FINAL REPORT

COMPUTER PROCESSING OF PEACH TREE DECLINE DATA

by

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INTRODUCTION

Description of Peach Short Life Problem

The peach tree decline problem has been recognized for many years. The condition exists in one form or another throughout the world where peaches are grown under intensive culture for a long period of time. This so-called "peach decline" has been referred to as "short life of peach trees", "the peach replant problem", "blight", and "winter injury". As most of the descriptive names indicate, there is a premature death of peach trees.

Peach orchards in the Southeastern United States have short productive lives. The average longevity of trees differs among locations--trees in Piedmont soils generally outliving those in Coastal Plain soils. In central Georgia where the state's greatest concentration of orchards is located, the average tree life is only six years. Because of the large number of tree deaths, many orchards are not profitable after their eighth year.

An estimated 200,000 to 300,000 trees died during the spring and summer of 1962. This rather substantial jump in tree decline was primarily due to unfavorable winter weather. This is commonly termed "winter injury". During the spring and summer of 1972, there was again a rather substantial rise in tree decline in the order of 200,000 trees, approximately 10% of the productive capacity of the state. The loss of trees continued in 1973 when a similar number of trees died. Peach tree decline is still a problem in Georgia and other portions of the Southeast although recent problems have not been as dramatic as those in 1972 and 1973.

Peach decline has been investigated in Georgia since 1929. The premature death of peach trees in the Southeast has been attributed to such disorders as Clitocybe root rot, peach tree borer, nematodes, bacterial canker, Pythiaceous fungi, cold damage, virus diseases, and repeated planting of peaches on the same site. Experiments with time of pruning, fertilization, and orchard management (mowing, herbicides, fumigation, and discing depth) have been beneficial but have not corrected the short life problem of peach trees.

A majority of scientists believe that cold damage is the cause of tree death and that predisposition to cold damage is a result of any or all of the above diseases, insects or improper cultural practices. Much effort has been expended in attempting to determine the cause and remedy of this problem, including analyses of climatic and meteorological, etomological, nematological, pathological, hydrological, and soil chemical factors, yet currently the nature of the decline remains elusive.

A high risk apparently exists that pecan and apple orchards are also threatened by a decline. Since the combined annual crop value of apples, peaches, and pecans averages approximately 41 million dollars for the State of Georgia and 180 million dollars for the southern United States, there is an urgent need to solve this problem to preserve the balance of the economy in the region.

Previous Remote Sensing Studies

During 1970 and 1971, 12 peach and pecan groves in southwestern and middle or central Georgia, that had been previously ground-mapped as containing one or more insect pests or diseases, were surveyed with infrared aero-film from altitudes of 600-4500 feet. Detection of three insect infestations, one mite infestation, and three diseases of peaches and pecans was enhanced by infrared film. Structural variations of foliage and slight color changes were evident for peach trees with European red mite infestations and for pecan trees with black pecan aphids, Prionus root borers, and Clitocybe root rot. Detection of infestations of yellow aphids and two diseases (phony peach and pecan bunch) was greatly enhanced because affected trees were colored differently on infrared film.

Following the peach tree death in the spring of 1972, the Georgia Department of Agriculture requested aid from the Environmental Applications Office, NASA/MSFC, Huntsville, Alabama, to assist in this disaster area in determining the extent of the peach decline and to determine the possibility of using the remote sensing techniques to predict future decline. Since the USDA Southeastern Fruit and Tree Nut Research Station, Byron, Georgia, had previous experience with infrared photography, it was asked to cooperate with NASA and to coordinate the Georgia effort for the peach tree decline study.

NASA/MSFC conducted two over-flights of the principal peach tree decline areas during the summer of 1972. Activity was concentrated in Peach, Bibb, Crawford, and Houston counties of Central Georgia. Twelve sites were chosen for the primary test. These sites contained peach orchards ranging from heavy decline (approximately 75%) to no appreciable decline. The first flight of June, 1972 was at altitudes of 1500, 3000, 6000, 10,000, and 12,000 feet with Kodak Aerochrome Infrared 2443 film. The second flight a few days later was flown at altitudes of 1500, 3000, 6000, and 10,000 feet using infrared 2424 film using a four band multispectral camera system. Photographic images are recorded in three visible and one near-infrared wavelength band simultaneously with this system. The multispectral sensing program was designed to permit detection of additional anomalies and allow the opportunity to view the peach orchard in three additional portions of the spectrum.

Results from study of the film from the first flight indicated that trees in advanced stages of decline can be counted from aerial photographs with accuracies above 90%. These trees were doomed to die before the end of 1972 growing season. The trees of importance in 1972 were those that looked or appeared healthy from the ground, for some of these were to be decline trees in the spring of 1973.

Two other studies were carried out using the color infrared and four band multispectral imagery flown by MSFC. One study was internally funded at the Engineering Experiment Station, Georgia Institute of Technology. The other was conducted by Computer Sciences Corporation, a support contractor to the Data Systems Laboratory at Marshall Space Flight Center. The methodology and results of these studies are discussed briefly below.

Both studies involved the digitization and computer processing of some of the multispectral and color infrared film to determine the success of automatic recognition of declining trees. The results of the computer processing experiments were used to plan future thermal scanner and multispectral scanner data collection missions over the test orchards.

A typical system for the digitization electronic enhancement of imagery consists of a television camera or micro-densitometer for an input, a computer or computer controlled unit for processing, and a television monitor and/or computer printer for output of the results. The multispectral or color infrared transparency is viewed by the television camera and the information in the image is transformed into a digital code so that it can be computer processed. Once the image is stored in the computer memory, various statistical processing techniques can be employed. The technique used in this study is known as multi-spectral density slicing, a form of spectral pattern recognition which, in effect, sorts out areas of the image which look alike to the computer. This process is very similar to the human process of recognizing and sorting objects by color differences.

After the statistical processing has taken place, areas of the image which have similar spectral characteristics (or look alike) are placed in categories. The number of categories depends on the number of different things (peach trees, weeds, bare ground, etc.) in the picture.

The Engineering Experiment Station investigated specifically the computer processing of the color infrared imagery. The actual processing of the peach orchard imagery was accomplished using General Electric's Image 100 system. The major advantage of using this system for the study is that it allows the results to be displayed rapidly on a color television monitor. Permanent records of the results were made by photographing the screen and by obtaining computer printouts.

As previously mentioned, the processing technique is known as multi-spectral density slicing or electronic image enhancement. The color infrared transparency is viewed with a color television camera. The red, green, and blue signals from the TV camera constitute three channels of data derived from the three dye layers on the film. These data can then be classified in spectral space so that all areas of the film having similar color characteristics fall into one category.

The original density slicing was performed at 32 levels per band for a total of $32^3 = 32,768$ categories. However, since this proved to be more categories than were necessary, the data were compressed to 125 categories with approximately 20 categories containing the information useful to the study. These categories were then displayed individually and in combination so that comparisons could be made with ground truth.

Computer Sciences Corporation (CSC) analyzed the four band multispectral photography by digital computer. The four bands of imagery (photographic transparencies) were digitized separately and digitally registered with the aid of a computer. CSC then utilized two different supervised classification methods (maximum likelihood and sequential linear) in analyzing the data.

Both studies concluded that it is feasible to use airborne multispectral data to identify declining peach trees and to separate these trees from the healthy trees and other vegetation in the peach orchard (e.g, weeds). CSC reported an approximate 70% correct classification. EES reported the identification of trees in several different stages of decline.

Overview of Current Project

This project is intended to extend the scope of previous efforts to the computer processing of digitally acquired thermal and multispectral scanner data. Digital data have several advantages over photographic data in evaluating plant stress. Specific objectives of this project are:

- Determination of the extent to which thermal and/or multispectral scanner data can be used to detect peach tree decline in its early stages.
- An analysis of the best techniques for detecting and studying peach tree decline.
- Determination of the best MSS band(s) to use in early detection of peach tree decline.
- An evaluation of the potential application of the use of these data in future peach tree disease studies.

The data available for processing during the time frame of this project were: October 18, 1973 thermal data; May 8, 1974 multispectral scanner data (24 channel); and June 9, 1976 multispectral scanner data (11 channel). The software available for data processing includes programs for level slicing, unsupervised classification and supervised classification. The computer capability is the Georgia Tech Cyber 74 and the Earth Resources Data Analysis System (ERDAS).

Organization of the Report

Section II of this report describes the thermal and multispectral scanner data available for processing, the equipment used in the processing effort, and the software/analysis techniques used. Section III describes the methodology which was used in the project. Section IV presents the results of the data processing effort and the conclusions that are drawn from this project.

Appendix A presents a brief discussion of the applicability of these techniques to other plant stress studies and summarizes the relevant considerations in designing other experiments. Appendix B is an annotated bibliography of useful reference materials and related agricultural studies. Appendix C contains listings of computer software for unpacking and display of data types used in this study.

II

DATA, EQUIPMENT, AND SOFTWARE DESCRIPTIONS

Data

Three sets of aircraft digital remote sensing data were utilized in this study.

- October 18, 1973 Thermal data
- May 8, 1974 Multispectral scanner data
- June 9, 1976 Multispectral scanner data

The 1973 thermal data (8-14μ) were taken late in the growing season to determine whether or not decline could be predicted for 1974. The data were taken with the NASA/JSC RS14 thermal scanner at approximately 2000 ft. altitude from 12:30 PM to 1:00 PM EST.

The 1974 multispectral scanner data were taken with the NASA/JSC 24 channel scanner (Bendix). This flight was scheduled for the early portion of the growing season to test for previsual detection of declining trees. (Previous studies with color infrared film had indicated that this was possible.) The requested altitude for this flight was 2000 ft; however, the actual flight was at 3100 ft.

The 1976 multispectral scanner data were taken with the NASA/MSFC 11 channel scanner (Daedalus). These data, taken in June of 1976, were intended to correct deficiencies, both in terms of timing and quality, of previously analyzed multispectral scanner data.

Problems with all three data sets severely limited the analyses which could be performed and the conclusions which could be drawn from these analyses. The nature of the problems encountered is discussed fully in Section III, Methodology.

The ground truth data for all the peach orchards investigated were supplied by personnel of the USDA Southeastern Fruit and Tree Nut Research Station at Byron, Ga. Data were available for the years 1972, 1973, 1974, 1975, and 1976. The peach orchards were mapped by experienced USDA researchers and each tree in the orchard was categorized (by visual examination) as to its state of health. Two diseases were specifically identified: phony peach and peach short life. Each tree that was identified as having one of these diseases was categorized as to the level (or stage of advancement) of the disease.

The ground truth maps of the orchards were provided to the project by USDA. In addition to specifically identifying and classifying the declining and phony trees, all dead/missing trees were identified as well as seedlings and trees with anomalies not related to either of these diseases. A sample of the type of ground truth available is shown in Figure 1.

Equipment

The computer equipment available for processing these peach orchard data included the Georgia Tech Cyber 74 and the Georgia Tech Earth Resources Data Analysis System (ERDAS). ERDAS was the primary system utilized in processing these data. ERDAS was designed and constructed by EES to allow true interactive digital processing of all types of remote sensing data. Figure 2 shows the organization of the ERDAS components. ERDAS consists of a set of 4 modules: 1) minicomputer subsystem, 2) input medium, 3) hardcopy output medium, and 4) display subsystem. The minicomputer subsystem consists of a NOVA-2/10 minicomputer with 64000 bytes of core memory and a dual Diablo disk system with 5.0 megabytes of storage for programs or data.

The input medium for the ERDAS system is a set of two nine track dual density (phase encoded/NRZI selectable) magnetic tape drives and controller -- both drives with a capacity for 10½ inch reels of tape. The hardcopy output medium is a twenty inch electrostatic dot matrix printer/plotter. Scaled maps of Earth Resources data can be made using this medium. A CROMALIN(R) photographic process may then be used to generate a color coded output hardcopy product. Color products may also be obtained through services offered by commercial producers of film writers.

The display subsystem consists of a high quality video monitor interfaced to the minicomputer for complete user interaction in the choice of training samples for earth resources classification. Elements of the subsystem are:

- Color monitor
- Trackball cursor
- Self contained refresh memory
  a. one image 512 x 512 elements by 8 bits or
  b. three image 256 x 256 elements by 8 bits

ERDAS is a completely software oriented system. Training statistics can be calculated instantaneously for cursor located fields. A histogram may then be displayed to check homogeneity of training fields. Classification may be performed on stored data sets or data sets read in from the system's magnetic tape drives. This system is inherently interactive, and ratioing of MSS bands, level slicing, classification, and change detection software will provide display data to be fed to the color monitor.

COLUMN \ ROW	1	2	3	4	5	6	7	8
1		P_3	X	X	X	X	X	X
2			P_3	D_2	X	P_3		
3		X		D_1	X		X	
4			P_3	P_3	X		P_3	
5			P_3		D_3			P_3
6					X	X		
7			X	X	X		D_1	P_3
8		D_3	D_2	D_3	X			
9			D_2	X	D_1	P_3	P_3	P_2
10				D_2	X	P_3		
11			X	X	P_2	X		P_1
12	X				X	X	X	
13	D	D_3	X	X	X	P_3	P_3	P_3
14	P_3	D_2	X	X	X	X		
15	D_2	X	X	X	X	P_3	P_1	P_3
16	P_3	D_3	X	X	X		P_1	
17	D_1	P_2	X	X	X			D_2
18	D_1	D_2	X	X	D_2	X	D_3	
19	P_3	D_3	X	X	X	X	D_1	P_3
20	X		X	X	X	X	X	X

Legend: P_1 - P_3 - Severity of Phony Peach (3 = severe)

D_1 - D_3 - Severity of Decline (3 = severe)

X - Missing Tree

Figure 1. 1974 Ground Truth for One of the Research Peach Orchards (Courtesy of USDA, Southeastern Fruit and Tree Nut Research Station)

Figure 2. Georgia Tech ERDAS System

The ERDAS may be used in either of two general modes. In Mode 1 an image may be displayed on the display screen with a resolution of 512 by 512 elements with data values ranging from 0 (black) to 255 (white). These data values may be color coded via a pseudo color memory to produce a false color display of the image. The user may select sixty-four display colors from a possible variety of 4096 colors (4 bits for each color gun). The colors are arranged in the pseudo color memory such that, for example, data values 0-3 are assigned the first color values, 4-7 are assigned the next, etc. A pseudo color scale that is often used varies from dark blue to green, yellow, orange, and red with different shades and combinations of these colors filling out the chart. This method is often used in displaying an image in as nearly a natural color state as possible. Figure 3 is a block diagram of the steps necessary to accomplish this display.

The second display mode of the ERDAS has a resolution of only 256 by 256 elements on the television screen but three multispectral scanner or other images may be displayed at the same time. As before, each image contains data values between 0 and 255, but in this case each image may be assigned specifically to one color gun of the television (Figure 4). For Landsat data, normally three of the four channels of Landsat data are assigned to individual color guns. If channel one and channel two (visible bands) of Landsat data are applied to the blue and green guns, and channel 4 (near infrared) is applied to the red gun, a simulated near infrared image is displayed on the screen. This type of picture incorporates three channels of Landsat data at one time and results in a very similar color scheme to that of color infrared aerial photography. Similar techniques are available for

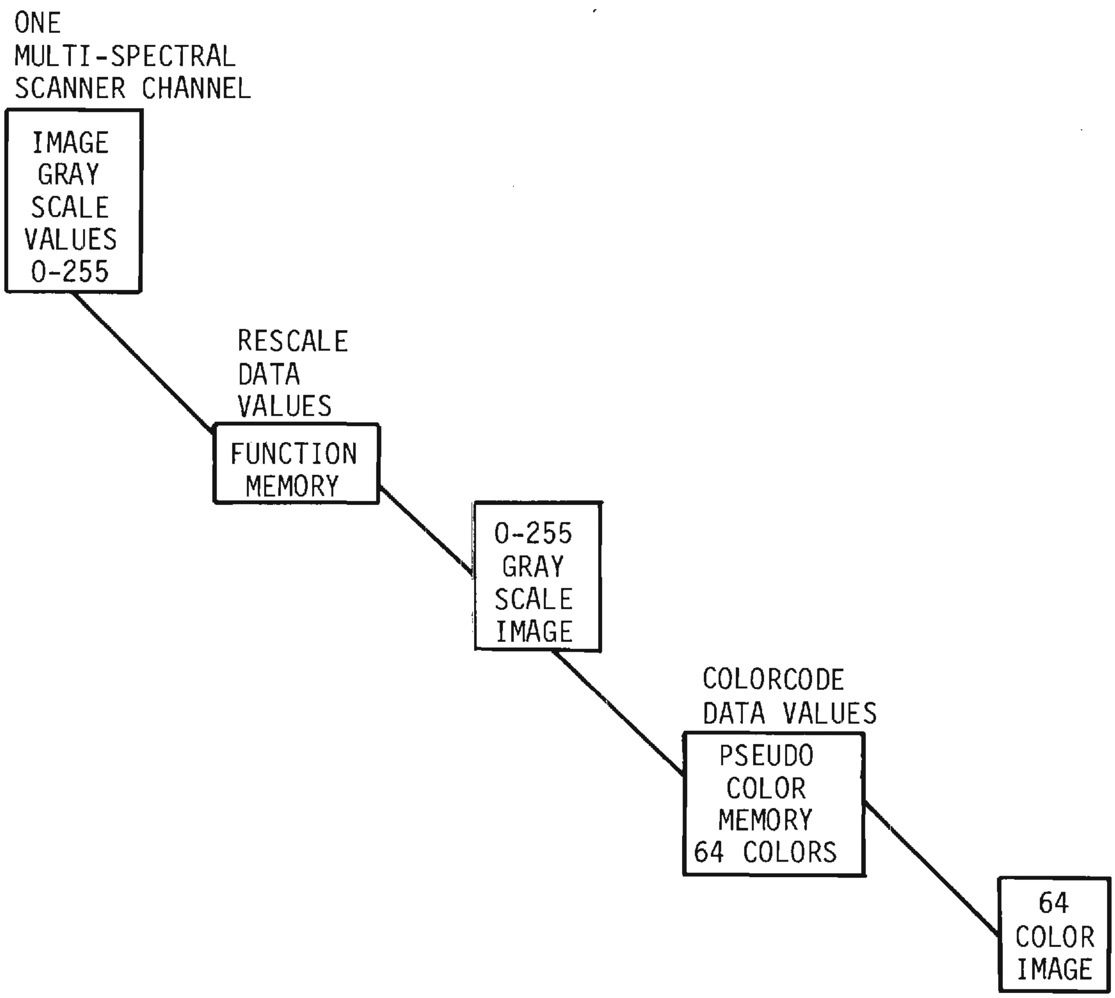

Figure 3. Color Video Display.

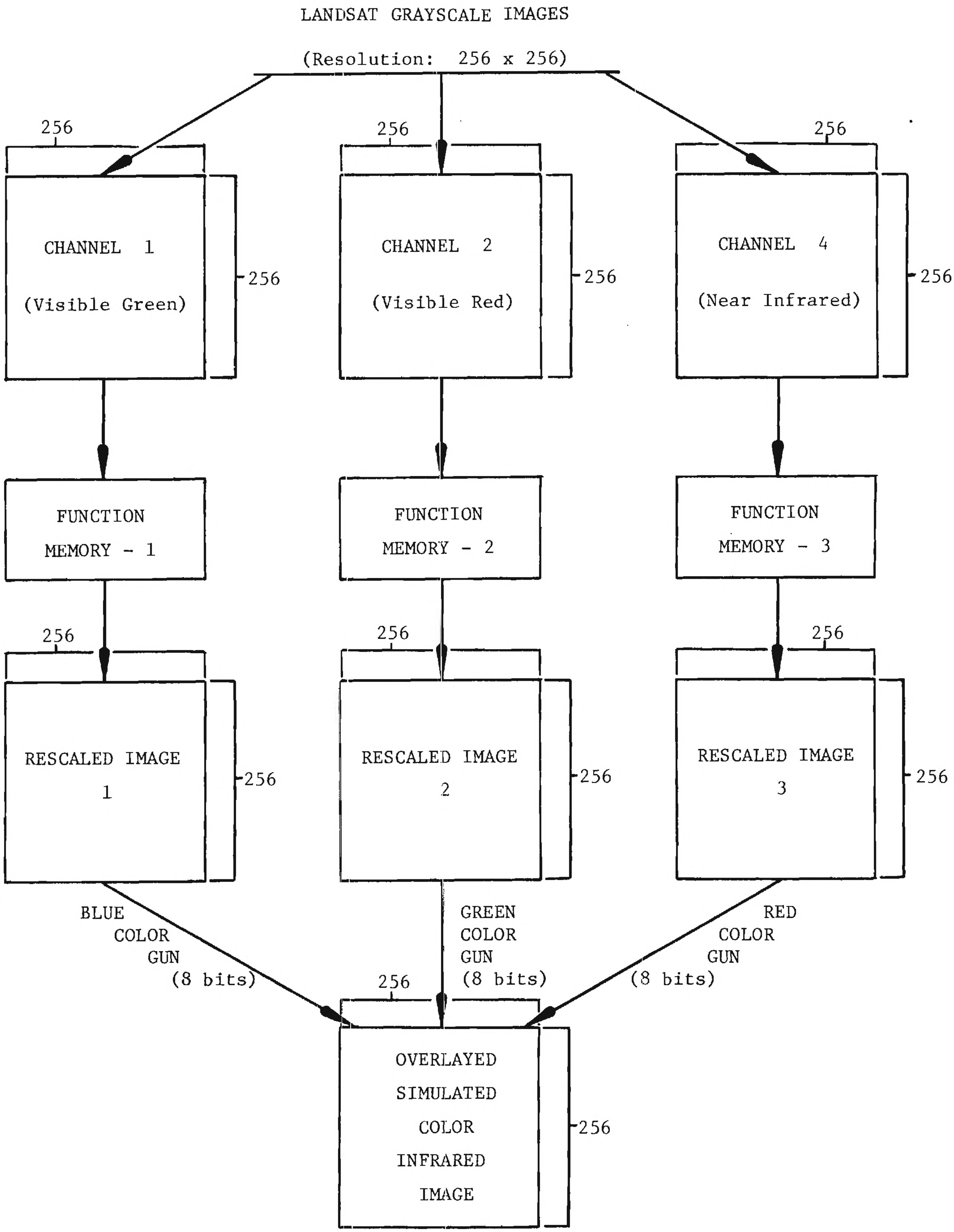

Figure 4. Block diagram of Mode 2 of the Color Video Display.

display of aircraft multispectral scanner data. This technique has been most effective in the location of training fields for classification of MSS data and as an aid in interpretation of the raw MSS image.

Software

Numerous software packages are available on ERDAS for processing Landsat and aircraft multispectral scanner data. Among the available analysis modules are:

- Supervised Classification (Maximum Likelihood)
- Linear Supervised Classification
- Sequential Unsupervised Classification (Clustering)
- Non-Sequential Clustering (ISODATA)
- Histogram Generation
- Level Slicing
- Registration and Rectification
- Factor Analysis
- Gray Scale Display
- FFT (Fast Fourier Transform)
- Change Detection
- Polygon Training Field
- Polygon Classification
- Edge Enhancement
- Ratioing

The primary techniques utilized in this project are level slicing and enhancement algorithms.

III

PROJECT METHODOLOGY

Introduction

The remote sensing data utilized in this project were supplied by NASA. The Earth Resources Office of NASA/Marshall Space Flight Center (MSFC) provided coordination for all three flights. The first two missions were flown by NASA/Johnson Space Flight Center. The third mission was flown by MSFC. The suggested dates for the missions were provided by personnel of the USDA Southeastern Fruit and Tree Nut Research Station at Byron, Georgia, based on their experience with peachtree decline and their knowledge of orchard conditions. These USDA personnel also provided the ground truth data utilized in the project. Flight parameters (altitude, etc.) were specified by Engineering Experiment Station (EES) personnel.

After each mission, computer compatible tapes of the thermal and MSS data were forwarded to EES. The data processing techniques used in this project consisted of level slicing (thermal data), linear and nonlinear density stretching, and pseudo color enhancement. Programs developed at EES were used for all processing.

Data Processing: October 18, 1973 Thermal Data

This flight was originally scheduled for September, 1973, but operational problems prevented its execution as planned. The purpose of this late season flight was to determine the possibility of predicting decline that would take place in the spring of 1974, based on the condition of the peach trees in late 1973. Had the flight been conducted in September, this hypothesis could have been tested. October 18, however, proved to be too late even to differentiate levels of decline.

Comparison of the level-sliced 1973 thermal data with 1973 and 1974 ground truth showed no correlation between levels categorized and the state of decline of the trees. Several level slicing techniques were utilized, but none of these evidenced a meaningful correlation with the ground truth data.

In general the data were noisy with data dropout problems intensifying the effort needed to locate the test field. Software had to be developed at EES for the unpacking and display of the thermal data on the newly developed Georgia Tech ERDAS system. The software needed for the display interface was complex and required extensive debugging. Since very little documentation was provided with the magnetic tapes, effort was expended in a trial and error mode to determine the proper format of the thermal data. One program generated at EES for the unpacking and display of the thermal data is listed in Appendix C. Figure 5 is a gray level photograph of the ERDAS display screen showing level sliced thermal data over the lime block test field. Some dropout is evident in these data. The primary limit to the usefulness of this data set seems to be the scanner resolution. As can be seen from Figure 5, the maximum number of pixels wholly contained in one peach tree was 12. In most cases the number of pixels was six to nine. For comparison, the number of data points per tree for the analysis of digitized color infrared data in the earlier EES study ranged from 40 to 110. Since any statistics or distribution for a set of nine points would be extremely questionable,

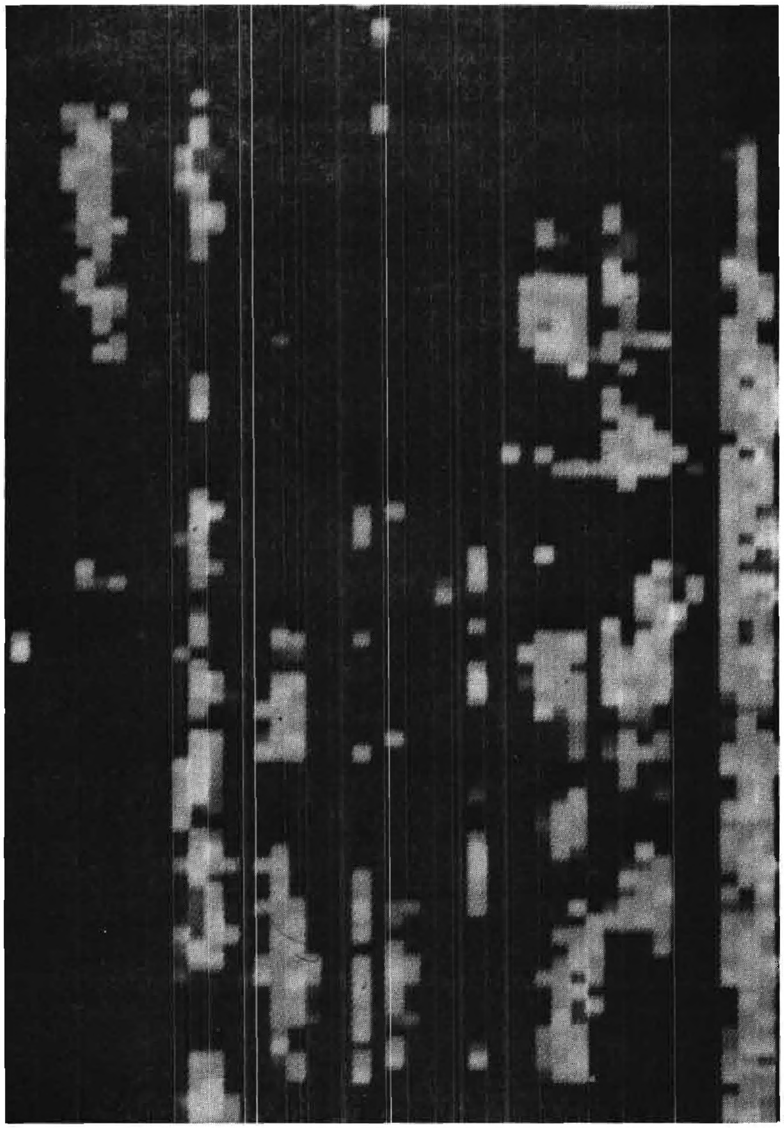

Figure 5. Level Sliced Thermal Data

only enhancement techniques and human interpretation were used to try to differentiate between diseased and healthy trees. Figure 6 is a ground truth map of the orchard showing healthy trees with an H, diseased trees with a D, and removed trees with an X. None of the enhancement techniques employed at EES were able to allow discrimination of healthy and diseased trees. The prime reasons for this failure were probably time of year of coverage and insufficient resolution.

Data Processing: May 8, 1974 MSS Data

Because of the failure of the late season thermal data to yield any useful information, a flight was scheduled for early 1974 utilizing a 24 channel multispectral scanner. At the time of the flight, however, only 12 channels were operable. Moreover, this was not the only problem with the data: a flight altitude of 1500 feet was requested and rejected. A compromise altitude of 2000 feet was agreed upon. This altitude was calculated to provide a sufficient number of data points for each tree. When actually flown, the flight altitude was approximately 3000 feet.

The processed data revealed an insufficient number of data points per tree to correlate with ground truths. At most, each tree had four data points; the majority of the trees were represented by one to three data points. Since no correlation between processed data and ground truth was possible, it was not possible to select the "best" bands for identifying decline.

Figure 7 shows a level sliced and enhanced image of one of the peach short life fields. The insufficient resolution of data is evident from this image.

	1	2	3	4	5	6	7	8
1	X	X	X	X	X	X	X	X
2	D	D	X	X	X	X	H	H
3	D	D	X	X	D	X	H	H
4	H	H	X	X	X	H	H	H
5	D	D	D	X	X	H	D	H
6	H	X	H	X	X	H	H	H
7	D	H	X	X	X	X	H	H
8	H	D	X	X	X	D	H	D
9	X	H	H	H	X	X	X	H
10	H	H	X	X	H	X	H	H
11	X	H	H	D	D	D	H	H
12	X	H	D	H	D	D	H	H
13	X	H	H	H	X	H	H	H
14	X	D	X	X	D	H	H	H
15	X	H	H	H	H	D	H	H
16	X	H	H	H	D	H	H	H
17	X	H	H	H	X	H	D	H
18	X	X	H	H	X	H	X	H
19	X	H	D	D	D	H	H	H
20	X	H	X	X	X	X	X	X

Figure 6. Ground Truth for 1973 Thermal Data

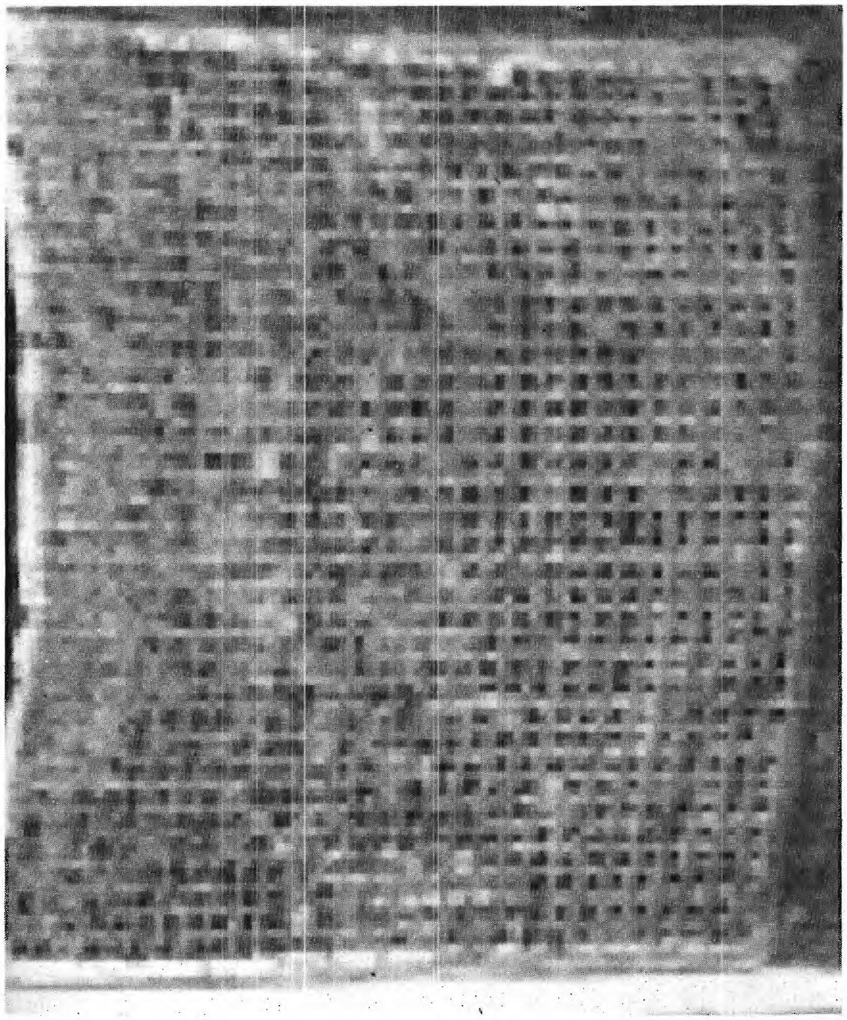

Figure 7. MSS 24 Channel Data of Peach Short Life Test Field

There was a significant amount of confusion between EES, NASA/MSFC and NASA/JSC when EES received the multispectral tapes as to whether the 11 channel or the 24 channel scanner had been used to take the data. Differing format descriptions had to be sifted through to decide which format and which sensor were used. While efforts were being pursued at NASA/MSFC and NASA/JSC to ascertain the sensor type, EES went through a trial and error procedure with the differing formats to decide which one was valid. The sensor type was finally found to be the 24 channel scanner and the data were extracted for the test fields. The primary cause for failure of this part of the test was the insufficient spatial resolution of the data.

Data Processing: June 9, 1976 MSS Data

The recent availability of an MSS at MSFC precipitated a change to this equipment for the third flight. All the mission parameters were reviewed in light of the previous failures. This mission did indeed produce data capable of analysis; however, no data were taken over the two research orchards for which ground truth data were available. The flight lines did not overlap and the desired orchards were between flight lines. Although peach trees in this data set are differentiable in categories using enhancement techniques, no ground truth data were available to check the accuracy of these classifications.

A significant amount of effort again went into the development of an unpacking and display algorithm for the Daedalus MSS data. The data format description of the MSS data proved to be incorrect because of sinusoidal power fluctuations in the scanner system. After trying unsuccessfully to decode the data, EES asked MSFC to help ascertain the problem in the data. Since MSFC transferred the data from high density tapes to computer compatible tapes, MSFC was partilarly helpful in finding the power fluctuation problem. Once the cause of the problem was known, EES worked on methods to correctly remove the sinusoidal effects. These data were subsequently forwarded to EES by MSFC, and Figure 8 is an example data set. Note that the number of points per tree is again small and probably is too few to provide a meaningful statistical sample for pattern recognition. Figure 9 shows the difference in the number of pixels for a peach tree versus the number for pecan trees which are below the peach trees on the image.

The computer programs developed for the display of Daedalus MSS data are shown in Appendix C.

Figure 10 is 1977 MSS data over a test field for the phony peach disease. Three ground surveys of the field were made to ascertain the degree of infection for this orchard. Trees that were healthy on all three visits are labeled healthy on the image. Trees that were identified to have the disease by the first survey are labeled P1. Those identified in the second survey are labeled P2, and those in the third survey are labeled P3. From this image it is evident that at the given resolution no discrimination is possible from these data.

Summary

Based on the remote sensing data and the ground truth data available to this project, no confirmation or extension of previously reported results is possible. While it appears, based on the last data set, that peach trees are clearly differentiable into categories utilizing enhancement techniques, no correlation with ground truth data was possible.

Figure 8. 1976 MSS Data - Level Sliced

Figure 9. 1976 MSS Data - Peach Trees vs Pecan Trees

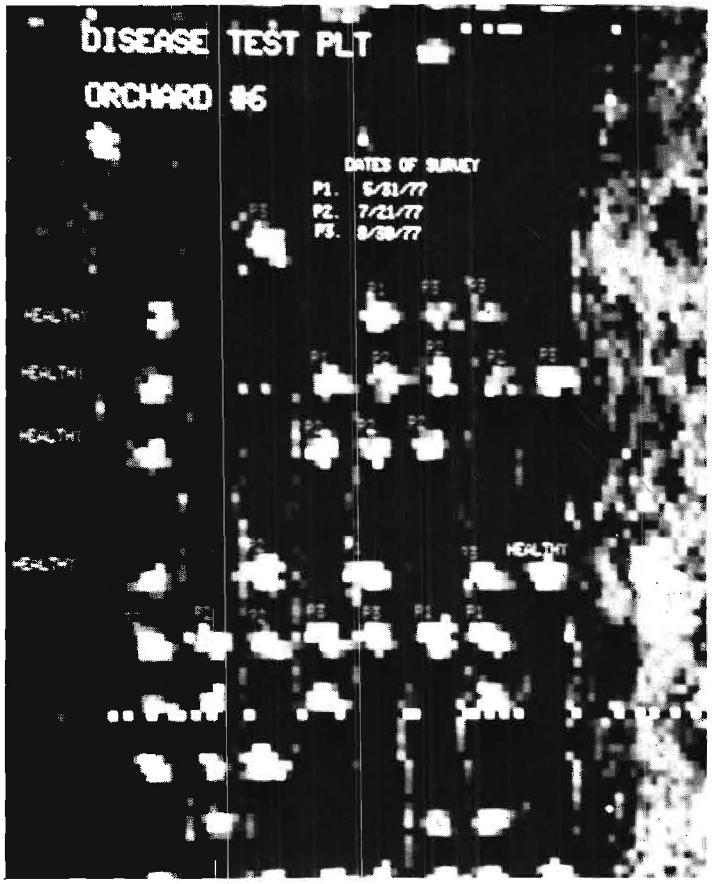

Figure 10. 1977 MSS Data for Phony Peach Test Orchard

IV

RESULTS AND CONCLUSIONS

Unfortunately, most of the useful results of this project led to negative conclusions. In the case of the thermal data, it was shown that very late season data have no predictive value for identifying declining trees the following spring. The resolution of the data was also a limiting factor. For the 1974 MSS data, it was shown that 1 to 4 data points per peach tree are entirely insufficient for classifying the trees according to their stages of decline. The final MSS data set did confirm that the peach trees could be separated using an enhancement (as had been done previously with photographic data), but ground truth data were unavailable for testing the accuracy of this separation. Again insufficient resolution was a problem.

The lack of success in this project emphasizes the importance of proper mission planning and coordination discussed in Appendix A. Several conditions, had it been possible to provide for them could have assured the success of the project. Among these conditions are:

- The ability to process the data within a reasonable time after they were taken
- The ability to provide back-up missions in the event that the MSS data were unacceptable.
- The ability to coordinate fully the aircraft missions with the ground truth data collection.

As pointed out in Appendix A, the ability to control these and other parameters determines, to a large extent, the likelihood of success of the project. Unfortunately, in this case, the inability to control certain parameters resulted in a project whose original aims were not met.

APPENDIX A

APPLICATION OF DIGITAL REMOTE SENSING DATA TO OTHER PLANT STRESS STUDIES

APPENDIX A

APPLICATION OF DIGITAL REMOTE SENSING DATA TO OTHER PLANT STRESS STUDIES

Introduction

The results of this project plus the results of other projects as published in the literature indicate the general applicability of digital remote sensing technology to plant stress studies. These studies have investigated plant stresses other than diseases, including insect damage and water/nutrient deficiencies. Specific information concerning some related investigations is given in Appendix B, Annotated Bibliography.

This appendix is designed to summarize briefly the types of plant stress applications that have been investigated by remote sensing techniques. This compilation is not intended to be comprehensive and, in some instances, research is underway so no firm conclusions are available. It is intended, however, to demonstrate the general types of problems that can be addressed, to outline the pertinent considerations in designing experiments, and to flow chart the major steps in carrying out similar studies.

Applicability of Technology

It appears that many of the techniques used in this project are applicable to other plant stress studies. As indicated previously, "phony" peach disease was identified utilizing the data from this project and ground truth from the USDA Southeastern Fruit and Tree Nut Research Station at Byron, Georgia. In a separate study, USDA personnel at Byron identified infestations of yellow pecan aphids (insects) and pecan bunch (disease) utilizing color infrared photography. Many similar studies have been carried out by other investigators.

Table A-1 presents a compilation of some of the types of plant stress parameters studied via remote sensing techniques. Many of these plant stress parameters were investigated using digital data and digital processing techniques. Some of the parameters have only been investigated using photography, but it is thought that digital processing techniques similar to those employed here could be employed in future investigations.

Experimental Design Considerations

There are several parameters that are important in designing an experimental plant stress investigation using digital remote sensing data. It is possible that not all parameters are under control of the investigator, but as many parameters as are controllable should be optimized for conditions existing at the time of the project. Based on the results of this project, crucial parameters would appear to be:

- time during growing season when data are taken,
- altitude of data acquisition platform (resolution), and
- types of data (spectral bands).

Table A-2 contains a detailed listing of the more important experimental design parameters. Some of these are discussed below in the context of the current project.

Time of Growing Season. Many investigators have found the time of growing season to be important in studying annual crops. Results of this project indicate that for peach trees the middle portion of the growing season is best for identifying and predicting decline. The

Table A-1. Examples of Plant Stress Parameters Investigated with Remote Sensing Technology

Diseases	Insects
Peach Short Life	European Red Mite (Peach)
Phony Peach	Black Pecan Aphids
Pecan Bunch	*Prionus* Root Borers (Pecans)
Ponderosa Pine (various)	Clitocybe Root Rot (Pecans)
Citrus Tree Decline	Yellow Pecan Aphids
Potato Blight	Pine Bark Beetles
Corn Blight	Ponderosa Pine (various)
Giallune (Rice)	Pink Bollworm (Cotton)
	Corn Aphids
	Honeydew Producing Insects (Citrus)
	Gypsy Moth Defoliation

Nutrient Deficiencies		
Iron (Sorghum)		
Phosphorus (Mexican Squash)		
Sulfur	"	"
Nitrogen	"	"
Potassium	"	"
Iron	"	"
Magnesium	"	"
Calcium	"	"
Nitrogen (Sweet Pepper)		
Nitrogen (Cabbage)		
Nitrogen (Spinach)		

Table A-2. Experimental Design Parameters

Time of Growing Season	
	One Date
	Multiple Dates
Altitude of Sensor (Resolution)	
	Preferred Altitude
	Maximum Acceptable Altitude
Spectral Bands of Data	
	Visible
	Near Infrared
	Thermal Infrared
Time of Day	
	Sun Angle
	Potential Cloud Cover, Haze, etc.
Meteorological Conditions	
	Cloud Cover
	Haze
	Atmospheric Moisture Content
	Soil Moisture
Availability of Ground Truth	
	Historical Data
	Current Data
	Future Data

October thermal data, for example, were not useful in predicting decline the following year.

Altitude of Sensor. When using aircraft MSS data, the altitude of the sensor is critical. In this project the requested altitude of 2000 feet for the 1974 MSS data was already 500-1000 feet above the desired altitude. Nevertheless, this altitude should have provided sufficient data for detailed analysis of individual peach trees. However, when the mission was actually flown at 3100 feet, the data were largely useless. A maximum acceptable altitude should be calculated for all proposed missions.

Spectral Bands. This parameter may be controlled entirely by the availability of equipment. However, to the extent that selections are available, one or more portions of the spectrum should be emphasized to reduce the amount of data to be taken.

Time of Day. Most investigators emphasize the time within two hours of the maximum sun elevation. However, if cloud cover is likely to increase during the day, an earlier time may be necessary to insure the best possible data.

Availability of Ground Truth. With annual crops such as corn, the only ground truth available is that for a single growing season. However, for peach trees and similar fruit crops, the availability of historical ground truth and the assurance of future ground truth is a consideration in selecting test sites.

Flowchart of Project Planning Techniques

Figure A-1 illustrates the general steps involved in carrying out a plot stress investigation using remote sensing techniques. In a particular investigation, one or more of the steps or procedures may have to

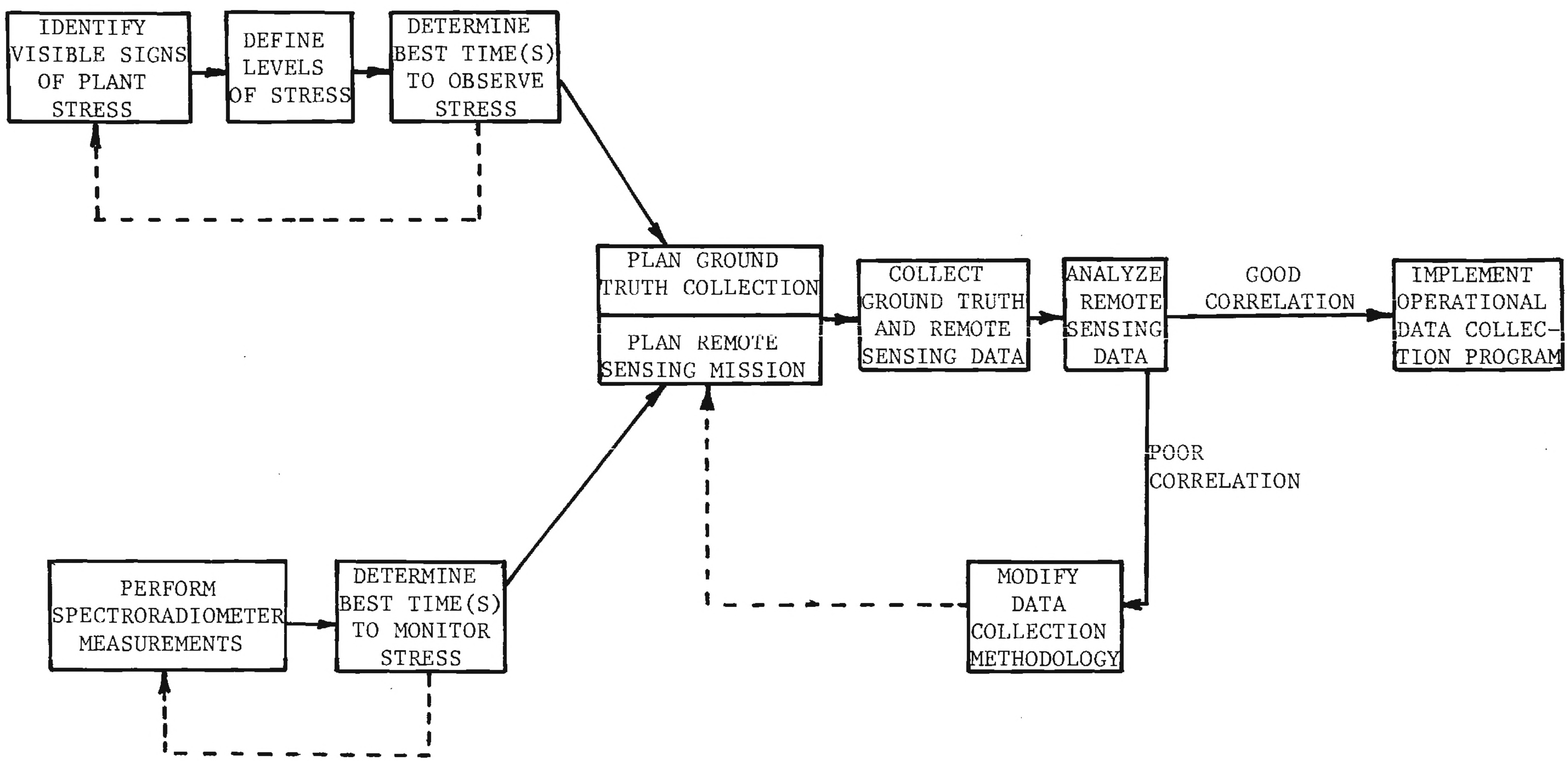

Figure A-1. Plant Stress Investigation Methodology be modified. The critical parameters and the general methodology, however, will remain the same. The paragraphs which follow elaborate on the steps and procedures outlined in Figure A-1.

Identify Visible Signs of Plant Stress. Recognition is usually the first step in any program of this nature. Once it is established that a plant stress exists, alternative study/treatment methodologies (including remote sensing) may be evaluated.

Define Levels of Stress. This is an attempt to quantify the stress in terms of specific criteria. These criteria will then facilitate the collection of ground truth data of uniform quality.

Determine Best Time(s) to Observe Stress. Initially this may have to be an educated guess on the part of an experienced researcher. As additional information about the particular stress situation becomes available, the time schedules for collecting ground truth may need to be modified or the criteria for categorizing stress levels may need revision.

Perform Spectroradiometer Measurements. Field measurements with a spectroradiometer are generally useful in defining the types (visible, IR, etc.) of remote sensing data to be collected and the frequency with which they should be collected. However, because the conditions observed by the spectroradiometer only approximate those observed by a multispectral scanner, the exact bands of coverage may need to be revised after initial data collection efforts.

Determine Best Time(s) to Monitor Stress. As with ground truth collection, initial remote sensing data collection efforts may need to be specified by an experienced researcher. A series of spectral measurements at different times of the year, however, should provide useful information for mission planning.

Plan Ground Truth Collection/Plan Remote Sensing Mission. A coordinated ground truth and remote sensing data collection effort is required. The appropriate parameters from Table A-2 should be completely specified for each remote sensing data collection mission. While ground truth data taken at other times may prove useful, there is no assurance that they will meet the needs of a particular study. Trained personnel using consistent criteria should be used for all ground truth activities. Limiting ground truth data collection to as few people as possible will tend to enhance its uniformity.

Collect Ground Truth and Remote Sensing Data. The data collection efforts should be carried out as nearly as possible in accordance with the plan developed in the preceding step. Of course, environmental factors (weather, etc.) may prevent full adherence to the plan, but every effort should be made to follow it.

Analyze Remote Sensing Data. The remote sensing data should be analyzed as soon after its receipt as possible. This will allow for a modification of the spatial/spectral/temporal parameters of the sampling plan as early in the experiment as possible. Of course, it is possible that the correct choices have been made initially, and no corrections are necessary. However, it is best to verify the appropriateness of the data collection plan as soon as possible.

Modify Data Collection Methodology. If this step is necessary, it should take into consideration the probable reasons for poor correlations between the remote sensing data and ground truth data. Appropriate changes in the data collection plan should be implemented and the experiment resumed.

Implement Operational Data Collection Program. Once a satisfactory data collection plan has been devised, the program can move toward operational status. Depending on the nature of the problem, the operational program may be as short as one additional mission; on the other hand, it may be a multiyear program involving many remote sensing and ground truth data collection missions.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

T. S. Bell, Ministry of Agriculture, Fisheries, and Food, Cambridge, England, "Remote Sensing for the Identification of Crops and Crop Diseases", Environmental Remote Sensing: Applications and Achievements; Proceedings of the Symposium, Bristol, England, October 2, 1972, p. 153.

Crop patterns are recorded in aerial photographs as changes in tone or color, and hence one of the main problems is the choice of film/filter combinations that will best record them. Aerial color films have rarely provided more information than is available on aerial panchromatic film, but they are often easier to interpret. Color infrared film is said to be the most revealing single film for crop studies, but there has been insufficient experience with this emulsion to draw firm conclusions. Crop identification is discussed, as well as crop diseases (airborne, seed-borne, and soil-borne diseases). Quantitative assessments of crops and diseases are made.

C. DeCarolis, et al, Rice Research Center, Ente Nazionale Risi, Mortara, Italy, "Thermal Behavior of Some Rice Fields Affected by a Yellows-Type Disease", Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., April 15-19, 1974, p. 1161.

Research on rice investigating the radiation behavior of areas of rice affected by a Yellows-type disease called "Giallume" was carried out in Northern Italy. This disease causes yellowing of leaves, stunting of growth, and a serious underproduction of rice. Both an on-ground thermal sensor and an airborne I.R. dual channel scanner were utilized. Results indicate anomalous thermal behavior of the diseased rice when compared with healthy rice.

Robert W. Douglass, et al, Forestry Remote Sensing Laboratory, California University, Berkeley, California, "Remote Sensing Applications to Forest Vegetation Classification and Conifer Vigor Loss Due to Dwarf Mistletoe", NASA Contractor Report NASA CR 138806, September, 1972.

Criteria were established for practical remote sensing of vegetation stress and mortality caused by dwarf mistletoe infections in black spruce subboreal forest stands. The project was accomplished in two stages: (1) A fixed tower-tramway site in an infected black spruce stand was used for periodic multispectral photo coverage to establish basic film/filter/scale/season/weather parameters: (2) The photographic combinations suggested by the tower-tramway tests were used in low, medium, and high altitude aerial photography.

Sanford W. Downs, NASA/MSFC, Huntsville, Alabama, "Remote Sensing in Agriculture", NASA-TN-X-64803, February, 1974.

Some examples are presented of the use of remote sensing in cultivated crops, forestry, and range management. Areas of concern include the determination of crop areas and types, prediction of yield and detection of disease, the determination of forest areas and types, timber volume estimation, detection of insect and disease attack and forest fires, the determination of range conditions and inventory, and livestock inventory. Articles in the literature are summarized and specific examples of work being performed at the Marshall Space Flight Center are given. Primarily, aerial photographs and photo-like ERTS images are considered.

G. J. Edwards, et al, University of Florida, Lake Alfred, Florida, "Multispectral Sensing of Citrus Young Life Decline", Photogrammetric Engineering and Remote Sensing, May, 1975, p. 653.

Computer processing of MSS data to identify and map citrus trees affected by young tree decline is analyzed. The data were obtained at 1500 feet altitude in six discrete spectral bands covering regions from 0.53 to 1.3 millimicrons as well as from instrumental ground truths of tree crowns. Measurable spectral reflectance intensity differences are observed in the leaves of healthy and diseased trees, especially at wavelengths of 500 to 600 nm and 700 to 800 nm. The overall accuracy of the method is found to be 89%.

Forestry Remote Sensing Laboratory, California University, Berkeley, Calif., "Monitoring Forest Land From High Altitudes and From Space", NASA Contractor Report NASA CR 138624, September, 1972.

The significant findings are reported for remote sensing of forest lands conducted during the period October 1, 1965 to December 31, 1972. Forest inventory research included the use of aircraft and space imagery for forest and nonforest land classification, and land use classification by automated procedures, multispectral scanning, and computerized mapping. Forest stress studies involved previsual detection of ponderosa pine under stress from insects and disease, bark beetle infestations in the Black Hills, and root disease impacts on forest stands. Standardization and calibration studies were made to develop a field test of an ERTS-matched four-channel spectrometer. Calibration of focal plane shutters and mathematical modeling of film characteristic curves were also studied. Documents published as a result of all forestry studies funded by NASA for the Earth Resources Survey Program from 1965 through 1972 are listed.

H. W. Gausman, USDA, Weslaco, Texas, "Light Reflectance of Leaf Constituents", Proceedings of the Second Conference on Earth Resources

Observation and Information Analysis System, Tullahoma, Tenn., March 26-28, 1973, Volume 2, p. 585.

It is shown how various leaf constituents differ in reflecting light over the 370-to 1100-nm wavelength interval. The premise tested is that refractive index discontinuities in leaves, other than air-cell interfaces, contribute to the reflectance of near infrared light.

Harold W. Gausman, USDA, Weslaco, Texas, "Discriminating Among Plant Nutrient Deficiencies with Reflectance Measurements", Proceedings of the Fourth Biennial Workshop on Color Aerial Photography in Plant Sciences and Related Fields, Orono, Maine, July 10-12, 1973 p. 13.

This study was conducted to ascertain if spectrophotometric reflectance measurements on plant leaves could be used to discriminate among several nutrient deficiencies over the 500- to 900-nm photographic wavelength interval (WLI). The indicator plant was Mexican squash. Plants were grown in a growth chamber with deficient -P (phosphorus), -S (sulfur), -N (nitrogen), -K (potassium, -FE (iron), -Mg (magnesium), -Ca (calcium) and sufficient (control, complete set of nutrients) nutrient solutions. Calcium-deficient plants died before their leaves were large enough for spectrophotometric measurements. Results indicate that -Fe or -Mg symptoms can be distinguished from either -P, control, or -S in the 550- to 650-nm (region with green reflectance peak) WLI; both -Mg or -Fe can be distinguished from either control or -P in the 650- to 750-nm (region with chlorophyll absorption band) WLI; and in the 750- to 900-nm (region with near-IR plateau) WLI, -Mg can be distinguished from either -Fe, control, -S, or -N, and -N can be distinguished from all other treatments. Wavelengths centered around 550, 680, and 850 nm are candidate bands for discriminating among plant nutrient deficiency symptoms.

Harold W. Gausman, USDA, Weslaco, Texas, "Leaf Reflectance of Near-Infrared", Photogrammetric Engineering, February 1974, p. 183.

The author discusses research related to the reflectance of near infrared radiation from plant leaves and plant cellular constituents. The discussion centers on the 750- to 1350 nm wavelength interval and includes light scattered by refractive index discontinuities at the interface of hydrated cell walls with intercellular air spaces and among cellular constituents.

Harold W. Gausman, et al, USDA, Weslaco, Texas, "Use of ERTS-1 Data to Detect Chlorotic Grain Sorghum", Photogrammetric Engineering and Remote Sensing, February 1975, p. 177.

This study was conducted to determine if multispectral data from ERTS-1 could be used to detect differences in chlorophyll concentration between chlorotic (iron deficient) and green (normal) grain sorghum (Sorghum bicolor (L.) Moench) plants. Band 5 (0.6 to 0.7 um) data were selected, representing the chlorophyll absorption band at the 0.65-um wavelength. Chlorotic sorghum areas 2.8 acres (1.1 hectare) or larger were identified on a computer printout of band 5 data. This resolution is sufficient for practical applications in detecting chlorotic areas in otherwise homogeneous grain sorghum fields.

W. G. Hart, et al, USDA, Weslaco, Texas, "The Use of Skylab Data to Study the Early Detection of Insect Infestations and Density and Distribution of Host Plants", Proceedings of the NASA Earth Resources Survey Symposium, Houston, Texas, July 1975, p. 203.

A study of the detection of insect infestations was undertaken using Skylab data, aerial photography, and ground truth simultaneously. Additional ground truth and aerial photography were acquired between Skylab passes. Results indicate that infestations of honeydew producing insects in citrus are detectable as well as the distribution of host plants.

W. A. Hodgson and G.C.C. Tai, Agricultural Canada Research Station, Fredericton, New Brunswick, "The Use of Color Infrared Aerial Photographs to Estimate the Loss in Yield Caused by Potato Late Blight", Proceedings of the Fourth Biennial Workshop on Color Aerial Photography in Plant Sciences and Related Fields, Orono, Maine, July 10-12, 1973, p. 1.

Late blight infected experimental potato plots were photographed sequentially from an altitude of 1,000 feet using color infrared film and a Contarex 35 mm camera equipped with an 85 mm lens and a Wratten No. 12 filter. Density readings of all photographs and the corresponding disease intensity levels in each plot at each photographing date were analyzed using regression and correlation techniques. A high correlation (r=0.91) was obtained between density and disease when these values were adjusted by subtracting the values obtained for control plots. Percent loss in yield due to blight was calculated using the derived regression equation, percent disease = 0.00 + 107.68 density, and a multiple regression equation which related disease intensity to yield loss. In 22 of the 25 treatments the calculated value was within 10% of the actual.

H. R. Jackson, et al, Canada Department of Agriculture, Ottawa, Canada, "Corn Aphid Infestation Computer Analyzed from Aerial Color-IR", Photogrammetric Engineering, August 1974, p. 943.

An automatic computer analysis technique to determine aphid infestation levels in corn fields was developed utilizing photographic color separation and image enhancement procedures from infrared aerochrome photographs. Panels of healthy and infested corn fields were selected for enhancement whereby density ranges of the cyan layer were compressed to a high-contrast mode. Finally the panels were scanned and the information recorded on magnetic tape and computer analyzed. Results of the automatic analysis compare favorably with the results obtained in earlier, manual analyses.

Lowell N. Lewis, et al, Citrus Research Center/Agricultural Experiment Station, California University, Riverside, Calif., "Evaluation of Remote Sensing in Control of Pink Bollworm in Cotton", NASA Contractor Report NASA CR 136910, March 1974.

This investigation evaluated the use of a satellite in monitoring the cotton production regulation program of the State of California as an aid in controlling pink bollworm infestation in the southern deserts of California. Color combined images of ERTS-1 multispectral images simulating color infrared were used for crop identification. The status of each field (crop, bare, harvested, wet, plowed) was mapped from the imagery and was then compared to ground survey information taken at the time of ERTS-1 overflights. A computer analysis was performed to compare field and satellite data to a crop calendar. Correlation was 97% for field condition. Actual crop identification varies; cotton identification was only 63% due to lack of full season coverage.

Robert B. McDonald, et al, NASA, "Results of the 1971 Corn Blight Watch Experiment", Proceedings of the Eighth International Symposium on Remote Sensing of Environment, Ann Arbor, Mich., Oct. 2-6, 1972, p. 157.

This paper presents the data collection methodology and analysis techniques used to evaluate the nature and extent of corn blight. High altitude color infrared photography and twelve-channel multispectral scanner data were used to evaluate plant vigor. Results indicate that outbreaks of moderate to severe infection levels were detected and the spread of the disease mapped with relatively high accuracy.

Victor I. Myers, editor, "Crops and Soils", Manual of Remote Sensing, Chapter 22, p. 1715, 1975.

This chapter contains a comprehensive discussion of the uses of remote sensing in agriculture. In particular, it includes discussions of the nature of radiation reflectance by healthy and diseased plants and the physical characteristics which give rise to this reflectance.

Charles F. Olsen, Jr., Forestry Remote Sensing Laboratory, California University, Berkeley, Calif., "Remote Sensing of Changes in Morphology and Physiology of Trees Under Stress", NASA Contractor Report NASA CR-138392, September, 1972.

Previsual detection of Fomes annosus in pine plantation was studied. Detailed analyses of photographic imagery obtained over the Ann Arbor Test Site during 1969 and 1970 reveal that the Ektachrome Infrared film was superior to Ektachrome Aerographic, Infrared Aerographic, or Plus-X Aerographic films for detecting Fomes annosus damage. Of far more significance in controlling the accuracy of damage detection, however, was the experience of the photo interpreter. Ratio processing of multispectral scanner data was investigated with data collected in June of 1970 and in June of 1972. Ratioing of the 1.5-1.8 and 1.0-1.4 micrometer channels gave good results at detecting openings in the crown canopy and adjacent infected trees. Combined level slicing of the 1.5-1.8 channels and the 1.5-1.8 to 1.0-1.4 micrometer ratio permitted separation and recognition of forest litter in the openings and stressed trees adjacent of the openings.

Jerry A. Payne, et al, USDA, Agricultural Research Service, Byron, Ga. "Detection of Peach and Pecan Pests and Diseases with Color Infrared Aerial Photography", Proceedings of the Third Biennial Workshop on Color Aerial Photography in the Plant Sciences, March 2-4, 1971, Gainesville, Florida.

Six previously ground-mapped Georgia peach and pecan groves containing one or more known insect pests or plant diseases were surveyed with Ektachrome Infrared Aero Film (Type 8443) at altitudes from 600-4500 feet. Detection of 3 insects, 1 mite, and 3 diseases of peaches and pecans was enhanced by infrared film. Structural variations of foliage and slight color changes were evident for peach trees with European red mite infestations and for pecan trees with black pecan aphids, Prionus root borers, and Clitocybe root rot. Detection of infestations of yellow pecan aphids and 2 diseases (phony peach and pecan bunch) was greatly enhanced because affected trees were colored differently on infrared film.

David E. Peltry, et al, "Use of Remote Sensing in Agriculture", NASA Contractor Report NASA CR-62098, Department of Agronomy, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, January 1974.

This report describes the work performed under a NASA-sponsored research program entitled "Remote Sensing in Agriculture", 1970-1973. The report deals with remote sensing studies at the Virginia Truck and Ornamentals Research Station and other Chesapeake Bay areas to investigate soil and plant conditions via remote sensing. A review of other literature pertinent to use of remote sensing for plant stress and related studies is also presented.

Darrel L. Williams, NASA/GSFC, "Computer Analysis and Mapping of Gypsy Moth Defoliation Levels in Pennsylvania using Landsat-1 Digital Data", Proceedings of the NASA Earth Resources Survey Symposium, Houston, Texas, June 1975, p. 167.

The purpose of this study was to investigate the effectiveness of using Landsat-1 multispectral digital data and imagery, supplemented by ground truth and aerial photography, as a new method of surveying gypsy moth defoliation, which has greatly increased in Pennsylvania in recent years. Since the acreage and severity of gypsy moth defoliation reaches a peak from mid-June through the first few days of July, the July 8, 1973, Landsat-1 scene was chosen for analysis. Results indicate that Landsat-1 data can be used to discriminate between defoliated and healthy vegetation in Pennsylvania and that digital processing methods can be used to map the extent and degree of defoliation.

APPENDIX C

PROGRAM LISTINGS

```
C                                                                          *
C       MSS                                                                *
C                                                                          *
C       UNPACKS AND DISPLAYS MULTISPECTRAL 12 CHANNEL DAEDALEUS            *
C       SCANNER DATA TO COMTAL AND DISPOSES REFORMATED DATA               *
C       TO TAPE                                                            *
C                                                                          *
C       SEQUENCE:  MSS MTU:F MTU:F                                         *
C                                                                          *
C***************************************************************************
C                                                                          *
C       CREATED AT GEORGIA TECH EES                                        *
C                                                                          *
C       PROGRAMMER:  MICHAEL D. FURMAN                                     *
C                                                                          *
C***************************************************************************
      INTEGER INPUT(700),IOUT(850),ITAPE1(10),ITAPE2(10),IMAG2(1700)
      INTEGER IMAG3(1100),ISW(2)
      CALL OPEN(1,"COM.CM",1,IERR)
      CALL COMARG(1,ITAPE1,ISW,IERR)
      CALL COMARG(1,ITAPE1,ISW,IERR)
      CALL COMARG(1,ITAPE2,ISW,IERR)
      CALL MTOPD(2,ITAPE1,0,IE)
      CALL MTOPD(3,ITAPE2,0,IE)
      ACCEPT "START WITH WHAT ELEMENT? ", IEL
      FOREVER
      :  CALL MTDIO(2,0,INPUT,IS,IE,IC)
      :  L=1
      :  DO (J1=1,565,3)
      :  :  M0=IAND(ISHFT(INPUT(J1),2),177400K)
      :  :  M1=IOR(M0,IAND(ISHFT(INPUT(J1),6),300K))
      :  :  IOUT(L)=IOR(M1,ISHFT(INPUT(J1+1),-10))
      :  :  M2=IOR(ISHFT(INPUT(J1+1),10),IAND(ISHFT(INPUT(J1+2),-6),1400K))
      :  :  IOUT(L+1)=IOR(M2,IAND(ISHFT(INPUT(J1+2),-2),377K))
      :  :  L=L+2
      :  :..FIN
      :  CALL UPAC8(IOUT,IMAG2,850)
      :  DO (I=1,40)
      :  :  IF ((IMAG2(I).EQ.255).AND.(IMAG2(I+1).LE.10)) IPAS1=I+4
      :  :..FIN
      :  IPAS2=0
      :  DO (I=IPAS1,512)
      :  :  IF ((IMAG2(I).EQ.255).AND.(IMAG2(I+1).LE.10)) IPAS2=I+4
      :  :..FIN
      :  L30=1
      :  WHEN (IPAS2.GT.0)
      :  :  DO (I=IPAS2,756)
      :  :  :  IMAG3(L30)=IMAG2(I)
      :  :  :  L30=L30+1
      :  :  :..FIN
      :  :..FIN
      :  ELSE
      :  :  L31=1
      :  :  DO (I=IPAS1,756)
      :  :  :  IMAG3(L31)=IMAG2(I)
      :  :  :  L31=L31+1
      :  :  :..FIN
      :  :..FIN
      :  CALL PAC8(IMAG3(IEL),IOUT,512)
      :  CALL RIMWRITE(0,0,IOUT,256)
      :  CALL MTDIO(3,50000K+850,IMAG3,IS,IE,IC)
      :..FIN
      STOP
```

```
C***********************************************************************
C                                                                      *
C        MSST                                                          *
C                                                                      *
C        READS TAPE CREATED BY MSS AND DISPLAYS DESIGNATED             *
C        PORTION TO COMTAL FOR VIEWING.                                *
C                                                                      *
C        SEQUENCE: MSST MTU:F                                          *
C                                                                      *
C***********************************************************************
C                                                                      *
C        CREATED AT GEORGIA TECH EES                                   *
C                                                                      *
C        PROGRAMMER:  MICHAEL D. FURMAN                                *
C                                                                      *
C***********************************************************************
      INTEGER INPUT(1000),IMAG(0:512),IMAG2(0:512),ITAPE(10),ISW(2)
      ACCEPT "SKIP FACTOR ",ISK
      ACCEPT "FAST SCAN (2=YES; 1=NO) ",IFSCAN
      IEL=1
      IEND=900
      IBLUP=1
      IF (IFSCAN.NE.2)
      :  ACCEPT "ELEMENT ",IEL
      :  IEND=IEL+511
      :  ACCEPT "BLOWUP FACTOR ",IBLUP
      :..FIN
      CALL OPEN(1,"COM.CM",1,IERR)
      CALL COMARG(1,ITAPE,ISW,IERR)
      CALL COMARG(1,ITAPE,ISW,IERR)
      CALL MTOPD(2,ITAPE,0,IE)
      IF (ISK.GT.0)
      :  DO (I=1,ISK) CALL MTDIO(2,0,INPUT,IS,IE,IC)
      :..FIN
      ILINE=ISK
      DO (M5=1,512)
      :  DO (I=1,IFSCAN) CALL MTDIO(2,0,INPUT,IS,IE,IC)
      :  ILINE=ILINE+IFSCAN
      :  TYPE "LINE NUMBER ",ILINE
      :  L=1
      :  DO (I=IEL,IEND,IFSCAN)
      :  :  IMAG(L)=INPUT(I)
      :  :  L=L+1
      :  :..FIN
      :  IF (IBLUP.GT.1) BLOWUP-IMAGE
      :  CALL PAC8(IMAG,IMAG2,512)
      :  DO (I=1,IBLUP) CALL RIMWRITE(0,0,IMAG2,256)
      :  IF (M5.EQ.512)
      :  :  ACCEPT "INPUT '1' TO CONTINUE ",IANS2
      :  :  WHEN (IANS2.EQ.1) M5=0
      :  :  ELSE STOP
      :  :..FIN
      :..FIN
      TO BLOWUP-IMAGE
      :  DO (K7=0,511)
      :  :  K9=512-K7
      :  :  KDB1=K9/IBLUP
      :  :  IMAG(K9)=IMAG(KDB1)
      :  :..FIN
      :..FIN
      STOP
      END
```

```
C************************************************************************
C                                                                       *
C       THERMAL                                                         *
C                                                                       *
C       UNPACKS THERMAL DATA TAPES AND DISPLAYS TO COMTAL               *
C                                                                       *
C       SEQUENCE:  THERMAL MTU:F                                        *
C                                                                       *
C************************************************************************
C                                                                       *
C       CREATED AT GEORGIA TECH EES                                     *
C                                                                       *
C       PROGRAMMER:  MICHAEL D. FURMAN                                  *
C                                                                       *
C************************************************************************
      INTEGER IDATA(1650),IMAG(266),IMAG2(255),ISW(2),ITAPE(10)
      CALL COLORSUB
      ACCEPT "FAST SCAN OPTION (2=YES, 1=NO) ",IFSCAN
      ISKB=ISKB+1
      IELEM=1
  100 IBLUP=1
      IF (IFSCAN.EQ.1)
      :  ACCEPT "INPUT BLOW-UP FACTOR ", IBLUP
      :  IF (ICUR.NE.1) ACCEPT "START WITH ELEMENT? ",IELEM
      :..FIN
      IBLUPM1=IBLUP-1
      K1=676+((IFSCAN-1)*2)-(IELEM/2)
      K2=IFSCAN*2-1
      J3=257-((IFSCAN-1)*32)-IBLUP
      CALL MTOPD(3,ITAPE,0,IERR)
      DO (I=1,ISKB) CALL MTDIO(3,0,IDATA,IST,IERR,ICNT)
      M2=512/IBLUP
      DO (M1=1,M2)
      :  IF (IFSCAN.EQ.2) CALL MTDIO(3,0,IDATA,IS,IE,IC)
      :  DO (N=1,IFSCAN) CALL MTDIO(3,0,IDATA,IS,IE,IC)
      :  J=1
      :  K=K1
      :  WHILE (J.LT.J3)
      :  :  K=K-K2
      :  :  IMAG(J)=IOR(IAND(IDATA(K),177400K),IAND(IDATA(K-IFSCAN),377K))
      :  :  IF (IBLUP.GT.1) BLOWUP-AREA
      :  :  J=J+IBLUP
      :  :..FIN
      :  DO (I=1,IBLUP) CALL RIMWRITE(0,0,IMAG,256)
      :  IF (IFSCAN.EQ.2) M1=2
      :..FIN
```

```
CALL MTDIO(3,40000K,IDATA,IST,IERR,ICNT)
IF  (IFSCAN.NE.2)
:  TYPE "CURSER POSITION, START OVER, OR END?(1=CUR.,2=START,3=END)"
:  READ(11) ICUR
:  IF (ICUR.EQ.1)
:  :  TYPE "POSITION CURSER AND ENTER A CHARACTER"
:  :  READ(11) I
:  :  CALL RTARG(IX,IY)
:  :  ISKB=ISKB+IY
:  :  IELEM=IELEM+IX
:  :  TYPE "LINE: ",ISKB,"  ELEMENT: ",IELEM
:  :  GOTO 100
:  :..FIN
:  IF (ICUR.EQ.2) GOTO 50
:..FIN
STOP
TO BLOWUP-AREA
:  J6=IAND(IMAG(J),177400K)
:  J7=IAND(IMAG(J),377K)
:  J8=IOR(J6,ISHFT(J6,-8))
:  J9=IMAG(J)
:  J10=IOR(ISHFT(J7,8),J7)
:  J11=IBLUP/2+J-1
:  J12=(IBLUP+1)/2+J
:  J13=J12+IBLUP/2-1
:  DO (I=J,J11) IMAG(I)=J8
:  IF(((IBLUP/2)*2).NE.IBLUP) IMAG(J11+1)=J9
:  DO(I=J12,J13)IMAG(I)=J10
:..FIN
END
```