusting seed, pesticide, fertilizer and tillage) as one goes across the field is in knowing the precise yields. Combines and other harvesting equipment can be equipped with weighing devices that are coupled to a GPS (Parsons et al. 1995). One literally measures yield on the go. With appropriate software, a yield map is produced showing the yield variation throughout the field. This allows farmers to inspect the precise location of the highest and the lowest yielding areas of the field and determine what caused the yield difference. It allows one to program cost and yield to determine the most profitable practices and rates that apply to each field location. In our opinion, the use of yield monitors is a excellent place to begin if one wants to get started in precision farming.

Yield data from the same field over 3^+ years would define the weak spots in the field and narrow down the probability of what is causing a low yield.

CONCLUSIONS

The information requirements are changing rapidly in agriculture because of the changes in technology. Improvements in spatial and spectral resolutions of remotely sensed data has started agriculturists to think of ways to use this additional information. The yield monitor images has started the demand for images during the crop growing season. This trend is actually starting new industries that are supplying equipment, software and consultation.

GPS has already made a big impact on providing precise data/information locations in precision farming. Where does GIS and remote sensing fit with this trend? Several companies are starting to market GIS record-keeping systems so farmers can record all of the field operations such as planting, spraying, cultivation and harvest (along with specific information such as type of equipment used, rates, weather information, time of day performed, etc.). Additionally the farmers are able to record observations through the growing season such as weed growth, unusual plant stress or coloring and growth conditions. Data collected by the GPS operations can be automatically recorded with the GIS program. Remotely sensed data can be analyzed and added to the GIS using soil maps, digital terrain and field operations information as ground truth.

This can be used to guide further field operations like spraying, fertilizing and irrigating plus it is part of the permanent record. Trends like precision farming will make a strong impact on the way growers manage their farm operations in the future. We will see a steady growth of the remote sensing, GIS and GPS technologies as a result of this method of acquiring agricultural information in the next decade.

Acknowledgments

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Lozano-Garcia, D.F., R.N. Fernandez, K. Gallo, C.J. Johannsen. (1995) "Monitoring the Droughts in Indiana, USA," International Journal of Remote Sensing, 16, (7): 1327-1340.

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

Technical Note No. 97-013

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Dr. Chris J. Johannsen [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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[2] The authors acknowledge the assistance of Jon Arvik with the interpretations of the results of this study.

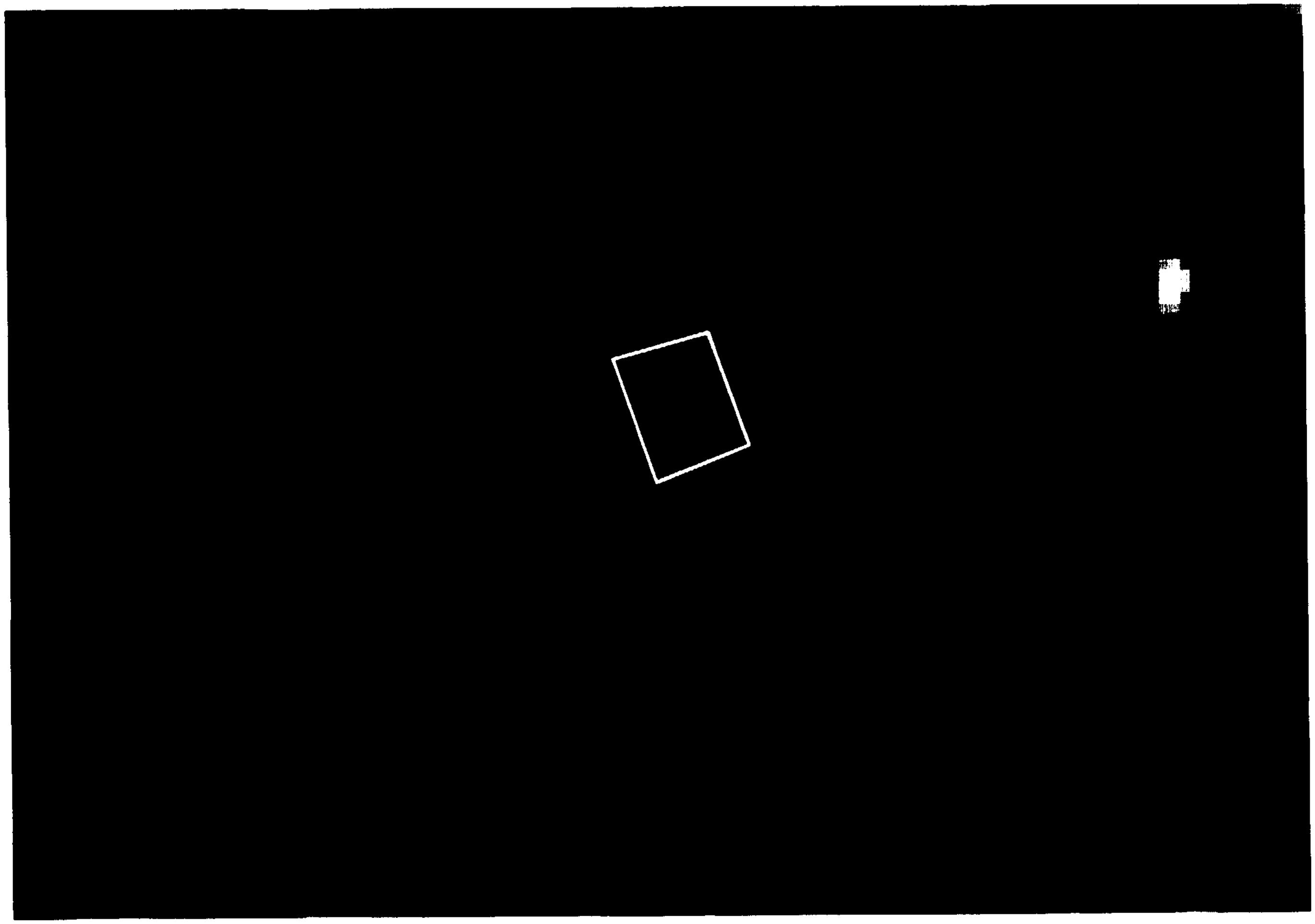


Figure 1. Landsat TM image obtained on October 14, 1996 in comparison to SIE aerial 1 Meter data obtained on October 15, 1996 of Salinas, CA ag data set. The outlined area, Block 8 of the Lanini Ranch, is the study site.

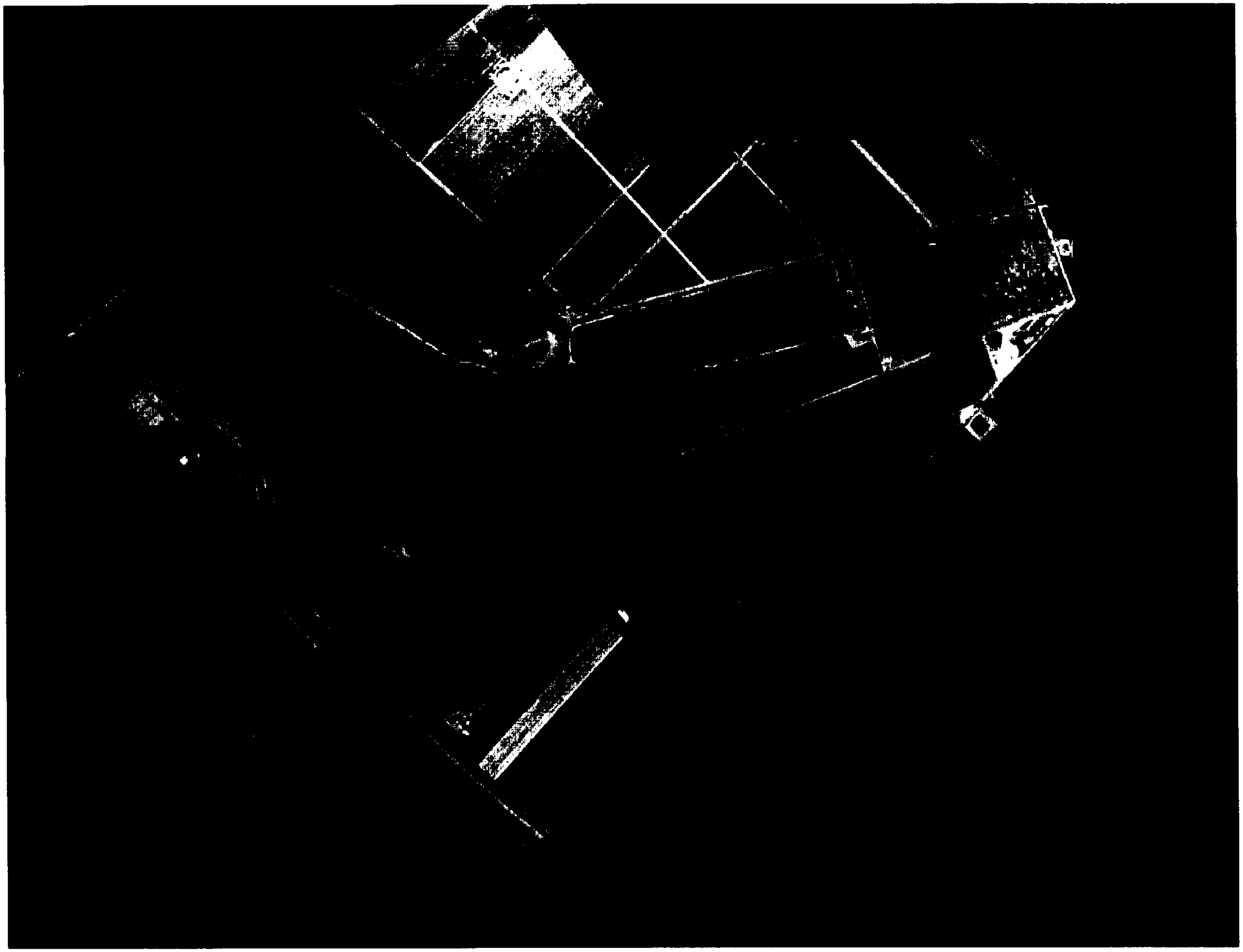
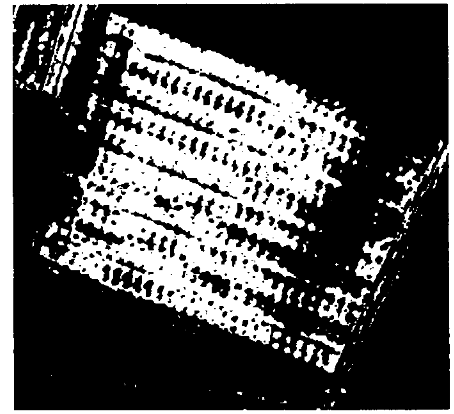


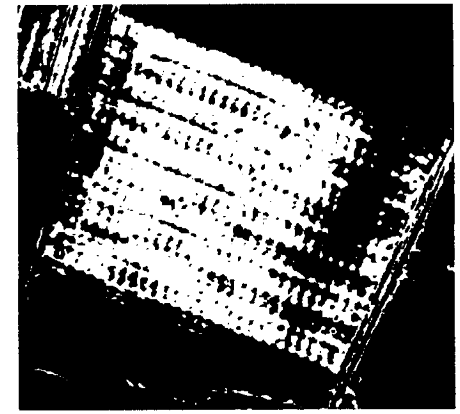
Figure 1 Continued.

Subset of F2, Color IR

6 clusters, CT = 4

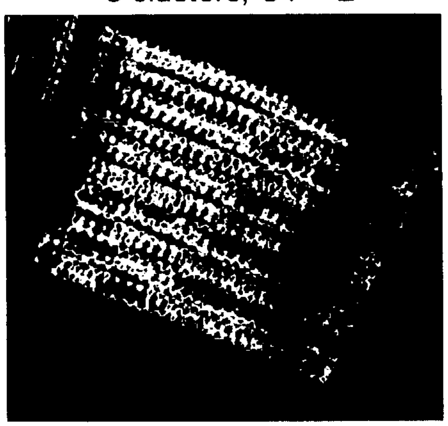


6 clusters, CT = 5

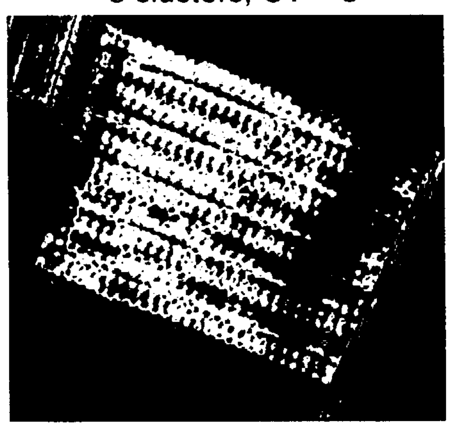


Notice that each of the above images contain 6 clusters and each of the below images contain 8 clusters. Keeping the number of clusters constant and varying the classification threshold (CT) entered in the ISODATA algorithm yields different results.

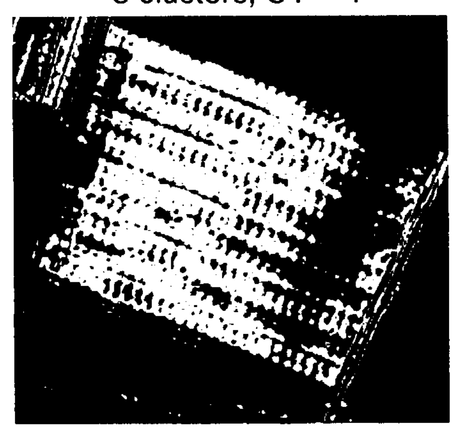
8 clusters, CT = 2



8 clusters, CT = 3



8 clusters, CT = 4



8 clusters, CT = 5

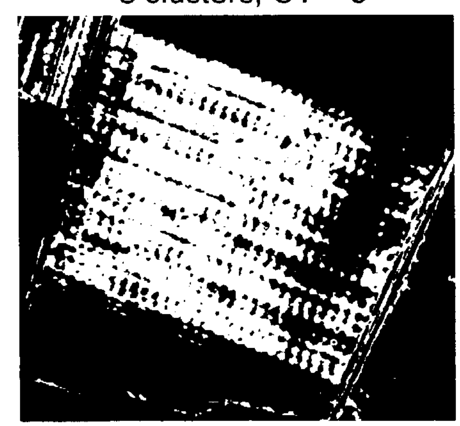


Figure 2. Varying the classification threshold (CT) provided slightly different results. Optimal CT appeared to be 5 for results that compared visually similar to CIR images.

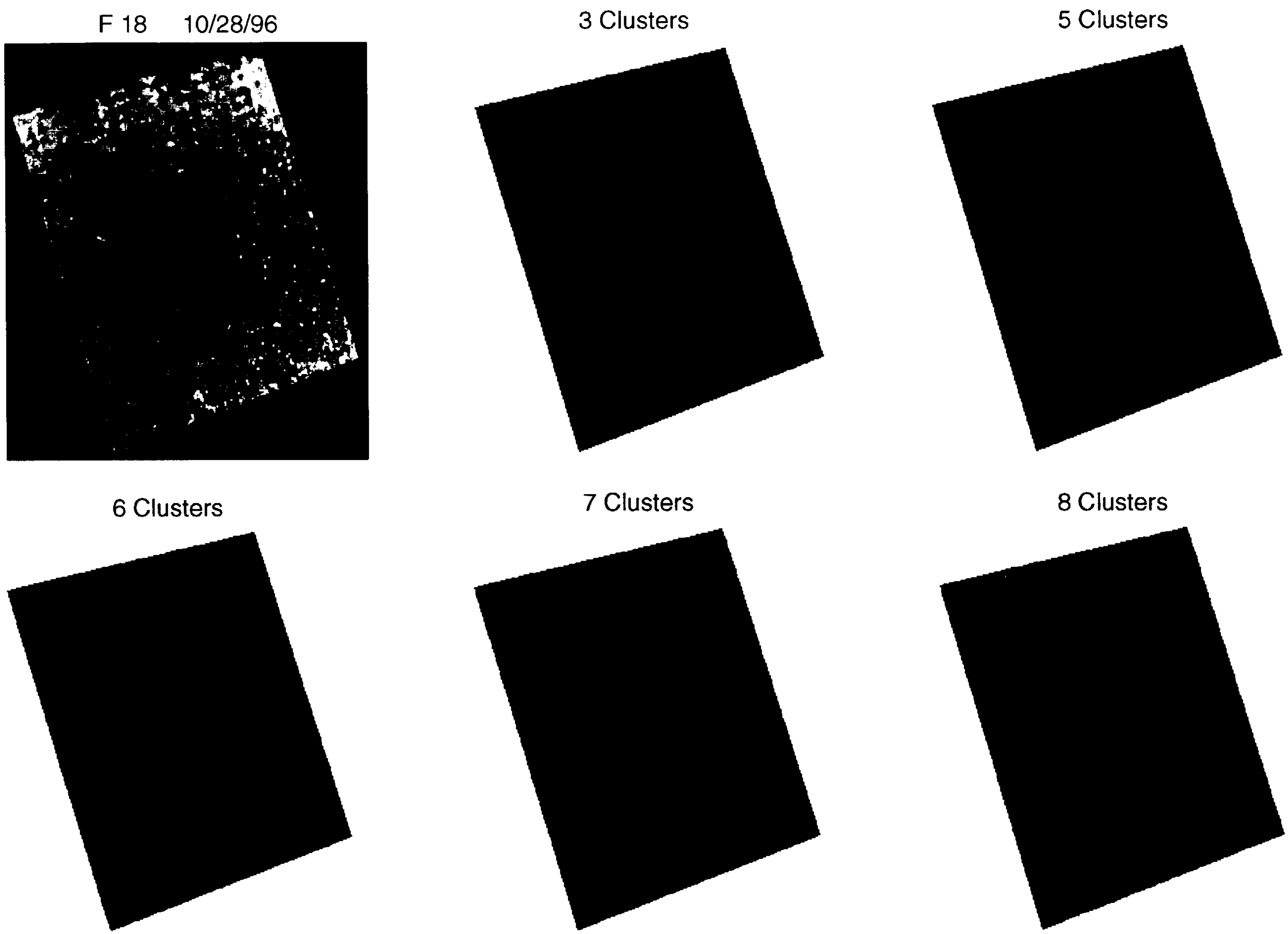


Figure 3. Varying the number of clusters for the October 28, 1996 image to determine the optimum number of clusters.

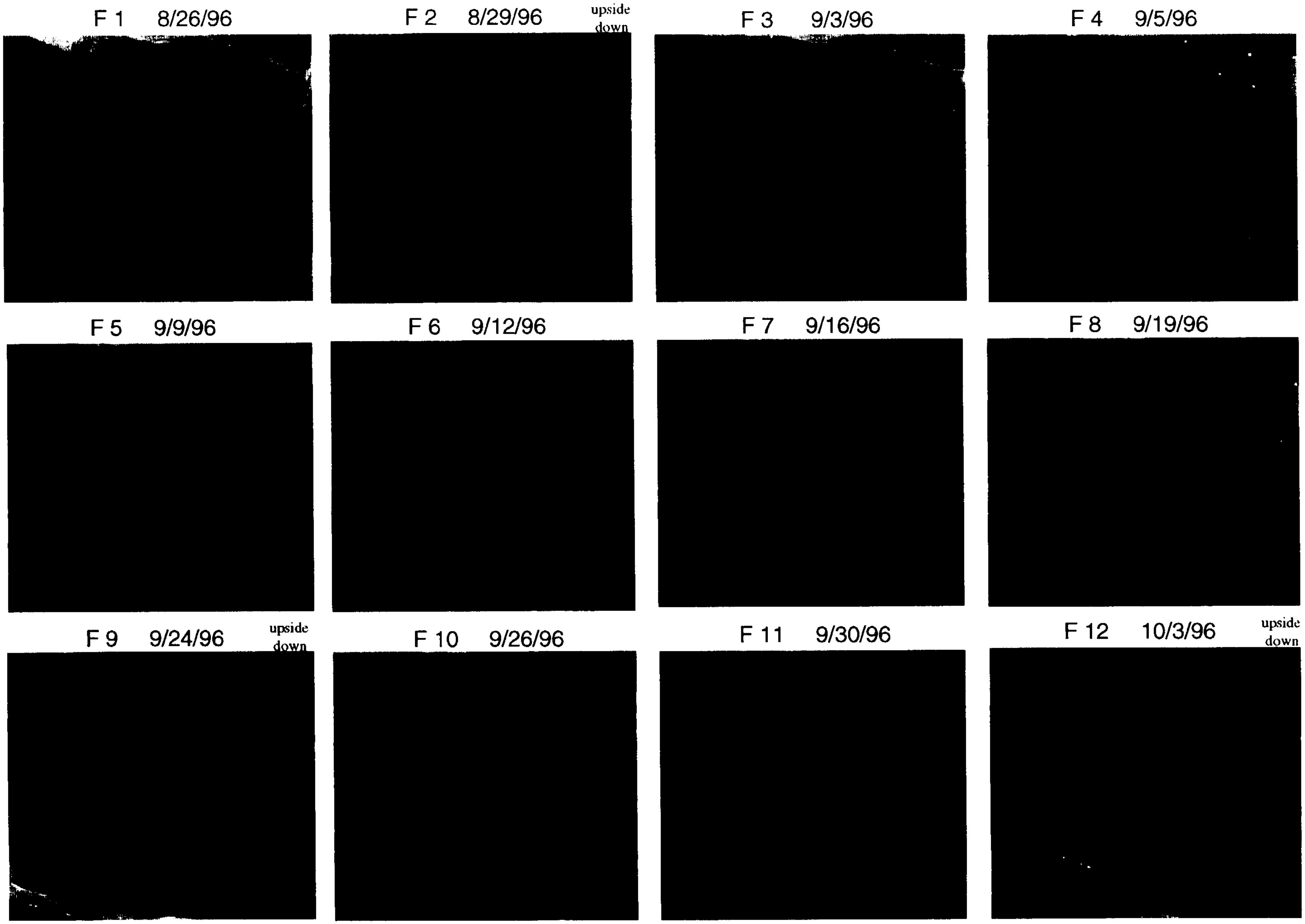


Figure 4. Aerial color infrared images for each of the 20 flight dates. The images have not been corrected for solar differences.

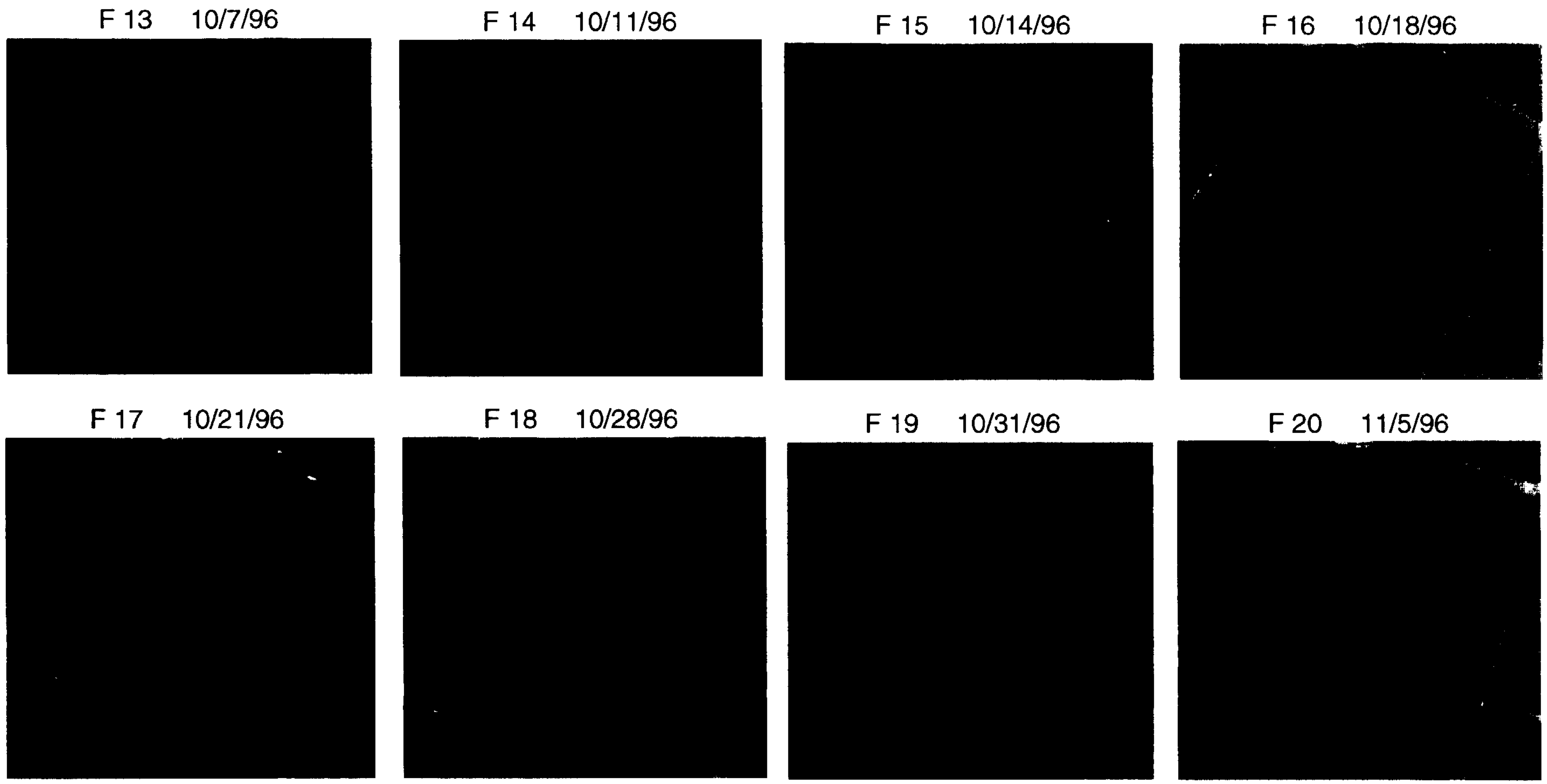


Figure 4. Continued.

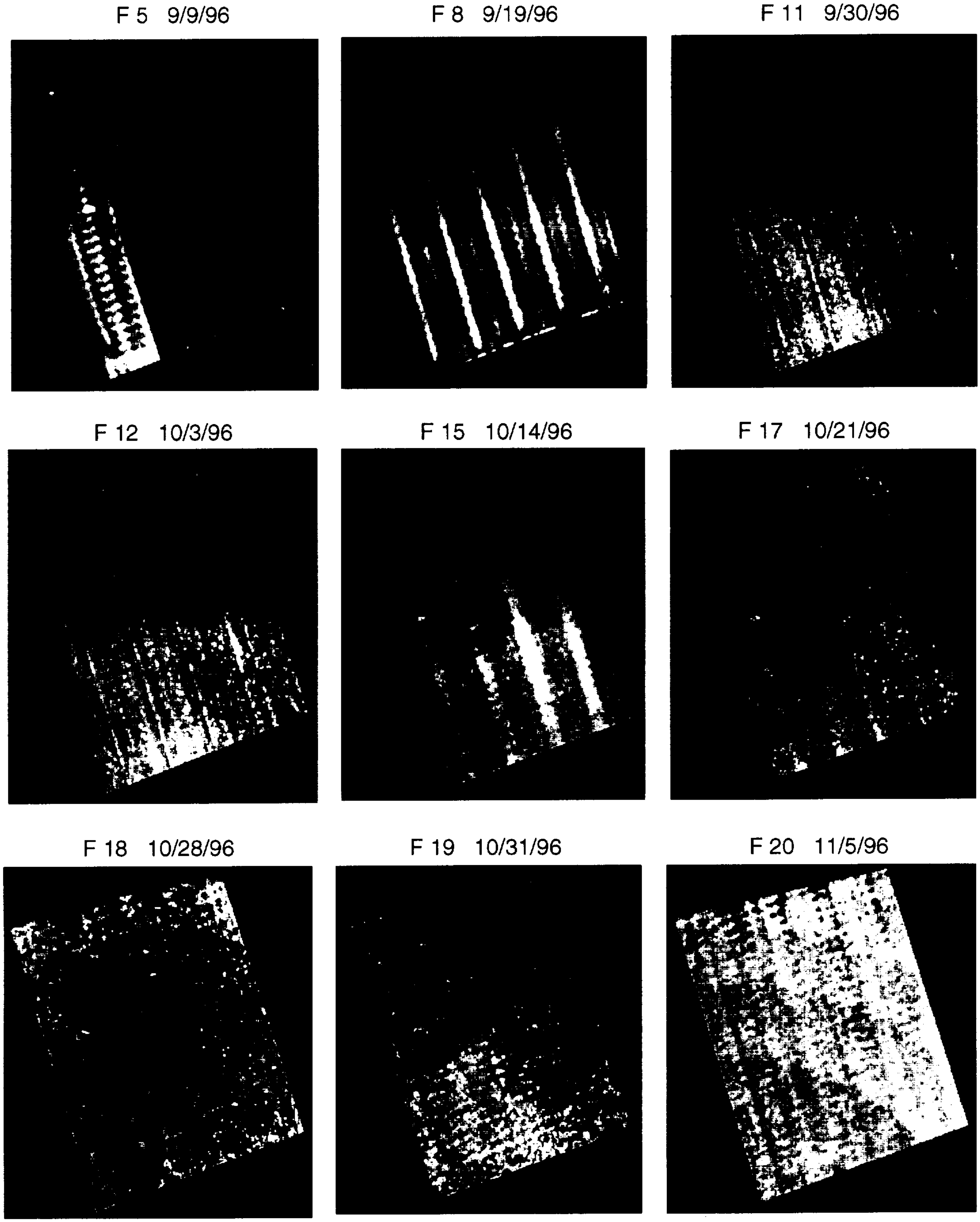


Figure 5. Solar and radiometrically corrected images from selected fight dates to demonstrate the field specific histogram stretch processing.

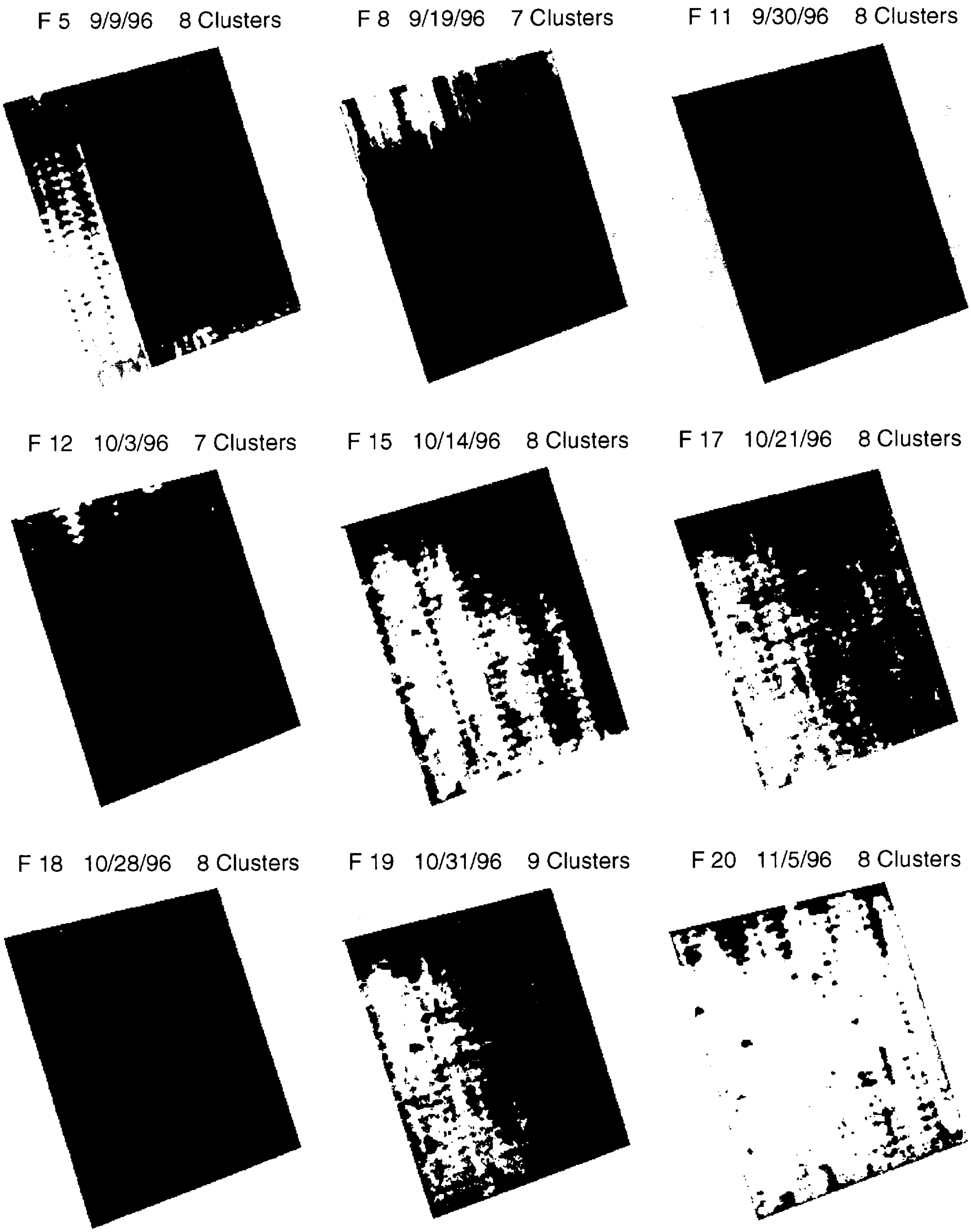
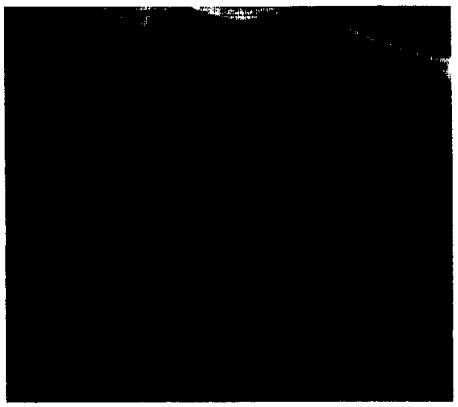
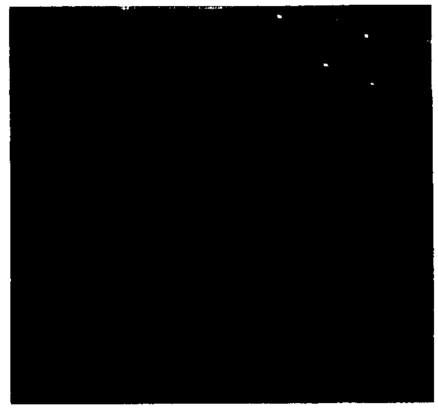


Figure 6. Field specific cluster analysis using ISODATA algorithm within the Eigenvector volume initialization option of the MutiSpec software.

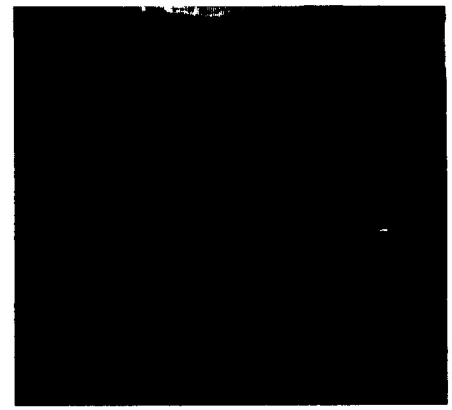
F 3 9/3/96



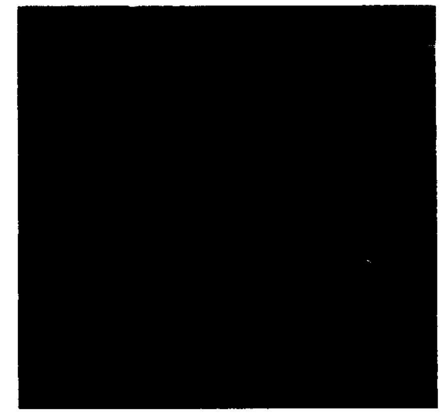
F 4 9/5/96



F 5 9/9/96

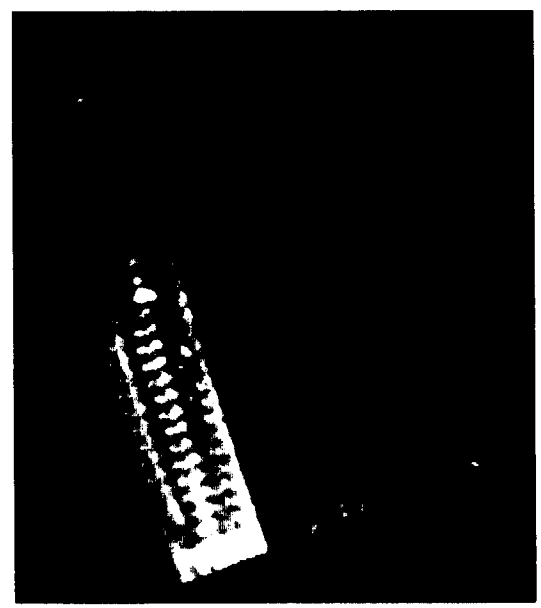


F 6 9/12/96



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.

F 5 9/9/96



8 Clusters

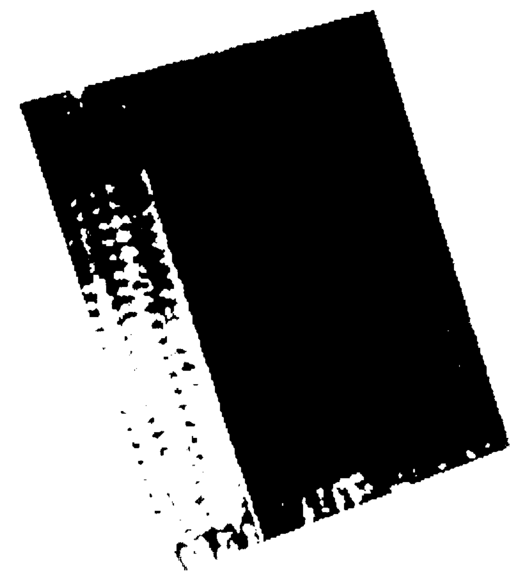
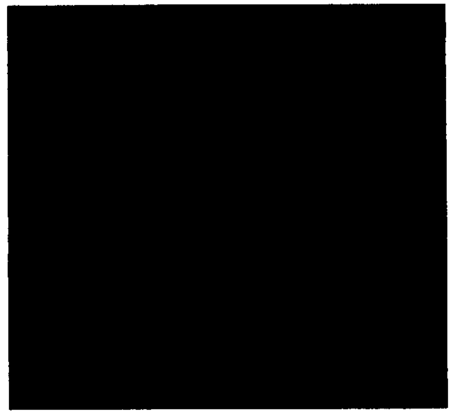
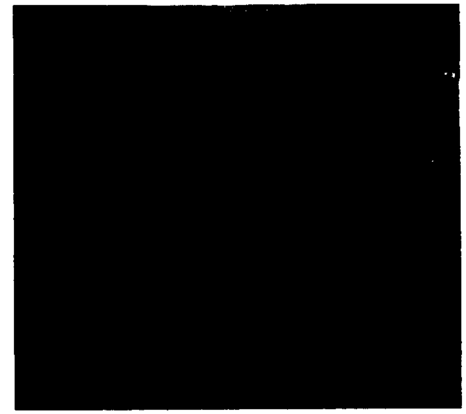


Figure 7. Cultivation activities observed in selected images.

F 7 9/16/96

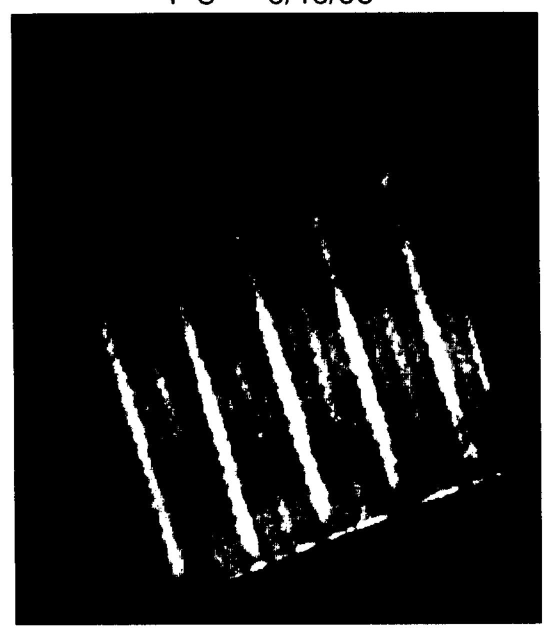


F 8 9/19/96



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.

F 8 9/19/96



7 Clusters

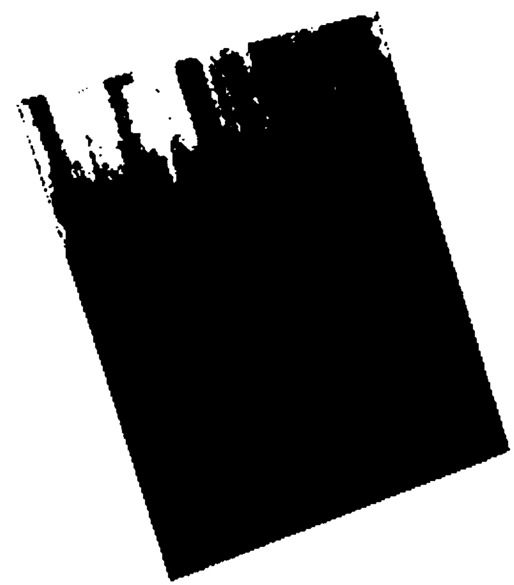


Figure 8. Irrigation and drainage patterns observed in selected images.

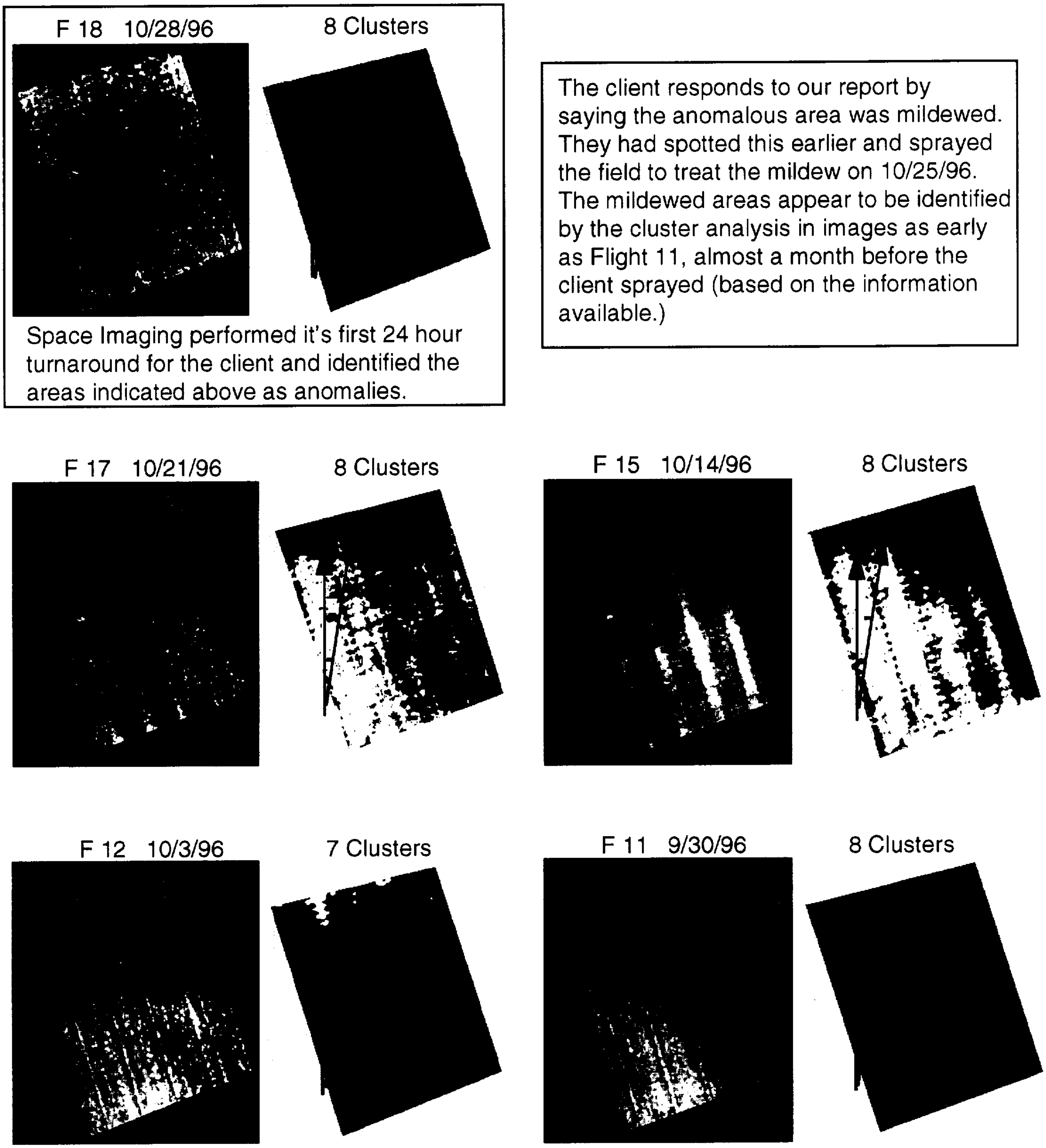
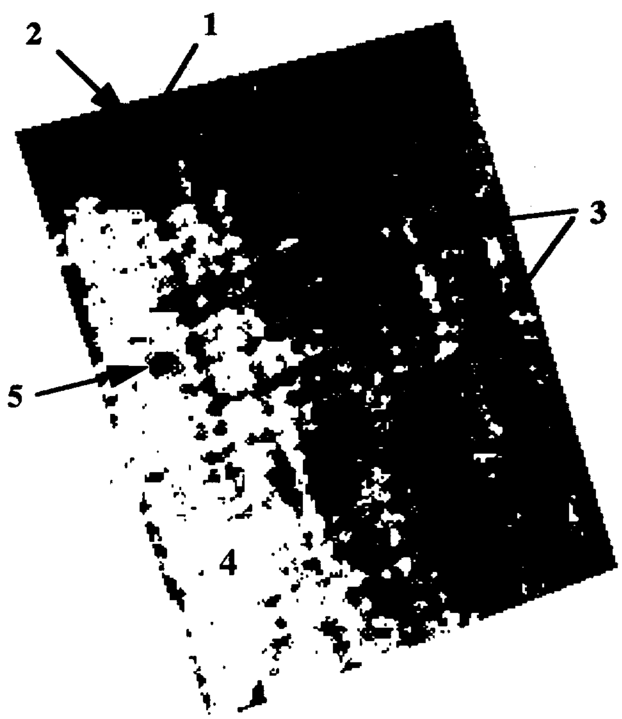


Figure 9. Distinguishing mildew in broccoli within the study site.

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.

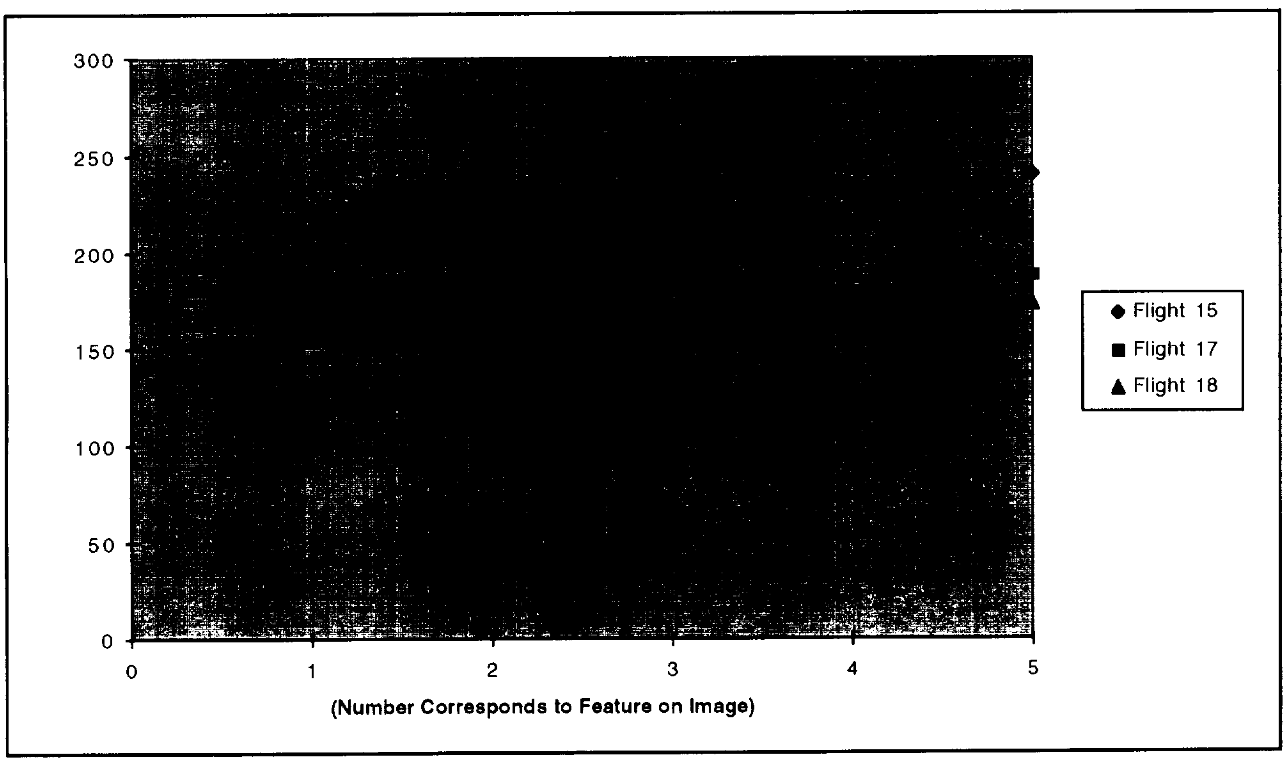


Figure 10. Relationship of cluster selection to spectral response over time.

Information Requirements for Precision Farming: The Next Decade

by Chris J. Johannsen, Jon H. Arvik and Judith A. Berglund

Space Imaging, Inc., Thornton, Colorado

Chris J. Johannsen

Information requirements for all phases of agriculture are changing very rapidly. Much of this change is being driven by technology and a focus on "precision farming" which is a current buzz word among agricultural circles. The term "precision farming" means using the best available technologies to tailor soil and crop management to fit the specific conditions found within an agricultural field or tract. Precision farming is sometimes called "prescription farming," and "site specific farming" and includes "variable rate technology." It has caused a resurgence of interest in remote sensing in addition to a reliance on geographic information systems (GIS) and global positioning systems (GPS).

All three technologies have been used intensively by NASA and the Department of Defense. Since Desert Storm, where GPS was demonstrated to have many practical uses, the technology has been readily adapted by agriculture for use in all phases of production. We have the opportunity to literally take "agriculture into the space age" with these technologies. Farmers will have services available to them that involve satellites collecting data, transmitting locational information, or providing data from a variety of other sources. Farmers can 1) analyze this satellite information with their own equipment, 2) rely on consultants to analyze and interpret the data for a fee, or 3) become associated with a company which provides the analysis as a service to insure retention of the farmer as a customer for other business.

Some farmers have already experienced the benefits of remote sensing data. Images from Landsat and SPOT satellites and aerial photography have been used to distinguish crop species and locate stress conditions. However, the cost and timeliness of obtaining the images have been the biggest deterrents in regular use of such data. The increased price of corn and soybeans during the 1996 growing season has caused farmers to explore opportunities for making more money per acre. Similarly, the recent government approval to use high-resolution images has allowed more practical applications of remote sensing to high-value, low-acreage crops.

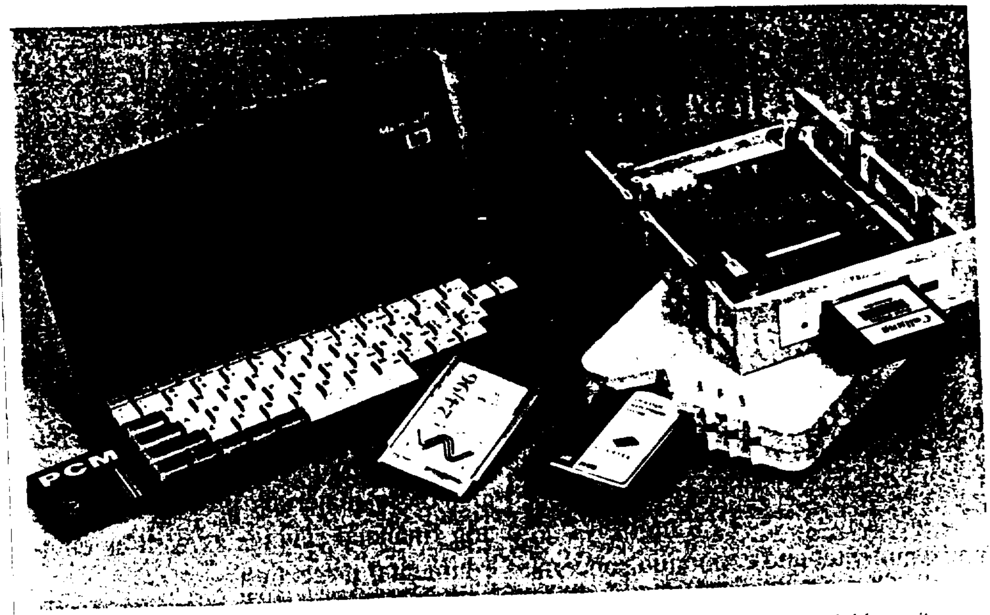
We predict that future satellite launches, including those from Space Imaging, the TRW Small Satellite, World View Imaging, Resource21, EarthWatch and GER, will be competing for the agricultural market with resulting value-added products specific to the needs of farmers, and we expect that reasonable prices will encourage farmers to participate. The remote sensing aspect of precision farming will need to be proven: it has been tested during the past few crop years by university, government and commercial researchers with a renewed interest of better spatial resolution and timeliness of delivery. Everyone is trying to determine wha one can see using remote sensin information and to establish a quicl way of getting the information to th farmer.

More attention is being paid to th type of information that farmers wi need. It would appear that mo remote sensing vendors will not b delivering raw images directly to a farmers. Rather they will provi data/information to the "informati

This article was presented at the Remote Sensing Science for Agriculture in the 21st Century Workshop, University of California, Davis, CA, October 23-25, 1996. It is reprinted with permission. Chris J. Johannsen is Director, Laboratory for Applications of Remote Sensing; and Professor of Agronomy, Purdue University. Currently he is Visiting Chief Scientist at Space Imaging EOSAT in Thornton, Colorado. BS and MS degrees are from University of Nebraska and Ph.D. from Purdue University. Dr. Johannsen has traveled in over 40 countries working on soil conservation, remote sensing and geographic information system concerns. He is the author or co-author of over 140 articles, papers, and book chapters and has edited a book on remote sensing. Johannsen is active in many professional societies, having served as International President of the Soil and Water Conservation Society. He is recognized with the distinction as "Fellow" of the Soil and Water Conservation Society, American Society of Agronomy and the Soil Science Society of America. Dr. Johaunsen is recognized as a national and international authority in land use applications of remote sensing technology and geographic information systems. Jon Arvik is Product Development Agronomist; and Judith Berglund is an M.A. Aspirant, University of Texas at Austin and currently a Student Intern, Space Imaging Inc., 9351 Grant St., Suite 500, Thornton CO 80229.

multipliers" or the "value-added vendors" such as agricultural business dealers, extension personnel, crop consultants, and special agricultural information services who in turn will analyze and interpret the data and deliver it to the farmer. Farmers are collecting a lot of supporting data and those analyzing the remote sensing data will need to gain access to the farmer's data. Large corporate farmers will be in a position to perform their own image analysis but we must remember the needed training aspects for this to be successful.

Farmers have recently gained access to site-specific technology GPS. GPS makes use of a series of military satellites that can identify the location of farm equipment within one meter of an actual site in the field. Knowing a precise location within inches has many valuable consequences: 1) locations of soil samples and the laboratory results can be used to prepare soil and yield maps, 2) fertilizer and pesticides can be prescribed to fit soil properties (texture and organic matter content) and soil conditions (relief and drainage), 3) tillage adjustments can be made as one finds various conditions across the field, and 4) one can monitor and record all of this data as one moves across the field.



Envoy Data Corporation's PCMCIA products for microcomputers allow data from yield monitors and GPS systems to be downloaded. Systems supported are John Deere, AG Leader, Case IH, Micro-Trak, SATLOC, and others. The Envoy product catalog is available on the Internet at http://www.envoydata.com

Other real values for the farmer include the ability to perform more accurate crop protection programs, provide more timely tillage, adjust seeding rates, and know the yield variation within a field. These benefits, if achieved, will enhance the overall cost effectiveness of the farmer's crop production.

Crop Management

The application of pesticides and fertilizers in proper proportions are of

> **"Precision farming will make a strong impact on ... farmers ... in the future."**

environmental and economic concern. Environmental regulations are calling for the discontinuance of certain pesticide applications within a prescribed distance of a stream, waterbody or well. Using a GPS along with a digital drainage map, the farmer is able to apply these pesticides in a more precise and economically sound manner. In fact, the spraying equipment can be preprogrammed to automatically turn off when it reaches the distance limitation or zone of the drainage feature. Additionally, farmers can preprogram the application rate of pesticide or fertilizer so that only the amount needed as determined by the soil conditions is applied, thereby allowing a variable rate from one area of the field to another.

Soil sampling has taken on new interest for many farmers since they can now adjust rates according to the test results. The more accurate the sampling, the more accurate the final management plan will be.

Much work is needed regarding the proper sampling patterns, the relationship of a soil test value to the actual conditions of the field, the proper depth of sampling, interpretation of results to the specific geographic location, innovative equipment for properly applying chemicals and fertilizers and many other factors. The farmer is looking at methods of applying these materials properly, providing financial savings as well as environmental protection.

Understanding the Soil Conditions

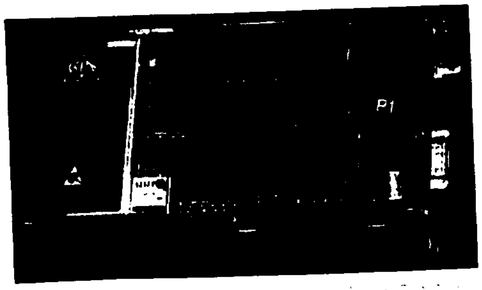
The ability to vary the depth of tillage as soil characteristics vary is important to proper seedbed preparation, control of weeds and fuel consumption, and therefore can reduce the cost to the farmer. Most farmers are using conservation tillage, or leaving residues on the soil surface for erosion control. The use of GPS in making equipment adjustments as one travels across the different soil types would mean higher yields and safer production at lower cost. This part of precision farming is in its infancy.

The equipment companies are announcing tillage equipment with GPS and have selected controls tailored to precision farming. Implement manufacturers, while wanting to accommodate farmer needs, are not really interested in major changes in the tillage equipment because of the costs of redesign, production and marketing. However, to remain competitive, it will be necessary to do so.

Seed Selection and Placement

Hybrid seeds perform best when placed at a spacing that allows the plants to obtain such benefits as maximum sunlight and moisture. This is best accomplished by varying the seeding rate according to soil conditions, such as texture, organic matter and available soil moisture. One would plant fewer seeds in sandy soil as compared to silt loam soils because of less available moisture. The lower seed population usually has larger heads (ears) of harvested seeds providing for a maximum yield. Since soils vary even across an individual farm field, the ability to change seeding rates allows the farmer to maximize this seeding rate according to the local conditions. A computerized soil map of a specific field on the GPS-equipped tractor can tell farmers and their equipment where they are in the field, allowing the opportunity to adjust this seeding rate as they go across their fields.

Recent results by major seed companies and universities show that wit present varieties, only a minor yiel gain can be achieved by adjustin seeding rates. This likely points to companies breeding for a wide range of climatic conditions for greater adaptability over a larger geographic area, thereby making a profit from a specific variety. This is likely to change in the future as farmers start to demand seeds for specific conditions.



NovAtel's PC Performance 3900 Series features a 2/3 length personal computer card designed for installation in PC compatible computers. This card allows integrators to provide accurate GPS functions in computer applications such as precision agriculture, GIS, mining, navigation, robotics and surveying.

Yield Variation

The proof in the use of variable rate technology (adjusting tillage, seed, pesticide and fertilizer) as one goes across the field is in knowing the precise yields. Combines and other harvesting equipment are being equipped with weighing devices or pressure plates that are coupled with a GPS. One literally measures yield "on the go." With appropriate software, a yield map is produced showing the variation throughout the field. This allows farmers to inspect the precise location of the highest and the lowest yielding areas of the field and seek to determine what caused the yield difference. It allows one to program cost and yield to determine the most profitable practices and rates that apply to each field location.

The use of yield monitors is a good place to begin if one wants to incorporate precision farming into their management. With a yield image, one can begin the search for what caused the high and low yields. It also helps familiarize farmers with imagery for an easy transition to remotely sensed images. Yield data from the same field over 3+ years would define the weak spots in the field and narrow down the probability of what is causing a low yield.

Information Requirements of the Future

GPS has already made a big impact on how farmers are viewing their farming operations. Now they are able to collect data, apply chemicals/nutrients, make observations and collect yield data at precise locations in the field. Where do information systems fit into farming in the next decade? They will be essential to nearly all operations on the farm.

Several companies are starting to market GIS record-keeping systems so farmers can record all of the field operations such as planting, spraying, cultivation and harvest (along with specific information such as type of equipment used, rates, weather information, time of day performed, etc.). In the very near future, this will occur automatically from GPS-based systems. Additionally, using remote sensing, farmers are able to record observations through the growing season such as weed growth, unusual plant stress or coloring and growth conditions. All of these data can be analyzed and added to the GIS using soil maps, digital terrain and field operations information as ground truth.

Precision farming can be used to guide additional field operations like spraying, fertilizing and irrigating. This also provides a permanent record on which to base management decisions . Precision farming will make a strong impact on the way farmers manage their farm operations in the future. We will see a steady growth of the remote sensing, GIS and GPS technologies as a result of the momentum already gained through the precision farming emphasis. AT

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 (creeging) - 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

CONFERENCE CALENDAR

[illegible]

6-7 First Annual Precision Agriculture Conference *in Columbia, MO. Contact: David Thompson or Jewel Coffman, 344 Hearnes Center, Columbia, MO 65211, Telephone: 573-882-2301.*

6-8 Canadian Int'l. Farm Equipment Show *in Toronto, ON. Contact: Judy Johnston, 1434 Chemong Road, Unit 3, R.R. 1, Peterborough, ON K9J 6X2, Telephone: 705-741-2536.*

11-13 California Farm Equipment Show and Int'l. Exposition *in Tulare, CA. Contact: International Agri-Center, Inc., P.O. Box 1475, Tulare, CA 93275, Telephone: 800-999-9186.*

12-15 National Farm Machinery Show *in Louisville, KY. Contact: Amanda Storment, Telephone: 502-367-5180.*

22-24 Annual Convention & Expo of the United Fresh Fruit & Vegetable Assoc. *in Orlando, FL. Contact: Shannon Delong, Telephone: 703-836-3410.*

26-March 1 Corn Classic 1997 *in Tampa, FL. Contact: National Corn Growers Assn., Telephone: 202-546-7611.*

[illegible]

5-8 Ag Expo Trade Show *in Lethridge, AB. Contact: Twyla Gurr, Telephone: 403-328-4491; Fax 403-320-8139.*

11-12 Triumph of Agriculture Expo Farm & Ranch Machinery Show *in Omaha, NE. Contact: Bob Mancuso, Telephone: 402-346-8003 or 800-475-SHOW.*

11-13 Hawkeye Farm Show *in Cedar Falls, IA. Contact: Penny Swank, Telephone: 507- 437-4577.*

17-21 9th GIS in Production Agriculture Workshops *in Waterloo, IA. Contact: Carol Snyder, Telephone: 970-493-1722.*

[illegible]

16-18 National Agri-Marketing Assoc. and Trade Show *in Nashville, TN. Contact: Judy Knoll or Shanon Weaver, 11701 Borman Dr., Ste. 100, St. Louis, MO 63146-2700, Telephone: 314- 569-2700.*

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.

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AD INDEX

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.

1/ Chris J. Johannsen is Professor of Agronomy & Director and Paul Carter is a Remote Sensing Specialist of the Laboratory for Applications of Remote Sensing (LARS) at Purdue University.

2/ Presented on August 7, 1997 at InfoAg Conference, Champaign, IL.

3/ Partial funding for this effort was obtained from Stennis Space Center, (NASA Grant NAG13-38).

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