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Aerial Color Infrared Photography Applications to Citriculture

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In 1978, succeeding photographic flights were flown over a citrus grove in Polk County, Florida, during winter, spring, and summer seasons using Aerochrome color infrared film. The spring season flight gave the best separation between healthy and stressed trees. The best scale for photo interpretation and use of inexpensive analysis equipment was 1 inch = 330 feet. Photographs taken with a 12-inch focal length lens were far superior than those taken with a 6-inch lens. A cell-unit system was developed for tree registration. The system was used with window-overlays for rapid photo interpretation and a black and white enlargement for ground verification. Use of the enlargement in ground surveys reduced the survey time from 25 to 2.5 hours. The cell-unit grid system was compatible with computer processing for rapid recording of photo interpreted data, storage, retrieval, and analysis. A mapping system with 99 percent accuracy was developed for the fast surveillance of tree vigor and stress.

INTRODUCTION

Aerial color infrared (CIR) film has been used extensively in disease detection of plants. Norman and Fritz (12) pioneered CIR in detecting stress in citrus trees. Benchley (2) monitored potato late blight epidemics with black and white aerial photography, and Manzer and Cooper (9) tested both color and black and white infrared film in potato late blight detection. Blazquez (3) used CIR in detecting diseases of vegetable crops, while Hart et al. (7) have used CIR in monitoring outbreaks and hotspots of citrus blackfly on citrus. Black and white aerial photography has been used by county tax appraisers for property valuation since it became available in 1945-48 (10).

Mapping of groves has been done by Hart et al. (7) and Edwards et al. (6) as part of their remote sensing research, but has not been described in detail or considered particularly important. Horticulturists have become aware of the importance of accurate grove mapping and are developing various approaches such as the one by Abbitt (1). The use of aerial photography and black and white infrared film has been tested in aerial surveys by Wolff (14) and compared with ground surveys of groves for accuracy, speed, and costs. Brittain et al. (4) reported the use of aerial photography and CIR in combination with pest monitoring and tree health profiles in compiling peach orchard case histories. In both of these reports (4, 14), mapping was an essential part of the research, although not emphasized. CIR aerial photography has been used in Israel by Hochbar et al. (8) for some time in surveys of citrus problems such as tristeza, foot rot, freeze damage, and while they made comparisons between ground and aerial surveys, they did not develop any particular levels of damage assessment. Murtha (11) discussed the philosophical and technical aspects of remote sensing for vegetation damage assessment and suggested possible methods. Watkins (13) reviewed the eco-
nomic of remote sensing in his summary of remote sensing papers presented at the First and Second Conferences on the Economics of Remote Sensing Systems and studied the elements of cost and benefits.

The Crop Reporting Service has mapped commercial citrus groves in Florida on a regular basis since 1965 (10). Photographs of any grove can be obtained in black and white prints at various scales from 1 inch = 24,000 feet to 1 inch = 660 feet. Little or no stress information can be obtained from these photographs due to the type of film used.

The use of grid overlays and the development of a cell system was recently reported by Civco et al. (5) who arbitrarily selected the approximate center of each 9-inch square print of a wetland scene and divided it into a 36 x 36 cell-grid for proper registration between spring and fall photographic frames.

The purpose of this paper is two-fold: First, to describe a complete aerial photographic experiment carried out during one year; Second, to discuss the many parameters involved in aerial photography, such as tree health/stress, damage assessment, inexpensive photo interpretation equipment, of Aerochrome color infrared photography.

**MATERIALS AND METHODS**

**Test Grove Location**

The grove selected for photographic experimentation (Gapway No. 3) is located in Township 27, Range 26, Section 26, Polk County. The grove on rough lemon rootstock spaced 30 feet x 30 feet has been used extensively for young tree decline transmission experiments and pest management trials. Varietal plantings were made without a definite pattern and the grove has irregular boarders. The 85-acre grove has "Hamlin" oranges planted in a large St. Lucie's series (St. Lucie's sand is a member of acid hyperthermic, uncoated, family Typic Quartzipsammens soil series) sandy area with "Valencia" oranges and "Marsh" grapefruit trees planted in adjacent areas. "Hamlin" trees are interplanted in a north-south direction with smaller "Hamlin" trees, resulting in a hedge row.

**Aerial Photography**

Aerial photographs were taken with a 9-inch x 9-inch Zeiss electric aerial camera model, with a 12-inch focal length lens and a "C" (yellow) color compensating filter, connected to an intervelometer. The camera was powered by the electrical system of an Aero Commander aircraft. Part of the spring photography was made with a 6-inch focal length lens also with a "C" filter. Photographs were taken from an altitude of 4,000 feet using Kodak Aerochrome 2443 Infrared film (CIR). The scale on the transparency was 1 inch = 333 feet. Photographs were taken during the winter of 1978 season (February), the spring season (April), and the summer season (July) of 1978 using a forward overlap of 60 percent for a total of 10 photographs per flight. Each color transparency covered a total of 208 acres. Color contact prints were made with Kodak color paper. Processing was done with required chemicals in a standard Versamat color processing unit. Aerial photography, processing, and printing were done by the Topographic-Section of the Florida State Department of Transportation (Topo. DOT) at Tallahassee, Florida.

**Photocopying**

Black and white (B&W) enlargements to a scale of 1 inch = 100 feet were made by copying the best color contact print of the grove (divided in cells of 64 trees) with a 4 x 5 Graflex camera and Plus X film. Photocopying was done at the AREC, Lake Alfred Photo Lab.

**Transparency Overlays**

Transparent overlays of the CIR transparencies were prepared by placing tracing paper over transparencies of the test grove and separating the grove into a grid of 64 trees per cell. The tracing paper was then copied with a Xerox 7000 (or a 3M Thermo-fax) copier into clear transparent sheets that would accurately register over the original transparency.

A second copy of the grid on the tracing paper was copied on light blue transparent sheets. A one-cell window was cut in the center of the light blue transparent sheet so that a
single cell of 64 trees would be distinctly visible when overlaying the light blue overlay on the clear grid properly registered on the original transparency on a light table. The use of this window-overlay method allowed the rapid photo interpretation of a cell of 64 trees, while minimizing the glare from the light table and allowing rapid movement of the window to other cells without loss of registration on the transparency.

Cells were numbered from 0 to 10 from the upper left hand corner of the transparency (northwest) to the right (northeast) whether trees were present or absent in the photograph. The row of cells below were numbered 11 to 20 also from left to right, making it possible to locate rapidly a specific cell without counting rows and trees in a transparency.

### Previous (Old) Photography

Two enlargements of older photographs taken by the Topographic Section of the Department of Transportation using a scale of 1 inch = 100 feet on December 23, 1953 and 1971 and most recent blue lines (1972) were obtained. The photography available from the Polk County Tax Appraiser was obtained at the scale of 1 inch = 200 and 400 feet. These copies were used in September 1976 with 7 minute U. S. Geological Survey Quadrangles as work sheets to plot flight lines and cell diagrams in the initial stages of the investigation. The most recent photographs small scale (1 inch = 24,000 feet) and medium scale (1 inch = 660 feet) were obtained from the Crop Reporting Service for use as orientation photographs for the photo-navigator.

### Photo Interpretation Equipment

In previous investigations (3, 6) reluctance to use remote sensing was encountered from users due to the cost of photo interpretation equipment. A light table was built on a 1 inch x 2 inch board frame covered with wood paneling made to fit standard 48-inch long fluorescent tubes. The table was covered with opaque plastic (simulating ground glass) and protected by a 12-inch wide, 50-inch long piece of window glass.

Photo interpretation was made with: (1) Hand held 5X and 10X magnifying lenses, (2) an 8X lupe magnifier, and (3) a 10X magnifying lens attached to a fluorescent lamp.

### Ground Surveys

Initial ground surveys were made without the aid of any type of photography. Old grove plot diagrams previously used in other YTD and pest management experiments by other researchers were used to determine the location and current stage of stress of trees. The old plot diagrams were used only in the December 1977 initial survey due to many grove changes (replanting, expanding of the grove, interplanting). Second and third grove maps in February 1977 were prepared using 1/4-inch blue line graph paper with color codes to separate the grove into areas (A, B) (Figure 1). Fourth grove maps were made with blue line copies of aerial photographs (1 inch = 200 feet scale) and were subsequently used for ground maps separating the grove into cells of 64 trees each. Flags on bamboo poles were located every 16 trees to expedite ground survey. They were plotted on the blue line maps. A fifth set of grove maps was prepared by delineating the 64 cells on the 1 inch = 100 feet photographic enlargements of the CIR transparency (Figure 2). Transparent mylar plastic overlays were used in all subsequent ground surveys. The photographic enlargements were taped on plywood boards and covered with mylar transparent overlay. Grove information was recorded on the overlay (Table 1, Figure 2).

A grid system superimposed over a black and white enlargement of the grove was tried to expedite ground surveys. The exact location of the tree was determined and topographic structures and certain vegetation used as reference points.

In April 1977, March 1978, July 1978 and May 1979 surveys of conditions other than healthy were recorded to speed up the survey and avoid excessive recording. Whenever the status on all the trees in one 64 tree cell were the same (the term "cell" will henceforth be referred to in this work to a group of 64 trees, or combination tree and empty spaces, or spaces where trees may be planted at the distance of 30 feet x 30 feet, the entire cell was marked with one large symbol, rather than with 64 individual symbols (Figure 3).
Ground Surveys--Aerial Photographic Comparisons

Comparisons between ground surveys and aerial photographs were made to determine the accuracy of the photo interpretations, the usefulness of the window-overlay method, and the benefit of grouping trees into cells.

Ground survey overlays with the various stages of tree stress, condition, age, size, and location were compared with the respective season overlay of the aerial transparencies.

Computer Compatible Recording

The information in each transparency was photo interpreted and recorded on computer sheets. The same recording code was used for the recording of information from photo interpretation and ground surveys. Both the photo interpreted and the ground survey data were transferred to computer compatible paper punch tapes for rapid processing and retrieval.

The results of the photo interpretation (PI) were stored and analyzed in a General Automation SPC-16/65 computer using a program in FORTRAN language. The program allows the analysis of the data and the printing of grove maps according to tree categories on a scale of 0 to 4 (0 being healthy; 4 being dead) (Table 1), with summaries of tree numbers in each category and a row listing for each category map.

Comparisons were made with the FORTRAN program in the computer between aerial CIR photographs of the Gapway Grove taken in April 1978 and visual observations (ground truth; GT) maps made in March 1978, November 1978, and May 1979. The medium sized trees were included with the healthy trees for comparison purposes. Nine 64 tree cells and two 61 tree cells were selected at random to determine the accuracy of the April 1978 PI previsual analysis of the grove condition. The mean number of trees was calculated for each category from the 11 cells for the 78 GT, the 78 PI, and the 79 GT (Table 2).

RESULTS AND DISCUSSIONS

Ground Surveys

The December 1977 and February 1978 records kept on graph paper with 1/4-inch squares as suggested by Abbitt (1), were satisfactory for general purposes but difficult to verify because of the irregular shape of the grove and two mixed varieties of oranges (Figure 1). Interplanting of two ages of "Hamlin" trees made the ground survey increasingly difficult. Integration of the "Hamlin" trees into an adjacent "Marsh" grapefruit grove without distinct borders was an additional confounding factor. There were not consistent number of trees that could be considered as a pattern for verifying counts. The absence of any markers or points of reference between the three varieties made it quite difficult to prepare an accurate grove map without additional checkups to verify borders between the three varieties (Table 2). It took approximately eight additional ground survey hours to verify all borders in 1977.

The use of color pencils and grouping of the grove into three distinct areas helped in improving the accuracy of tree location and condition. The three area map did not reduce the survey time.

Best grid results were obtained within the blue lines from the county tax appraiser with a grid at the scale of 1 foot = 200 feet. The other blue lines at the scale of 1 foot = 400 feet had much less detail and were more difficult to use for grid testing. The blue lines obtained from the Crop Reporting Service had a smaller scale of magnification of 1 inch = 660 feet and were not suitable for grid testing. Blue line maps were used in conjunction with cells and were marked in appropriate corners. The use of the marked blue line maps greatly expedited ground surveys, but problems still remained because of the trees removed or replanted since the original of the blue line taken in 1972. The use of an up-to-date enlargement became obvious. Ground surveys with blue lines were completed in 20 hours, but many corrections were needed to improve accuracy.
Ground surveys using B&W enlargements and clear film overlays made it possible to reduce the survey time while increasing the accuracy of benefits of ground surveys (Table 2). An advantage of the enlargement-aided survey is that you not only have a permanent record of the condition of the trees, but you can verify results.

Photography

Aerial photographs taken during the spring season in April clearly indicated that separation of healthy (productive) and diseased (non-productive) trees was easiest during the flushing of young leaves in the spring. It was also much easier to detect levels of stress (Table 1) than in photography from either the winter or summer seasons. Although it was more difficult to pinpoint the differences in stress in winter and summer photography, it was possible to separate diseased from healthy trees.

The unexpected malfunction of the camera with the 12-inch focal length lens during the flush season necessitated the use of a 6-inch focal length lens for the remainder of the spring photography. This change in lenses allowed the comparison of both lenses under similar conditions. The 6-inch focal length lens produced transparencies with considerable distortion by displacement of the image away from the photograph’s principal point. In addition, there was considerable color degradation due to general increases in density near the transparency’s edges. These conditions were greatly minimized in transparencies taken with a 12-inch focal length lens, making photo interpretation far easier and more accurate.

Photo Interpretation

The combination of the clear transparent grid overlay and the light blue transparent window made it possible to photo interpret a transparency on a cell by cell basis without losing orientation when shifting from one cell to another. The method was particularly helpful in pinpointing trees different in condition or size than the majority in each respective cell. The method of numbering cells from 0 to 10, 11 to 20, etc., in a descending order on a transparency made it far easier to locate a specific area on a transparency than counting row and tree numbers. It was also easier to retrieve information from a computer by using the cell number. The use of row and tree numbers was essential when making lists of trees with a specific condition or stress. The use of both cell number and row and tree numbers allowed greater flexibility for retrieval, enumeration, and analysis of the photo interpreted and ground survey data.

The results obtained in this experiment were similar to those obtained by Brittain et al. (4) in South Carolina using CIR in a pest management program.

The use of a grid method divided into 36 x 36 cells by Civco (5) and called cell analytical method (CAM) varied considerably from the cell method used for both photo interpretation and ground truth mapping of citrus trees. The CAM was always assigned to an area 3.6 inches square in the center of a 9-inch print taken with a 6-inch focal length lens, while the window overlay cell method was registered over tree location rather than a specific photographic area.

While some of the questions outlined by Murtha (11) were answered in this preliminary effort in citrus aerial CIR, he oriented his questions more toward forestry problems than toward tree-crop or plantation type tree crops, and was therefore not particularly concerned with the registration of each individual tree, which is the foundation of tree-crop aerial photography. In all of the work reviewed none of the above reports used an enlargement-overlay to expedite their ground surveys. While Brittain et al. (4) did use computers to store grove and block information, they were not used for individual tree information. Wolff’s (14) results indicated preference for photographic interpretation with stereoscopic microscopes, normal color photographs, and an interpretation code carried out with the Jena-made Topopret.

A computer analysis of the results of the mean tree comparisons of the 11 cells indicated that the 78 PI indicated more accurately the
condition of the trees, when compared with the 79 GT, than the 78 GT (Table 2). However, in comparisons between cells 46 and 43 the 78 PI was closer to the 78 GT than to the 79 GT. In comparisons between cells 55 and 22, the 78 PI more closely approximated the 79 GT than the 78 GT.

A more accurate comparison of the trees in the grove can be made by incorporating the various tree categories (Table 1), into general classes of: (1) Healthy trees (healthy and medium), (2) productive (healthy, medium, Nos. 1 and 2 trees), (3) non-productive (Nos. 3 and 4 trees, missing trees, and replacements), (4) immediate nursery order (Nos. 3 and 4 and missing trees), and (5) next year nursery order (Nos. 1 and 2 trees) (Table 3).

In a summary of all the comparisons of the incorporated classes, the 78 PI more closely agrees with the 79 GT than with the 78 GT (Table 3). These results indicate that it is possible to estimate the future condition of the trees in the grove by aerial CIR photography and may indicate previsual detection of tree stress.

CONCLUSIONS

A one-year preliminary study of the use of aerial color infrared photography in citrus grove management determined that the spring season, when trees are in flush (have young leaves), is the best season to photograph visible differences between healthy and diseased (stressed) trees. It was also determined that the best photography can be obtained with a 12-inch focal length lens. The photographic scale that allowed good photo interpretation with simple inexpensive equipment was 1 inch = 330 feet.

B&W enlargements of CIR transparencies with transparent plastic overlays accelerated ground mapping by a factor of 10 when compared with ground surveys without the use of enlargements.

The use of a window-overlay transparency method allowed the rapid photo interpretation and recording of data in computer compatible forms.

A computer program was developed to store, retrieve, and analyze both photo interpretation and ground survey data using the cell method and row and tree numbers.

A mapping system with the cell system allowed for more accurate tree registration.

Aerial CIR photography carried out during the spring season revealed a more accurate status of tree condition than visual inspection that can be separated into productive, non-productive, immediate replacement, and future replacement.

Aerial CIR photography is a management tool that allows the acquisition of greater amounts of information with reduced energy input for sound management decisions.

REFERENCES


<table>
<thead>
<tr>
<th>Tree Condition</th>
<th>Computer Printouts</th>
<th>Field Maps</th>
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<tbody>
<tr>
<td>Healthy, normal foliage</td>
<td>0</td>
<td>●</td>
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<tr>
<td>Nearly healthy, thin foliage</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Poor health, dead twigs/branches</td>
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<td>2</td>
</tr>
<tr>
<td>Nearly dead tree, little fruit</td>
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<td>3</td>
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<td>Dead tree</td>
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<table>
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<th>Tree Location and Size</th>
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<tr>
<td>No tree</td>
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<td>Replacement (less than 1 year old)</td>
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<td>R</td>
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<tr>
<td>Young tree (less than 4 years old, over 1 year old)</td>
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<td>-</td>
</tr>
<tr>
<td>Large, normal tree size*</td>
<td>N</td>
<td>●</td>
</tr>
<tr>
<td>Medium size</td>
<td>M</td>
<td>A</td>
</tr>
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Table 1: Description of symbols used for grove mapping as written in the field and in computer printouts of grove conditions.**

*Normal large size trees and healthy trees are considered to be synonymous conditions for evaluation purposes.

**Descriptions of tree condition and size were arbitrarily assigned and may differ greatly from other systems used.
<table>
<thead>
<tr>
<th>Cell</th>
<th>Date</th>
<th>Healthy</th>
<th>Young</th>
<th>Replant</th>
<th>Stress</th>
<th>Rating</th>
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<tr>
<td>Mean No. of trees in 11 cells</td>
<td>Mar 23, 1978 GT</td>
<td>50.91</td>
<td>5.27</td>
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<td>4.91</td>
<td>2.91</td>
<td>7.91</td>
<td>1.46</td>
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<td>May 14, 1979 GT</td>
<td>40.00</td>
<td>4.36</td>
<td>2.36</td>
<td>10.82</td>
<td>2.46</td>
<td>0.91</td>
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Table 2: Mean tree comparisons in cells between visual observations (ground truth; GT) and photo interpretation (PI) of tree categories in cells of Gapway Grove.
<table>
<thead>
<tr>
<th>Incorporated Classes</th>
<th>% of Total Spaces</th>
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<tr>
<td>Healthy and medium sized</td>
<td>63</td>
<td>78</td>
<td>61</td>
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<tr>
<td>Productive (healthy and medium and Nos. 1 and 2 trees)</td>
<td>81</td>
<td>92</td>
<td>82</td>
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<tr>
<td>Non-productive (Nos. 3 and 4, and missing and replacement trees)</td>
<td>19</td>
<td>17</td>
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<td>Immediate Replacements (Nos. 3 and 4 and missing trees)</td>
<td>7</td>
<td>5</td>
<td>8</td>
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<tr>
<td>Future Replacements--next year (Nos. 1 and 2 trees)</td>
<td>18</td>
<td>5</td>
<td>18</td>
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Table 3: Comparisons between the photo interpretation of April 6, 1978 (PI) and the visual observations (ground truth; GT) for March 23, 1978 and May 14, 1979 expressed as total percent of tree spaces in the Gapway Grove. Tree categories have been incorporated into general classes for easier comparisons.
Figure 1: Plot diagram of Gapway 3 grove made on 1/4-inch graph paper showing the division of the grove into areas (A, B) with tree, row numbers, and tree condition.

Key: 0 = healthy tree 4 = dead tree
1 = slightly diseased tree  X = missing tree
2 = moderate diseased tree  Y = young tree
3 = severely diseased tree
4-30
Figure 2: Black and white copy of color infrared print showing separation of trees into 64 tree cell units
Figure 3: Computer compatible form for recording photointerpretation results from aerial color infrared transparencies or ground mapping with black and white enlargements of the aerial photographs. Symbols were arbitrarily assigned to speed up recording.

Key: = medium sized tree  / = large sized tree  R = replacement tree  Ø = missing tree  S = small sized tree