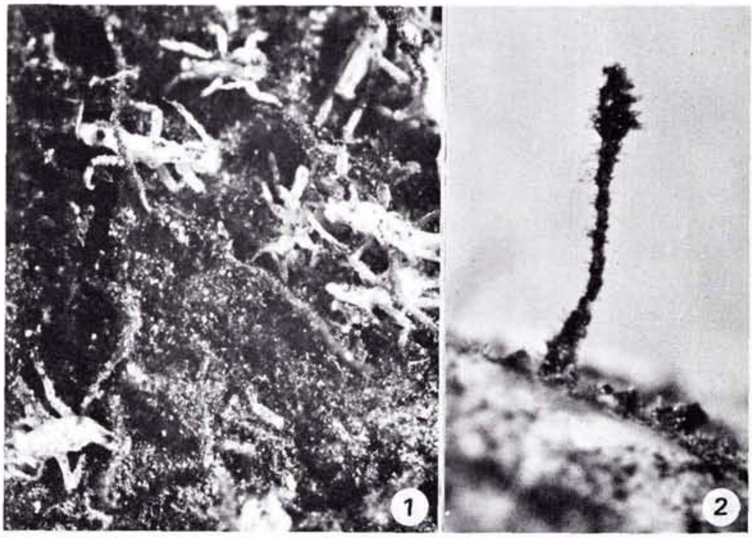

FIG. 1. *(Left)*. Cast skins of corn aphid *Rhopalosiphum maidis* and mycelium of sooty mold fungi overgrowing cast skins. Photomacrograph magnification × 20.
FIG. 2. *(Right)*. Cast skin appendage of corn aphid *Rhopalosiphum maidis* overgrown with sooty mold fungi. Photomacrograph magnification × 55.

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Corn Aphid Infestation Computer Analyzed from Aerial Color-IR*

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.

(Abstract on next page)

INTRODUCTION

In 1970, corn fields (Zea mays) nearing maturity and with various levels of corn aphid infestations were successfully photographed with aerial color-infrared film in Harwich township near the city of Chatham in southwestern Ontario[3]. Infestations were detected at scales as small as 1:9600. This was possible because tassels and leaves heavily infested with corn aphid *Rhopalosiphum maidis* Fitch., subsequently became covered with sooty mold fungi, *Alternaria tenuis* and

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Cladosporium herbarum, (Figures 1-4). The infrared reflectance of these tassels was decreased by the sooty mold fungi and was in sharp contrast to the high reflectance from adjacent healthy plants, thus indirectly indicating the presence of the aphids. Field infestation percentages were determined initially by using a technique originally developed for the determination of field areas infected with bacterial blight, employing interpretation, manual scribing, and photographic procedures for the final measurements on an IBM drum scanner[2,3,4]. Although this technique is quite satisfactory for the determination of bean blight, aphid infestations in corn represent much smaller areas on film and are difficult to trace manually with the same degree of accuracy.

Healthy green plants reflect high levels of near or "photographic" infrared radiation (.7-.9 μm) and some crops at maturity produce a complete canopy. However, with corn, because of spacing and the height of the plants, shadows, which reflect little radiation, occur tation, represents the degree of infestation.

This paper outlines and discusses an automatic technique for the computer assessment of corn aphid infestation by comparing images of healthy and infested corn after preparation through a series of photographic and scanning procedures.

ABSTRACT: *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.*

between rows. To assess a stress condition in a crop caused by disease or insect infestation where a complete canopy does not exist, it is first necessary to remove the effect of the non-reflecting areas, such as shadows, contained in the image.

Because those parts of infested rows are recorded on the aerial photographs as non-infrared reflecting, as are the shadow areas, it is first necessary in this method to determine the average shadow content of healthy fields. This can only be approximate, because such factors as plant age, row spacing (28 inches in this area), area coverage, nutrition, precise scale and cultural condition all contribute to differences from field to field. Nevertheless, the same conditions exist in fields that are infested. Infested plants increase the total *dark* or low-reflective areas recorded on the photographs. If the shadow area, measured from healthy fields, is subtracted from the total area of shadow image plus infested plant image, the difference, within the above limi-

MATERIALS AND METHODS

To reduce the amount of information contained in the aerial photographs and translate the images into a mode suitable for measurement by computer, seven frames of 9½-inch KODAK AEROCHROME Infrared Film 2443 (ESTAR Base) processed as positives (scale of 1:3,600) which had recorded aphid infestation were selected (Plate 1, lower). From these, portions of 10 fields were chosen for scanning. For comparisons, eight frames were selected which had been exposed over healthy corn fields and from these, 11 scanner panels representative of the fields were obtained (Plate 1, upper).

For the area measurement procedure[2], the drum scanner can accept only a maximum density on a translucent white. Therefore, the continuous-tone color images of the AEROCHROME 2443 require conversion to high-contrast black-and-white. This is accomplished through a series of photographic printing steps each of which increases the contrast (reducing the density scale) until the final positive contains only areas of maximum and minimum density.

Continuous-tone separation negatives were optically prepared from the images contained in these frames on KODAK Contrast Process Pan Film 4155 (ESTAR Thick Base) through KODAK WRATTEN Filters No. 47 (blue), 58 (green) and 25 (red) for the yellow, magenta and cyan layers, respectively (Figure 5). This procedure produces a negative aspect of the original with a deliberately compressed density scale, as 4155 is a high-contrast, continuous-tone, black-and-white film. The contrast of this material was further

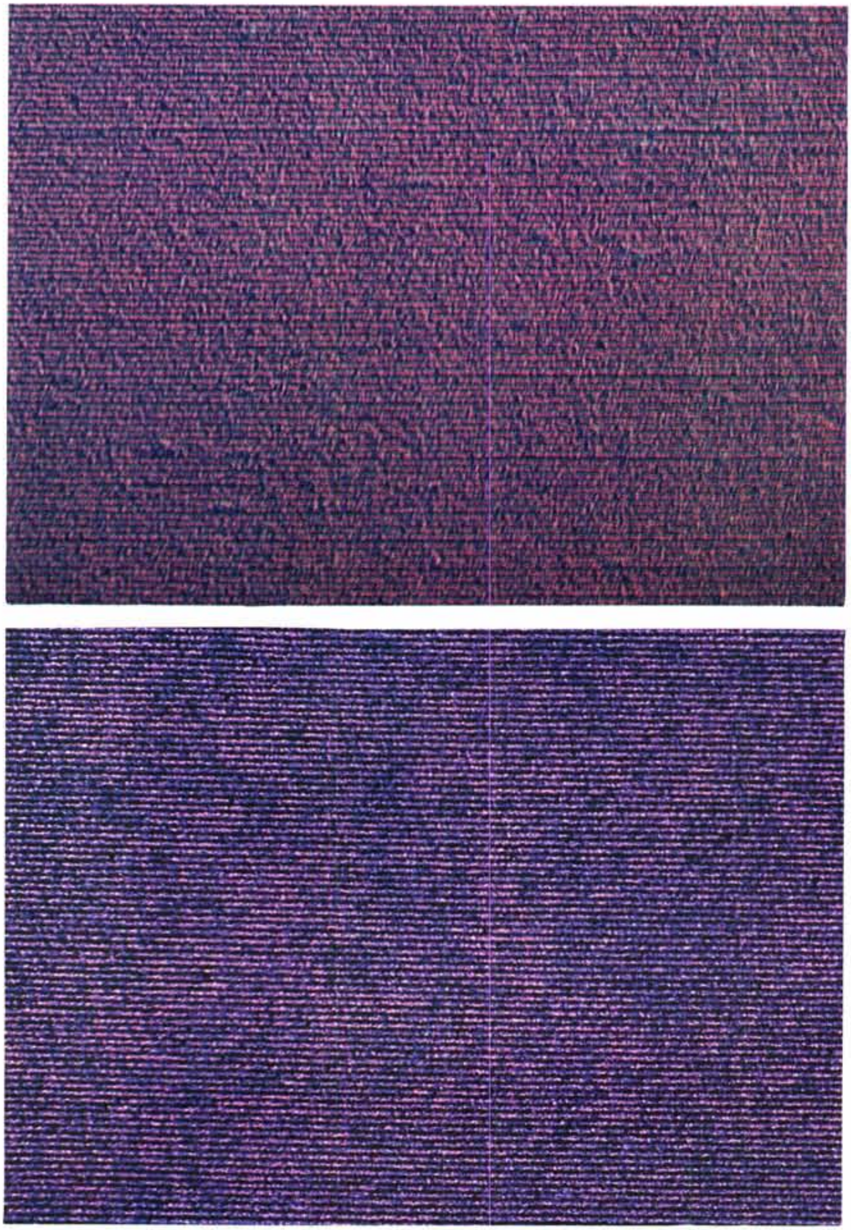

Plate 1. Color reproductions from portions of KODAK AEROCHROME Infrared Film 2443, 9.5″ format, photographed at an original scale of 1:3,600. Upper: healthy corn field; lower: field infested with corn aphids. These are enlarged sections of duplicates from original exposures and are reproduced here at an approximate scale of 1:1,200. The differences in scale between the two illustrations and consequently the area represented, is due either to a slight change in the original scale at the times of photography or to different row spacing at the time of planting. (National Air Photo Library, Ottawa; upper: A 30285-73, lower: A 30286-62).

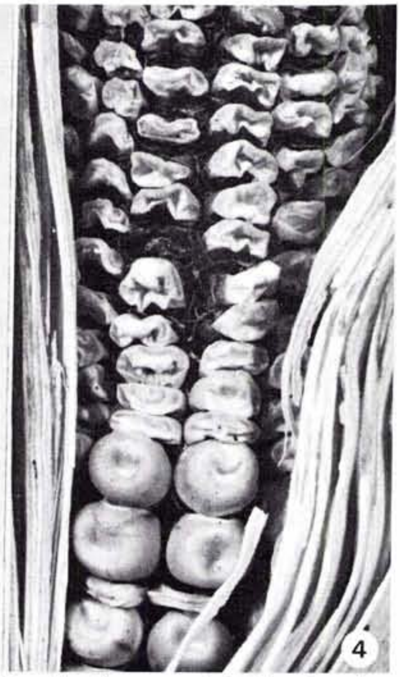

FIG. 3. *(Left)*. Corn plant heavily infested with corn aphid *Rhopalosiphum maidis* followed by invasion of sooty mold fungi.
FIG. 4. *(Right)*. Effect of infestation of corn aphid *Rhopalosiphum maidis* on corn seed set.

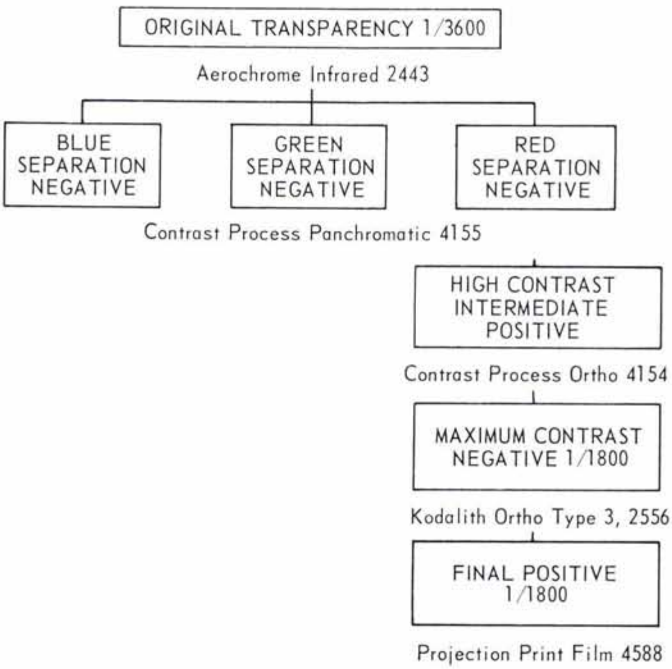

FIG. 5. Progressive steps in the optical separation of original transparencies and subsequent enhancement.

increased by processing in a moderately active developer similar to KODAK Developer D-11. A 21-step Stouffer step tablet was printed with all frames to insure that image alterations were known and within control limits. In the separation phase, above, the 21 density gradations were reduced to 11. At this stage of the study only the degree of infrared reflectance was of interest, therefore, only the red separation negatives were used in subsequent steps. Intermediate positives were made from the red separation negatives by contact exposures onto KODAK Contrast Process Ortho Film 4154 (ESTAR Thick Base), which further reduced the density scale from the eleven steps on the Stouffer step tablet to only five (Table 1).

Maximum contrast is achieved by a further step which transposes the positive image on 4154 to a negative on KODALITH Ortho Film 2556, Type 3 (ESTAR Base). This produces a further reduction of the density variations contained in the intermediate positives. In other words, the grays are eliminated and those areas in the original scene that were high-infrared reflecting are translated into areas of maximum silver density, and areas of low-infrared reflectance become clear film.

The scanner reads only maximum density areas on the film and analyzes bits with diameters greater than 0.004 inches. As some of the areas of maximum density at the 1:3,600 scale were smaller than 0.004 inches, the maximum density negatives were made on a photomechanical camera at a 2× enlargement (scale 1:1,800) that produced a 4× increase in the area of the original panels selected.

The final photographic step is to return the tonal relationships to those of the original transparency; that is, areas of maximum density represent either shadows between rows or very low infrared reflectance from plants, and areas of minimum density represent areas of high-infrared reflectance. This is accomplished by contact printing the Kodalith 2556 negatives onto KODAK Projection Print Film 4588 (ESTAR Thick Base) (Figure 6). This final step provides an image suitable for evaluation by the drum scanner.

Vignetting due to uneven exposure across the film plane from lens distortions causes

TABLE 1. TRANSMISSION DENSITIES SHOWING PROGRESSIVE REDUCTION OF THE TONAL SCALE FROM 11 STEPS ON THE STOUFFER GUIDE TO MAXIMUM CONTRAST IN FINAL NEGATIVES

Stouffer step tablet densities[1]		Red separation negatives[2]	High-contrast intermediate positives	Maximum-contrast negatives
Step		Transmission densities		
6	0.81	3.20		
7	0.98	2.68		
8	1.14	2.10		
9	1.32	1.60	0.12	
10	1.50	0.95	0.72	
11	1.72	0.57	1.68	D_{max}
12	1.88	0.37	2.39	D_{min}
13	2.04	0.26	2.71	
14	2.18	0.20		
15	2.31	0.16		
16	2.45	0.14		
ΔD[3]	0.72	1.34	2.59	D_{max}[4]

[1]Exposed with original transparency to produce red separation negatives as no readings available from original to determine actual density range.

[2]Mean step densities from all separation negatives. If density for step number 10 was within 0.10 of 0.93, it was considered to be within acceptable range. A density of 0.93 was arbitrarily selected as a "standard" for the study fields, rather than determining the range for the whole area of the 9 × 9-inch transparency.

[3]Density differences between steps 9 and 13, indicating degree of compression of tonal scale.

[4]Specific D_{max} for Kodalith Ortho 2556.

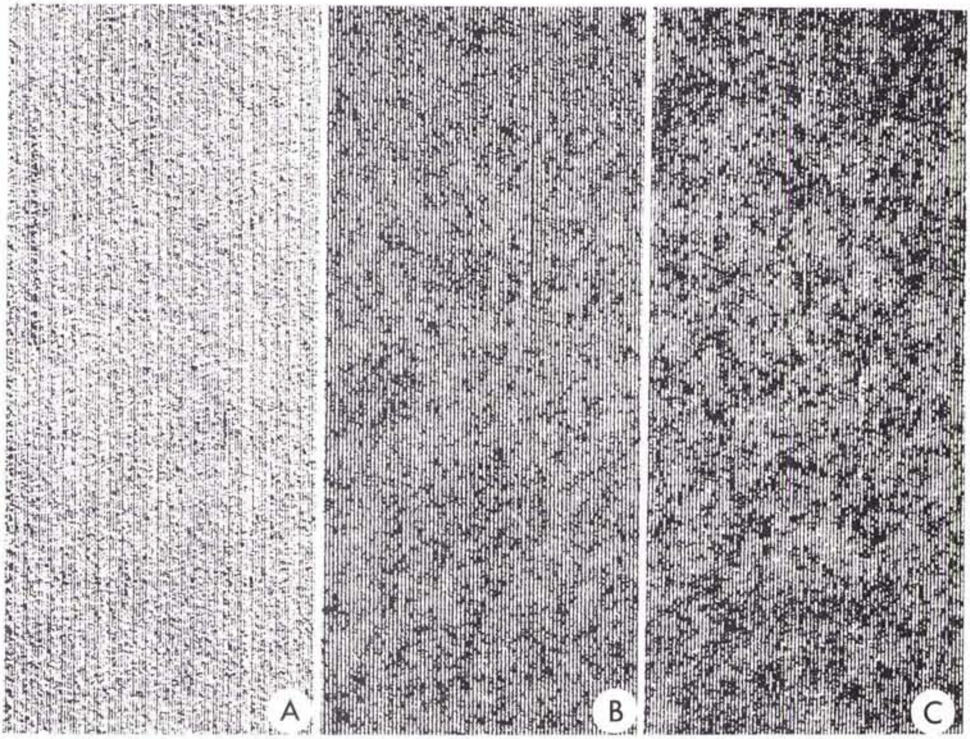

FIG. 6. Examples of final step in high-contrast enhancement procedure showing portions of panels in a format suitable for drum scanner counting. These are prints enlarged 2× from the original scale of 1:3,600 and represent (a) healthy corn, (b) moderately infested and (c) heavily infested. (N.A.P.L., numbers A 30285-63, A 30286-101 and A 30286-62 representatively.)

TABLE 2. ACREAGE AND PERCENTAGE FIELD INFESTATION COMPUTER ANALYSIS, DETERMINED FROM IMAGE ENHANCED PHOTOGRAPHS.

*Field No.**	*Total acreage*	*Infested acreage*	*% infestation*
A 30286-100	17.9	10.1	56.4
A 30286-75	22.9	12.2	53.0
A 30286-100	18.3	11.0	59.8
A 30286-107	5.4	2.7	50.2
A 30286-113	16.7	3.3	19.9
A 30286-119	9.2	6.3	68.7
A 30286-119	10.8	7.4	68.8
A 30286-121	18.5	8.4	45.6
A 30286-121	27.6	15.4	55.9
A 30286-124	24.9	14.1	56.8

*The above numbers indicate where the portions of fields analyzed were located on the film according to the nomenclature of the National Air Photo Library, Department of Energy, Mines and Resources, 615 Booth Street, Ottawa, Canada.

problems in image assessment[1]. In this study, although the original transparencies were adequate for visual evaluation, the required higher contrast obtained with each procedural step restricted the usable portion within the frames to smaller and smaller areas. Consequently only those fields that were photographed in the center of the frame and only those portions which were of even density, or that had *balanced* uneven densities, could be used.

Some of the enhanced images produced

during this study (Figures 7-10) emphasized certain field conditions which were difficult to interpret. The causal factors of the conditions were determined from field inspections and interviews with the growers.

COMPUTER ANALYSIS

The physical format of the material measured by the IBM drum scanner for total area, shadow area, and infestation as well as shadow area in corn fields, is a series of panels on Projection Print Film 4588. An all black panel, representative of the field under study, is used to ascertain field size in computer bits. The high-contrast, image-enhanced panel, where maximum density represents the infested area as well as the shadow area, is similarly scanned. After the areas are determined for this panel, it is necessary to remove that area represented by shadow. This was accomplished by preparing and scanning 11 fields of corn plants free from infestation or disease.

The ratio of shadow bits to total area bits for the 11 fields was 0.2413, which represents the fraction of shadow area normally present in a healthy corn field. The number of bits were converted to square inches by dividing by 62,500; i.e., the number of bits in 1 square inch of totally black scanned area. The amount of shadow area in a given infested field is determined by multiplying the size of the field in square inches by the ratio 0.2413, determined above.

The area of infestation in a field may then be represented by the equation:

$$I_a = IS - S$$

where I_a is the area of infestation in square inches of the field image under study; IS is the area due to infestation as well as shadow area in square inches of the field image; and S determines the shadow area from the formula: $S = T_A \times 0.2413$ where T_A is the total area of the field in square inches.

I_a (infestation area) can be converted to acres if the photographic scale is known; at a scale of 1:1,800, 1 square inch on the photographs represents 0.5165 acres.

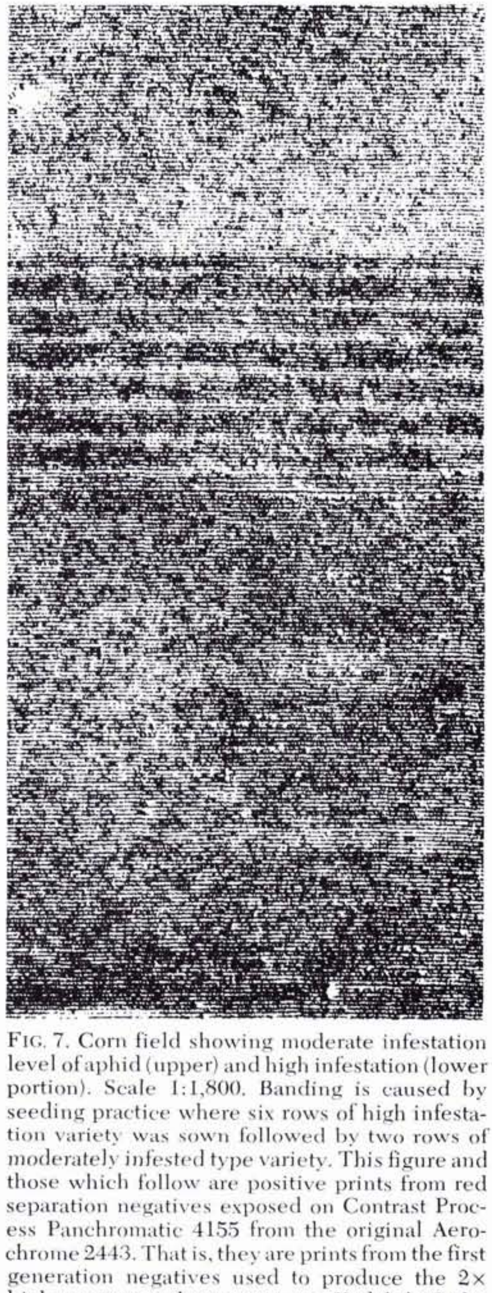

FIG. 7. Corn field showing moderate infestation level of aphid (upper) and high infestation (lower portion). Scale 1:1,800. Banding is caused by seeding practice where six rows of high infestation variety was sown followed by two rows of moderately infested type variety. This figure and those which follow are positive prints from red separation negatives exposed on Contrast Process Panchromatic 4155 from the original Aerochrome 2443. That is, they are prints from the first generation negatives used to produce the 2× high contrast enlargements on Kodalith Ortho 2556, (see text). (N.A.P.L., A 30286-107.)

RESULTS AND DISCUSSION

Infestation levels in the 10 selected fields (or portions of them), that were analyzed, varied from 10 to over 68 percent (Table 2). These levels were much higher than the average infestation levels that occurred in corn crops in the Chatham, Ontario, area; this may be because only portions of fields were selected, to give as much differentiation as possible between healthy and infested fields.

Direct comparison with the results that were obtained by the manual tracing method followed by drum scanning technique[3] is not possible because only portions of fields were used in the present technique whereas com-

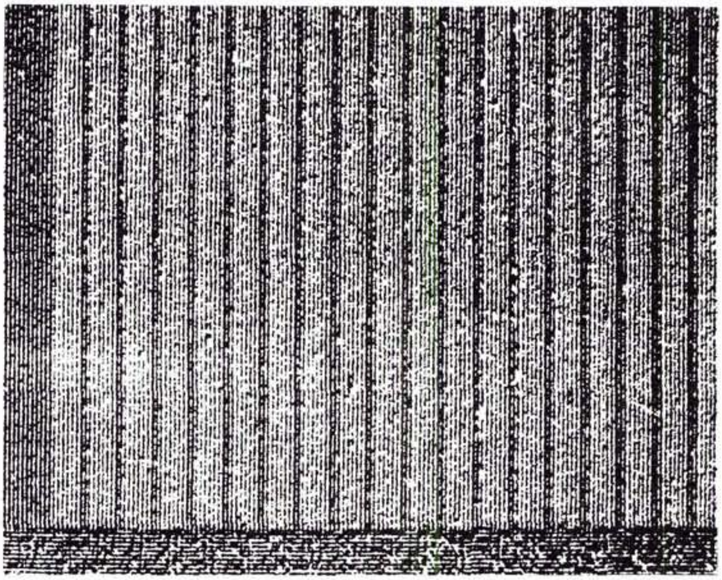

FIG. 8. Portion of hybrid corn seed field showing repeated series of six rows of detasseled female plants with two rows of complete male plants, i.e., not detasseled. In the photographs, which are an approximate scale of 1:1,800, this condition appears reversed as the male plants appear to be detasseled. The reason for this misinterpretation is due to a difference in height, as the male plants are three feet shorter than the female plants. (N.A.P.L., A 30286-113.)

plete fields were used in the former technique. However, the highest level of infestation found with the earlier method, 64 percent, compares favorably with the 68 percent obtained by this procedure.

An advantage of the computer analysis image enhancement technique is the absence of manual operation and consequent human error. However, because small changes in exposure or processing will change the range of compressed densities and may alter the size of the D_{max} areas (areas of shadow or infestation), each photographic step requires accurate control to insure reproducibility of results. Therefore, all panels must be given identical treatment. The consistency of this procedure depends on the quality of the original photographs because the levels of camera exposure will dictate the range of densities extracted from them. Consequently, photographs intended for comparison must be made on the same day and, as nearly as possible, at the same solar altitude.

Although the model used to develop this technique is ideal, because of the sharp contrast between the sooty-mold low-reflectance areas that follow aphid infestation and the high reflectivity of healthy corn plants (Figure 7), the technique should have application for other insect, disease and stress situations that produce extremely low reflecting conditions.

This technique may have direct application for inspection purposes in monitoring detasseling practices (Figure 8) to determine if detasseling has been completed. Similarly the banding produced by the differential reflectance of interplanted hybrid corn varieties (Figure 7) may be of value in monitoring hybrid seed planting practices.

Further work will explore a direct positive-to-positive method using a high-contrast, panchromatic, photomechancial camera material which should eliminate a number of steps in the present technique.

Row spacing within the corn fields was 28 inches and this is the general practice within the area under study. However, a few fields were noted where greater spacing occurred. In order to assess these fields or other fields with different row spacing, correct values would have to be determined for the average shadow areas in healthy fields. Furthermore, slight scale deviations were detected in the original transparencies from the nominal 1:3,600. Actual scales ranged from 1:3,492 to 1:3,639, as determined by ground measurements (1 to 3 percent variance from 1:3,600

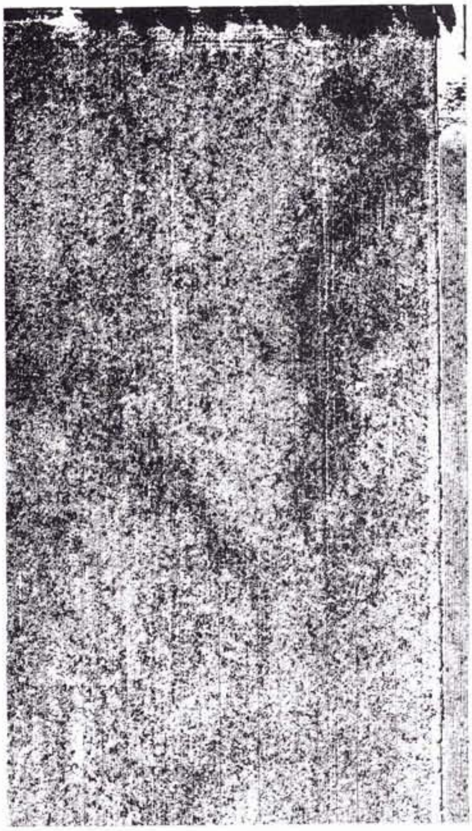

FIG. 9. Portion of commercial corn field showing patterns of aphid infestation. Severe infestation pattern on right is caused by low area in field where larger populations of aphids congregated. Scale: 1:3,600. (N.A.P.L., A 30286-121.)

FIG. 10. Corn field showing banding due to differential reflective response of corn varieties. Scale 1:1,800. (N.A.P.L., A 30285-64.)

and, although these were within acceptable limits, precise assessments would require accommodation of the errors.

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