SECTION 31

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PREDICTION OF DIRECTIONAL REFLECTANCE
OF A CORN FIELD UNDER STRESS

by

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INTRODUCTION

The remote sensing of symptoms of pathological conditions in vegetative canopies such as Southern Corn Leaf Blight depends upon a consistent relationship between the pathological symptoms and the remotely sensed effects. The use of training sets show only that in particular cases, and at a particular time, a certain pathological condition occurs concurrently with some remotely sensed effect. There may be no necessary connection between them. The use of a mathematical model to predict the remotely sensed effect from the fundamental biological causes allows one to establish the expected consistency between the conditions and the sensed effects as well as to provide insight leading to the best remote sensing techniques to use for a particular application.

A new method of calculating the directional reflectance of a vegetative canopy (1) has been used to calculate the directional spectral reflectance of a corn canopy under stress. The comparison of predicted reflectance with field measurements indicate that the model is sufficiently accurate when applied to corn fields to warrant the use of the model for application to other conditions. The prediction of the expected reflectance differences between a healthy and a blighted one-month old corn field illustrates the application to other conditions.

THE CANOPY MODEL CONCEPTS

A vegetative canopy has been idealized by assuming that any vegetative canopy, such as an agricultural crop, can be represented by several layers of uniform but randomly distributed biological components as shown in Figure 1. For example, a corn field might consist of three layers, the top layer contains tassels, the second layer contains the main body of the corn plant, and the bottom layer contains a dead leaf region or a blighted region. The canopy is bounded on the bottom by the soil.

The biological components which exist in these layers are idealized as shown in Figure 2. The horizontal and vertical projection of leaves, for example, replace the actual leaf. The accumulative horizontal projection leads to the quantity called the horizontal leaf area index while the accumulative vertical projection leads to a quantity called the vertical leaf area index for each layer. The spectral properties of the projections are obtained from the spectral properties of the biological components. These vertical and horizontal indices, their spectral properties, the number of layers and the soil reflectance provide an idealized physical description of the vegetative canopy which is all that is required to calculate the spectral reflectance of the canopy under any conditions of illumination and for any angles of view.

VERIFICATION OF THE MODEL PREDICTION

The structure and contents of two mature corn fields at Michigan State University were measured and the calculation of the expected directional spectral reflectances were made on the basis of these measurements. Three sample plants in each field were used for measurements. Figure 3 shows the summary of the measurements. Field B data is on the left and Field G data is on the right. Each field is divided into two layers; the data for the top layer (number one) is on the left and the bottom layer (number two) is on the right. Each layer contains an accumulative horizontal index on the left and a vertical index on the right. Finally, each index type is divided into the spectral types; the green healthy leaf material is shown in cross hatch bar on the left, the chlorotic material is shown by the clear bar, the necrotic material is shown by the black bar, and the stalk material is shown by the vertical lined bar.

Both fields are Texas-male-sterile corn with about 21,000 plants per acre. Field B is an unblighted field but is under drought stress which was the prevailing condition in southern Michigan during the growing season of 1971. Field G is blighted by Southern Corn Leaf Blight to an estimated blight level of 3 but the field is also under irrigation. The difference in character of these two types of stress are made manifest by these structural measurements. Note the extensive necrotic material in layer two of field G caused by the blight. Compare, also, the vigor of layer one of field G to layer one of field B. This difference is due to the effects of irrigation in field G.

It is not difficult to foresee the consequences of this structure in influencing the spectral reflectance of the canopy. The top layer will tend to be dominant so that field G will have a spectrum of a nearly healthy undroughted field while field B will have a spectrum in which the lower layer and soil will contribute,

The comparison between the predicted directional reflectance and the measured directional reflectance for two polar viewing angles, 0° and 45°, are shown in Figure 4 for field B and Figure 5 for field G. The correspondence is good between predicted and measured spectra indicating that the model of biological structure and content accounts for the major causes of the remotely sensed effects.

APPLICATIONS TO HYPOTHETICAL CASES

In order to illustrate what can be done with a predictive directional reflectance model, suppose one wished to know what the reflectance of a blighted field of Texas-male-sterile corn would be like one month after planting and in what way that reflectance would differ from the reflectance of a similar but unblighted field. The procedure which was followed by the authors was to grow greenhouse samples, to make geometric measurements on these plants, and to introduce this data into the predictive model. Naturally, for realistic results, these sample plants must be grown under such conditions that they will be physiologically equivalent to field grown plants.

The structural measurements of representative plants at the age of one month were begun on April 5, 1971, twenty-four hours after inoculation with *Helminthosporium maydis* (Southern Corn Leaf Blight). Data from a control plant which remained uninoculated were also taken. Figure 6 shows the progression of these measurements as obtained on April 5, 9, and 12. The data labeled C-2 is obtained from control plant number two; the data labeled I-2 is from inoculated plant number two. Total leaf areas are plotted to the right of the corresponding data graphs. The cross-hatch coding is the same as used before in Figure 3. The vigorous growth of the healthy plant, C-2, is in sharp contrast to the retarded growth of I-2. Note also the change in the ratios of horizontal to vertical leaf areas indicative of important geometrical orientation changes of the leaves in I-2.

The comparison of predicted reflectances of a field of C-2 and a field of I-2 with 21,000 plants per acre is shown in Figure 7. In the infrared range, the difference in reflectance is modest but significant; however, notice that the difference due purely to polar viewing angle is greater than the difference between blight and healthy fields. While blighted fields viewed at 0° are darker than healthy fields at that same viewing angle, the blighted field viewed at 50° polar angle is brighter than the downward view of healthy fields. Thus, a remote sensing system, which is based upon the assumption that blighted fields are always darker in the infrared than healthy fields, would misclassify fields if the healthy field were at 0° and the blighted fields were at 50°.

The reflectances in the chlorophyll absorption band near 0.67 μm behave quite differently. In this band, the difference between reflectances of blighted fields and healthy fields is greater than the differences due to viewing angle so that one could rely upon the blighted fields always being brigher than the healthy fields by a considerable margin.

SUMMARY

A new way of calculating the directional spectral reflectance of a vegetative canopy has been applied to corn fields under stress conditions. The predicted and field measured spectra are in good agreement so that predicted spectra for hypothetical cases can be trusted to indicate significant directional spectral reflectance properties which may be useful in applying remote sensing techniques to a variety of vegetative canopies and aid in interpreting the results.

REFERENCE

(1) G. Suits, "Calculation of the Directional Reflectance of a Vegetative Canopy," Remote Sensing of Environment, Vol. 2.2, in publication, American Elsevier.

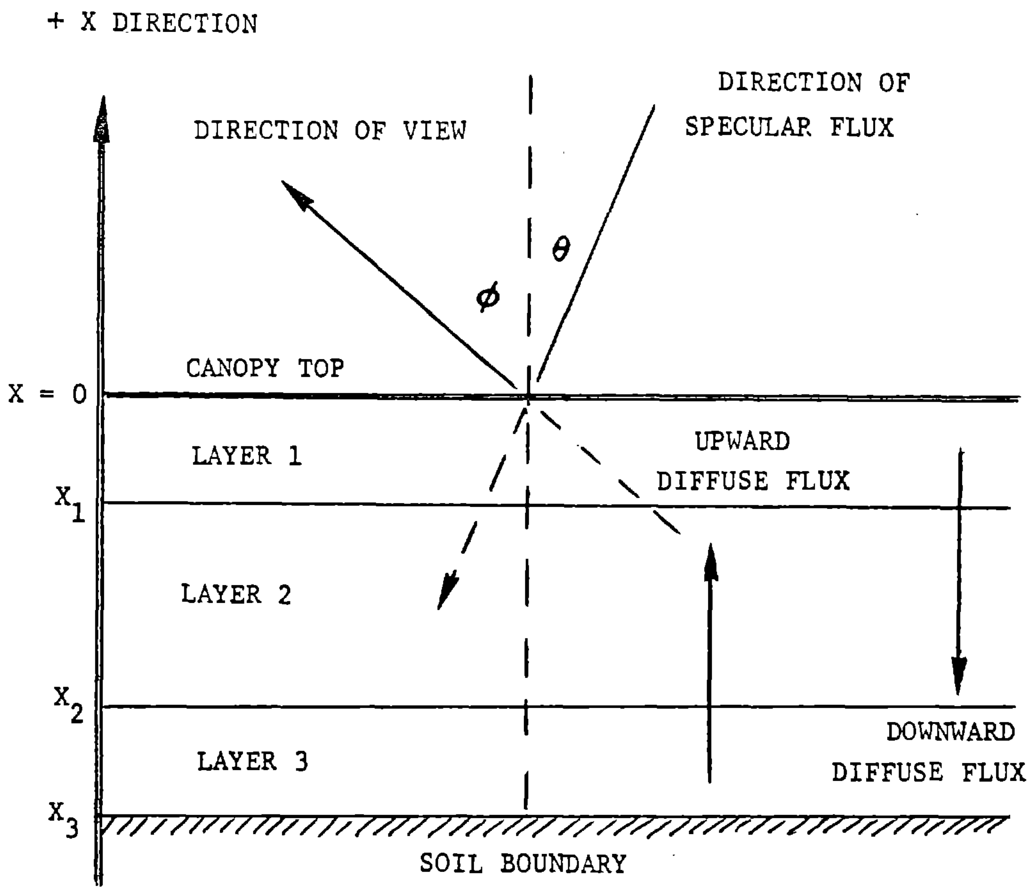

FIGURE 1. IDEALIZED LAYER STRUCTURE OF A CANOPY. Each layer represents a uniform mixture of biological elements normally found at that level in the vegetative canopy.

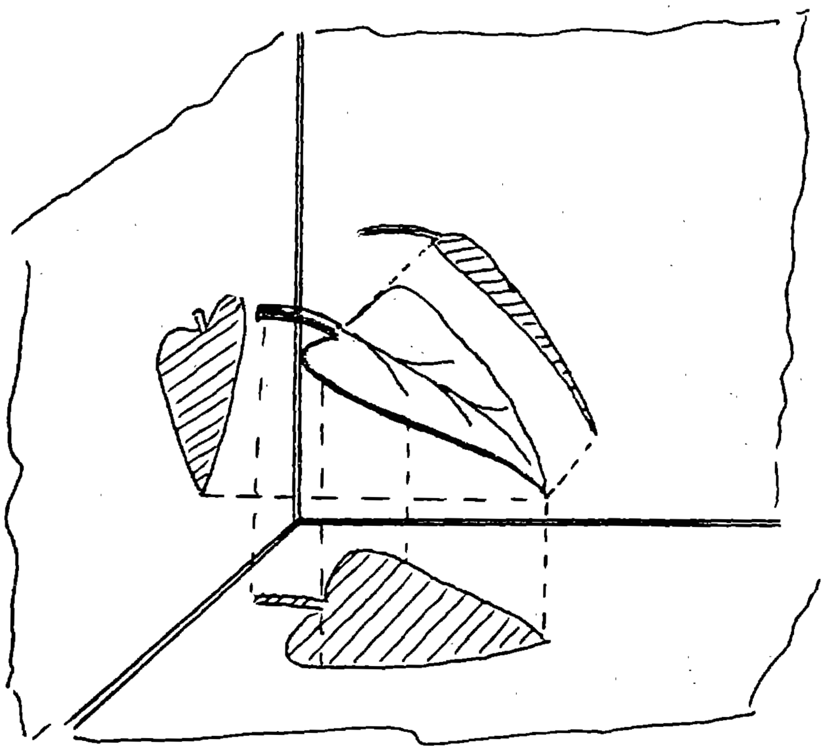

FIGURE 2. ORTHOGONAL PROJECTIONS MAKING IDEALIZED BIOLOGICAL COMPONENTS. The horizontal projections taken together lead to a quantity called the horizontal leaf area index. The vertical projections taken together lead to a quantity called the vertical leaf area index.

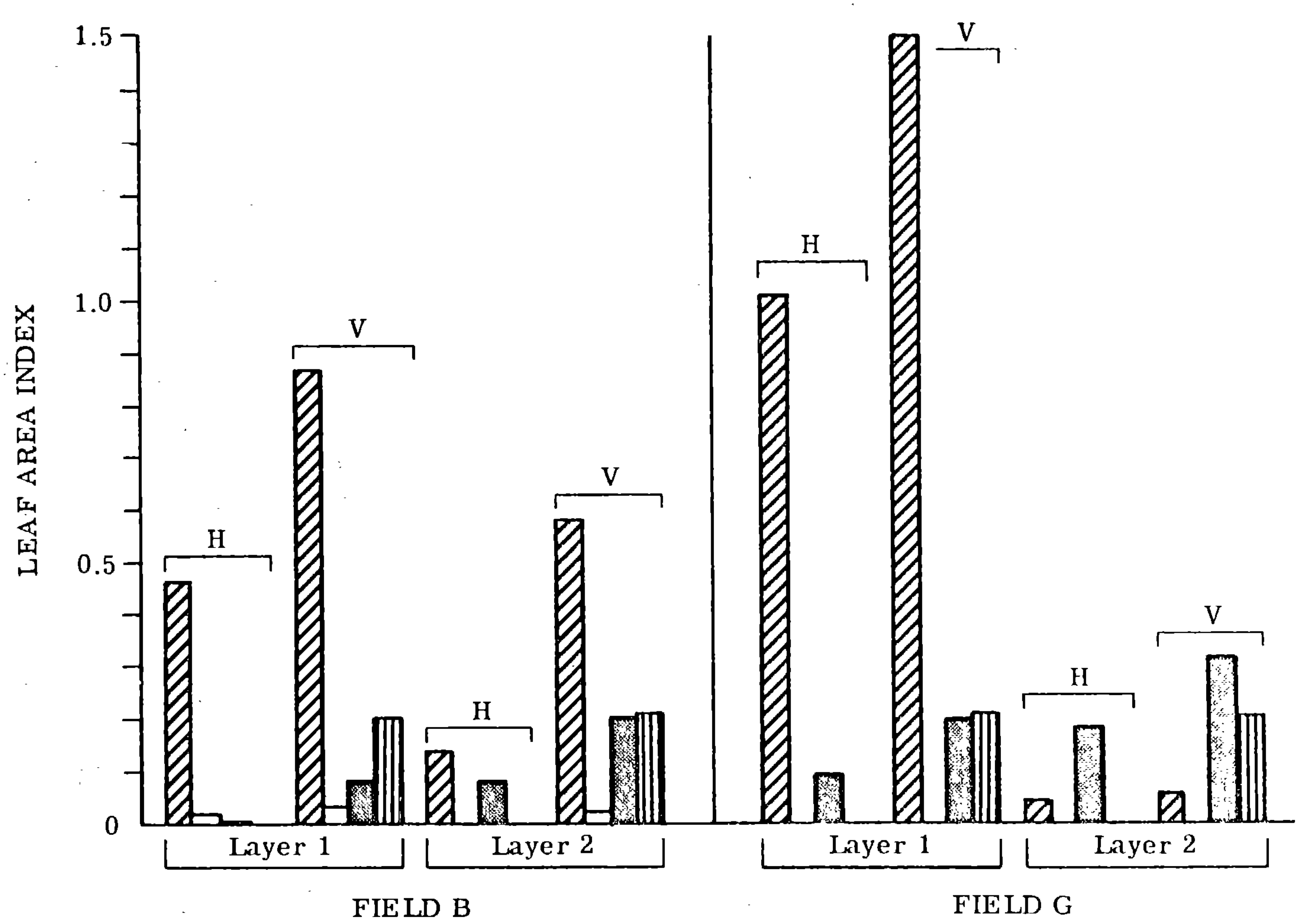

FIGURE 3. STRUCTURAL MEASUREMENTS OF TWO MATURE CORN FIELDS. Layer 1 is the top layer; layer 2 is the bottom layer. The horizontal and vertical leaf area indices for each layer are shown by bar graph. Cross hatched is green healthy material; clear is chlorotic material; black is necrotic material; and vertical hatched is stalk material.

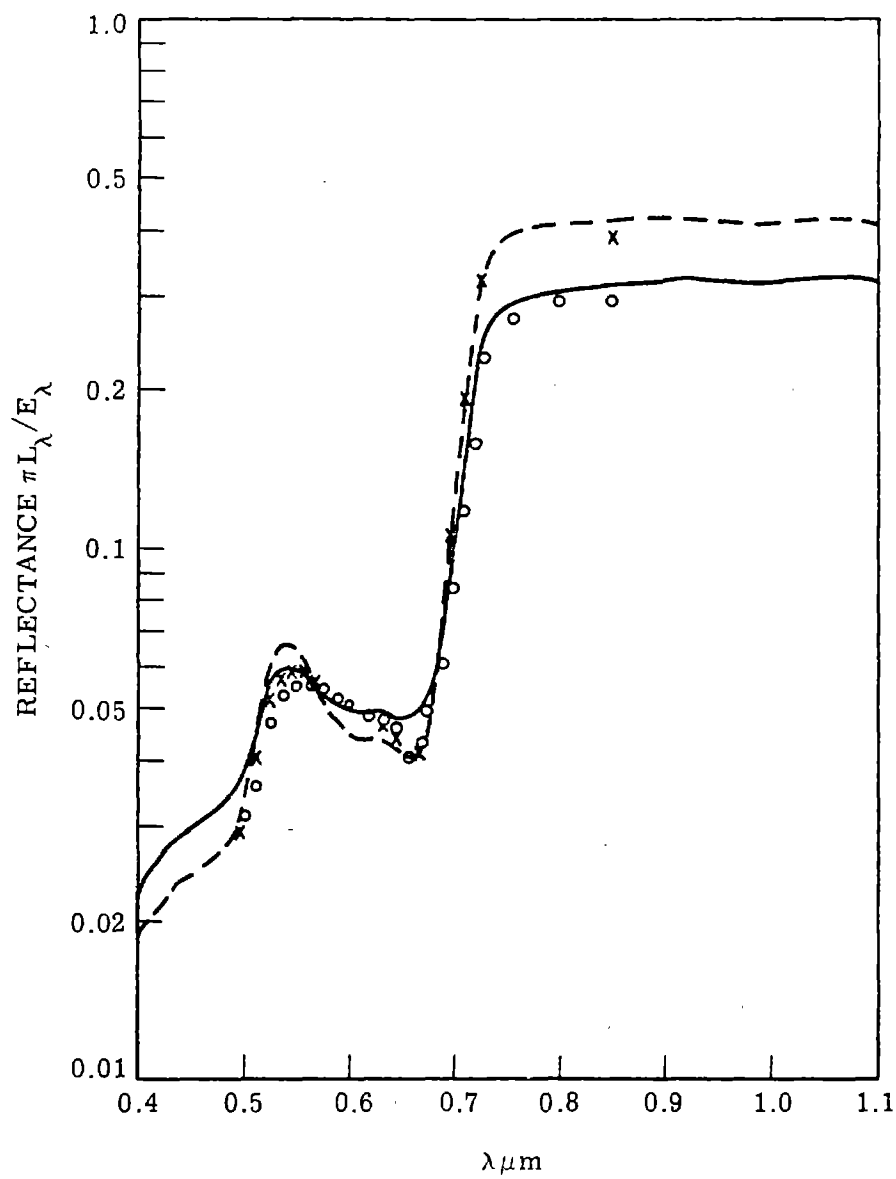

FIGURE 4. FIELD B SPECTRAL REFLECTANCE. The predicted and measured directional spectral reflectance of MSU corn field B is shown for the day 8-24-71. The field is under drought stress. It contains Texas-male-sterile corn with about 21,000 plants per acre. The canopy is about 2 meters high. The sun is 38° from zenith. The azimuth of view is 160° relative to the sun (azimuth of 0° means sun at observers back). The calculated solid curve is for polar view angle of 0°; the calculated dashed curve is for polar view angle of 45°. Field measurements corresponding to the 0° view angle are designated by 0. The field measurements for the 45° view angle are designated by x.

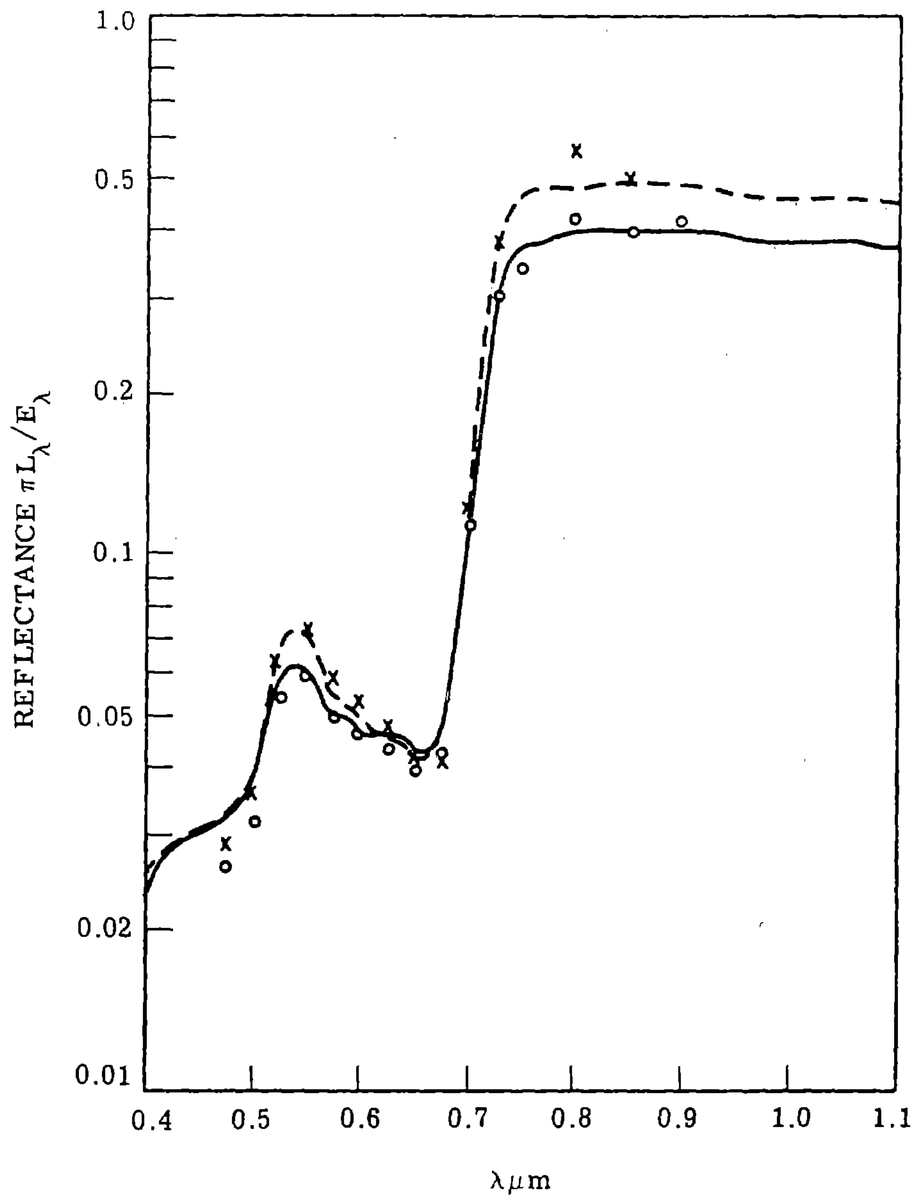

FIGURE 5. FIELD G SPECTRAL REFLECTANCE. The predicted and measured directional reflectance of MSU corn field G is shown for day 8-13-71. The field is under irrigation but also under level 3 Southern Corn Leaf Blight stress. It contains Texas-male-sterile corn, 21,000 plants per acre at a height of about 2 meters. The sun is 38° from zenith. The azimuth of view is 90° (at right angles to the direction of solar flux). The calculated solid curve is for polar view angle of 0°; the calculated dashed curve is for polar view angle of 45°. Field measurements corresponding to view angles of 0° and 45° are designated by 0 and x respectively.

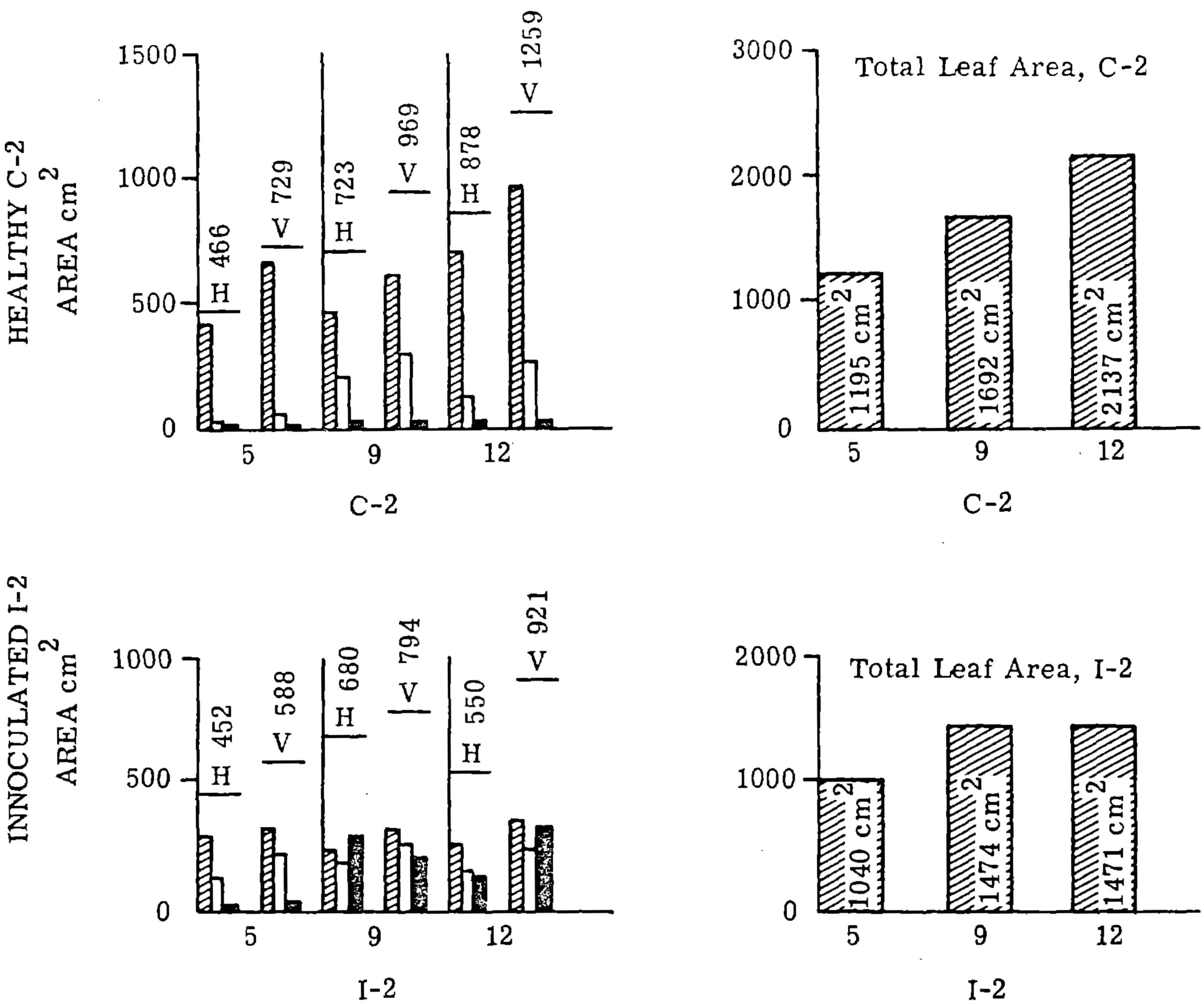

FIGURE 6. STRUCTURAL PROGRESSION OF GROWTH OF YOUNG CORN. Two one month old corn plants, C-2 and I-2, were measured beginning one day after I-2 was innoculated with Southern Corn Leaf Blight, April 5, 9, and 12. Cross hatched bars show areas of green healthy material; clear bars show areas of chlorotic material, and black bars show acres of necrotic material.

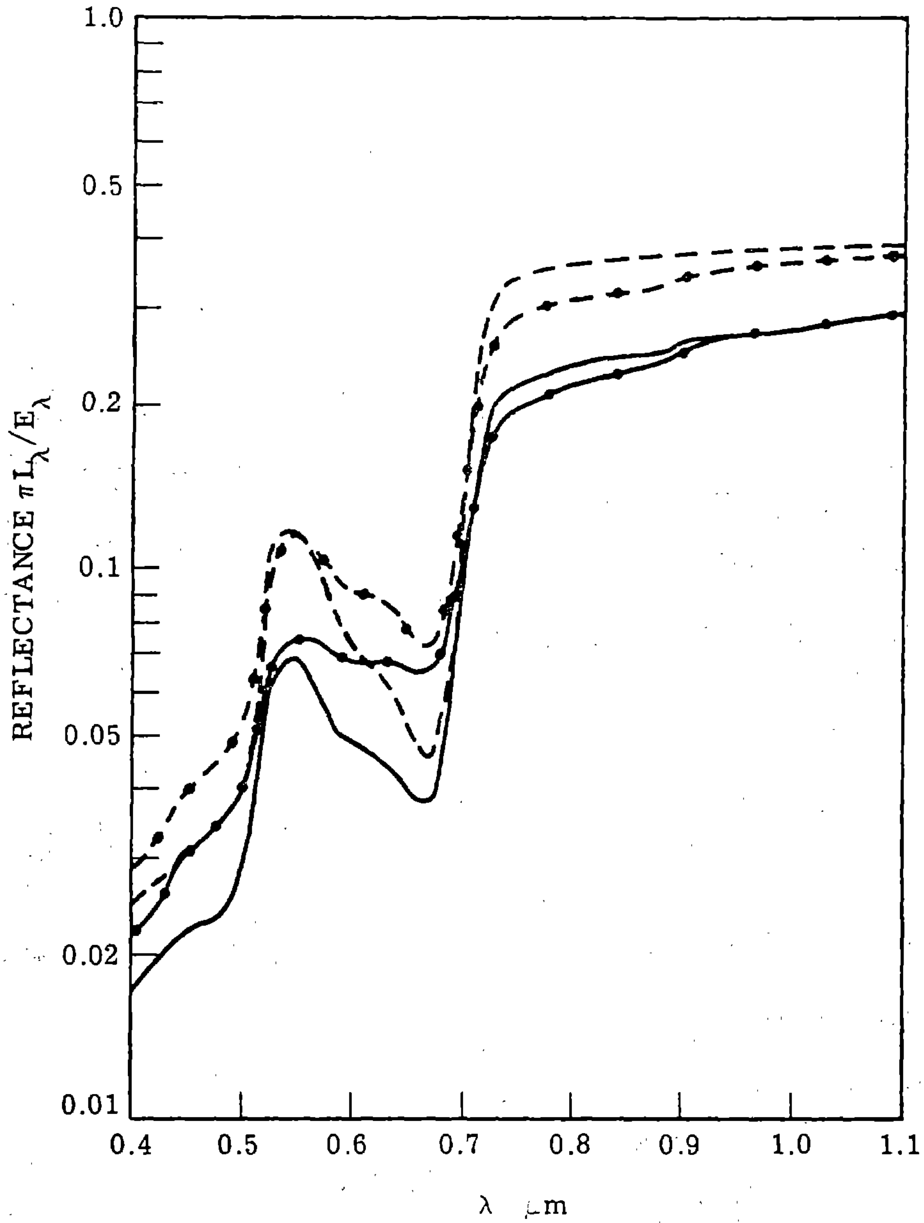

FIGURE 7. PREDICTED SPECTRAL REFLECTANCES OF YOUNG CORN. The calculations assumed a polar sun angle of 50°, a polar view angle of 0° (solid curves) and 50° (dashed curves) and a viewing azimuth relative to the sun of 45°. The smooth curves are for a field of plants like C-2; the rough curves are for a field of plants like I-2 8 days after innoculation. Plant density is assumed to be 21,000 per acre on the soil type found at the Michigan State University Agricultural Experiment Station.