

Microcomputer-Assisted Video Image Analysis of Lodging in Winter Wheat

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ABSTRACT: Microcomputer-assisted video image analysis (VIA) was used to measure lodging in winter wheat (*Triticum aestivum* L. em. Tell.), a symptom of foot rot (*Pseudocercospora herpotrichoides* (Fron) Dei.) disease. The percent area of lodged versus erect winter wheat in seven fields was measured from 35-mm true color and color-infrared aerial photos and from manually prepared photointerpretations made onto frosted Mylar sheets, which were used as standard images for the purpose of comparison. Lodged wheat areas measured from the standard images ranged from 0.5 to 7.6 ha per field. Measurements made directly from photos consistently underestimated lodging by 0.2 to 2.4 ha per field relative to measurements from the standard images. Manual measurement of foot rot symptoms and grain yield in the seven fields showed 9 percent more severe lesions, and grain yield reductions of 1389 to 3416 kg/ha, in lodged wheat relative to erect wheat. Yield measurements combined with VIA lodging measurements made from the standard images showed the lodging-foot rot complex reduced yields by 138 to 796 kg/ha per field.

INTRODUCTION

Accurate estimation of disease impact on crop yield depends on accurate and reproducible measurement of disease incidence and severity. This report summarizes the potential and use of video image analysis (VIA) techniques to measure the incidence of lodging in winter wheat (*Triticum aestivum* L. em. Tell.) as a symptom of foot rot disease caused by the soilborne fungus *Pseudocercospora herpotrichoides* (Fron) Dei.

FOOT ROT

Foot rot is an important disease of winter wheat throughout the world (Wiese, 1977). This disease is especially damaging in eastern Washington (Bruehl *et al.*, 1968) and portions of eastern Oregon and northern Idaho (Rowe and Powelson, 1973), and causes lodging of wheat and other graminaceous hosts as a terminal symptom. Early diagnostic symptoms of foot rot are tan, elliptical, or "eye" shaped lesions that occur at the base of wheat stems. The lesions develop superficially on leaf sheaths and progress inward to the stem, eventually girdling the stem and becoming sunken and brittle. Diseased stems are weakened and fall (lodge) in a non-directional manner. Lodging caused by wind, rain, and other mechanical disturbances is aggravated where wheat has been predisposed by foot rot (Booth and Waller, 1973). However, unlike wheat lodged by mechanical disturbances, diseased wheat has little or no capacity to reassume an erect growth habit. Large areas of lodged wheat typically occur in cases of severe and widespread foot rot infection (Wiese, 1977).

VIDEO IMAGE ANALYSIS (VIA)

VIA is an electronic technique whereby pictorial information from a video input source is numerically represented (digitized) to enable subsequent computer analysis (Schowengerdt, 1983). The digitizing process sequentially isolates specific picture elements (pixels) within the video image using a rectangular grid scanning pattern. A data quantization level (grey level) is assigned to each pixel (Castleman, 1979). The proportional area occupied by pixels of an operator-specified subset of grey levels is quantified by means of density slicing, whereby these pixels are displayed on the computer monitor and their spatial correspondence to the specific image feature(s) to be measured is examined. In this project, images of 35-mm color (0.4- to 0.7- μ m) and color infrared (0.5 to 0.9- μ m) photographic transparencies were transmitted by a video camera to an Apple IIe microcomputer and digitized by means of analog-to-digital

conversion to a matrix of 65,536 pixels, each assigned one of 64 data quantization (grey) levels. Each pixel represented 7.32×10^{-5} hectares of ground surface area.

The advantages of using microcomputer-assisted VIA equipment relative to VIA systems utilizing more powerful computers having greater memory capacities is the relatively low cost of the equipment, its portability, and its ease of operation. Also, sophisticated image manipulation routines, unavailable with microcomputer-assisted VIA, are unnecessary for certain basic applications.

PREVIOUS WORK

Analysis of aerial photographs with microdensitometers has been used to quantify disease incidence and severity (Jackson *et al.*, 1971; Wallen and Jackson, 1971; Wallen and Philpotts, 1971; Jackson and Wallen, 1975) and to derive yield impact estimates (Wallen and Jackson, 1975; Basu *et al.*, 1978). Sophisticated VIA systems capable of discriminating 256 grey levels have been used to measure plant disease symptoms either directly from fresh specimens or from aerial photographs (Nilsson, 1980; Greaves *et al.*, 1983).

Microcomputer-assisted VIA systems comparable to that used in this project have been used to measure foliar disease symptoms either directly or from photographs of individual leaves (Eyal and Brown, 1976; Lindow, 1983; Lindow and Webb, 1983). Bronson and Klittich (1984) developed microcomputer-compatible VIA software for measuring foliar disease symptoms. Synoptic measurement of whole-crop disease symptoms from aerial photos using microcomputer-assisted VIA systems has not previously been attempted.

OBJECTIVES

The objectives of this study were

- To determine if lodged wheat areas could be electronically discriminated and measured from large scale true color and color-infrared aerial photographs by microcomputer-assisted VIA;
- To compare the accuracy and repeatability of VIA measurements of lodged and erect wheat areas digitized directly from the aerial photographs relative to VIA measurements of photo interpretations manually prepared beforehand and used as control (or standard) images; and
- To use resultant VIA measurements, in conjunction with manual measurements of yield and foot rot incidence, to derive estimates of yield impact due to the lodging-foot rot complex in seven winter wheat fields.

MATERIALS AND METHODS

AERIAL PHOTOGRAPHY

Three aerial missions were flown in the Palouse area of eastern Washington between 21 June and 2 August 1983. All missions were flown on clear, sunny days between 10:30 AM and 2:00 PM. The first mission (21 June) was flown to determine an appropriate photographic scale for resolving lodged areas for VIA purposes. Aerial photos were taken of one winter wheat and two winter barley fields in Whitman County, Washington, which had visible lodging. The aircraft used was a Cessna 182 with a porthole cut into the cabin floor to permit hand-held near-vertical aerial photography. The cameras used were 35-mm single lens reflex (Nikon model F2 and Canon model F1) equipped with motor drives and 50-mm lenses. The film/filter combinations used were (1) Kodak Kodachrome color with a Wratten 2A filter and (2) Kodak color infrared with a Wratten 15 filter. Photographic scales were nominally 1:5,000; 1:7,500; and 1:10,000.

Seven winter wheat fields in Whitman County, Washington with visible lodging were photographed on 18 July and 2 August 1983 using the same aircraft and cameras, and both films. A nominal scale of 1:7,500 was chosen as a best compromise for lodged area resolution and photographic coverage (about 4.8 square ha/frame).

For all aerial photography, camera F-stops were adjusted according to the film/filter used and prevailing light conditions. A shutter speed of 1/500 was used. The motor drives were adjusted to result in approximately 30 percent endlap between successive photos. Full stereoscopic coverage was not considered to be necessary for this particular application. One or two lines of photos were obtained per field. When two lines were taken, no photographic sidelap resulted.

FOOT ROT INCIDENCE, SEVERITY, AND YIELD IMPACT

The photographed winter wheat fields were manually examined for incidence and severity of foot rot caused by *P. herpotrichoides* and also were sampled for yield within lodged and erect areas.

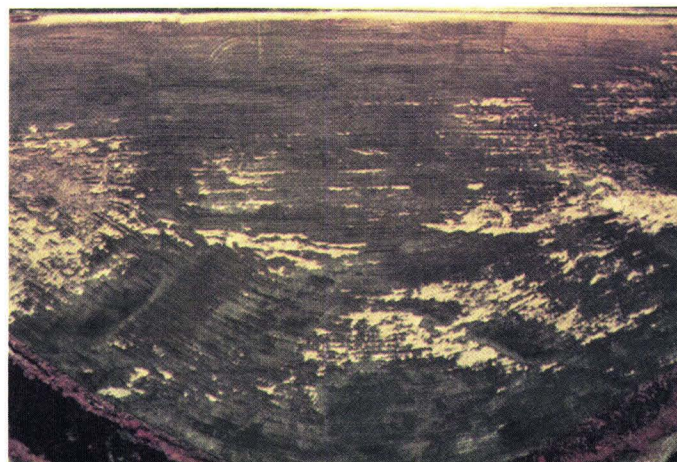
Three areas each of lodged and adjacent erect wheat were sampled in each field at plant growth stage (GS) 11.1 (Large, 1954). Ten subsamples of lodged wheat stems were collected along a line transect oriented to the long axis of the lodged areas. In adjacent erect wheat, ten subsamples were collected from an area approximately the size of the lodged area. Total sample sizes (bulk of ten subsamples/area) ranged from 117 to 210 stems.

Disease severity was rated on the sampled stems according to Powelson and Rohde (1972). Lesions occupying approximately 50 percent or more of the stem circumference were rated as "severe," while those occupying less than 50 percent were rated as "moderate." Stems without visible lesions were considered uninfected. Differences in foot rot incidence and severity between lodged and erect samples were analyzed according to log linear model analysis.

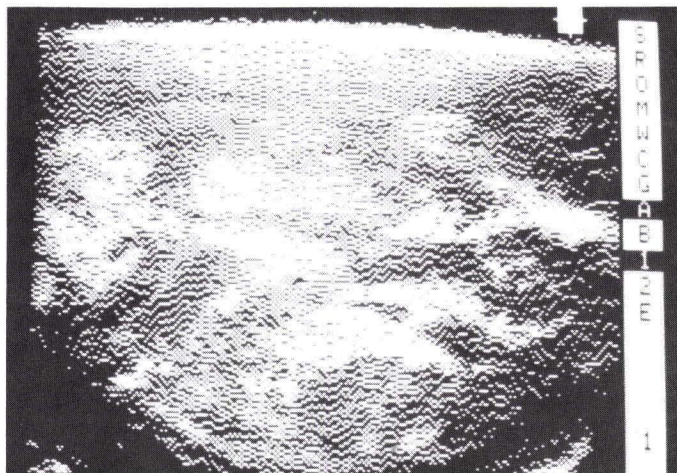
Yield was measured within one-square-metre samples from each of five areas of lodged and adjacent erect mature wheat (GS 11.2-11.4) in each field. After a period of moisture equilibration at room temperature, grain weight was recorded to the nearest 0.1 g. The mean differences in weight of five pairs of lodged and erect samples for each field were analyzed according to paired t-test.

VIDEO IMAGE ANALYSIS

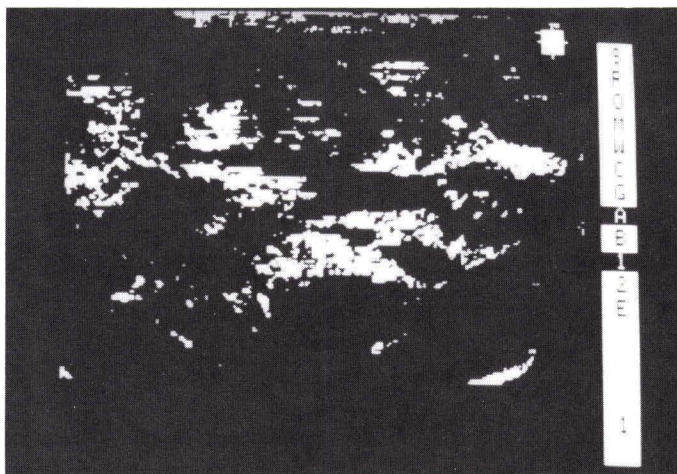
The July and August aerial photographic missions each produced true color and color-infrared series (sets) of sequential 35-mm transparencies (Figure 1a) for each winter wheat field. In order to avoid duplication of effort during VIA, the area of no photographic overlap (central 40 percent; no stereoscopic coverage) was delineated within each photo. The delineated



(a)



(b)



(c)

FIG. 1. (a) Aerial photograph (1:7,500 nominal scale, reduced to approximately 13,000) of a winter wheat field with lodging. Light areas are lodged, darker areas are erect. (b) The digitized image of the photograph displayed on the computer monitor. (c) A density-sliced image of the photograph displayed on the computer monitor.

areas were then measured with an electronic planimeter (Numonics Graphic Calculator, Numonics Corporation, North Wales, PA 19454) to determine their approximate area in hectares.

In order to prepare a corresponding series of standard images for the purposes of VIA evaluation and comparison, a 2× enlargement of each photograph was made using a Zoom

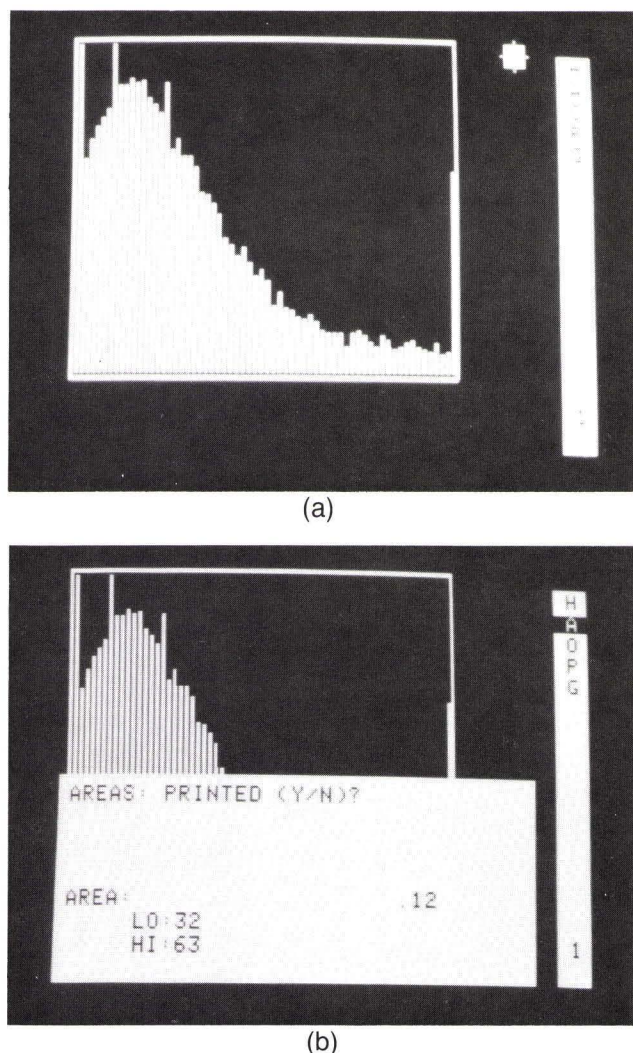


FIG. 2. (a) A computer-generated histogram describes the relative frequencies of pixels occupying each of the 64 grey levels. Values increase in brightness from "black" (0) on the left to "white" (63) on the right. (b) The percentage of density-sliced pixels is automatically calculated and displayed on the computer monitor.

Transfer Scope (Bausch and Lomb, Rochester, NY 14602). Within the delineated area of each photo, lodged areas were visually interpreted and manually delimited and blackened onto frosted Mylar sheets with a Rapidograph pen. Lodged areas were visually interpreted based on their distinctive visual appearance, particularly their lighter color and smoother texture relative to erect wheat areas, as confirmed by ground observation. VIA measurements of the standard images (indirect VIA) were made and statistically compared to VIA measurements made of the original photographs (direct VIA).

Analyses of all photos and corresponding standard images were conducted on an Apple IIe microcomputer equipped with a video monitor, two disk drives, a printer, and a light pen. The computer also was equipped with 192K memory, a DS-65 digitizer card (The Microworks, Del Mar, CA 92014), and interfaced with an RCA model TC2000 black-and-white video camera (RCA Closed-Circuit Video Equipment, Lancaster, PA 17604). Total cost of the equipment was approximately \$3,000. Basic and machine language programming enabled the microcomputer to function as an image processor. A photograph (or standard image) was placed directly under the camera on a light table, over which a black paper mask had been placed to exclude all light except that passing through the transparency. The entire camera and light table assembly were covered with

a black felt hood to exclude external light. The analog image could then be displayed on the monitor.

Next, the computer was instructed to begin a scanning routine whereby the analog image produced by the video camera was digitized. A representation of the digitized image could then be displayed on the monitor (Figure 1b). A polygonal "window" was positioned on the video monitor using the light pen to delineate the image subarea to be analyzed.

A histogram was produced for each digitized image subarea to indicate the relative frequency of pixels occurring within each of the 64 grey levels (Figure 2a). Pixel distribution in the histogram could be changed by adjusting brightness and contrast controls on the digitizer card and/or adjusting the lens *f*-stop on the camera. Such adjustments were necessary to maximize the contrast and clarity of lodged relative to erect wheat areas within photographs, but were not necessary when working with the standard images.

A density slicing procedure was performed in which the spatial arrangement of pixels within an operator-specified subset of grey levels was displayed (Figure 1c) and visually compared to lodged areas within the analog image of the photograph (or standard image). The density slice was adjusted as necessary to produce the best representation of lodged areas. In direct VIA, lodged areas in the original photos generally were represented by the brightest levels (those closest to the "white" end of the histogram). The area percentage of the digitized image subarea occupied by the density-sliced pixels was automatically calculated and displayed (Figure 2b).

Five independent direct VIA measurements were obtained and statistically compared to five independent indirect VIA measurements. Mean differences between direct and indirect VIA measurements were analyzed according to *t*-test on least-square means.

CALCULATION OF YIELD IMPACT

Lodged wheat hectares per delineated photo subarea (or corresponding standard image) were calculated by multiplying the mean percent lodged area (determined by VIA measurement) by the total wheat hectares represented in the delineated area (from planimeter measurement). Total lodged hectares per field were found by adding the lodged hectareage of each constituent field photo (or standard image). Total lodged hectares multiplied by the yield difference between standing and lodged wheat (measured from field samples) provided an estimate of yield impact due to the lodging-foot rot complex in each field.

RESULTS

VIDEO IMAGE ANALYSIS

The 18 July and 2 August photographic missions each produced both true color and color-infrared photo sets of the seven winter wheat fields. For both film types, it was found that direct VIA yielded lower measurements (underestimations) of percent lodging than those obtained from indirect VIA.

The mean underestimation of lodging by direct VIA of 28 color-infrared and 27 true color July photographs (of all seven fields) relative to indirect VIA was 4.35 and 7.37 percent, respectively. The mean underestimation by direct VIA of 30 color-infrared and 29 true color August photographs relative to indirect VIA was 6.74 and 7.50 percent, respectively (Table 1).

Pooled variances of five independent, direct VIA measurements of each of the 55 July true color and color-infrared wheat field photographs and of five independent, indirect VIA measurements from the corresponding standard images were 3.7 and 0.58, respectively. Pooled variances of five independent, direct VIA measurements of each of the 59 August photographs and of five independent, indirect VIA measurements from the corresponding standard images were 9.59 and 1.21, respectively. Variances of both July and August direct VIA measurements differ significantly from those of the indirect VIA

TABLE 1. COMPARISON OF LODGED WHEAT AREAS MEASURED USING DIRECT VIA OF ORIGINAL INFRARED (IR) AND TRUE COLOR (TC) PHOTOGRAPHS AND INDIRECT VIA.

Film	n ^a	Lodging ^b (%)		Underestimation ^c (%)
		Direct	Indirect	
July				
IR	28	12.18	16.53	4.35 ** x
TC	27	11.97	19.34	7.37 ** y
August				
IR	30	15.90	22.64	6.74 ** z
TC	29	16.13	23.63	7.50 ** z

^aNumber of true color or color-infrared photographs or standard images analyzed.

^bOverall mean per photo or standard image, based on the means of five independent measurements per of lodging within each of *n* infrared or true color photographs or standard images.

^cUnderestimations significantly different from zero at **: *p* = 0.01 according to paired t-test. Underestimations by film type followed by the same letter are not significantly different at *p* = 0.05 according to t-test.

TABLE 2. FOOT ROT INCIDENCE^a AND SEVERITY ON STEMS COLLECTED FROM ADJACENT LODGED AND ERECT AREAS IN EACH OF SEVEN WINTER WHEAT FIELDS.

	Severe lesion ^b (%)	Moderate lesion ^c (%)	Uninfected %
Erect	67	16	16
Lodged	76	9	14

^aMean percentage based on a minimum sample of 117 (maximum 210) erect or lodged stems from each of three locations in each of seven fields. Differences between erect and lodged percentages significant at *p* = 0.005 according to log linear model analysis.

^bEncompassing greater than 50% of stem circumference.

^cEncompassing less than 50% of stem circumference.

TABLE 3. GRAIN YIELD IN LODGED VERSUS ADJACENT ERECT WINTER WHEAT AREAS IN EACH OF SEVEN FIELDS.

Field	Yield ^a (kg/ha)		Yield difference ^b (kg/ha)
	Erect	Lodged	
1	4375.8	959.4	3416.4 **
2	2975.8	703.0	2272.8 **
3	4565.4	1976.8	2588.6 **
4	4407.4	2158.6	2248.8 **
5	3064.8	1657.2	1407.6 *
6	4205.8	2817.2	1388.6 *
7	4892.8	2485.8	2407.0 **

^aMean yield of cleaned grain based on five samples one-square-metre in size within lodged and adjacent erect wheat areas.

^bYield differences significant at *: *p* = 0.05 and **: *p* = 0.01 according to paired t-test.

measurements at *p* = 0.01 according to the F-max test (a test used to ascertain the equivalence of two variances) (Ott, 1977).

FOOT ROT INCIDENCE, SEVERITY, AND YIELD DIFFERENCE

Samples of erect wheat had a high percentage of severely infected stems. However, there were 9 percent fewer severe lesions on erect than on lodged stems (Table 2).

Lodged wheat samples had lower grain weights than adjacent erect samples. In lodged areas, yields were 1407.6 to 3416.4 kg/ha lower than in erect areas (Table 3).

YIELD IMPACT ESTIMATION

Harvest of yield samples within erect and lodged wheat areas was conducted concurrently with the 2 August photographic mission. Therefore, VIA measurements of only the 2 August field photograph and corresponding standard image sets were

used to measure lodging and estimate yield impacts within each of the seven fields.

For each of the seven fields, two measurements of total lodged wheat hectares were determined - one using the mean of the direct VIA measurements of the true color and color-infrared photo sets, and the other using the mean of the indirect VIA measurements of the two corresponding sets of standard images. Underestimation of total lodged hectares by direct versus indirect VIA measurements ranged from 0.2 to 2.4 hectares (Table 4).

Overall yield impact of the lodging-foot rot complex in each field was calculated by multiplying total lodged hectares per field (Table 4) by the yield difference between erect and lodged areas (Table 3), and dividing by total wheat hectares (determined by planimeter measurement) (Table 4). Thus

$$I = \frac{LD}{A}$$

where *I* = yield impact (kg/ha),

L = lodged area (ha),

D = yield difference between erect and lodged areas (kg/ha), and

A = total field area (ha).

Yield impact estimates calculated using direct VIA measurements were lower than those determined using indirect VIA measurements by 40.8 to 293.4 kg (Table 4).

DISCUSSION

FOOT ROT INCIDENCE AND SEVERITY VERSUS LODGING AND YIELD

Wheat samples from lodged areas of winter wheat fields had 9 percent more severe lesions than adjacent areas of standing wheat (Table 2). The relationship between lesion incidence and severity and the expression of lodging therefore is not clearly defined. However, foot rot was significantly (*p* = 0.005) more severe in lodged wheat. Yield was significantly decreased in lodged versus standing wheat in all cases (Table 3). It is possible that yield also was limited in standing wheat by foot rot infection which was not expressed as lodging; however, the extent of such limitation could not be measured using VIA. In addition, it is possible that some wheat was lodged due to factors other than foot rot.

It is unknown whether the acquisition of true color or color-infrared photography early on in the growing season can be used to detect foot rot-infected wheat before the expression of the lodging symptom; this possibility was not explored in this research.

VIA MEASUREMENT OF PERCENT LODGING

In all cases, direct VIA measurements underestimated percent lodging relative to indirect VIA measurements (Table 1). These

TABLE 4. TOTAL WHEAT^a AND TOTAL LODGED WHEAT AREA AND CORRESPONDING YIELD IMPACT ESTIMATES OF THE LODGING-FOOT ROT COMPLEX IN SEVEN WINTER WHEAT FIELDS.

Field	Total Wheat Area (ha)	Total Lodged Area ^b		Yield Impact ^c (kg/ha)	
		Direct	Indirect	Direct	Indirect
1	11.1	0.2	0.5	46.2	138.5
2	6.6	0.6	1.1	189.4	361.6
3	18.4	1.8	3.1	253.3	436.1
4	2.3	0.3	0.6	244.4	537.8
5	16.5	3.6	6.0	302.9	511.9
6	20.4	7.0	7.6	473.1	513.9
7	6.2	1.9	2.1	718.2	795.9

^aTotal wheat hectares per field determined from planimeter measurement of infrared and true color photographs.

^bDetermined by multiplying VIA measurements of percent lodging by total wheat hectares.

^cTotal lodged hectares per field multiplied by the yield difference between erect and lodged areas (Table 3), then divided by total wheat hectares per field.

underestimations led, in turn, to sizeable underestimates of yield impact (Table 4). In addition, the variances of five independent, direct VIA measurements were higher than, and differed significantly from, indirect VIA measurements, which were low. Direct VIA measurements were, therefore, more variable than indirect VIA measurements.

Increased variability of measurements and underestimation of lodged areas during direct VIA may have been due to impaired density slicing of the digitized photographs. While density slicing the lodged areas represented on the standard images, which were a uniform high-contrast black on transparent plastic, was uncomplicated, the lodged areas in the centers of the photos frequently were represented by lighter grey levels than those towards the edges, which often were inseparable from other field areas (particularly light-colored clay knobs and eroded areas) in terms of grey levels, resulting to poor density slides. This problem was most likely due to the use of a video camera (RCA TC2000) not equipped with "shading" and "blanking" compensators, which stabilize the video signal exiting the vidicon tube. Use of video cameras lacking these compensators will often lead to difficulty in density slicing discrete groups of grey levels (density windows) normally characteristic of specific image features (W. D. Harrison, personal communication).

It may be that more accurate and less variable VIA measurements of lodged wheat areas are obtained by analyzing photointerpretations (indirect VIA) rather than using the photographs directly. The visual clues of color, texture, size, and relative placement in the field allow straightforward identification and interpretation, although area delineation is painstaking and time-consuming (up to 15 minutes is required per interpretation). Color-infrared and true color photos were equally straightforward to interpret; however, lodged areas in the infrared photos appeared even brighter in relation to erect areas than did those in the true color photos.

However, the use of a video camera equipped with shading and blanking compensators may be a way to improve the performance of VIA of photos directly, perhaps eliminating the need for an interpretation step altogether. Harrison (1984) acknowledged difficulty in obtaining accurate density slices during measurement of range vegetation from aerial photos using the microcomputer-assisted LMS II (Linear Measuring System, Measurionics Corp, Great Falls, MT 59401), which was equipped with an RCA video surveillance camera lacking the compensators. This difficulty has been largely eliminated by the use of a special imaging camera (Cohu Inc., Electronics Division, San Diego, CA 92138) having the compensators, which has been interfaced to a Measurionics VGS-300 (Video Graphics System, EERONCA Electronics Inc., Charlotte, NC 28210) (W. D. Harrison, personal communication).

Alternatively, a microcomputer with enhanced graphics capabilities such as the MacIntosh (Apple Computer Co., Cupertino, CA 95015) could possibly be programmed to combine VIA technology with built-in photo-interpretation capacity, enabling the user to precisely delineate lodged image areas directly on the computer monitor in cases of difficult density slices (M. J. Grube, personal communication). This type of system could offer this capability without the need for a special camera, and at a purchase cost comparable to that of the equipment used in this study.

This study demonstrated that microcomputer-assisted VIA can be used to measure the incidence of lodging in maturing winter wheat fields. Aerial photographs of several fields can be procured in a single photographic mission and interpreted and/or video analyzed at any later or convenient time. Also, indirect VIA procedures enable the performance of timely and reasonably accurate measurement of lodged areas in large-hectare wheat fields, whereas on-the-ground estimates or measurements may be difficult or impossible to obtain due to logistics or time and/or resource constraints. In addition to providing a basis for estimates of yield impact, the photographs also would provide

a permanent record of lodging for use in year-to-year comparisons.

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BOOK REVIEW

Airphoto Interpretation and the Canadian Landscape, by J.D. Mollard and J.R. Janes. Energy, Mines and Resources Canada, Ottawa, Ontario, 1984. 415 pages, spiral bound. Available from Canadian Government Publishing Centre, Ottawa, Ontario K1A 0S9. Price: \$60.00 (Canada), \$72.00 (other countries).

THIS MULTIDISCIPLINARY MANUAL on applied interpretation of aerial photographs is intended for Earth scientists, engineers, and other professionals interested in the use of airphoto interpretation techniques for a systematic evaluation of Canadian landscapes. The book consists of two parts: text (183 pages) and plates (218 pages).

The text part, with 148 Figures and 16 Tables, is divided into eight chapters. The first chapter, "Black and White Air Photographs and their Interpretation," provides a comprehensive introduction to aerial photography and its practical use for the recognition of landforms and surface materials. Chapters 2 to 7 inclusive cover a systematic analysis of aerial photographs and interpretation of specific ground conditions associated with landscapes that were subjected to various geomorphic processes: "Bedrock Terrain" (Chapter 2), "Glacial Landscapes" (Chapter 3), "Slope Movements" (Chapter 4), "Running Water and Groundwater" (Chapter 5), "Shorelines and Wind Effects" (Chapter 6), and "Permafrost Terrain and Peatland Features" (Chapter 7). The use of color aerial photography and non-photographic imagery is discussed in the last chapter, "Remote Sensing and Satellite Imagery." A list of selected references is provided at the end of each chapter ("Further Reading").

The "Plates" section of the book consists of full-page (43cm by 28cm) stereograms (112 stereo-pairs and 116 stereo-triplets), reproduced at contact scales of original prints and arranged in the same order as the eight chapters in the text section. Each stereogram is clearly annotated and a 5-mm grid along the edges of the plate with alpha numeric designation of grid coordinates provides a simple guide for pin-pointing some specific details or locations. A short title, geographic location, data on aerial photographs, latitude and longitude, number of NTS mapsheet, and a scale bar are provided for each stereogram.

A "Glossary" of remote sensing and geologic terms and a comprehensive index are found on pages 401 to 415.

The quality of reproductions — diagrams, maps, photographs and non-photographic imagery in text, as well as all stereograms — is excellent. The annotations on individual examples, interpretation of displayed landscape features, and explanations of specific patterns or conditions are superb. Most of these examples came from Dr. Mollard's numerous projects and may be considered as classical "case studies," widely used in his numerous lectures and training courses during the past 25 years. This book, *Airphoto Interpretation and the Canadian Landscape*, is based to a large extent on the material used in two such training manuals: *Airphoto Analysis and Interpretation — A Laboratory Manual of Selected Airphotos Showing Landforms and Soil Conditions in Western Canada*, prepared for University of Alberta Short Course in 1960, and "Landforms and Landscapes of Canada — A Stereoscopically Illustrated Guide to Airphoto Identification and Interpretation," prepared for his two-week course at the University of Saskatchewan in 1972. The 1960 Manual, known as "The Blue Book", played an important role in training photointerpreters during the Canada Land Inventory (CIL) Program, while the 1972 Guide, under its revised title, *Landforms and Surface Materials of Canada — A Stereoscopic Airphoto Atlas and Glossary* (1973), became a standard Canadian airphoto interpretation reference. About two-thirds of the stereograms in "Airphoto Interpretation and the Canadian Landscape" were selected from the seventh (1982) edition of this *Airphoto Atlas*.

Airphoto Interpretation and the Canadian Landscape is a unique book in many respects: it is an authoritative textbook of geomorphic processes in various parts of Canada, and a training manual, with many expertly selected and interpreted examples for a classroom use, or as a comprehensive guide for self study. It is also an indispensable reference volume on practical use of conventional aerial photographs and remote sensing technology for evaluation of land resources.

At \$60.00 per copy, this book is a bargain, when one considers that the preparation of annotated examples required 668 black and white, and ten color conventional aerial photographs, 16 Color Composite Landsat prints, and 14 "hard copies" of digital imagery (SLAR, Seasat, and thermal IR). The cost of these prints alone is an excess \$1700.00.

—Philip Gimbarzevsky,
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