BIOGRAPHICAL SKETCH

Harold W. Gausman

Dr. Harold W. Gausman is a Plant Physiologist in the USDA's remote sensing program at the Rio Grande Valley Soil and Water Research Center, Weslaco, Texas. He obtained a B.S. degree at the University of Maine in 1949, and M.S. and Ph.D. degrees at the University of Illinois in 1950 and 1952, respectively. He has been employed in research and teaching by the Universities of Illinois, Texas A&M, Rutgers (New Jersey), and Maine. He was a Full Professor at the University of Maine from 1959 to 1967, and the University Radiation Protection Officer from 1956 to 1960. At the University of Maine, he taught Experimental Design, Soil and Plant Relationships, and Radiobiology. He has done Post-Doctoral studies in nuclear physics and radiochemistry, statistics, and plant physiology (NSF Fellowship) at the Universities of Rutgers, Florida, and Texas A&M respectively. He was on the visiting scientist panel of the American Society of Agronomy, 1964-1967.

PHOTOGRAPHIC REMOTE SENSING OF "SICK" CITRUS TREES

Harold W. Gausman

Southern Plains Branch
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture
Weslaco, Texas

INTRODUCTION

This paper considers remote sensing with infrared color aerial photography (Kodak Ektachrome Infrared Aero 8443 film) for detecting citrus tree anomalies ("sick" citrus trees). Illustrations and discussions are given to detecting nutrient toxicity symptoms, to detecting foot rot and sooty mold fungal diseases, and to distinguishing among citrus species. Also, the influence of internal leaf structure on light reflectance, transmittance, and absorptance will be considered; and physiological and environmental factors that affect citrus leaf light reflectance will be reviewed briefly and illustrated.

REVIEW OF LEAF STRUCTURE AND SPECTRA

Internal Leaf Structure

Figure 1 is shown to review leaf structure. The leaf structure in Fig. 1 is similar to the structure of a citrus leaf that will be considered later.

The top layer of cells is the upper epidermis. The epidermal cells have a cuticular layer on their upper surfaces that diffuses but reflects very little light. The long narrow cells below the upper epidermis are palisade cells. They house many chloroplasts with chlorophyll pigments that absorb visible light. The cells below the palisade cells are spongy mesophyll cells. They have many air spaces among them (intercellular air spaces). It is here that oxygen and carbon dioxide exchange takes place for photosynthesis and respiration. The lower epidermis is like the upper epidermis, except a stoma or port is present where gases enter and leave a leaf.

The spongy mesophyll is important in remote sensing because it scatters near-infrared light. For a mature citrus leaf, approximately 55% of the incoming near-infrared light is reflected from the leaf, 40% is transmitted through the leaf, and 5% is absorbed within the leaf.

Leaf Spectra

The 500- to 2500-nanometer (nm) spectral range will be considered. This spectral region can be divided into: the visible region of 500 to 750 nm, dominated by pigment absorption (chlorophylls and carotenoids); the 750- to 1350-nm near-infrared wavelength interval, a region of high reflectance and low absorptance that is affected primarily by internal leaf structure; and the 1350- to 2500-nm wavelength interval, a region of high absorption by water--the strongest water absorption bands occurring at 1450 and 1950 nm.

Figure 2 shows the diffuse reflectance, transmittance, and absorptance of mature citrus leaves (orange, *Citrus sinensis* (L.) Osbeck). The reflectance and transmittance spectra are each averages of measurements made on upper (adaxial) surfaces of 10 leaves. Measurements were made with a Beckman Model DK-2A spectrophotometer and its reflectance attachment[1]. Data were corrected for the reflectance of the MgO standard to obtain absolute radiometric values. Absorptance was then calculated as: [100 - (percent reflectance + percent transmittance)].

Figure 2 shows that reflectance, transmittance, and absorptance were 10, 2, and 90%, respectively, at the 550-nm green peak within the 500- to 750-nm visible wavelength range. Absorption in this region was primarily caused by pigments. Within the 750- to 1350-nm near-infrared range, there was approximately 55% reflectance, 40% transmittance, and 5% absorptance. Above 1350 nm, absorptance greatly increased because of water absorption of light energy.

FACTORS AFFECTING LEAF LIGHT REFLECTANCE AND THEIR DETECTION

Introduction

Citrus leaf light reflectance is affected by diseases, hormones, insects, leaf age, leaf drying, nutrient levels, and spray residues. For example, drying of a leaf increases its light reflectance, particularly over the 750- to 2500-nm wavelength interval. Because of limited time, we cannot discuss all of the factors listed. Thus we will consider only diseases, insects, leaf age, and nutrient levels.

Leaf Age

A young citrus leaf is compact with few air spaces in its mesophyll, while an old or mature leaf is "spongy" or has many air spaces. The "spongy" effect in the mature leaf increases reflectance, because there are more intercellular air spaces. Scattering of light within leaves occurs at cell walls (hydrated

---

[1] Use of a company or product name by the Department does not imply approval or recommendation of the product to the exclusion of others that may also be suitable.

cellulose)-air cavity interfaces that have refractive indices of 1.4 and 1.0, respectively. Healthy citrus leaves also had more spongy mesophylls (Fig. 4) than leaves from trees grown with too much salt. Their differences in light reflectance will be shown in Fig. 5.

Figure 3 shows that the mature leaf represented by the solid black line, compared with the young leaf represented by the dotted line, had about 5 and 15 percentage points more reflectance in the visible (550 to 750 nm) and near-infrared wavelength (750 to 1350 nm) ranges, respectively. This increase in reflectance was caused primarily by air voids (air spaces) in the "spongy mesophyll" of the mature leaf.

Nutrient Levels (Toxic Levels of Boron (B) and Chloride (Cl^-)

Healthy citrus leaves also had more spongy mesophylls (Fig. 4) than leaves from trees grown with too much boron (B) and chloride (Cl^-). Figure 5 shows that healthy compared with salt-affected leaves had approximately 12 percentage points less reflectance at the visible green peak of 550 nm within the 500- to 750-nm wavelength interval caused by light absorption by more chlorophyll; and about 4 percentage points more reflectance in the 750- to 1350-nm near-infrared range, caused by a more "spongy" mesophyll.

The use of infrared color photography to discriminate between healthy citrus trees and trees whose foliage exhibit boron (B) and chloride (Cl^-) toxicity symptoms is being tested. Too much salt in the soil or irrigation water affects physiological functions of plants and subsequently plants become stunted and toxicity symptoms become apparent in their foliage. Too much boron (B) produces citrus leaves with yellowish areas on their leaf surfaces, and too much chloride (Cl^-) gives a brownish tip burn.

An experiment with toxic levels of boron (B) and chloride (Cl^-) is being conducted on citrus trees by A. Peynado, Research Chemist, Plant Science Research Division, Weslaco, Texas (Cardenas et al., 1971). There are 16 Red Blush grapefruit (*Citrus paradisi*, Macf.) and 16 Valencia orange (*Citrus sinensis* (L.) Osbeck) trees within each of four blocks. The grapefruit and orange trees are each on 16 different rootstocks. The trees have grown together and individual trees can not be distinguished. Two treatments, that began in 1963, have been applied to the grapefruit and the orange trees within each block. Eight orange and eight grapefruit trees in each block have been irrigated with canal water (control treatment); and eight orange and eight grapefruit trees in each block have been irrigated with irrigation water with 4,000 ppm (parts per million) sodium chloride (NaCl) and calcium chloride ($CaCl_2$) and 6 ppm of boron (B) added (salt treatment).

When aerial photographs were taken with infrared color film, 16 orange trees that showed no signs of being affected with salt and 12 grapefruit trees with salt-insensitive rootstocks photographed as dark-red trees. The photographs were taken at an altitude of 914 m with a 50-mm lens. Grapefruit trees with the salt-sensitive *Troyer citrange* rootstock gave whitish-tree images. Thus it seems feasible that remote sensing with aerial photography can be used to detect the presence of salinity-stressed citrus trees.

Citrus Species Differences

Aerial infrared color photographs were taken of an orchard of Red Blush grapefruit, Valencia and Navel oranges, and Cleopatra tangerine trees. Photographs were taken at an altitude of 610 m with a 50-mm lens. All trees had new growth except for the tangerine trees. The tangerine trees gave dark red images on the infrared color transparencies in contrast to lighter red colored images for the grapefruit and orange trees; because new foliage on citrus trees is lighter green in color (less chlorophyll) than older foliage. One of the main problems in the photographic remote sensing of citrus maladies is to distinguish them from new foliage growth.

Citrus Foot Rot (Fungus)

Citrus foot rot is a fungal disease caused by *Phytophthora citrophthora* (Sm. & Sm.) Leonian and *Phytophthora parasitica* Dast. These fungi produce a gummy exudate at or near the graft union on citrus trees; wood rots underneath, leaves lose color, and decline sets in (Gausman et al., 1970). The foliage of foot rot-affected citrus trees lose their chlorophyll and become chlorotic (yellowish-white) in contrast to the dark-green foliage of healthy trees.

Figure 6 is a negative print of Ektachrome color (film type B) and shows the photographic comparison of a white grapefruit leaf on the left (yellowish-white on color film) from a foot rot-affected tree with a dark leaf on the right (dark-green on color film) from a healthy tree.

An overflight of a grapefruit citrus orchard, *Citrus paradisi* Macf., Nucellar - CES-3 selection of Red Blush on *Citrus aurantium* Linn. Sour Orange rootstock, near Monte Alto, Texas was made at an altitude of 610 m (under cloudless skies with moderate haze), at 11:29 a.m., central standard time, December 5, 1968, in an easterly direction. Photographs were taken with a Zeiss, 150-mm focal length camera, using 229 mm Kodak Ektachrome Infrared Aero 8443 film (infrared color) and a Zeiss D light-orange filter, approximate 100% absorption edge at 500 nm.

On infrared color transparencies, healthy trees produced red images in contrast to white images for trees severely infected with foot rot.

Figure 7 is a negative print from an infrared color positive from an overflight of a grapefruit orchard, showing images of dark-appearing (white on infrared color film) foot rot-infected trees, upper center; and white-appearing (red on infrared color film) healthy trees. Various degrees of white-appearing trees were detected among the red-appearing trees on the infrared color film. An outstanding example of a very white-appearing tree found on the color film is represented by the dark tree in the center of the upper row of the black and white negative print. Eventually, the foot rot fungus girdles the tree and kills it.

Sooty Mold (Insect and Fungus)

Brown soft scale insects (Coccus hesperidum L.) start excreting large quantities of a sugary solution known as "honeydew" soon after establishment on the citrus leaf. The black sooty mold fungus, Capnodium citri, Berk. and Desm., develops rapidly on the leaf surface when the honeydew is abundant, and forms a dense black coating of interwoven filaments (hyphae). If the coating is heavy, it impairs plant growth and production. Light reflectance in the visible and near-infrared is considerably reduced (Hart and Myers, 1968).

Figure 8 shows that spectrophotometric measurements of diffuse reflectance of upper citrus leaf surfaces having varying amounts of sooty mold revealed that mature citrus leaves (spectrum 1) with no trace of sooty mold had reflectance values of 58 and 53% at 770 and 1300 nm, respectively. Leaves heavily coated with sooty mold (spectrum 4) had reflectance values of 9 and 23% at 770 and 1300 nm, respectively. A light sooty mold coating (spectrum 2) reduced reflectance 14 percentage points at 770 nm and 2 percentage points at 1300 nm.

When aerial photographs are taken with infrared color film, citrus trees with deposits of sooty mold give black images and noninfested trees give red images. It is, therefore, very easy to distinguish among infested and noninfested trees.

The detection of brown soft scale infestation of citrus trees with infrared color film has been demonstrated. A commercial service to the growers is feasible at the present time. It could function as entomological ground surveys now function; that is, a commercial service would photograph the trees, ground check suspicious areas in groves, and make recommendations for spraying of the orchards. It is estimated that the cost of surveys could be reduced up to 50% with this technique (Hart and Myers, 1968).

FUTURE PLANS

Further work is planned for comparing infrared color film transparencies of boron and chloride toxicities, iron deficiency, and foot rot of citrus trees. If visual interpretation among foot rot and the nutritional maladies is impractical, computer discrimination procedures (Richardson et al., 1970) will be applied to densitometer readings on infrared color film transparencies.

The detection of brown soft scale infestations of citrus trees with infrared color film is practical. A commercial service to the growers is a possibility in the near future.

Research is in progress to detect insect damage on citrus trees with infrared color films to assess the effectiveness of biological and chemical insect control applications.

ACKNOWLEDGEMENTS

The author is indebted to Marcia Schupp for preparing leaf transections, Ruben Cardenas for supplying an overflight transparency, Ron Bowen for photographic assistance, Guadalupe Cardona and Armando Berumen for illustrative assistance, and Jean Ryan for stenographic assistance.

LITERATURE CITED

Cardenas, R., A. Peynado, H. W. Gausman, A. H. Gerbermann, and R. L. Bowen. Photographic sensing of boron and chloride toxicities of citrus trees. To be submitted to Jour. Rio Grande Valley Hort. Soc.

Gausman, H. W., W. A. Allen, R. Cardenas, and R. L. Bowen. 1970. Detection of foot rot disease of grapefruit trees with infrared color film. 1970 Jour. Rio Grande Valley Hort. Soc., Vol. 24:36-42.

Hart, W. G., and V. I. Myers. 1968. Infrared aerial color photography for detection of populations of brown soft scale in citrus groves. J. Econ. Entomol. 61:617-624.

Richardson, A. J., R. J. Torline, D. A. Weber, R. W. Leamer, and C. L. Wiegand. Comparison of computer discrimination procedures using film optical densities. In House Technical Report, USDA, Weslaco, Texas.

Van Nostrand's Scientific Encyclopedia. 1947. 2nd ed., D. Van Nostrand Co., Inc., New York. p 850.

GLOSSARY OF TERMS

Abaxial	Leaf surface faces away from stem, or dorsal (lower) side.
Adaxial	Leaf surface faces toward stem, or ventral (upper) side.
Air cavities	Spaces among leaf mesophyll cells.
Carotenoids	The yellow to orange pigments in plastids. Carotenes and xanthophylls belong to the carotenoids.
Chlorophylls	The green pigments present in chloroplastids.
Chloroplastid	Specialized protoplasmic body containing chlorophylls and other pigments.
Cuticle	For this report it is considered as a waxy material (cutin), on or within the outer epidermal cell wall.
Epidermis	The outer layer of cells on both the dorsal and ventral side of a leaf.
Intercellular spaces	Spaces among cells within the leaf mesophyll.
Mesophyll	Parenchyma tissue of a leaf between the epidermal layers.
Mesophyll cell	A cell located between the epidermal layers of a leaf. If cell contains chloroplasts it is a chlorenchyma cell.
Nanometer	One billionth (10^{-9}) of a meter.
Palisade layer	A layer of elongated cells containing many chloroplasts.
Paradermal	Refers to section made parallel with the surface of a leaf.
Parenchyma	Thin-walled cells capable of growth and division, found in leaves between the lower and upper epidermis.
Refractive index	The ratio of the velocity of light in a vacuum to the velocity of light of a particular wavelength in any substance.

Spongy parenchyma	Mesophyll parenchyma with noticeable air cavities.
Stoma	An opening in the epidermis with two guard cells surrounding it where gas exchange takes place between the plant and air.
Transection	See transverse.
Transverse	A cross section. Section taken perpendicular to the longitudinal axis of the cell. Also called transection.
Vein	Strand of vascular material (in a leaf) containing xylem and phloem.

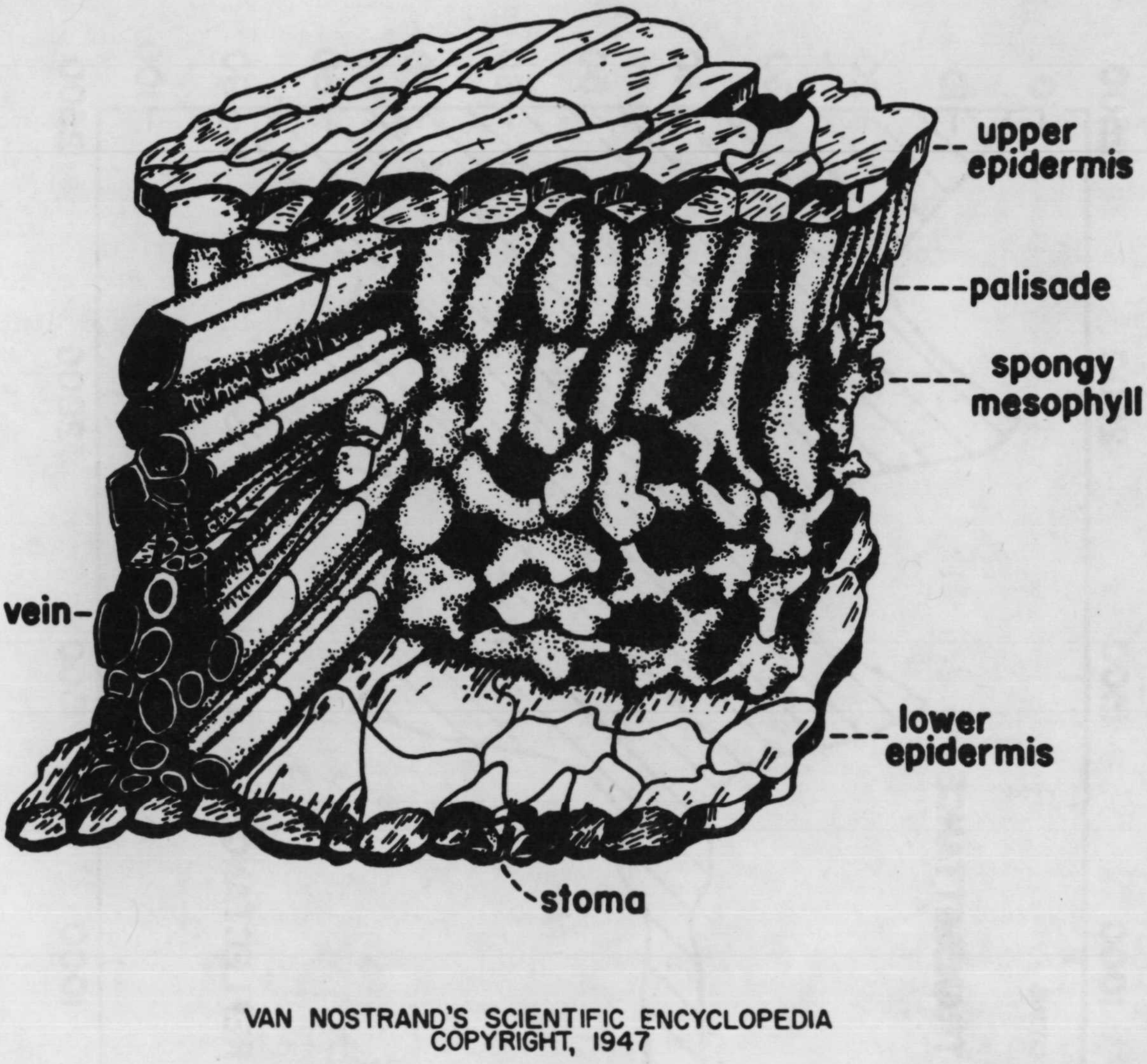

Figure 1. Three-dimensional drawing of a leaf structure that is similar to the structure of a citrus leaf (redrawn from Van Nostrand's Scientific Encyclopedia, 1947).

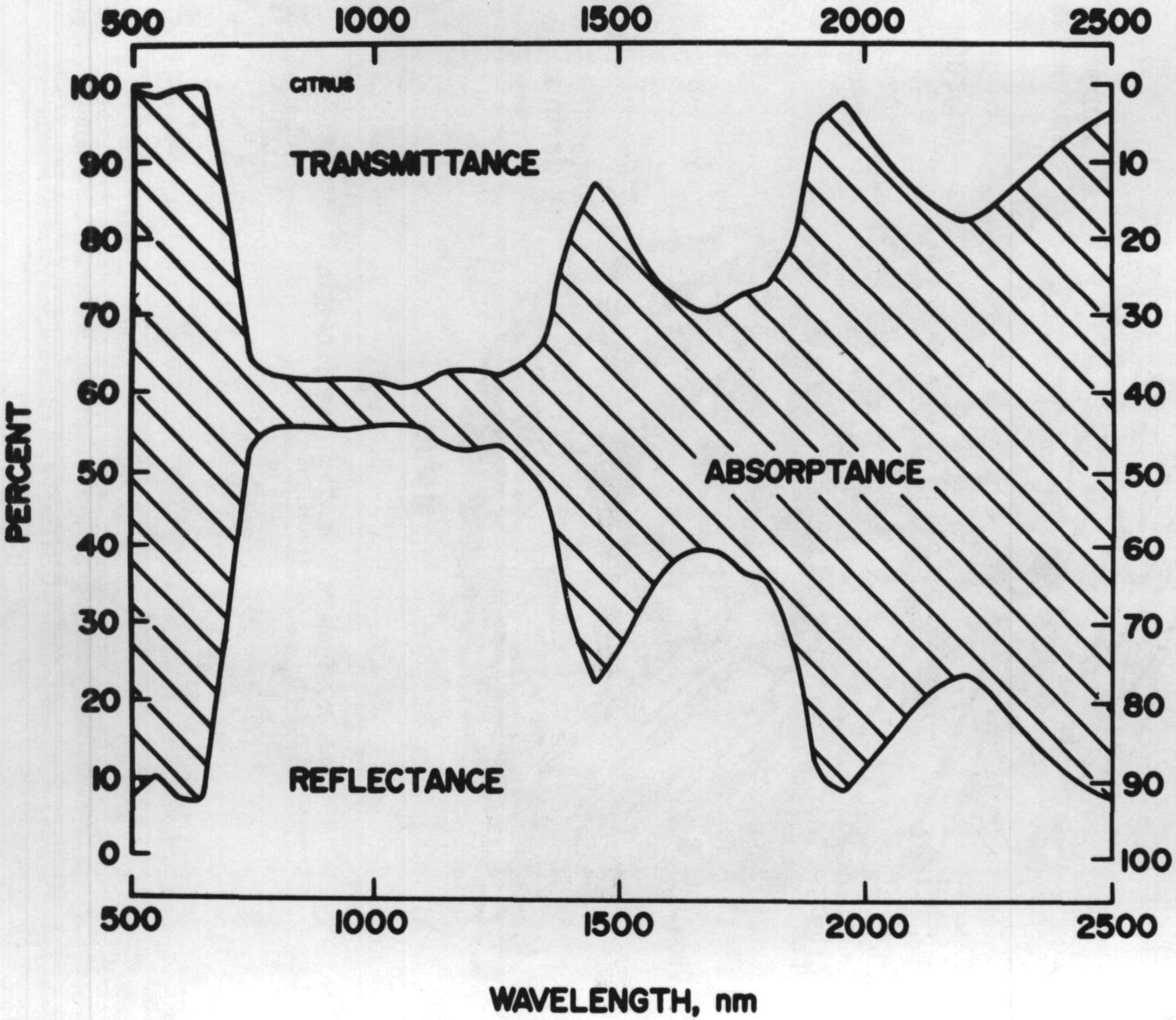

Figure 2. Diffuse reflectance, transmittance, and absorptance [100 - (percent transmittance + percent reflectance)] of the upper (adaxial) surface of a mature orange leaf (*Citrus sinensis* (L.) Osbeck).

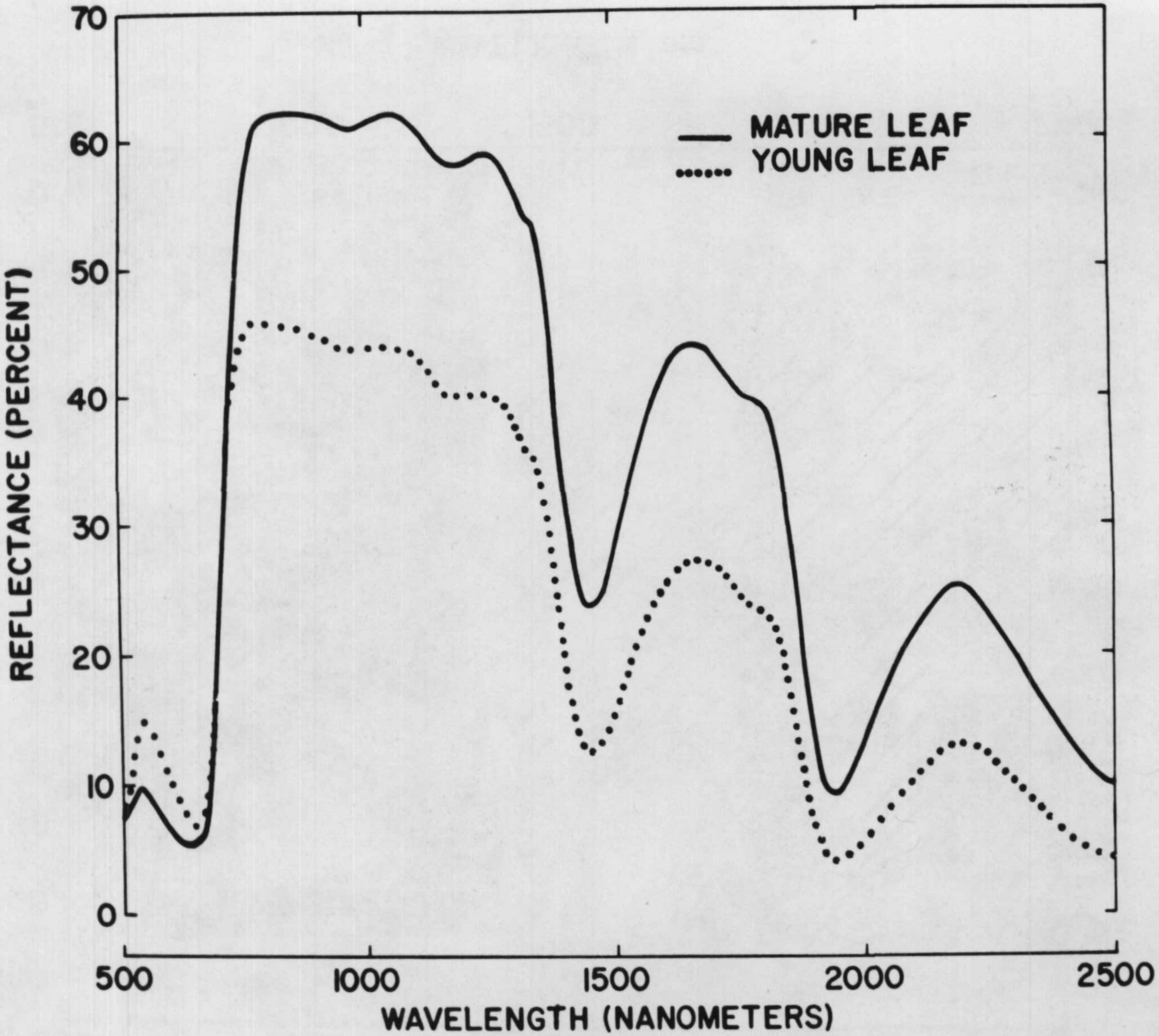

Figure 3. Diffuse reflectance of the upper (adaxial) surfaces of young (bottom dotted line spectrum) and mature (upper solid line spectrum) orange leaves (Citrus sinensis (L.) Osbeck).

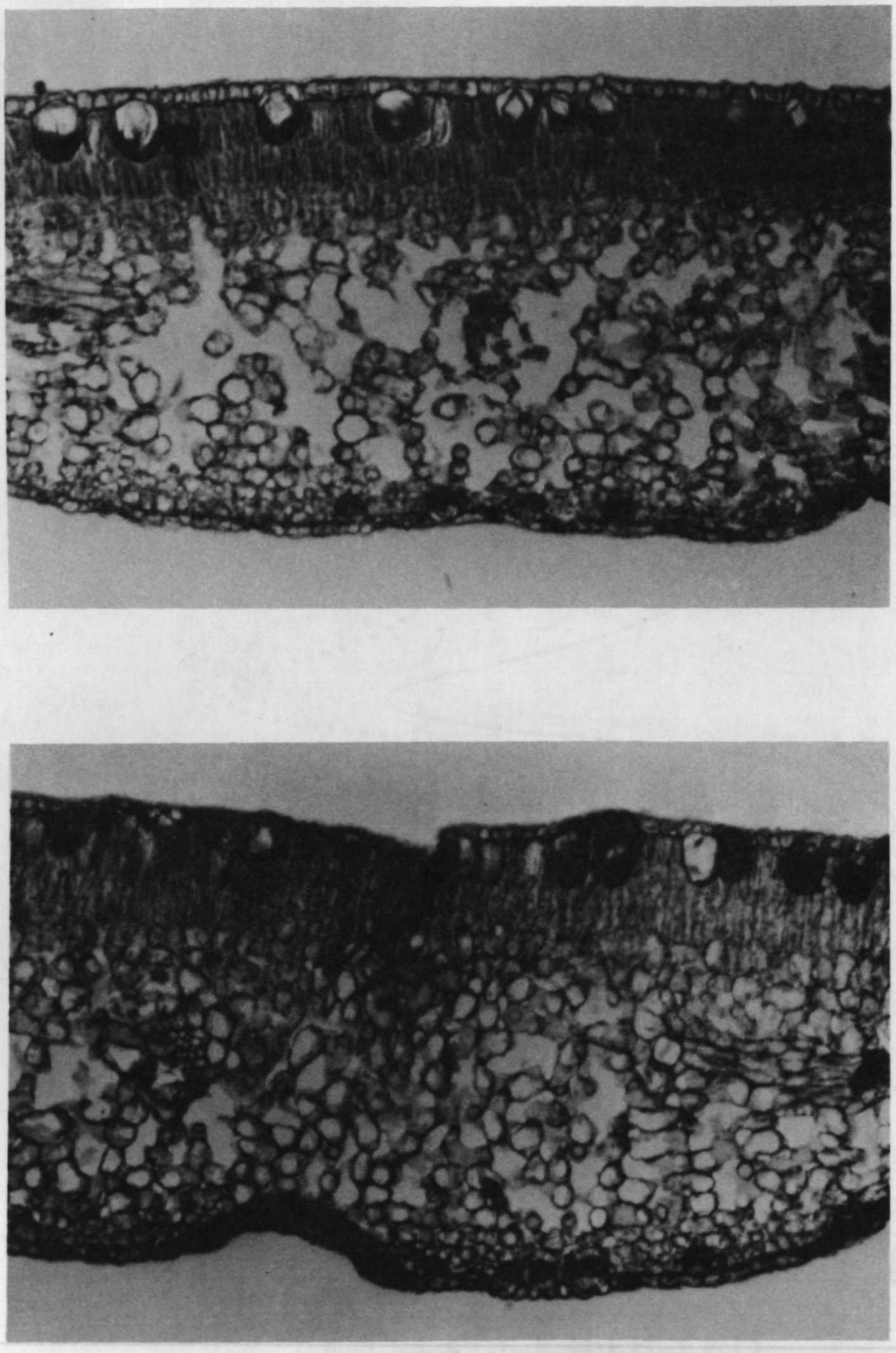

Figure 4. Photomicrographs of leaf transections of healthy (top, 200 X) and salt-affected (bottom, 200 X) citrus leaves.

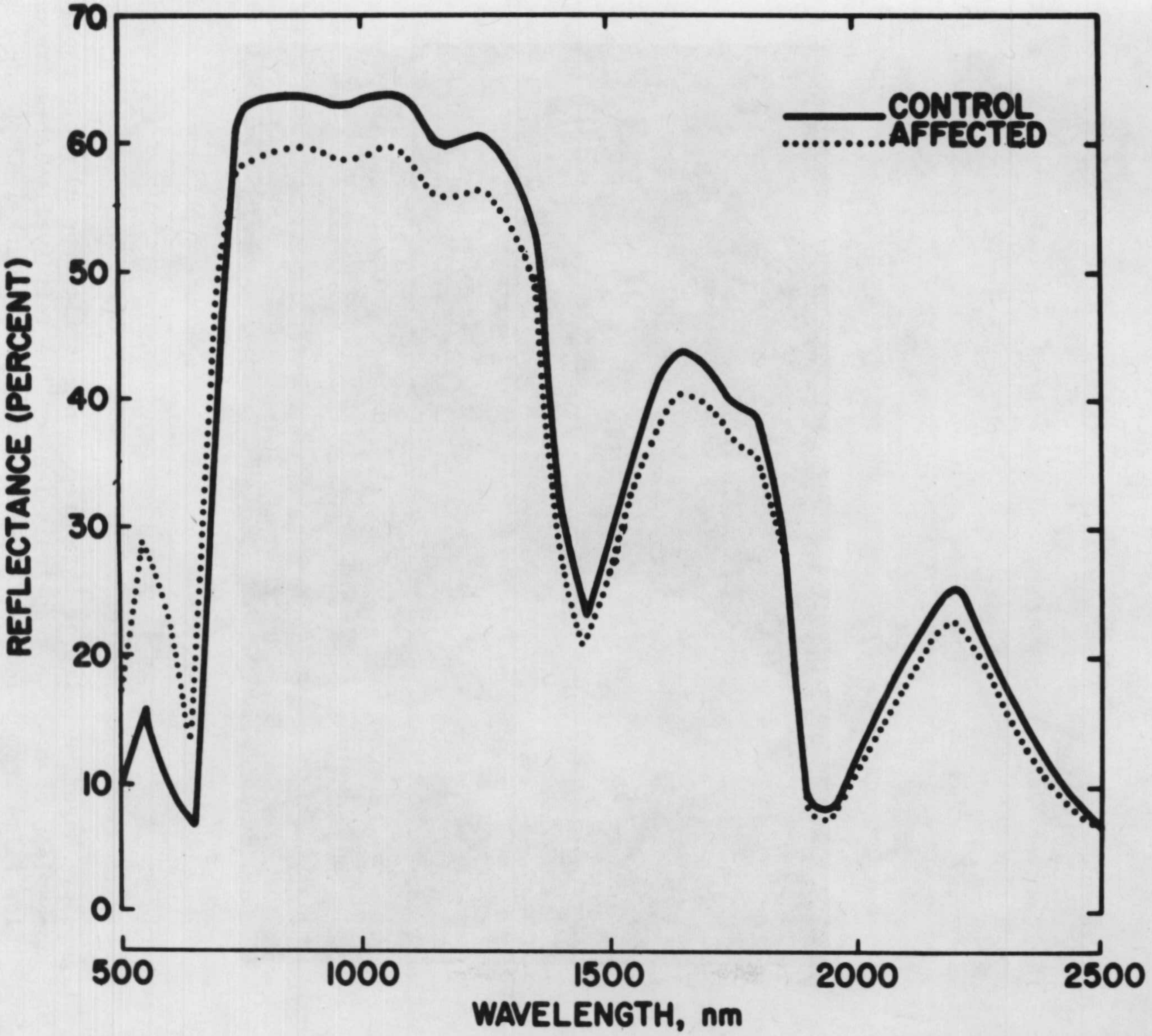

Figure 5. Diffuse reflectance of upper (adaxial) leaf surfaces of healthy (control, solid line) and salt-affected (dotted line) citrus leaves.

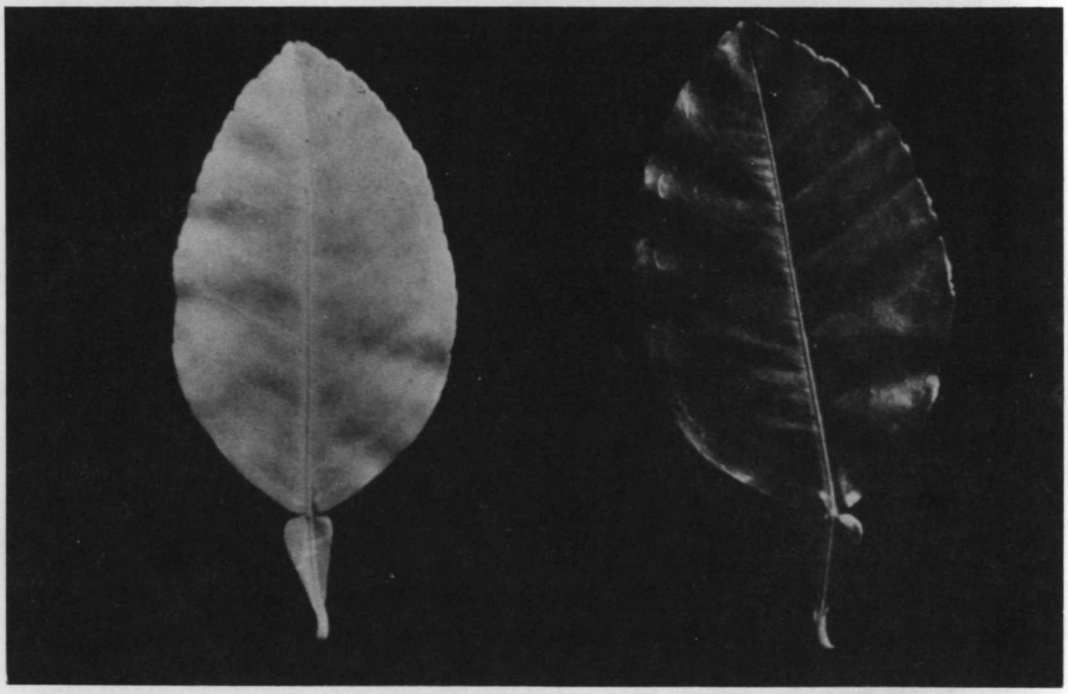

Figure 6. Negative print of Ektachrome color (film type B) photographic comparison of a white grapefruit leaf on the left (yellowish-white on color film) from a foot rot-infected tree with a dark leaf on the right (dark-green on color film) from a healthy tree.

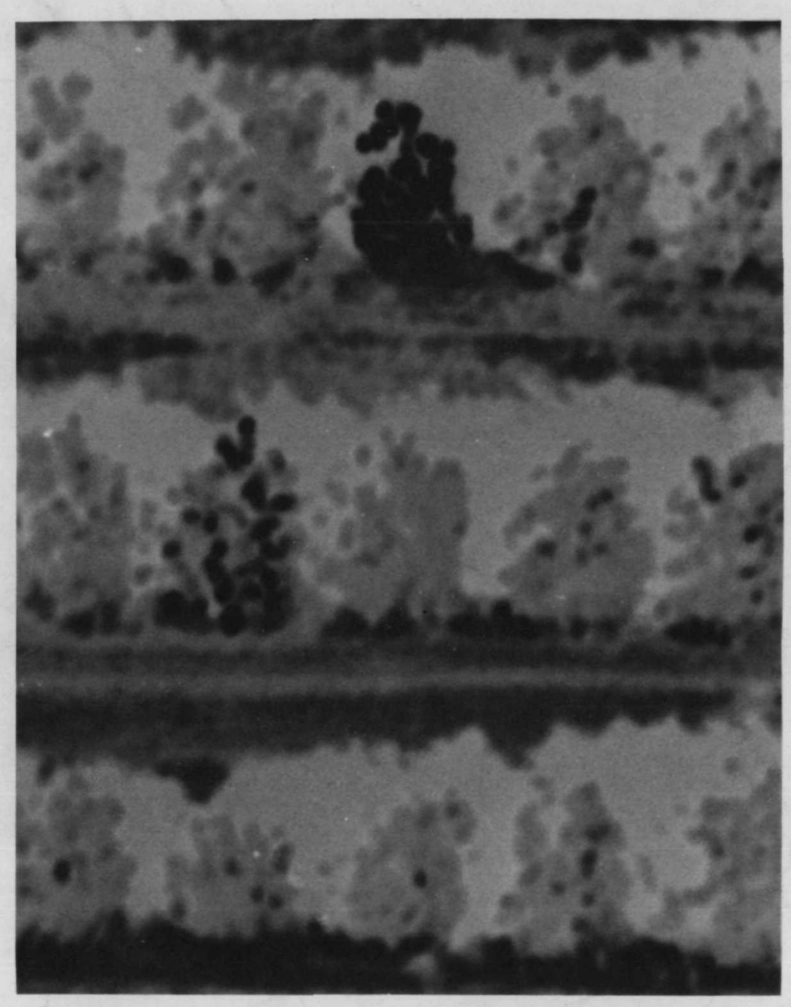

Figure 7. Kodak Ektaprint from a Kodak Ektachrome Infrared Aero 8443 (infrared color) positive from an overflight of a grapefruit orchard showing two images of dark-appearing (white on infrared color positive), foot rot-infected trees, and white-appearing (red on infrared color positive) healthy trees. The upper dark tree (top row) had a severe infection of foot rot, while the lower dark tree (middle row) was beginning to be affected by the foot rot fungus.

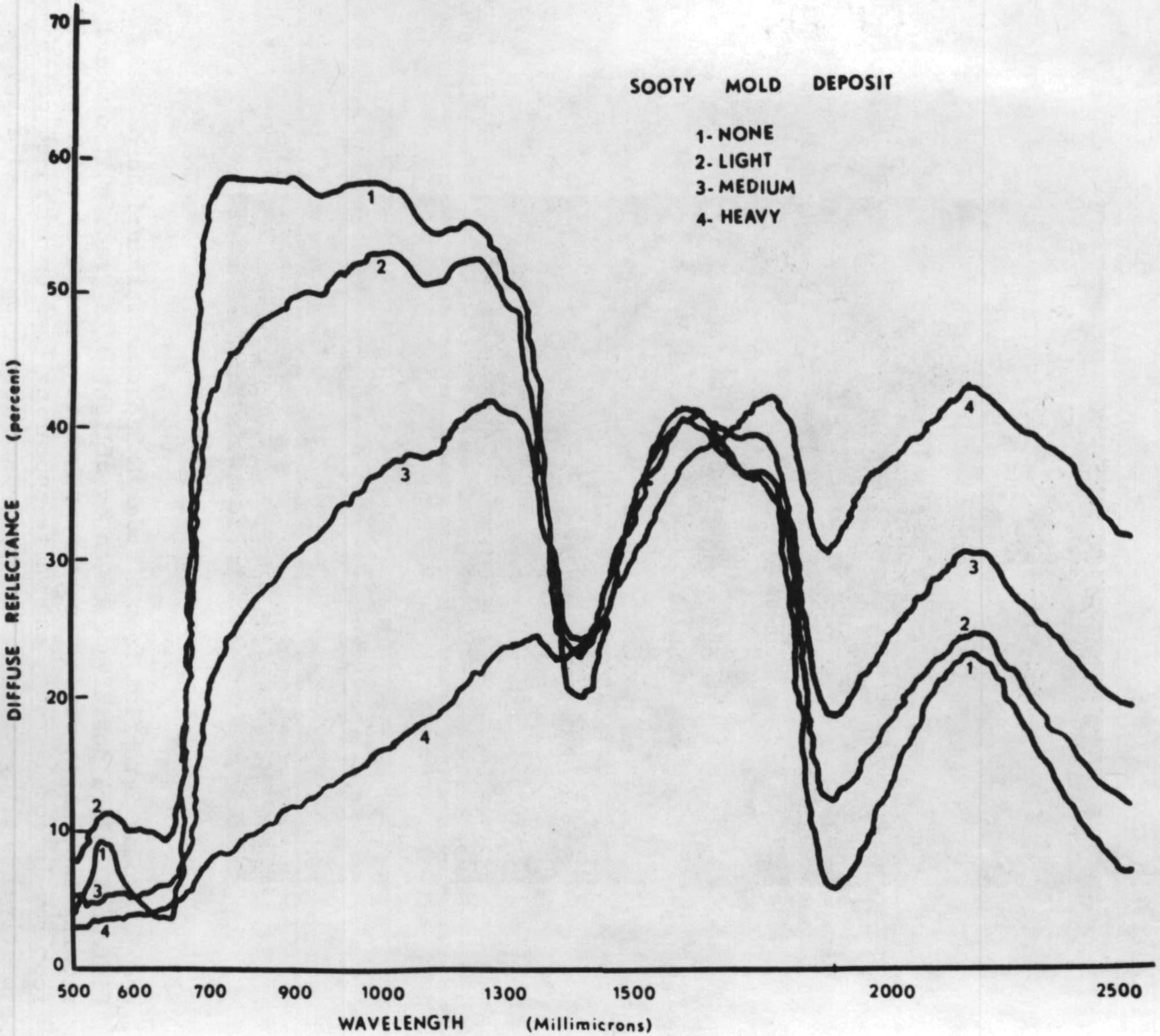

Figure 8. Effect of sooty mold on reflectance (percent) of leaves coated with varying amounts of the fungus (reproduced from Hart and Myers, 1968).