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Electronic Image Analysis of Crop Residue Cover on Soil

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ABSTRACT

CLASSIFICATION procedures for using both black-and-white and color imaging systems were developed and tested for determination of percent residue cover on the soil surface from video and slide images. A spectral analysis of the image components was used for determining applicable wavelengths and filters. Color imagery provided an acceptable replacement for manual visual procedures. Black-and-white imagery also worked when appropriate blocking filters were used.

INTRODUCTION

Interest in applications of computer vision for automation of visual processes has increased during recent years. This is due in part to low-cost digitizing hardware, compatible with personal computers. Recent applications have included apple sorting (Rehkugler and Throop, 1986), identification of plants (Guyer et al., 1986), and plant growth measurements (Meyer and Davison, 1987). The primary consideration of image processing is to simulate human vision to the extent that the computer can replace, interpret, and speed up visual data-gathering activities.

Lighting requirements for simulating human vision with a video camera and computer are quite important. Paulsen and McClure (1986) suggest that the video camera and the light source be matched to wavelengths corresponding to peak sensitivity of the human eye. (The scope (rods) and photopic (cones) systems of the human eye have peak responses around the 500 to 590 μm waveband.) This is particularly important for black-and-white computer vision. However, the main problem with black-and-white computer vision is that a highly sensitive image digitizer (6-bit analog-to-digital or better) will show all of the variations (bright spots and shadows) in the illumination system. The digitized illumination data are interlaced with the subject data. This tends to make a classification system based on computer vision more difficult to implement. To remove this noise, a low pass digital filter or special optical filters attached to the lens of the camera are required.

Recently, low-cost color imaging systems have become available for personal computers. These systems are available in spatial renditions ranging from 50,000 to 200,000 pixels per frame. A pixel (sometimes called a pel) represents the smallest spatial element of an image frame.

A color imaging system has three analog-to-digital converters for each primary color circuit used in a National Television Systems Committee (NTSC) color television camera. Generally, a 4- or 5-bit analog-to-digital converter is satisfactory to generate 4,000 or 32,000 possible colors on a video screen, respectively. The color television format is partially based on the C.I.E. Standards (Commission Internationale de l'Eclairage—the International Commission on Illumination, 1931). This internationally accepted color system includes warmness (red) and coolness (blue) response curves, in addition to the luminosity (green) curve given by Paulsen and McClure (1986).

A low-cost color digitizer could be quite useful for many agricultural applications. One important application is the determination of surface residue cover. The objective of this paper is to compare computer vision methods using both black-and-white and color imagery with manual visual methods for estimating percent crop residue cover.

MATERIALS AND METHODS

Soil erosion control is fundamentally related to the amount of soil surface covered with residue, which will intercept and dissipate the energy of a rain droplet. Two image processing systems were tested for estimating crop residue cover. Method one was based on a black-and-white digitizer using the Chorus PC-EYE video capture board. Method two was based on a color digitizing system, using the AT&T True Vision Image Capture Board (ICB). Both boards were used with IBM personal computers. A schematic of the two systems is shown in Figs. 1a and 1b. Each method was used to test a photographic slide-to-video, camera to computer transfer process, as outlined in detail below. Direct video tape to computer transfer was also tested, but with the Image Capture Board only. A spectral analysis was performed on the lighting system and was used to develop the best procedure for classifying the soil and residue components.

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Mention of any specific commercial products is for reference only and not to the exclusion of others that may be suitable.

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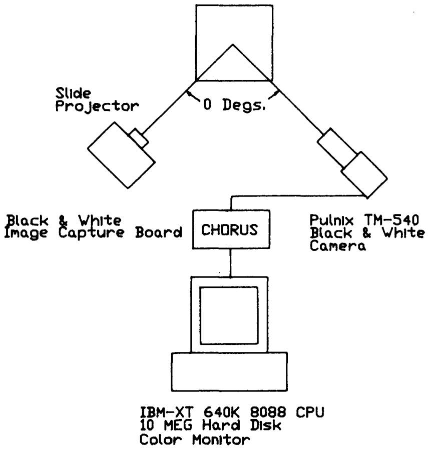

Fig. 1a—Layout for black and white (Chorus) image processing system.

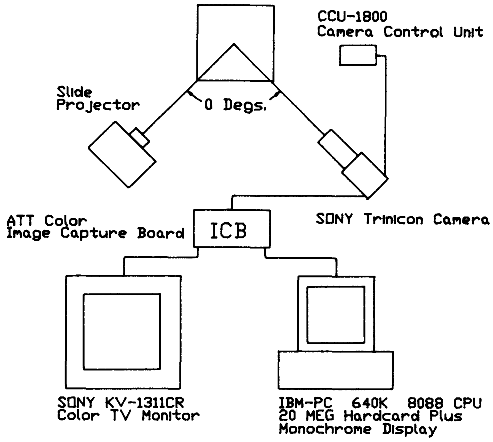

Fig.1b—Layout for color(ICB) image processing system.

****Note: Camera actually positioned above slide projector.**

Manual Photographic Grid

Photographic slides were used to permanently record soybean and corn residue cover existing in the field at various times from harvest through the completion of tillage and planting operations (Burr, 1986; Burr et al., 1986; and Burr et al., 1987). Approximately 5,200 photographic slides required human visual analysis for the 1985 to 86 observations and approximately 14,000 photographic slides were obtained during the 1986 to 87 measurements.

Each photographic slide covered an area of the field approximately 0.76 m by 1.20 m. Slides were taken using a tripod-mounted 35-mm camera equipped with a 28-mm focal length lens, approximately 1 m above the soil surface. The area photographed was shaded from direct sunlight, and an electronic flash was used to provide consistent lighting for either cloudy or sunny days. Kodachrome 64 film was used (Burr, 1986).

Percent residue cover represented by each slide was first determined using the photographic grid method (Laflen et al., 1981). With this method, the slide image was projected onto a grid pattern comprised of intersecting lines. A total of 130 intersection points were observed for each slide to determine if a piece of residue covered the intersection. The number of covered intersections divided by the total possible intersections, gave the percent cover.

Using the large slide database outlined above, a set of 160 photographic slides was chosen to test the computer image processing method. These slides were divided into two categories of wet and dry conditions according to their apparent soil surface color. A spectral analysis was performed on the slide projection system, as was seen by the television cameras during the image analysis. In a second test, selected frames from a VHS-format video tape of corn and soybean residue, acquired with a Panasonic AG-155 camcorder were analyzed with the imaging system.

Black-and-White Image Analysis

Black-and-white imagery is based on the digital representation of various brightness levels of reflected light over the visible and near-infrared spectral regions, depending on the camera sensitivity. It is based on the assumption that two subjects being classified have sufficiently different reflectance coefficients, and that the digitizing hardware and software can make the distinction. An IBM-XT personal computer equipped with a Chorus PC-EYE Image Capture Board, a Tecmar Graphics Master Board, and a Pulnix TM-540 miniature solid-state (CCD) black-and-white camera were used to acquire crop residue information from the color slide set. Image data acquired with the Chorus board was stored immediately in the video display RAM of the Graphics Master. The digitizer provided 256 grey or brightness levels. However, only 16 grey levels could be displayed as false colors for the 640 x 400 pixel (Tecmar) display format, and only two grey levels for the 320 x 200 (IBM format. Sixty-five percent of the display was included in each frame analysis. This corresponded to 166,400 and 41,600 intersection points for the Tecmar and IBM systems, respectively. This percentage also represents the amount of coverage for the photographic grid (manual) method. A simple histogram program written in Microsoft-C was used to classify the pixels displayed.

The CCD camera provided 525 scanning lines (510 Pixels horizontally), which was more than enough to saturate the spatial sensitivity of the image processor. The camera was equipped with an F16, 12.5 to 75-mm focal length zoom lens and focused onto a projected slide image provided by a Kodak Carousel projector. Kodak Wratten Filters 87C and 89B that block the visible range were tested, leaving the near-infrared wavelengths for image analysis.

Color Image Analysis

Color imagery was tested using an AT&T Image Capture Board (ICB), a Sony DXC-1800 SMF Trinicon color video camera, and an IBM-PC personal computer. The camera was equipped with an F1.4, 11 to 70 mm focal length zoom lens. This camera uses a 2/3 in., SMF Trinicon tube, producing a 2:1 interlace NTSC color signal, with a horizontal resolution of 300 lines. The camera has three built-in filters, each of which were tested. To obtain and maintain a faithful color reproduction, the white balance was adjusted by pointing the camera at a blank white screen under the projection lighting conditions, and actuating the white balance switch.

The Image Capture Board was used to capture NTSC signals from either the Sony camera or a Panasonic NV-8420 VHS portable video cassette recorder. The Image Capture Board worked well with a VCR, while the Chorus system did not. A Sony Trinitron KV-1311CR video monitor was used to display both live and captured images. The standard IBM monochrome display was used for displaying numerical data and image processing commands.

The Image Capture Board converted an analog video image into a 200-row by 256-column array of 15-bit pixels, using three 5-bit analog-to-digital converters and then stored the data in the on-board memory. Sixty-five percent of the image frame was analyzed, essentially equivalent to a grid of 33,280 intersection lines. The Image Capture Board digitized all three primary color components (red, green, and blue) during one screen scan time of 1/60 s. The sixteenth bit, or overlay graphics control bit, was not used in this analysis.

A simple, but interactive image pixel analysis program was written in Microsoft-C, using a Mouse Systems Mouse as a pointing device. This program allowed the user to isolate a single pixel and gave its intensity values of the red, green, and blue components as integers on the display console. Once the target pixel was identified, all other pixels of this type within a given tolerance were counted within the window defined.

Spectral Analysis

An analysis of the slide projection lighting system was performed using a Spectron Engineering CE-950 Field Portable Data-Logging Spectroradiometer as suggested by Paulsen and McClure (1986). This instrument provided a spectral analysis of visible and near-infrared light (400 to 1100 μm). The instrument contained a photodiode array-based detector head capable of simultaneously acquiring 256 bands of energy counts across the spectrum in only a fraction of a second. A standard head with a 10 deg acceptance angle was used. The scan time used was 1/2 s and was based on the intensity of the background lighting source. Count data were taken of the reflected light surface generated by the projection system, during the slide-to-video transfer, as was seen by the video cameras. The spectral analog signal was converted into 12-bit integers, representing the relative light intensity of each wavelength band. The slide-to-video transfer process was undertaken in a dark room, with no significant sources of light other than the projection system. The projection light source was a GE-ELH multi-mirror projection lamp (Kodak Carousel), whose spectral output is shown by Fig. 2. For this study it was not necessary to convert the count data directly to energy values in SI units since only the relative amounts of blue, green, red, and near-infrared were of importance in interpreting image pixel values. The spectral reflectance count data were then weighted by the C.I.E. tristimulus weighting functions, shown in Fig. 3. These weighted values gave the estimates of the three primary colors as previously discussed. The camera was adjusted according to the weighted spectral output, to more closely match the human color perception of the slides.

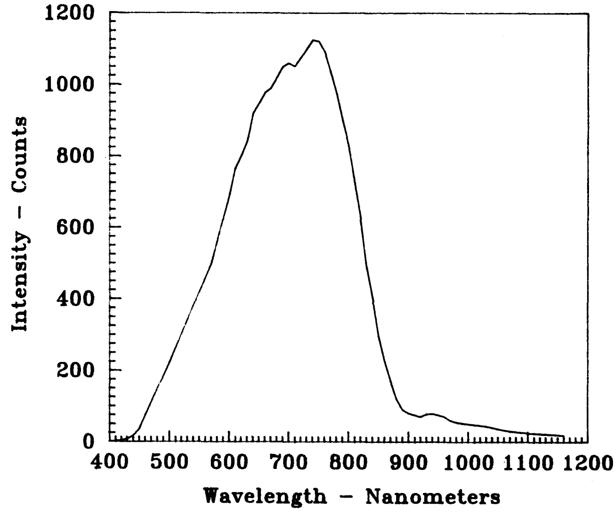

Fig. 2—Spectral intensity versus wavelength for GE ELH multi-mirror projection lamp.

Image Classification Logic

The image classification problem of determining residue cover involved sorting and summing the various pixel types found in the image frame according to a set of rules. These rules were developed using the single pixel analysis, with a visual inspection, and with the spectral analysis providing a ground truth of data. Pixel categories included dry soil, wet soil, corn residue, soybean residue, and green plants. A simple set of pixel selection rules were programmed in Microsoft-C. To aid in the visual inspection, the selected pixels were assigned a false color on the display monitor, as the computer classification proceeded.

RESULTS AND DISCUSSION

The prospects of automating the human visual perception of the photographic grid method (Laflen et al., 1981) using the IBM personal computer as a processor with a color television camera system from photographic slides or video tape are very good. Manual (photo grid) determination of crop residue cover is partially a function of pattern recognition, with color determinations reinforcing the decision-making process.

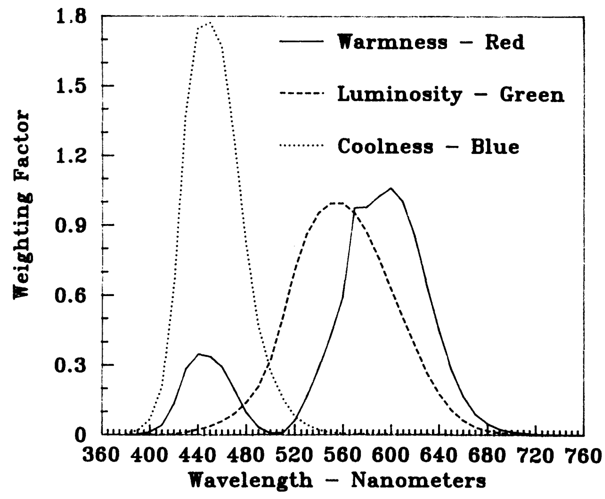

Fig. 3—C.I.E. tristimulus weighting factors for chromaticity.

TABLE 1. COMPARISON OF MANUAL READINGS OF SOIL RESIDUE COVER BY THREE HUMAN OBSERVERS

Slide number	Observers			Average	Standard error
	1	2	3		
	Percent residue cover*				
1	14.0	15.0	12.0	13.7	1.5
2	15.0	11.0	12.0	12.7	2.1
3	19.0	10.0	19.0	16.0	5.2
4	20.0	21.0	19.0	20.0	1.0
5	22.0	17.0	22.0	20.3	2.9
6	24.0	26.0	29.0	26.3	2.5
7	43.0	42.0	41.0	42.0	1.0
8	43.0	54.0	43.0	46.7	6.4
9	43.0	39.0	47.0	43.0	4.0
10	44.0	43.0	35;0	40.7	4.9
11	45.0	43.0	46.0	44.7	1.5
12	55.0	49.0	41.0	48.3	7.0
13	59.0	62.0	61.0	60.7	1.5
14	61.0	57.0	63.0	60.3	3.1
				Average:	3.2

*Based on 130 sample points per photgraphic slide

However, the manual method is a very tedious job and subject to some variation as shown in Table 1. Even very well-trained observers do not arrive at the same results. This process can be replaced by an image pixel color classification method. No computer pattern recognition algorithms were used in this study.

Slide-Video Camera to Computer Transfer

The most serious difficulty encounterd with color imagery was the proper set-up of each hardware system. A spectral analysis of the slide-video transfer process was necessary to delineate and verify the camera set-up for correct color rendition and possible courses of classification. Fig. 4 shows the spectra as seen by the spectroradiometer for corn and soybean residue, bare soil, and a clear section of slide film media. The clear film media blocks the 700 μm band; however, there is still a considerable amount of information in the red and near-infrared bands. The spectral separation of the soil from residue components is shown in the difference in intensities of these bands, especially if the soil surface has a high moisture content. The built-in camera filters for "Iodine lamps" and "indoor lighting" were tried, but

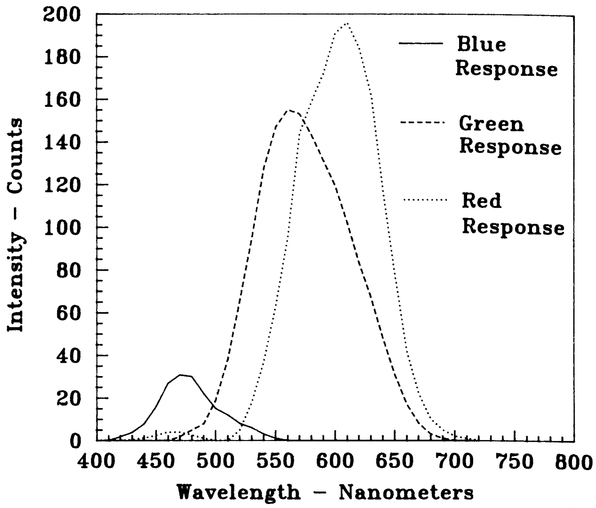

Fig. 5—C.I.E. weighted spectral intensity versus wavelength for corn residue cover.

produced substantial amounts of green and blue images. The filter "cloudy and rainy conditions" gave the best color rendition and agreed with the spectral analysis.

The Trinicon camera has many contrast, color, and brightness control settings. The spectral analysis was absolutely necessary to properly adjust the Sony Trinicon camera for maximum effectiveness. Fig. 5 shows the weighted spectral distribution applying the C.I.E. tristimulus weighting factors to the corn spectra. This is similar to the spectra seen by the television camera. The peak values of the weighted curves correspond to the digital red, green, and blue pixel values obtained with the Image Capture Board. Good separation of soil and residue can be achieved at 650 μm, which is the peak of the (red) tristimulus weighting function. The combination of all three tristimulus values contribute to the resultant color appearance to the human eye.

Since the Pulnix black-and-white CCD camera is sensitive to the near-infrared, the use of Kodak Infrared Filters 88A or 89B can provide good separation of soil and residue as shown by the filter transmittance spectra in Fig. 6, by blocking out the visible spectra. The 89B

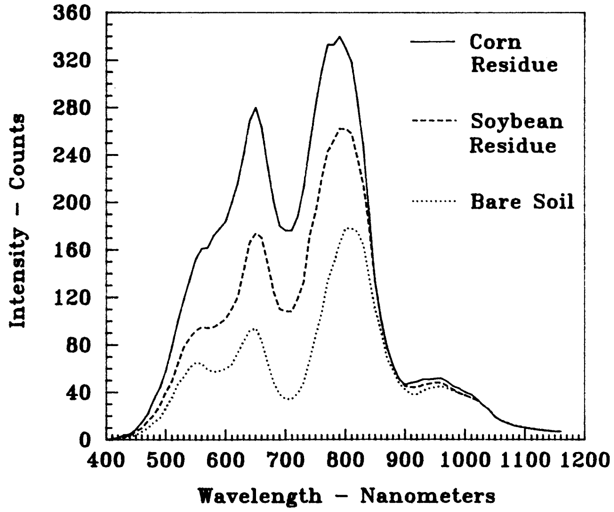

Fig. 4—Spectral intensity versus wavelength for soil-residue components.

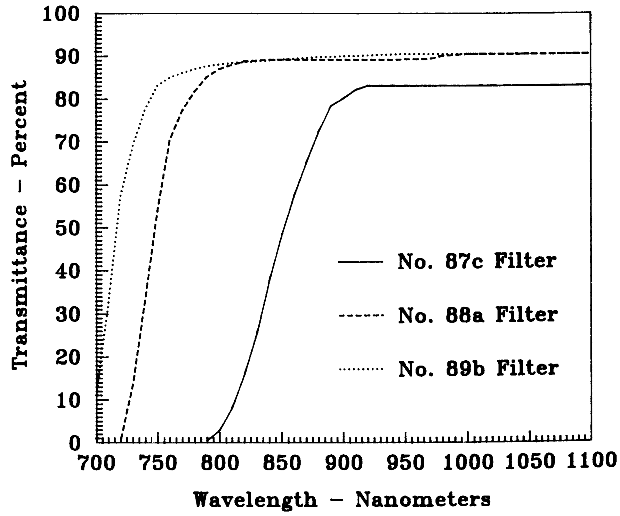

Fig. 6—Filters for black and white near infrared residue analysis.

TABLE 2. COMPARISON OF PIXEL VALUES FOR SLIDE-VIDEO CASSETTE TAPE TO COMPUTER SOIL RESIDUE ANALYSIS*

Method to transfer	Image subject	Pixel values† Red intensity	Green intensity	Blue intensity
35-mm slide-video				
	Dry soil	21.3 ± 4.6	15.7 ± 3.0	7.9 ± 2.7
	Wet soil	3.1 ± 1.2	1.9 ± 0.9	0.6 ± 0.9
	Corn residue	22.1 ± 6.1	16.6 ± 4.8	7.9 ± 3.7
	Soybean residue	25.2 ± 5.0	19.7 ± 4.5	11.2 ± 3.4
Video tape				
	Bare soil	17.6 ± 4.5	12.2 ± 4.2	12.9 ± 6.2
	Corn residue	29.9 ± 2.7	22.6 ± 5.6	20.5 ± 7.5
	Soybean residue	29.3 ± 2.6	22.7 ± 4.5	22.9 ± 5.9

*Obtained with AT&T-ICB System
†Average of 50 values each with standard error. In practice, intensity = 0 (no color) and intensity = 31 (maximum brightness of primary color).

filter was tried with the Chorus black-and-white system and provided sufficient contrast. An 87C filter was also tried but did not work well at all. The contrast was manifested in only two or three brightness levels, but could be detected with either the Chorus or ICB digitizers.

Video Tape to Computer Transfer

Video tape is perhaps an even better way than photographic slides for presenting data to the computer imaging systems. Table 2 shows a comparison of typical pixel values using either slides or video tape. Color intensities of corn and soybean residue were approximately 20% greater with video tape (31 being the highest integer intensity value with a 5-bit ICB digitizer) than with the slide-video transfer method. The resulting contrast with residue and wet soils seemed to be even greater than with dry soils, which generally have higher reflectance or albedo.

Residue Classification Color

A comparison of manual-read and machine-read images was made for the slide-transfer system. Fig. 7 shows the comparison for wet soil surface conditions and soybean residue which resulted in a very high correlation ($R^2 = 0.95$). There was no significant difference in variation between greater or lesser amounts of residue cover.

Dry soil surface conditions created a slightly more difficult situation to analyze. Fig. 8 shows a comparison for dry surface conditions and soybean residue. In most cases, the frame was divided into smaller windows and the classification rules were modified to obtain better machine readings. With a little more work, the results also show a good correlation. This system worked as sell for corn residue as for soybean residue. The data in Fig. 9 shows a high correlation for corn residue.

Residue Classification—Black and White

With the Chorus Tecmar image capture system, there were 256 possible classification levels (8-bit), of which a maximum of only 16 could be displayed as false color at the console. Contrast thresholds for the 16 levels were set using the Chorus CALIBR routine (Release 2.2). The

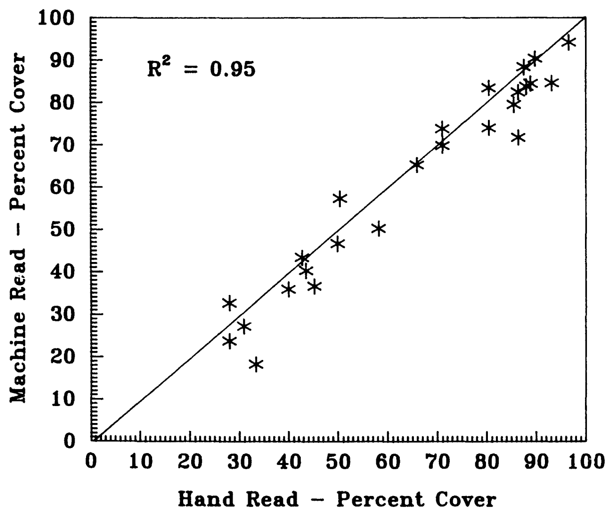

Fig. 7—Comparison of machine and hand read soybean residue on wet soil.

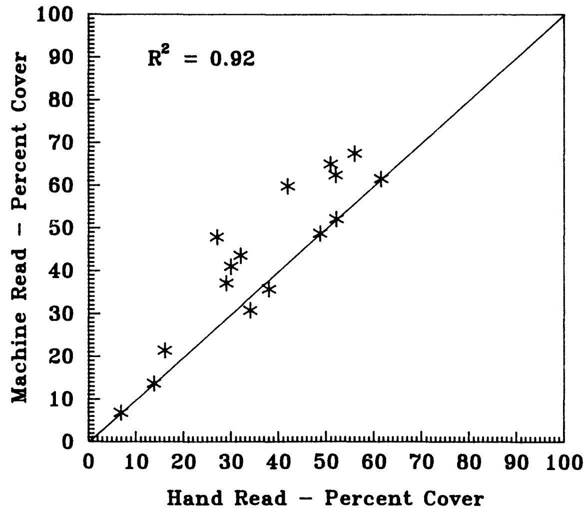

Fig. 8—Comparison of machine and hand read soybean residue on dry soil.

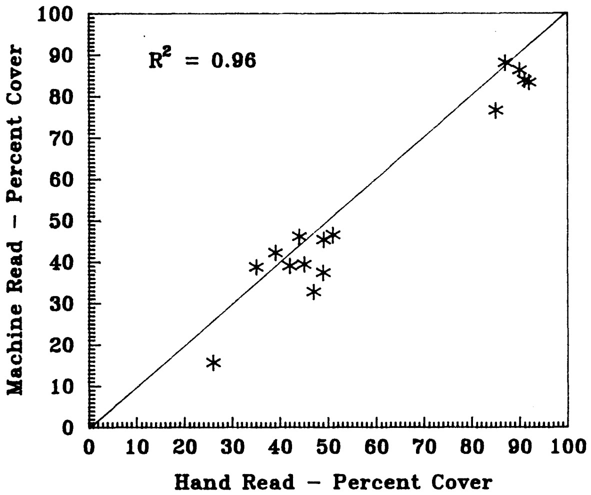

Fig. 9—Comparison of machine and hand read corn residue on dry soil.

BLACK parameter sets the analog-to-digital level below which video signals will be digitized as black. The WHITE parameter sets the analog-to-digital level above which video signals will be digitized as white. When through trial and error, the appropriate BLACK and WHITE values are found, it is possible to reduce the image to only two false colors or brightness levels. The pixel count for residue or soil was then easily obtained. Higher spatial levels and sensitivity with the Tecmar configuration showed too much of the projection lighting gradients, making it difficult to obtain a correlation better than $R^2 = 0.75$. The best configuration was the IBM 320 x 200 pixel format. This format automatically gave only two false colors. A comparison of machine-read black-and-white with the manual readings showed a reasonable correlation of $R^2 = 0.85$. However, a major disadvantage of the Chorus capture system is that it depends on the IBM system bus, making capture speeds too slow. Thus, it would not work with the video tape.

CONCLUSIONS

1. The spectra of soil-residue-slide projection system indicated that residue can be identified from 35-mm slides, using either the red band of a color television system or the near-infrared band using a visible blocking filter with a black-and-white television system. The color system worked better in all cases than the black-and-white system.

2. Video tape is preferred over a slide-to-television transfer system for color analysis and results in a better color presentation to the computer. However, current VCR's only store images of 200 - 400 line resolution, which may not be the desired media to archive data. Much data is currently stored with 35-mm slides, which have a greater spatial resolution.

3. Classification of residue via computer provides considerably more node points than with manual methods. It, therefore, should be a far more accurate and consistent system. However, color systems require careful tuning of the television camera to achieve accurate and consistent color renditions.

4. High spatial and brightness digitizing levels of the black-and-white system provided too much data to be analyzed. Projection lighting variations are interlaced with the subject data. A system with 40,000 to 60,000 pixel spatial rendition and no more than 32 brightness levels worked the best.

5. It is recommended that for each set of different residue conditions to be analyzed, that the pixel contents of sample frames be carefully analyzed first. The classification rules can be adjusted accordingly, to establish a valid ground truth of the system. The system must be adjusted as background lighting conditions are changed.

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