Aerial Detection of Maize Dwarf Mosaic Virus-Diseased Corn

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ABSTRACT

Maize dwarf mosaic virus (MDMV) was detected in corn, and severity estimates were made using aerial photographic techniques. Two ground truth sites in Tennessee were photographed periodically from a remote platform during growing seasons of 1969 and 1970. Photographic imagery using: Kodak panchromatic, type 8401; Ektachrome aerial color, type 2448; Ektachrome Aero Infrared, type 8443; and Kodak Infrared Aerographic, type 5424 was obtained from a cluster of four 70-mm Hasselblad cameras. Automated data analysis of imagery yielded density signatures of healthy and diseased corn, and was accomplished using a microdensitometer and digital computer. Computer-drawn histograms supplied counts of density points per density range allowing calculation of percentages of each disease rating as a function of the total area scanned by the microdensitometer. MDMV-diseased corn was detected using all four emulsions in late season, but with infrared imagery only prior to peak symptom development. The order of preference of emulsions for MDMV detection was: type 8443, type 5424, type 2448, and type 8401. Disease severity ratings were assigned accurately and rapidly using these techniques.

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As early as 1927, photographic techniques were applied to plant disease studies (9). The major technological developments, however, were initiated by Colwell's (2) studies of cereal grain diseases. Two principles emerged from the study: (i) parameters (scale, emulsion, filter, time of day, sensor) necessary for detecting and identifying certain important diseases can be quantified; and (ii) signatures for a specific disease in a specific crop can be defined. Norman & Fritz (10) explored infrared photography as a survey technique for citrus diseases. At specified times and conditions, color infrared emulsions recorded infected plants, in certain cases previsually. Aerial photography has been shown by Manzer & Cooper (8) to be a valuable tool in the detection of late blight and other potato diseases. The loss of near-infrared reflectivity by diseased vegetation was registered on color infrared emulsion and was found to vary in proportion to the magnitude of vine damage. Damage resulting from the fungus was detected on both black and white and color infrared emulsions. Conventional color and panchromatic emulsions were found useful in the detection of Verticillium wilt, but were distinctly less effective than infrared emulsions for late blight detection.

The Laboratory for Applications of Remote Sensing (5, 6) attempted detection of maize dwarf mosaic virus (MDMV) -infected corn briefly in 1964 using low flying aircraft yielding imagery taken obliquely to the fields. A slight difference between infected and healthy areas was noted on color infrared emulsion because of decreased crop canopy in infected areas. Preliminary reflectance studies on MDMV-diseased and healthy leaves by Ausmus & Hilty (1) indicated that infrared emulsions should differentiate MDMV-diseased corn from healthy corn.

The objective of this study was to develop a system of aerial detection and estimation of severity of MDMV disease in corn. This study encompassed emulsion-filter combination studies, studies of influences of meterological parameters and altitude on disease detection, and development of analytical techniques which were rapid, objective, and quantitative.

MATERIALS AND METHODS.—Seven sets of imagery were obtained on monthly flights during the growing seasons of 1969 and 1970 over the Plant Sciences Farm at Knoxville and over Waverly corn test plots. The last two flights of 1970, however, were not used for MDMV studies because lesion development of *Helminthosporium maydis* on leaves masked virus detection on the ground. Flight dates varied because minimum weather conditions of less than 25% cloud cover and minimum haze had to be met for this photographic system to be functional. Within acceptable weather conditions, temperature, humidity, and sky cover were monitored and correlated to imagery interpretation. Time of sensing consistently was between 1200 and 1400 hr (EDT) at Knoxville and at 1000 hr at Waverly. The sensor viewing angle of the target was 90 degrees. Altitudes used were 150,305, and 455 m above mean ground level.

A cluster of four 70-mm Hasselblad cameras equipped with various emulsion-filter combinations was mounted in a DC-3 aircraft which served as the sensing platform. Four emulsions were tested as potential disease detectors: Ektachrome Aero Infrared, type 8443 (0.7-0.9 μm); Kodak Infrared Aerographic, type 5424 (0.7-0.9 μm); Ektachrome aerial color, type 2448 (0.4-0.7 μm); and Kodak panchromatic, type 8401 (0.4-0.7 μm). No photographic filters were used with either conventional emulsion. The Wratten 25 filter (0.59-0.7 μm) was coupled with the 5424 emulsion. In 1969, the Wratten 87 (0.7-0.9 μm) was used with the emulsion 8443 exclusively. In 1970, single filters and combinations of two and three filters were tested with emulsion 8443: two Wratten filters, 15 and 80B (0.5-0.9 and 0.4-0.7 μm, respectively), and a Corning filter, CS1-89. The Corning filter, designed to age all 8443 emulsion batches equally, was tested in combination with Wratten filters and did not change the densities of the imagery obtained.

In 1969, two commercial corn hybrids occupying adjacent 18.3 $\times$ 18.3 m plots at Knoxville served as primary targets. They were monitored through the season to determine meterological parameters affecting interpretation of imagery taken at intervals over the season. Primary targets in 1970 consisted of three corn hybrids in four replications of 7.6 $\times$ 6.4 m plots at Knoxville. One replication was planted at twice the plant population of adjoining plots to determine canopy density effects on imagery interpretation. All 1970 weather information was obtained from the Knoxville Weather Bureau.

Corn hybrids in order of increasing resistance to MDMV were DeKalb 805A, Pioneer 3048, and Tennessee 5009 (1970 only). On 3 July 1969 and 22 June 1970, plants in the three- to four-leaf stage in selected plots were artificially inoculated with MDMV using an artist's air brush (11). Disease development and spread through plots were monitored closely through the season. Plants were assigned to ratings corresponding to healthy (rating 1) and increasing severity of infection through nine ratings, the ninth being a plant completely collapsed, bearing no ear (4). Although there were nine ratings of corn, for purposes of imagery analysis blends of these into three generalized ratings were made. Rating 1 is defined as a healthy plant; rating 3, as a plant unstunted but mottled above the ear (a blend of ratings 2 and 3); and rating 5, as a stunted, mottled plant (a blend of ratings 4 through 9). Ratings were made close to each flight date. Loci of infection were noted and the plots mapped according to these loci; therefore, for each imagery set there was established a ground truth disease map.

Secondary targets at Waverly were designed to give minimum ground truth in order to test the system's predictive value. Plots consisted of corn inbreds and single and double crosses being tested for reaction to MDMV, including those used in Knoxville plots. Only natural infection from overwintering Johnson grass occurred. Sky condition, temperature, and humidity during flight were the only meterological parameters observed. Disease ratings were determined at the corn "boot" stage and in late August at peak symptom development during both years.

Imagery analysis was performed using a Scandig microdensitometer with red, blue, green, and neutral gray filters and scan-raster aperature options of 25, 50, and 100 μm. This system was based on the Techs/Ops Scandig Model 25 high-speed, digital, x-y scanning microdensitometer and IBM 360/65 computer. The microdensitometer uses an electro-optical rotating drum which converts pictorial information for an emulsion transparency or negative into digital format stored on magnetic tape. The apparatus quantitatively measures optical density up to 3D, through 256 levels with a resolution of 0.012D, digitizing the specimen at a rate of 20,000 points/sec. The use of the microdensitometer, magnetic tape, and digital computer yielded automated imagery analysis based entirely on optical densities of the exposed emulsions. Automated analysis was attempted to determine the best emulsion-filter combination for plant disease surveys and to determine the best microdensitometer scan-raster aperature and filter for scanning choice emulsion-filter combinations. Systems similar to this have been demonstrated to be a great aid in imagery interpretation and an improvement in time and accuracy over stereoscopic viewing or other subjective procedures (3, 7).

Portions of imagery to be analyzed were scanned by the microdensitometer. Computer output was in column digital or gray scale format. The gray scale was developed by clustering techniques in order for assignment of symbols to ranges which occurred together on column digital printout. The gray scale, therefore, yielded a symbolic map of target fields with different symbols assigned to designated disease ratings 1, 3, and 5. Computer-drawn histograms furnished the number of points in each density range per acre scanned by the microdensitometer. Hence, the percentage of each corresponding disease rating in a target field was determined.

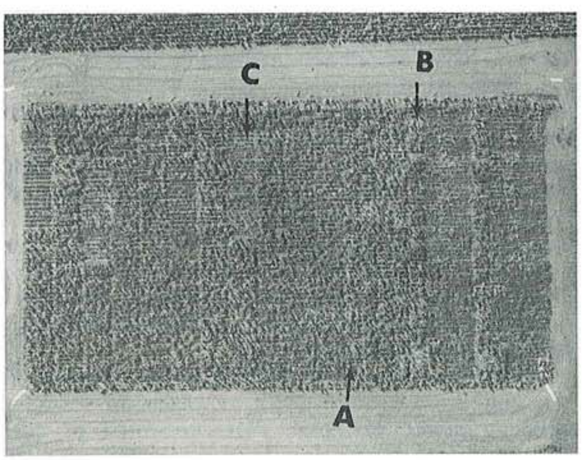

Fig. 1. Waverly test plots, 25 August 1969, as imaged on emulsion 5424 with Wratten 25 filter from an altitude of 304.8 meters. (A) Rating 1 corn; (B) rating 3 corn; (C) rating 5 corn.

RESULTS AND DISCUSSION.–*Microdensitometer analysis.*–The microdensitometer scanned imagery automatically in assigned intervals of 25, 50, or 100 μm; digitized optical density data; and stored it on magnetic tape. The magnetic tape could be programmed to yield data in a variety of formats which allowed great flexibility in data presentation. The use of histograms in calculation of areas of fields in each disease rating improved disease severity estimates and predicted the value of this detection program in surveying disease losses.

Although column digital printout was cumbersomely large, it allowed the development of the gray scale. Clusters of densities which consistently occurred together on either infrared emulsion were defined into a density range and designated a symbol which would be printed each time any of those digits was encountered by the computer. The versatility of the programming allowed the removal of those symbols corresponding to soil, roads, shadows, and other images irrelevant to the study by a simple coding of the symbols blanks. Since the microdensitometer digitizes imagery as the reverse of the photographic process (positive as negative and vice versa), densities corresponding to dark vegetation are low numbers rather than high numbers. These density ranges were established for infrared imagery: densities 0-49 represented rating one corn; densities 55-80 rating three corn; and densities 85-99 rating five corn. These ranges are defined as signatures and were checked for accuracy against disease-rating plot maps by assignment of symbols and then the dumping of the same data file to the gray scale printout.

Of the four available microdensitometer filters, the red filter was superior for vegetational analysis on both infrared and conventional emulsions. The neutral gray filter was equally good as red with either black and white infrared and conventional emulsions. The scan-raster aperature best for analysis depended on the purpose of that analysis. Detailed vegetational analysis attempting to detect early disease development, particularly from higher altitudes (305, 455 meters), necessitates the use of the 25-μm aperature. Surveys of disease loss made later in the season can be accurately analyzed using 50- or 100-μm aperatures. The larger the disease loci, the larger the aperature needed for defining them accurately. Such surveys from 150, 305, and 455 m were equally well analyzed using the 100-μm aperature. If higher altitudes were used, the use of smaller aperatures would allow maximum resolution by integrating less imaged area into each density reading.

Disease identification.–MDMV-diseased corn was differentiated from healthy corn in both 1969 and 1970. In 1970, the *H. maydis* epiphytotic interfered with MDMV detection late in the season because of severe lesion development over entire plants.

Infrared emulsions were consistently more accurate than conventional emulsions in

COUNT	NO.
25	5
26	9
27	37
28	11
29	11
30	15
31	301
32	385
33	141
34	63
35	277
36	251
37	165
38	76
39	889
40	845
41	307
42	211
43	859
44	457
45	266
46	239
47	2889
48	2899
49	626
50	374
51	1159
52	1189
53	474
54	397
55	2773
56	2119
57	281
58	396
59	881
60	1201
61	234
62	980
63	4514
64	5323
65	673
66	155
67	677
68	616
69	211
70	123
71	941
72	1480
73	170
74	153
75	388
76	427
77	92
78	219
79	1247
80	1701
81	105
82	68
83	138
84	332
85	55
86	90
87	282
88	459
89	17
90	53
91	53
92	212
93	12
94	118
95	300

RATING 1; 25% (COUNT 25–48)

RATING 3; 53% (COUNT 55–79)

RATING 5; 4% (COUNT 85–95)

Fig. 2. Computer-drawn histogram of the imagery shown in Fig. 1. Column 1, COUNT, represents a segment of the 256 density levels. Column 2, NO., represents the number of data points at each level. Column 3 is the graphic representation of the number of points per level. Severity ratings 1, 3, and 5 are bracketed.

differentiating diseased from healthy plants and in differentiating severities of disease within target plots. Emulsion 8401 was of little or no disease interpretative value, and was used only in 1969. Emulsion 2448 only differentiated between healthy and severely diseased plants at peak symptom development, and did not resolve severity ratings 3 and 5. Although emulsion 8443 was superior to emulsion 5424 in early disease detection, emulsion 5424 was as accurate as emulsion 8443 later in the season. The difference early in disease development is probably due to the greater number of hues and therefore densities inherent in the color emulsion which registers the first subtle loss in reflectivity by plants infected with MDMV. Therefore, the order of preference of emulsions for MDMV detection was: 8443, 5424, 2448, and 8401. The preference order of filter combinations for emulsion 8443 based on efficiency of signature assignments to disease loci was: Wratten 15 + Corning CS1-89; Wratten 15 + Wratten 80B + Corning CSl-89; Wratten 15; Wratten 80B + Wratten 15; and Wratten 87. Both Wratten 87 and 80B blended the red hues and reduced resolution among images. Although the CS1-89 did not change the densities of imagery taken using it, the filter was an asset to the sensor system because of its property of synchronizing emulsion batches.

Imagery taken 25 August 1969 over Knoxville and Waverly targets revealed three distinct density clusters on both emulsion 8443 (with Wratten 87 filter) and emulsion 5424 corresponding to ratings 1, 3, and 5 (Fig. 1). Signatures were assigned on the basis of this imagery. Imagery taken on 9 July 1969 could then be analyzed. Although plants in the primary target plots were too small to analyze accurately (less than 0.6 m), early-maturing corn in adjoining fields which was sensed simultaneously was suitable for analysis. Signatures corresponding to ratings 1 and 3 were assigned by the microdensitometer to areas in these fields imaged on both infrared emulsions. Therefore, evidence was obtained that only spot ground truth is necessary as a check once disease signatures are determined.

On 29 June 1970 over Knoxville and on 5 August 1970 over Knoxville and Waverly, both infrared emulsions imaged *H. maydis*-diseased corn as well as MDMV-diseased corn. Microdensitometer analysis assigned different signatures to these two diseases. Imagery taken 28 August over Waverly and 11 September over Knoxville, however, yielded no signatures of MDMV-diseased corn. MDMV infections were masked by severe blight in all target areas. Only rating 1 corn was assigned the correct signature. All rating 1 corn imaged during the last two flights was Tennessee 5009, resistant to both pathogens.

Percentages of each disease rating, imaged on any of the emulsions, were calculated from computer drawn histograms. The histogram of the Waverly target imaged 25 August 1969, using emulsion 5424 with Wratten 25 filter analyzed at an aperature of 100 μm with the red microdensitometer filter revealed 25% rating 1, 53% rating 3, and 4% rating 5 corn (Fig. 2).

Variable weather conditions within the limits defined for any flight did not affect imagery interpretation. Cloud cover was apparent on 5 August 1970 imagery over Waverly, but did not change relative density range positions. Therefore, by subtracting a constant number from all density values, correct signatures were assigned to corn ratings. Altitude was not a limiting factor in interpretation. No significant differences were found in signatures assigned to imaged corn from 150 to 455 m. Plant population density and inherent varietal differences were found not to affect imagery interpretation. Signatures for ratings 1, 3, and 5 were constant for plants from ca. 1.0 m tall through flowering.

Aerial infrared photography is a useful tool in disease detection and severity estimation. This method is more accurate than ground surveys, more rapidly accomplished, and is permanently recorded. Computer programming flexibility allows calculation of areas in each rating, the rate of disease spread between periodic flights, and direction of disease movement.

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