Use of Aerial Color Infrared Photography to Evaluate Crop Disease

Robert W. Toler, B. D. Smith, and J. C. Harlan
Texas A&M University, College Station

Aerial crop disease surveys can cover a greater land area in a far shorter time than ground surveys because the view from the air is more expansive and because aircraft can travel much faster than land vehicles. When surveys are carried out with such technology as vertical aerial false color infrared (IR) photography (commonly referred to as remote sensing), near simultaneous data can be collected over large areas and analyzed at the convenience of the surveyor. Photographic records can be used to compare past disease incidence with current-season data. When photography is to scale, measurements can be taken directly from photographs to determine acreages affected by disease, permitting a dollar evaluation of crop loss. The greatest advantage of photography is the permanent record of disease incidence data, with no dependence on memory or sketches.

False Color, Reflectance, and Spectral Signature

False color infrared (IR) film was developed during World War II as a camouflage detection aid. The film is called "false color" because healthy green vegetation appears red or pink on the positive photographic transparency. The film is sensitive to light in the regions of green and red at 500–700 nm and in the region of near IR at 700–950 nm in wavelength (16). A film such as Kodak 2443 is ordinarily used with a minus 500-nm filter (Wratten 12 or Wratten 15) that cuts off light wavelengths shorter than 500 nm. The spectral region detected on this film is 500–950 nm, which includes green, red, and near IR bands. This portion of the electromagnetic spectrum represents light—not heat or thermal—energy radiation. In most uses of this film for crop disease detection, reflected sunlight is the source of illumination.

Strong reflectance characteristics of healthy leaves lie in the green and near IR regions of the spectrum (500–600 and 700–950 nm), respectively (Fig. 1). High reflectance in the near IR region is caused by multiple reflection of photons from the cell walls in turgid leaves (2). Such air-water interfaces are found in the spongy mesophyll region of healthy leaves. Light energy in the near IR region, interacting with more than 40 interfaces, is reflected toward the camera (Fig. 2) (2,5). Such factors as reductions in leaf density and area and leaf reorientation due to wilting may combine a lower canopy reflectance and increase soil reflectance.

Changes in leaf water content, caused by wilting or drought and other stresses, alter the reflectance of the leaf structure and, subsequently, the photographic signature of a stressed or diseased leaf (8). Because of change in reflectance, vegetation that has been cut down can be detected or distinguished from nearby healthy growing vegetation as early as 2 hours after cutting. Such changes in the spectral signature (response of film to reflected IR light from leaves) of diseased plants allows detection of crop diseases by providing contrasts on photographs (1,2,4,7,9). Vertical aerial false color IR photography taken to a known scale (ratio of photographic image size to actual size, usually expressed in inches) can aid detection and identification of certain types of diseases, including wilts and foliar, soilborne, and virus diseases (8,10,18).

From Hand-Held Cameras to Remote Sensing Techniques

Several investigators have used aerial photography to study crop disease incidence. Among the first were Taubenhaus et al (17), who, in the late 1920s, flew in army aircraft at an altitude of 75–150 m to photograph cotton fields in the Blackland region of Texas, near Temple. Using hand-held cameras, black and white panchromatic film, and a light yellow filter, they obtained oblique-view photographs to record and assess Phymatotrichum root rot (*P. omnivorum*) damage.

Once the concept of aerial photography was established, new camera, film, and filter combinations were tried, especially with the development of false color IR film. In 1956, Colwell (1) reported the results of several years' use of aerial false color IR photography to detect and identify cereal diseases in California; wheat rust and other diseases of small grains were detectable on the photographs.

Colwell's work was the first major study concerning remote sensing of plant diseases. He theorized that for any particular film/filter combination, the photographic tone or color of an object can be predicted provided the following are known: spectral reflectance of the object being photographed, spectral sensitivity of the film, spectral scattering by atmospheric haze, and spectral transmission of the filter. Colwell was able to differentiate healthy and rusted wheat and oats on black and white or color film. During the 25 years since Colwell's basic investigations, remote sensing capabilities, particularly aerial false color IR photography, have been developed for diseases on a variety of agricultural crops.

Brenchley and Dadd, cited by Odle and Toler (10), detected late blight (*Phytophthora infestans* [Mont.] de Bary) of potato (*Solanum tuberosum* L.) with black and white aerial infrared photography and subsequently revealed some interesting aspects of disease initiation and spread over the course of a growing season. They were also able to detect halo blight (*Pseudomonas phaseolicola* [Burk.] Dows.) of bean (*Phaseolus vulgaris* L.). With close-up photography in the laboratory, using black and white infrared film, Jackson (5) readily detected foliar symptoms of two bacterial pathogens, *Xanthomonas phaseoli* (Erw. Smith) Dows. and *Pseudomonas glycinea* Coerper, on soybean (*Glycine max* [L.] Merr.) leaves; black and white panchromatic film did not detect symptoms. Manzer and Cooper (7) reported previsual detection of potato late blight on IR film and were also able to correlate disease ratings from ground surveys with film densities measured by a densitometer.

False color IR film has proved to be a valuable tool for disease detection in several important field crops. Cercospora leaf spot (*C. beticola* Sacc.) of sugar beets (*Beta vulgaris* L.) was found by Meyer and Calpouzos, as cited by Myers (8), to produce a distinctive signature on color infrared transparencies. Monitoring disease development in this manner enabled more timely fungicide applications.

Because of its economic impact in 1970, southern corn leaf blight (*Helminthosporium maydis* Nisik. & Miyake) has been the subject of extensive remote sensing efforts (8,10). Coffman, cited by Odle and Toler (10), reported that various levels of blight severity could be distinguished on color infrared aerial photographs as a progressive loss of near IR reflectance.

Efforts have also been made to remotely sense diseases of several orchard crops. Odle and Toler (10) cite Brodrick and co-workers as using multispectral photographic techniques to detect and rate avocado trees (*Persea americana* Mill.) with root rot (*Phytophthora cinnamomi* Rands). Selected spectral filters were used on a four-lens, multispectral camera to photograph orchards from an altitude of 1,500 m. The photographs were analyzed by computer color enhancement techniques to increase contrast, and 100% of the trees shown to be diseased by ground-truth surveys were identified. Color infrared film was 80% accurate, and conventional color film was ineffective.

Edwards and co-workers, cited by Myers (8) and Odle and Toler (10), tested the effectiveness of remote sensing techniques to detect another citrus disease, young tree decline. Aerial photography with color IR film identified severely declined trees.

Superiority of IR Films in Detecting Virus Diseases

In his classic 1956 report, Colwell (1) mentioned that wheat infected with

0191-2917/81/01002408/$03.00/0

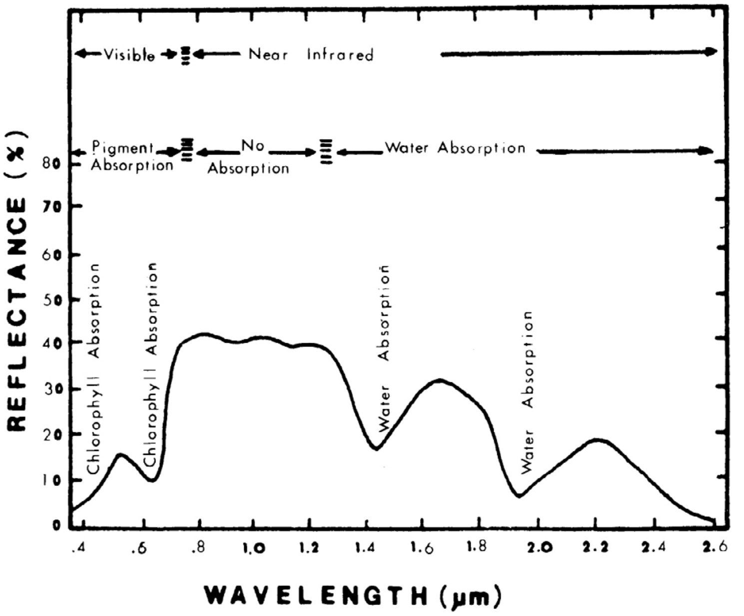

Fig. 1. Reflectance properties of a typical green leaf for the visible light spectrum.

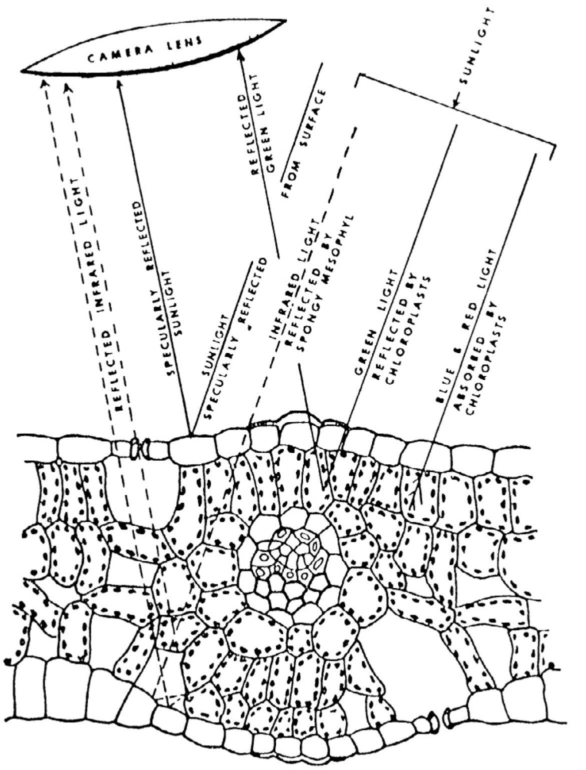

Fig. 2. Light interaction with various leaf compounds. (From Colwell [1].)

barley yellow dwarf virus produced a variation in tonal signature on black and white infrared film similar to that produced by rusted wheat. Since that time, only a few reports dealing with aerial detection of virus diseases have been published.

Several laboratory investigations have shown the superiority of infrared films for detecting virus symptoms on individual leaves. In an early study, Bawden, cited by Odle and Toler (10), found that black and white IR film was more effective than conventional panchromatic film for detecting tobacco necrosis virus symptoms on potato leaves. He found the reverse to be true, however, for detecting the same disease in tobacco (*Nicotiana tabacum* L.) leaves. More recent investigations have shown that symptoms caused by tobacco ringspot virus and watermelon mosaic virus can be detected earlier and better with false color IR photography than with conventional color film or visual observation (10).

Hill and co-workers, cited by Odle and Toler (10), used low-altitude color IR photography to detect tobacco ringspot virus infection of soybeans, which causes plants to become dwarfed and retain foliage longer than mature healthy plants. Defoliated healthy plants and green diseased plants were readily detected. Photographs revealed that disease severity was highest in field areas nearest native vegetation. Spread of the pathogen in the direction of prevailing winds suggested a windborne vector.

Remote sensing of maize dwarf mosaic virus disease of corn (*Zea mays* L.) was studied by Ausmus and Hilty, cited by Odle and Toler (10). Infected corn leaves with various symptoms had a significantly lower near IR reflectance than healthy leaves. Although advanced stages of disease were detected with conventional panchromatic and color films, early stages could be detected only by false color IR.

Factors Involved in Aerial Photographic Data Acquisition

The use of vertical aerial photography with false color IR film for crop disease surveys of large areas requires evaluation of several factors, including resolution, scale, growth stage, timing for maximum detection, and costs of photographic data acquisition. The economics and effectiveness of such a survey are the compromises around which the survey must be built. Film and camera costs increase with progression from the simple 35-mm camera to the 9 × 9 in. aerial format camera. Results vary according to filter combinations (5,8).

The requirements for resolution of individual plants govern the scale needed for acquisition of photographic data. Scale—the ratio between photographic image size and actual ground size—is a function of altitude of the camera platform and effective focal length of the lens system. Small-scale photography may be used when crop acreages are large and uniform, as with cotton fields. In such situations as orchards, however, plant resolution requires large-scale photography, which increases costs.

Photographic data acquisition should be timed during the crop's growing season to detect the greatest extent of the disease being studied. Proper timing requires prior knowledge of disease cycles or a series of photographic data acquisition missions for studying the extent of disease as a function of time within the crop's growing season.

Phymatotrichum Root Rot of Cotton—a Good Example

Phymatotrichum root rot of cotton in the Blackland region of Texas offers a good example of a disease amenable to detection and subsequent study with aerial false color IR photography. The suddenness of plant death (48 hours) (15) after the onset of symptoms creates strong contrasts in signatures of diseased plants, and infested areas can be delineated by these contrasting signatures. Recurrence of the disease in similar locations in cotton fields year after year indicates that historical photographic data are of value in postseason application of controls and in studying epidemiology of the disease.

Smith et al (11–14) evaluated seasonal timing of photographic data acquisition, effective scales, and methods of photogrammetric analysis (measurements from photography) for a large-area study of Phymatotrichum root rot. Seasonal timing was studied with 1:3,000 scale photography in 1976 (Figs. 3 and 4). In the 3-week interval between Figure 3 and Figure 4, over 15% more of the cotton crop in the field was affected with the disease. Timing of photographic acquisition obviously must be as close as possible to the end of the cotton-growing season before harvest to determine maximum extent of disease. Vegetation discrimination in August 1976, when Figures 3 and 4 were taken, was assisted by previous harvest of grain sorghum, the other predominant crop in the area, which has primarily a cotton-sorghum rotation.

Photographic scale was evaluated by obtaining data at three scales: large, 1:3,000 (Figs. 5 and 6); intermediate, 1:20,000 (Fig. 7); and small, 1:120,000 (Fig. 8). Photographs were then examined and the three scales compared for detection of Phymatotrichum root rot in cotton. While large scales like 1:3,000 offer excellent resolution, often with individual plants being distinguishable, the amount of film required for coverage of an area such as Falls County in Texas (764 sq. mi.) is prohibitively expensive and is too bulky to store easily. Photographs at the 1:120,000 scale do not have sufficient resolution to identify small areas of infestation in large fields. Because complex, high-altitude camera platforms are necessary to obtain such scales, aircraft operating cost becomes the limiting factor in data acquisition. For surveys of the entire Falls County area in 1976, 1977, and 1978, photographs at the 1:20,000 scale offered the best compromise among area of coverage, film and aircraft cost, resolution, and storage bulk.

Photographs taken during the 1976 cotton-growing season were analyzed photogrammetrically for a number of cotton fields, and the percentage of land area diseased with Phymatotrichum root

Table 1. Data from remote sensing survey for Phymatotrichum root rot of cotton in Falls County, TX, compared with available crop reporting statistical data (CRSD) for 1976

	Remote sensing[a]	CRSD[b]
Total cotton acreage in county	21,045	21,600
Root rot infested cotton acreage	3,171	1,728[c]
Number of fields measured	742	...
Percent of total cotton area diseased	1.50	8.00[c]
Per acre production costs[d]	$136.36	$136.36
Total countywide direct production losses[e]	$432,475.00	$235,630.00
Average per acre direct loss of gross income[f]	$161.96	$161.96
Countywide direct loss of gross income[g]	$513,680.00	$279,873.00
Turnover estimated losses[h]	$1,993,079.00	...

[a] From 1:20,000 scale photographs taken 24 August and 9 September 1976.

[b] From W. J. Walla (*personal communications*), USDA-AR statistics, and Cotton Disease Council data and estimates.

[c] From W. J. Walla (*personal communication*), 1,728 acres calculated from 8% estimate.

[d] From Lovell (6); calculated from budget data for 1976 dryland cotton, Blackland region, and including all production costs except harvesting and ginning.

[e] Diseased acreage × per acre costs.

[f] Calculated on average per acre yield of 231 lb of lint at 62.4¢/lb and 0.18 ton of seed at $99/ton (19).

[g] Diseased acreage × per acre seasonal gross income (19).

[h] Based on turnover factor from Texas input-output model (3.88) and calculated summation of direct losses to producers.

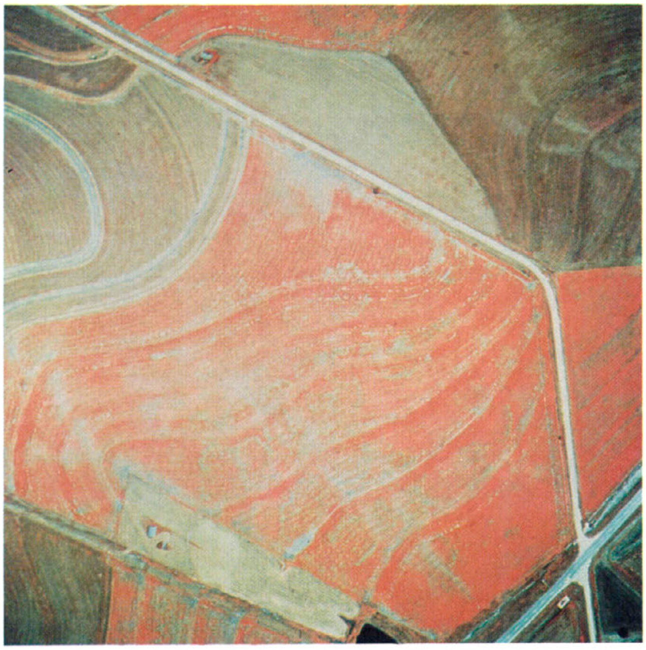

Fig. 3. A 1:3,000 scale photograph of a cotton field designated 4C was taken 4 August 1976. Beginning Phymatotrichum root rot appears as green patches in the reddish pink areas of healthy cotton.

Fig. 4. A 1:3,000 scale photograph of field 4C taken 26 August 1976, approximately 3 weeks after Figure 3, shows the increase in Phymatotrichum root rot.

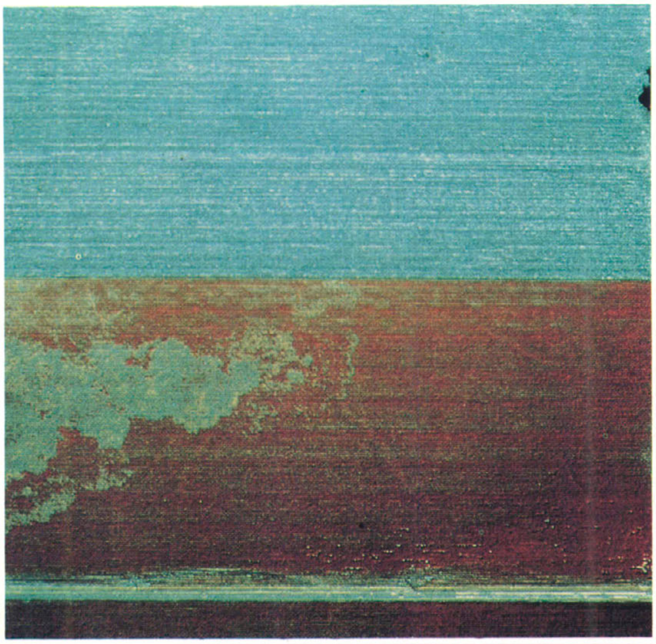

Fig. 6. Magnification of a 1:3,000 scale photograph allows identification of individual plants, including healthy (red) escapes in diseased (green) areas.

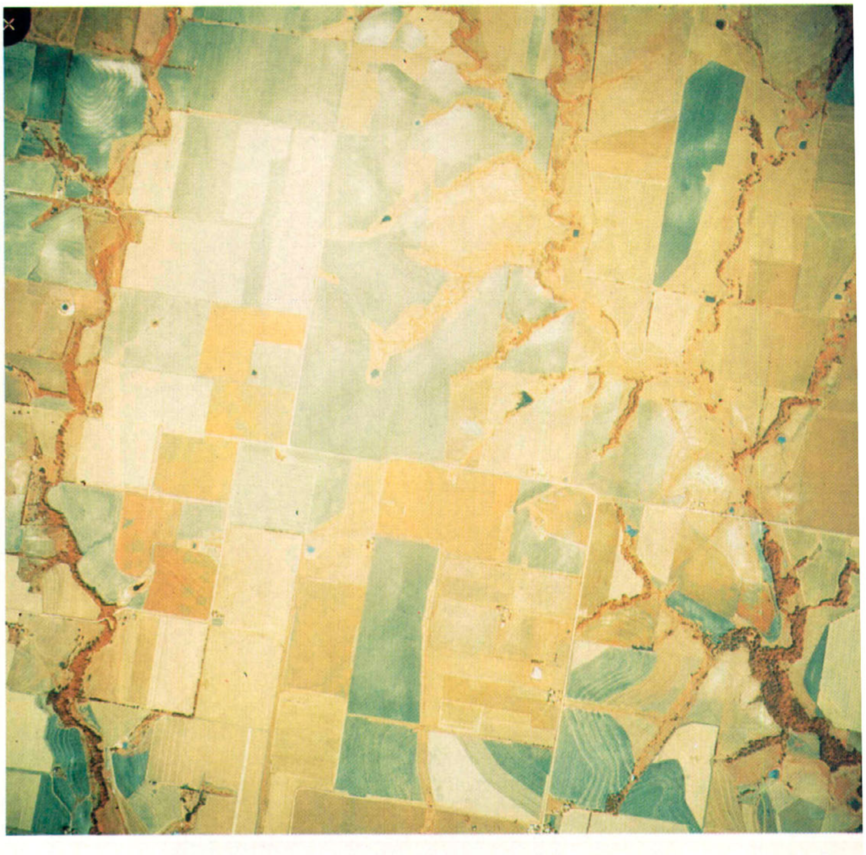

Fig. 7. A 1:20,000 scale photograph containing the field shown in Figure 5 (left, center) has sufficient resolution to identify Phymatotrichum root rot.

rot was determined. Cotton fields were located and identified by signature from photographs covering all of Falls County. Identification was verified by ground-truth surveys of actual conditions, especially in areas of questionable identity. Cotton field identification was enhanced by photographs taken 24 August 1976 after harvest of grain sorghum, leaving cotton as the only row crop. Cotton acreage in the county was measured by transferring boundaries of field areas from a 1:120,000 scale to a 1:24,000 scale, using 7.5-minute USGS topographic quadrangle maps. The area was then computed with a planimeter.

Percentages of field areas diseased were ascertained from 1:20,000 scale photographs. Dot grids were projected onto the field photographs with a Bausch and Lomb Zoom Transfer Scope, and the

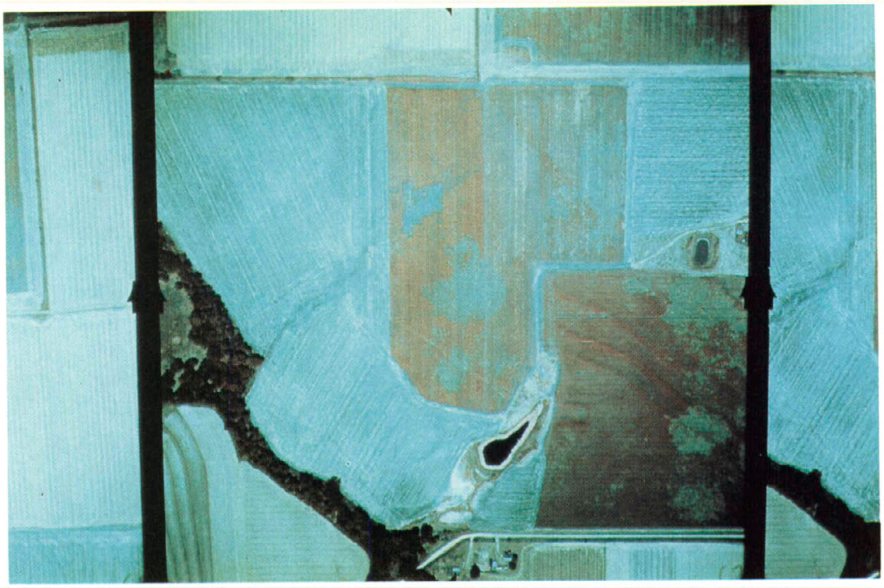

Fig. 5. Resolution on this 1:3,000 scale photograph is sufficient to identify individual rows in a cotton field.

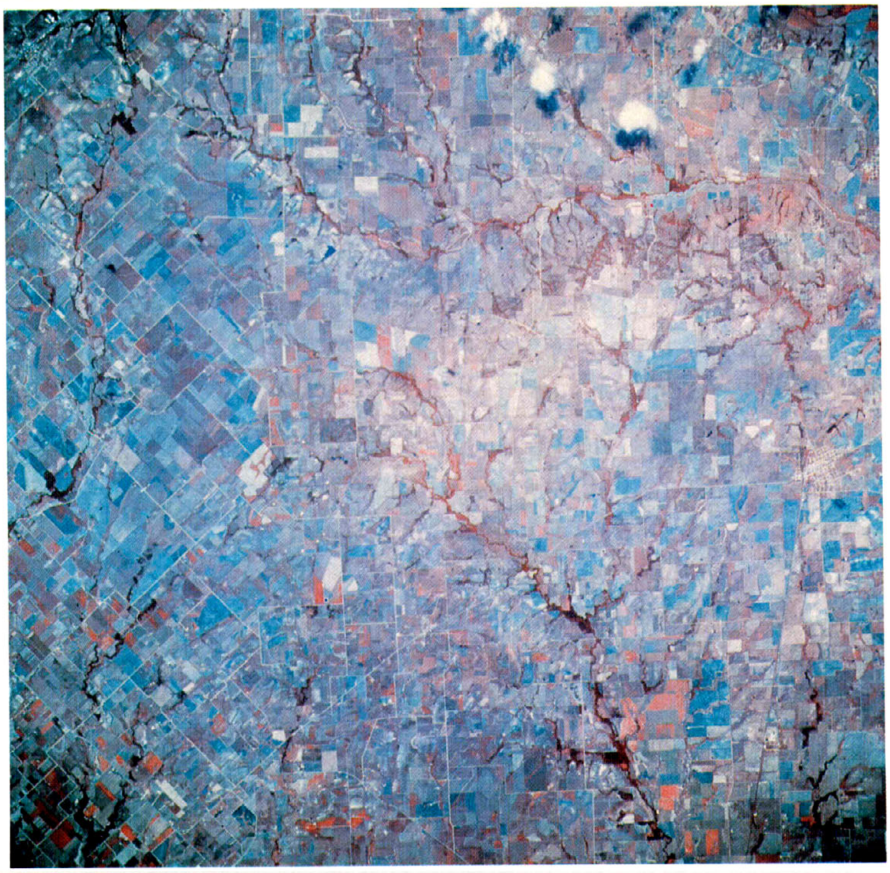

Fig. 8. A 1:120,000 scale photograph covering 185,950 acres (290 sq. mi.) and including the fields shown in Figures 5 and 7 has sufficient resolution to identify the larger infested areas under high magnification.

number of dots overlying healthy areas and the number of dots overlying areas showing the Phymatotrichum root rot signature were counted. The number of "diseased dots" was divided by the total number of dots lying within a field boundary. This fraction multiplied by the total field area from planimetry gave the acreage infected with Phymatotrichum root rot. The diseased and total field acreages were compiled to provide the figures for Falls County for 1976 (Table 1).

The economic impact of Phymatotrichum root rot of cotton in Falls County in 1976 was calculated with data obtained from photogrammetric analysis (13) (Table 1). Areas infested with Phymatotrichum root rot were usually considered total losses because the easily uprooted infected cotton plants and unopened bolls jammed harvesting equipment. For calculating the disease's economic impact on cotton production, infested areas were considered total losses.

The three categories of losses were actual production cost, projected gross income, and state agribusiness economy. Actual production cost losses were calculated on the basis of middle-level management cost for preparation and planting; costs of harvesting and ginning were not included (6). The per acre production costs and total countywide direct production losses are shown in Table 1.

Gross income losses were calculated from the seasonal average price for cotton (62.4¢/lb of lint, $99/ton of seed) and the average yield per acre (231 lb of lint, 0.18 ton of seed) (19). Countywide gross income losses were calculated by multiplying diseased acreage by the per acre seasonal gross income ($161.96) for seed and lint (19) (Table 1).

Impact on the agribusiness economy of Texas was calculated by multiplying gross income losses by 3.88 (3), the number of dollars generated in the agribusiness economy for every dollar of cotton income generated. The potential loss of income to the agribusiness economy of Texas from Phymatotrichum root rot of cotton in Falls County for 1976, calculated from remotely sensed data, was $1,993,079 (13) (Table 1).

Cost Considerations

The cost of aerial surveys for crop disease using false color IR photography varies with the scale used, area covered, type of aircraft needed, camera system used, and film required. Analysis of the photographs depends on the type and complexity of photogrammetric procedures and can be a cost factor. The amount of film and length of flight time can be reduced by using the smallest scale that will give the desired resolution, and a 35- or 70-mm camera is less expensive to operate than the 9 × 9 in. aerial format mapping camera used in the Fall County survey.

Four scales are compared in Tables 2 and 3. Photography costs are high with low-altitude flights and a 1:3,000 scale because of the amount of film and the number of flight line miles required to cover a large area. With small-scale photography, on the other hand, very little film is needed but a complex, expensive, high-altitude camera platform must be used. For example, with a Lear jet flying at 40,000 ft, 1:80,000 scale photographs can be obtained using a 6-in. focal length lens. Operating costs for such aircraft run $1,500–1,800 an hour; the cost per flight line mile depends on the total

Table 2. Comparison of ground area coverage, number of frames required for conventional coverage, and number of frames required for stereo coverage in a countywide[a] survey of Falls County, TX, by photographic scale

Scale	1 in. equals: (ft)	Land area covered by 9 × 9 in. frame (acres)	Minimum number of frames to cover entire county[b]	Minimum number of frames for stereo coverage	Total number of survey frames[c]	Flight line miles[d]
1:3,000	250.00	116.22	4,208	15,027	18,275	3,080
1:20,000	1,666.67	5,165.29	95	339	441	455
1:80,000	6,666.67	82,644.63	6	22	48	140
1:120,000	10,000.00	185,950.41	3 or 4	10	18	70

[a] 764 sq. mi. (488,960 acres).

[b] Calculated by scale on basis of 9 × 9 in. transparency frame; stereo coverage has 60% forward lap, 30% side lap.

[c] Based on frames on each end of flight line plus 10% contingency frames.

[d] Calculated on basis of 30% side lap.

Table 3. Comparison of cost of ground coverage on photography in a large Phymatotrichum root rot disease survey covering the entire area[a] of Falls County, TX, by photographic scale

Scale	Total number of frames for survey in stereo[b]	Flight line miles[c]	Cost ($) Air time	Cost ($) Processed film[d]	Cost ($) Total	Added cost per acre of cotton countywide[e] ($)
1:3,000	18,275	3,080	5,900[f]	98,900	104,890	4.98
1:20,000	441	455	872[f]	2,389	3,261	0.16
1:80,000	48	140	7,000[g]	260	10,260[h]	0.49
1:120,000	18	70	N/A[i]	98	N/A[i]	N/A

[a] 764 sq. mi. (488,960 acres).

[b] Calculated from drawn flight lines; includes end photographs plus 10% contingency frames.

[c] Calculated on basis of 30% side lap.

[d] Number of frames × 10 ÷ 12 in./ft × $1/ft processed.

[e] Total cost divided by total number of acres of cotton in Falls County for 1976 = $21,045.

[f] Cessna TU-206 camera platform.

[g] Lear jet $50/mi, commercial firms; does not include ferry costs.

[h] Total cost includes 2 hr ferry time for Lear jet.

[i] NASA RB-57 camera platform; costs unavailable.

number of miles, ie, the more miles, the lower the per mile cost. The intermediate 1:20,000 scale offers the best compromise between costs and resolution; the added cost of only 16¢ per acre for film and flight time may make annual surveys economically feasible for producers.

A Useful Tool

Remote-sensing technology offers a useful tool for controlling diseases of food and fiber crops. The technology is ideal for orchards, where historical records of disease can be maintained for each tree, disease trends can be studied and infected trees rogued or treated (8), and the cultivars with greatest resistance can be detected.

The economic base of some annual crops may not be large enough to support photographic data acquisition and analysis. The best application of remote-sensing technology is perhaps to soilborne pathogens that annually cause disease in similar locations. For example, Phymatotrichum root rot of cotton can be studied and the spread of infestation compared with historical incidence data. Management alternatives, such as rotation of cotton with grain sorghum or another nonsusceptible crop, or mapping of infested areas for possible treatment may be guided by photographs. Infested areas may be located even after the crop has been removed. Photographic evidence of the pathogen would preclude planting susceptible perennial crops, such as peaches and pecans, or susceptible annual crops, such as cotton. Demonstration through several years of photographic data that a soilborne pathogen is absent could result in a greater return when the land is sold.

Detection of diseases caused by windborne pathogens, such as the agent of wheat stem rust (*Puccinia graminis tritici*), is also feasible (1). Because such pathogens are not always endemic in an area, historical data may not be useful for predicting the next season's infestation. The value of false color IR photography lies in determining disease losses and evaluating breeding lines or cultivars for disease resistance.

Literature Cited

1. COLWELL, T. N. 1956. Determining the prevalence of cereal crops by aerial photography. Hilgardia 26:223-286.
2. GAUSMAN, H. W. 1974. Leaf reflectance of near infrared. Photogramm. Eng. 40:182-191.
3. GRUBB, H. W., and M. L. WRIGHT. 1978. The Texas input-output model, 1972. Texas Department of Water Resources LP-24, Austin. 447 pp.
4. HEALD, C. M., W. H. THAMES, and C. L. WIEGAND. 1972. Detection of *Rotylenchulus reniformis* infestations by aerial infrared photography. J. Nematol. 4:298-300.
5. JACKSON, R. 1964. Detection of plant disease symptoms by infrared photography. J. Biol. Photogr. Assoc. 32:45-58.
6. LOVELL, A. 1976. Cotton, dryland, Texas Blacklands region estimated costs and returns per acre typical management. Pages 21-22 in: Texas Blacklands Region Crop and Livestock Budget. Texas Agricultural Extension Service, Texas A&M University, College Station. 73 pp.
7. MANZER, F. E., and G. R. COOPER. 1967. Aerial photographic methods of potato disease detection. Maine Agric. Exp. Stn. Bull. 646. 14 pp.
8. MYERS, V. I. 1975. Crops and soils. Pages 1715-1813 in: R. G. Reeves, A. Anson, and D. Landen, eds. Manual of Remote Sensing. American Society of Photogrammetry, Falls Church, VA. 2,144 pp.
9. NIXON, R. P., S. D. LYDA, M. D. HEILMAN, and R. L. BOWEN. 1975. Incidence and control of cotton root rot observed with color infrared photography. M.P. 1214, July 1975. Texas Agricultural Experiment Station, Texas A&M University, College Station. 4 pp.
10. ODLE, W. C., and R. W. TOLER. 1976. Remote sensing of St. Augustine-grass decline disease. Remote Sensing Center TR-77, Texas A&M University, College Station. 164 pp.
11. SMITH, B. D., J. C. HARLAN, R. W. TOLER, and H. W. EATON, JR. 1977. Determining definitive disease losses of cotton root rot employing aerial remote sensing. Page 105 in: Proceedings of Sixth Biennial Workshop on Aerial Color Photography in The Plant Sciences. American Society of Photogrammetry, Falls Church, VA. 153 pp.
12. SMITH, B. D., R. W. TOLER, J. C. HARLAN, and H. T. EATON, JR. 1978. Aerial remote sensing, an aid to cotton root rot control. (Abstr.) Proc. Am. Phytopathol. Soc. 4:149.
13. SMITH, B. D., R. W. TOLER, J. C.

HARLAN, and H. T. EATON, JR. 1978. Remote sensing for disease management and economic impact assessments of cotton root rot. (Abstr.) Phytopathol. News 12:158.

14. SMITH, B. D., R. W. TOLER, and S. D. LYDA. 1977. Remote sensing as a tool in an integrated cotton root rot disease management system. (Abstr.) Proc. Am. Phytopathol. Soc. 4:229.
15. STREETS, R. B., and H. E. BLOSS. 1973. Phymatotrichum root rot. Monograph No. 8. The American Phytopathological Society, Inc., St. Paul, MN. 38 pp.
16. TARKINGTON, R. G., and A. L. SEREN. 1963. Color and false color films for aerial photography. Photogramm. Eng. 29:88-95.
17. TAUBENHAUS, J. J., W. N. EZEKIEL, and C. B. NEBLETTE. 1929. Airplane photography in the study of cotton root rot. Phytopathology 19:1025-1029.
18. WALLEN, V. R., and H. R. JACKSON. 1975. Model for yield loss determination of bacterial blight of field beans utilizing aerial infrared photography combined with field plot studies. Phytopathology 65:942-948.
19. WALTHER, W. H., P. M. WILLIAMSON, M. D. HUMPHREY, JR., A. J. OLSON, L. CANION, and A. MILLER. 1977. 1976 Texas cotton statistics. Bull. 150. Texas Cotton Statistics, Texas Crop and Livestock Reporting Service, Austin. 21 pp.

Robert W. Toler

Dr. Toler is a professor of plant pathology in the Department of Plant Sciences at Texas A&M University, College Station. He has been responsible for virus and virus disease research on corn, sorghum, and grasses since 1966. In addition, he has conducted research on remote sensing of diseased crops since 1970. He is a member of the Remote Sensing Center at Texas A&M University.

Brandon D. Smith

Mr. Smith is a graduate student in the Department of Plant Sciences at Texas A&M University, College Station, where he is working on remote sensing of cotton root rot.

James C. Harlan

Dr. Harlan is an associate research scientist with the Remote Sensing Center at Texas A&M University, College Station. His current research deals with remote sensing of cultivated and natural vegetation. He received his Ph.D. from the Earth Resources Department at Colorado State University.