Evaluation of the Mid-Infrared (1.45 to 2.0 μm) with a Black-and-White Infrared Video Camera

J. H. Everitt and *D. E. Escobar*
USDA Agricultural Research Service, Weslaco, TX 78596
C. H. Blazquez
University of Florida Agricultural Research and Education Center, Lake Alfred, FL 33850
M. A. Hussey
Texas A&M Agricultural Experiment Station, Weslaco, TX 78596
P. R. Nixon
USDA Agricultural Research Service, Weslaco, TX 78596

ABSTRACT: A 0.9- to 2.2-μm sensitive black-and-white infrared video camera, filtered to record radiation within the 1.45- to 2.0-μm mid-infrared water absorption region, was evaluated as a potential tool for remote sensing research studies. Imagery obtained in the laboratory of *Peperomia obtusifolia* A. Dietr. leaves successfully demonstrated the influence of its unusual internal leaf structure on its light absorption in the mid-infrared water absorption region. Ground-based field video recordings of the succulent prickly pear (*Opuntia lindheimeri* Engelm.) showed the influence of its high water content on its mid-infrared light absorption. The camera provided acceptable airborne imagery that detected severly drought-stressed grass from lightly stressed grass. Grass plots with differing levels of green phytomass (cumulative water content), which were obtained with five rates of nitrogen fertilizer, could also be differentiated using airborne video imagery. Due to the lower radiation intensity in the mid-infrared region of the electromagnetic spectrum, video images were not as sharp as those obtained with visible (0.4 to 0.7 μm) or near-infrared (0.75 to 1.1 μm) sensitive video cameras. These results, however, demonstrated that a video camera with sensitivity in the mid-infrared water absorption region of the spectrum has considerable potential as an applied remote sensing tool.

INTRODUCTION

WATER IN PLANT LEAVES is a strong absorber of infrared light over the 1.35 to 2.5 μm mid-infrared water absorption region (Gates *et al.*, 1965; Hoffer and Johannsen, 1969; Knipling, 1970; Allen *et al.*, 1970; Thomas *et al.*, 1971; Woolley, 1971). Several studies have shown that reflectance measurements in the mid-infrared water absorption region can be useful for distinguishing between succulent and nonsucculent plant species (Gausman *et al.*, 1977; 1978), separation of soil from vegetation (Leamer *et al.*, 1978), and detecting plant stresses (Hoffer and Johannsen, 1969; Peynado *et al.*, 1979; Gausman, 1985). Interest in the mid-infrared water absorption region has been regenerated by NASA's Landsat-D thematic mapper (TM) which has the 1.55 to 1.75 μm (TM 5) and 2.08 to 2.35 μm (TM 7) water bands. Other than TM 5 and TM 7 data, little other imagery is available in the mid-infrared water absorption region.

Recently, video cameras and recording systems have been used as remote sensing tools because of the informative and immediately useful imagery they provide. Both color-infrared and black-and-white video systems have been developed and used successfully to assess agricultural and rangeland resources (Edwards, 1982; Manzer and Cooper, 1982; Escobar *et al.*, 1983; Nixon *et al.*, 1985; Meisner and Lindstrom, 1985; Everitt and Nixon, 1985). These studies, however, have been conducted using video cameras with sensitivity within the visible to near-infrared light (0.40 to 1.10 μm) region of the electromagnetic spectrum. The objective of this study was to evaluate a black-and-white video camera with sensitivity in the mid-infrared water absorption region as a possible tool for laboratory and field studies.

METHODS AND MATERIALS

The video equipment consisted of an Image Technology Methods[1, 2] (ITM) 203-A video camera, a Sony

[1]Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U.S. Department of Agriculture.
[2]Image Technology Methods, 103 Moody Street, Waltham, MA 02154.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 52, No. 10, October 1986, pp. 1655–1660.

0099-1112/86/5210-1655$02.25/0

AVC-3450 video camera, and a Sony SLO-340 cassette recorder (½-inch format). The ITM camera had a PbS vidicon camera tube (1.0 inch) to give sensitivity to reflected light energy from the 0.9 to 2.2 μm. The Sony camera was modified with an RCA Ultricon (TM) 4875/U camera tube (0.7 inch) to give a sensitivity to light from the 0.3 to 1.1 μm. A filter combination of 2 long wavepass filters (LO 1368 + SO 2147[3]) allowing transmittance of light from the 1.45 to 2.0 μm were used on the ITM camera, giving it sensitivity in the mid-infrared water absorption light region. Light transmittance of the filter combination peaked at 80 percent at the 1.65 μm. An infrared (0.85 to 0.89 μm) narrowband filter (60 percent transmittance) was used on the Sony camera giving it sensitivity in the near-infrared (0.75 to 1.1 μm) light region. The camera lens focal length of the Sony camera was 50 mm while that of the ITM camera was 75 mm.

Video recordings were obtained in both the laboratory and field. Laboratory video recordings were made of upper (adaxial) and lower (abaxial) surfaces of peperomia (*Peperomia obtusifolia* A. Dietr.) leaves. Ground-based video recordings were made of the succulent prickly pear (*Opuntia lindheimeri* Engelm.) at a rangeland area near Weslaco, Texas, in May 1985. Aerial video recordings were taken of grass plots with different levels of phytomass near Mercedes, Texas, in April 1985, and of a buffelgrass (*Cenchrus ciliaris* L.) range under drought stress near Sullivan City, Texas, in August 1985. The grass plots were arranged in a randomized complete block design with four replications of five fertility treatments: 0, 56, 112, 168, and 224 kg elemental N/ha from ammonium nitrate that was applied in early March 1985. Recordings of prickly pear were taken with both the ITM and Sony cameras, but all other recordings were obtained with only the ITM camera. Aerial recordings of the grass plots were taken at an altitude of 900 m, whereas those of the stressed rangeland area were obtained at 1500 m. All aerial recordings were obtained between 1200 and 1400 hours using a Cessna 182 aircraft. Images shown here were photographed from a TV monitor.

The mid-infrared video image of the grass plots was digitally entered into an I²S image processor using a SLO-383 Betamax I video cassette recorder/player. The recorder/player was interfaced to the image processor's video digitizer through an Edutron time base corrector. The image processor's Train and Prepare functions were used with the image to acquire digitized data and compute the mean for each plot.

Plant canopy reflectance measurements were made at the Mercedes and Weslaco sites at or near the time video imagery was obtained using an Exotech Model 20 spectroradiometer (Leamer *et al.*, 1973). Reflectance measurements were taken on three plant canopies within each grass plot at the Mercedes site, and their mean reflectance was used to represent each plot. Reflectance measurements were made on six plant canopies for each of four plant species at the Weslaco site: prickly pear, huisache [*Acacia farnesiana* (L.) Willd.], honey mesquite (*Prosopis glandulosa* Torr.), and bermudagrass [*Cyndon dactylon* (L.) Pers.]. Honey mesquite, huisache, and bermudagrass were dominant species growing in association with prickly pear. Reflected radiation was measured at 0.05-μm increments over the 1.50 to 1.75 μm mid-infrared water absorption region with a sensor that had a 15-degree field-of-view. Reflectance measurements were made at 2.0 to 3.0 m above each plant canopy under clear conditions between 1100 and 1400 hours. To obtain reflectance from field spectral data, radiant energy is converted into an analog signal in the range of 1 to 5 volts for both incoming and reflected light. Percent reflectance is then calculated by ratioing the incoming and reflected light multiplied by percent transmission of a diffusing plate.

Herbaceous phytomass measurements were taken in each grass plot at the Mercedes site. Phytomass measurements were taken by clipping all vegetation at ground level within four 50- by 50-cm quadrats in each plot. Green weight measurements of the samples were determined immediately after clipping so that water content could be calculated. The mean phytomass and water content of the four samples was used to represent each plot. Water content was also determined on prickly pear and the other three plant species at the Weslaco site. One mature leaf or stem was sampled from each of ten randomly selected plants of each species. Stems were sampled from prickly pear because it produces rudimentary leaves that are not always present. All samples were oven-dried for 72 hours at 65°C.

Canopy reflectance data were subjected to analyses of variance, and the least significant difference was used to evaluate differences among means (Steel and Torrie, 1960). Regression analyses was used to relate reflectance and digital video data to green phytomass measurements and plant water content of the grass plots.

RESULTS AND DISCUSSION

Figure 1 shows a mid-infrared (1.45 to 2.0 μm) video image of upper (left) and lower (right) leaf surfaces of peperomia leaves. Gausman *et al.* (1977) described the leaf reflectance characteristics and internal leaf anatomy of peperomia and reported that peperomia's upper leaf surface was a strong absorber of mid-infrared light over the 1.45- to 2.5-μm water absorption region, but that its lower leaf surface did not show this characteristic. The strong absorption of mid-infrared light by peperomia's upper leaf surface was caused by a thick layer of hypodermal (water storage) cells below the leaf epidermis. The hypodermal cells were not present adjacent to the lower leaf epidermis. Thus, peperomia's lower

[3]Optical Filter Corporation, 2 Mercer Road, Natick, MA 01760.

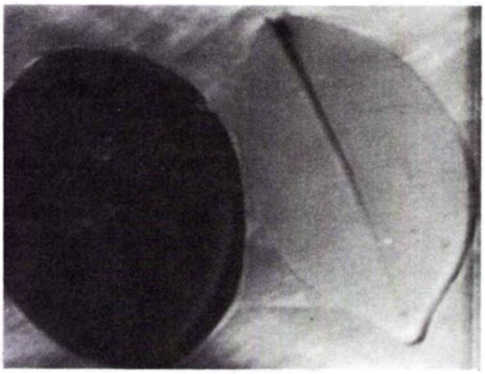


FIG. 1. Upper (left) and lower (right) leaf surfaces of *Peperomia obtusifolia*.

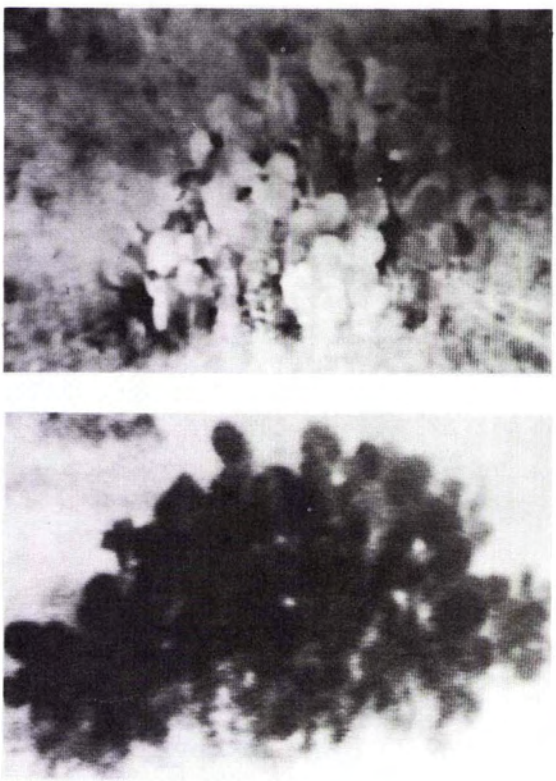


FIG. 2. Near-infrared (upper) and mid-infrared (lower) ground video images of the succullent prickly pear.

leaf surface had significantly higher reflectance than its upper leaf surface. Figure 1 clearly demonstrates the influence of peperomia's unusual internal leaf structure on its leaf reflectance characteristics in the mid-infrared water absorption region.

Figure 2 shows near-infrared (0.85 to 0.89 μm) (upper) and mid-infrared (lower) ground video images of the succulent prickly pear in a rangeland area near Weslaco, Texas. Prickly pear's whitish image is similar to that of surrounding vegetation in the near-infrared image, but it is easily distinguished in the mid-infrared image. The very dark tone of prickly pear in the mid-infrared image is attributed to its high water content (92 percent), which absorbed a large percentage of the radiation in the mid-infrared water absorption region (Gausman *et al.*, 1978). Spectroradiometric plant canopy reflectance measurements over the 1.50- to 1.75-μm mid-infrared water absorption region showed that prickly pear had significantly lower ($p = 0.05$) reflectance than that of three other associated plant species (Figure 3). Prickly pear also had significantly higher ($p = 0.01$) water content than that of the other three species (data not shown). These data support prickly pear's dark image in the mid-infrared video image. Our results are in close agreement with those of Gausman *et al.* (1978), who reported that succulent plant species could be distinguished from nonsucculent plant species in the mid-infrared water absorption region of the electromagnetic spectrum.

The mid-infrared video image of the drought-stressed buffelgrass range is shown in Figure 4 (upper photo). Heavily stressed (brown) grass has a light gray tone while lightly stressed (green) grass has a dark gray tone. The light gray image of the heavily stressed grass was also contributed to by more bare soil exposure in this area. Huisache and honey mesquite trees have an almost black tone, indicating that they probably had higher water content than the lightly stressed buffelgrass. Their darker images, however, may also be partially contributed to inner canopy shadowing (Richardson *et al.*, 1975). The lower photo in Figure 4 shows a ground photo

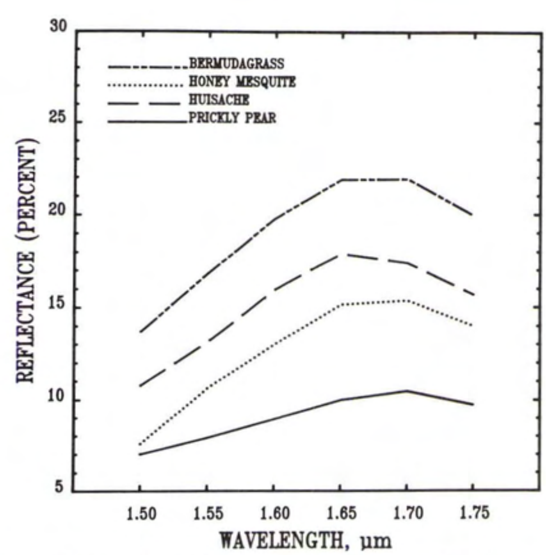


FIG. 3. Field spectroradiometric measured canopy light reflectance over the 1.50 to 1.75 μm for prickly pear and three other associated plant species.

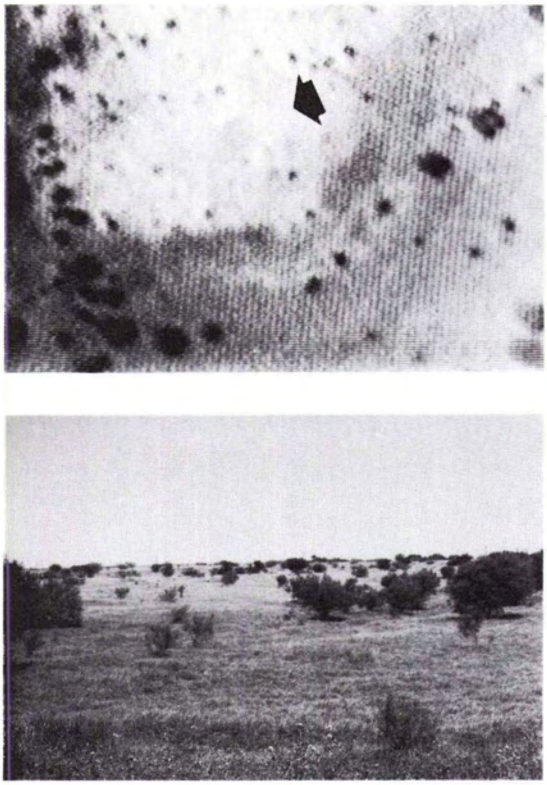
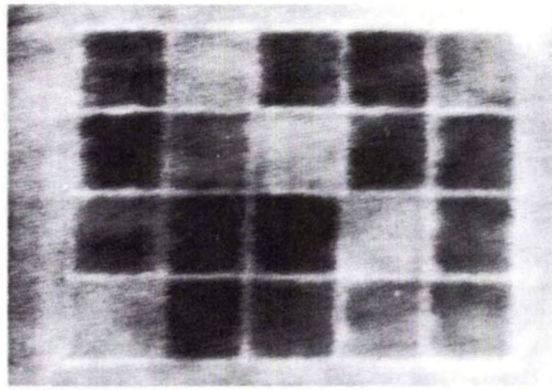


FIG. 4. Mid-infrared aerial video image (upper) and ground photograph (lower) of the drought-stressed buffelgrass range. The arrow on the video image points to the light gray tone of the heavily stressed grass.



R-4	3	1	4	5	2
R-3	4	2	1	3	5
R-2	2	3	5	1	4
R-1	1	5	4	2	3

FIG. 5. Mid-infrared aerial video image (upper) and plot diagram (lower) of grass plots with different levels of nitrogen fertilizer. Treatments are (1) nonfertilized, (2) 56 kg N/ha, (3) 112 kg N/ha, (4) 168 kg N/ha, and (5) 224 kg N/ha.

of the buffelgrass range. The light gray area in the background is heavily stressed grass while the dark gray area in the foreground is lightly stressed grass. The area has a undulating topography with slopes of 3 to 20 percent (Thompson *et al.*, 1972). Soils on the slopes are shallower and have less water holding capacity than those in the depressed areas. Consequently, grass growing on the slopes shows moisture stress much sooner than grass in the depressed areas.

Shown in Figure 5 are the mid-infrared video image (upper) and plot diagram (lower) of the grass plots with different levels of N fertilizer. Nonfertilized control plots (1) have a light gray image that can be differentiated from fertilized plots (2, 3, 4, 5). Most plots receiving 56 kg N/ha (2) can be distinguished from plots receiving 112, 168, and 224 kg N/ha (3, 4, and 5, respectively). However, plots receiving 112, 168, and 224 kg N/ha generally can not be differentiated. Canopy reflectance measurements made on the grass plots over the 1.50 to 1.75 μm confirmed their video images (Figure 6). Nonfertilized control plots had significantly higher (p = 0.05) reflectance than the fertilized plots, while plots fertilized with 56 kg N/ha had higher reflectance than those fertilized with 112, 168, and 224 kg N/ha.

The coefficients of determination (r^2) obtained by regressing reflectance and digital video data on plant water content for the different grass plots were not significant (r^2 = 0.27 and 0.16, respectively). Canopy reflectance and digital video data, however, were both inversely related to green phytomass measurements. These relations were best described by asymptotic regression models. Figure 7 shows the inverse correlations of reflectance (upper) and digital video (lower) on green phytomass. The coefficients of determination (r^2) were highly significant (p = 0.01) for both regressions. These results indicate that differences in video image (Figure 5) characteristics among the different grass plots (treatments) are primarily due to cumulative water content, as a function of green phytomass, rather than plant water content *per se*.

CONCLUSIONS

Our findings demonstrated that a video camera with sensitivity in the mid-infrared water absorption region can be an effective tool for both labo-

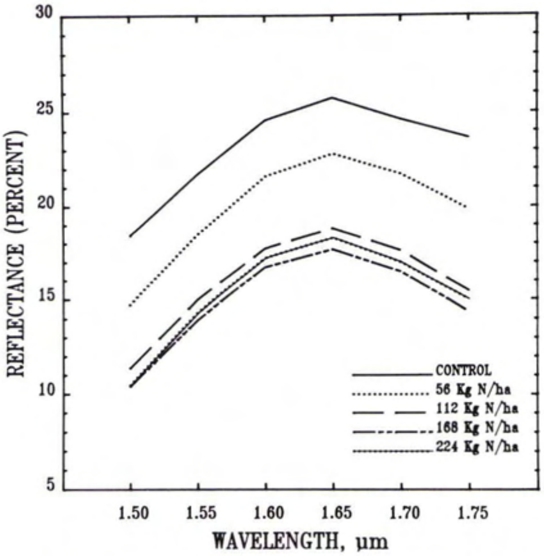


FIG. 6. Field spectroradimetric measured canopy light reflectance over the 1.50 to 1.75 µm for grass plots with different levels of nitrogen fertilizer.

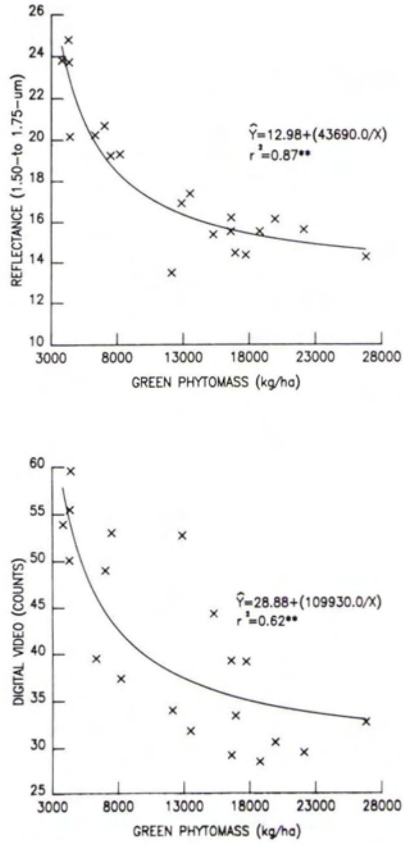


FIG. 7. Asymptotic regressions of reflectance (upper) and digital video data (lower) on green phytomass yield of the grass plots treated with five levels of nitrogen fertilizer. The equations of both regressions are shown on the figures.

ratory and field research studies. The major disadvantage of mid-infrared video imagery is its poor resolution and subsequent image quality, as compared with that obtained with visible and near-infrared sensitive video cameras (Meisner and Lindstrom, 1985; Nixon *et al.*, 1985; Everitt and Nixon, 1985). The poor resolution of mid-infrared video imagery is probably due to the lower radiation intensity in the mid-infrared region of the electromagnetic spectrum. Solar radiation at the Earth's surface ranges from about 2.3 Cal cm^{-2} min^{-1} μm^{-1} in the visible (0.55 µm) region to approximately 0.4 Cal cm^{-2} min^{-1} μm^{-1} in the mid-infrared (1.65 µm) region (Coulson, 1975). Despite this limitation, a video camera with mid-infrared sensitivity has considerable potential for applied remote sensing. With improved technology, mid-infrared video image quality may also be enhanced.

ACKNOWLEDGMENTS

The authors thank Mario Alaniz, Ben Gonzalez, and Saul Moreno for their assistance in the field, and Rene Davis for obtaining the imagery. Thanks are also extended to Ricardo Villarreal and Cris Castro for helping with the image processing.

REFERENCES

Allen W. A., H. W. Gausman, A. J. Richardson, and C. L. Wiegand, 1970. Mean effective optical constants of thirteen kinds of plant leaves. *Appl. Opt.* 9:2573–2577.

Coulson, K. L., 1975. *Solar and terrestrial radiation*. Academic Press, New York. 322 p.

Edwards, G. J., 1982. Near-infrared aerial video evaluation for freeze damage. *Proc. Fla. State Hort. Soc.* 95:1–3.

Escobar, D. E., R. L. Bowen, H. W. Gausman, and G. R. Cooper, 1983. Use of near-infraral video recording system for the detection of freeze-damaged citrus leaves. *J. Rio Grande Valley Hort. Soc.* 36:61–66.

Everitt, J. H., and P. R. Nixon, 1985. Video imagery: A new remote sensing tool for range management. *J. Range Manage.* 38:421–424.

Gates, D. M., H. J. Keegan, J. C. Schleter, and V. P. Weidner, 1965. Spectral properties of plants. *Appl. Opt.* 4:11–20.

Gausman, H. W., 1985. *Plant leaf optical properties in visible and near-infrared light*. Graduate Studies Texas Tech. University No. 29. Texas Tech. Press, Lubbock, Texas. 78 p.

Gausman, H. W., D. E. Escobar, J. H. Everitt, A. J. Richardson, and R. R. Rodriguez, 1978. Distinguishing succulent plants from crop and woody plants. *Photogram. Eng. and Remote Sens.* 44:487–491.

Gausman, H. W., D. E. Escobar, and E. B. Knipling, 1977. Anomalous leaf reflectance and leaf anatomy of *Peperomia obtusifolia*. *Photogram. Eng. and Remote Sens.* 43:1183–1185.

Hoffer, R. M., and C. J. Johannsen, 1969. Ecological potentials in spectral signature analysis. Pp. 1–16 In *Remote Sensing in Ecology* (P.O. Johnston, ed.), University of Georgia Press, Athens, Georgia.

Knipling, E. B., 1970. Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sens. Envir.* 1:155–159.

Leamer, R. W., V. I. Myers, and L. F. Silva, 1973. A spectroradiometer for field use. *Rev. Sci. Instrum.* 44:611–614.

Leamer, R. W., J. R. Noriega, and C. L. Wiegand, 1978. Seasonal changes in reflectance of two wheat cultivars. *Agron. J.* 70:113–118.

Manzer, F. E., and G. R. Cooper, 1982. Use of portable videotaping for aerial infrared detection of potato diseases. *Plant Disease* 66:665–667.

Meisner, D. E., and D. M. Lindstrom, 1985. Design and operation of a color infrared aerial video system. *Photogram. Eng. and Remote Sens.* 51:555–560.

Nixon, P. R., D. E. Escobar, and R. M. Menges, 1985. Use of a multi-band video system for quick assessment of vegetal condition and discrimination of plant species. *Remote Sens. Envir.* 17:203–208.

Peynado, A., H. W. Gausman, D. E. Escobar, R. R. Rodriguez, and M. V. Garza, 1979. Evidence of cell membrane injury detected by reflectance measurements. *Cryobiology*. 16:63–68.

Richardson, A. J., C. L. Weigand, H. W. Gausman, and J. A. Cuellar, 1975. Plant, soil, and shadow reflectance components of row crops. *Photogram. Eng. and Remote Sens.* 41:1401–1407.

Steel, R. G. D., and J. H. Torrie, 1960. *Principles and Procedures of Statistics*. McGraw-Hill Book Co., Inc., New York. 481 p.

Thomas, J. R., L. N. Namken, G. F. Oerther, and R. G. Brown, 1971. Estimating leaf water content by reflectance measurements. *Agron. J.* 63:845–847.

Thompson, C. M., R. S. Sanders, and D. Williams, 1972. *Soil Survey of Starr County, Texas*. Soil Conservation Service, USDA, Washington, D.C. 62 p.

Woolley, J. T., 1971. Reflectance and transmittance of light by leaves. *Plant Physiol.* 47:656–662.

(Received 23 December 1985; accepted 14 February 1986; revised 21 March 1986)