A. H. GERBERMANN
J. A. CUELLAR
C. L. WIEGAND
U. S. Department of Agriculture
Weslaco, TX 78596

Ground Cover Estimated from Aerial Photographs

A high correlation was found between per cent crop cover determined from groundobservations and per cent cover estimated from aerial photographs.

ABSTRACT: *Per cent ground cover is an important characteristic needed for interpreting reflectance and emission signatures of crops for estimation of crop maturity, vigor, and probable yield. Ground survey teams are limited in the area they can cover. In this study, per cent crop cover obtained from ground observations is correlated with per cent cover estimated from aerial photographs.*

Six flight lines totaling about 64 km were overflown during a 4-month period at altitudes from 488 to 1219 m using Kodak Ektachrome Infrared Aero 8443 film. Ground observers estimated per cent crop cover at the time of the overflights. Later, independent observers estimated per cent cover from the photographs with the aid of a magnifying stereoscope.

Simple correlation coefficients between per cent cover by the two estimating techniques were highly significant ($p = 0.01$) and were as follows for six crops: cantaloupe, 0.957; citrus, 0.939; corn, 0.950; cotton, 0.982; onion, 0.807; and grain sorghum, 0.945. Number of paired observations was greatest for cotton and sorghum at 182 and 167, respectively.

The results indicate that photo estimates of row crop ground cover can be used to replace the tedious and time consuming observations made by ground survey teams.

PER CENT GROUND COVER is an important parameter for assessing the growth, maturity, vigor, and yield potential of field crops. The use of ground survey teams provides accurate cover measurements and generally is a feasible approach for small acreages. However, ground-based crews may lack the mobility to observe large areas adequately in a timely manner. Thus, alternative methods of acquiring ground cover measurements, such as low-altitude photography and high-altitude ERTS and SKYLAB photography, merit consideration. By correlation of ground cover measurements obtained in this manner with reflectance and emission signatures of crops on the photographic and multispectral imagery, a definitive approach to the use of the imagery characteristics to estimate crop vigor and yield potential can be established. This study compares estimates of per cent ground cover made by ground observers with independent estimates made by examining low-altitude aerial photographs of the same fields in order to determine the adequacy of using imagery for estimating ground cover.

Foresters have developed methods to determine tree heights, crown diameters,

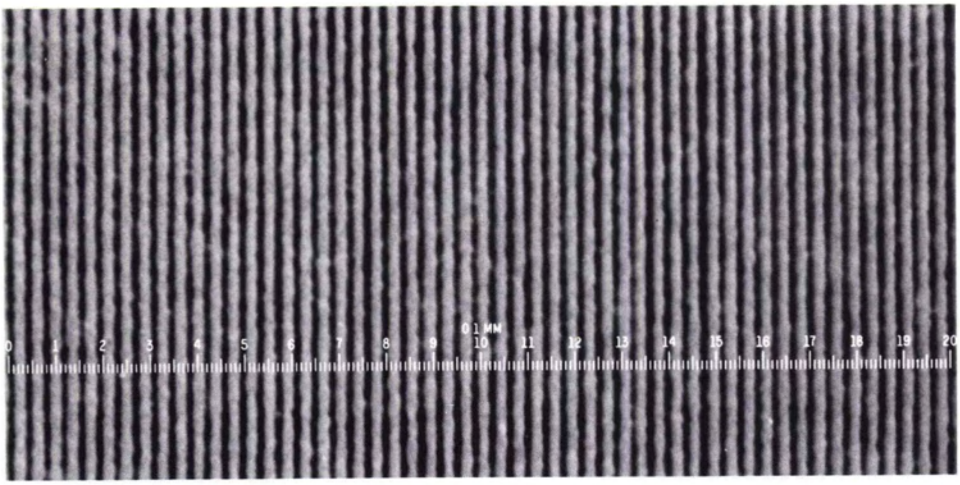

FIG. 1. Cotton is used to illustrate appearance of crops through Bausch and Lomb Zoom 70 magnifier for estimating per cent ground cover from aerial photographs. The black-and-white print in the illustration is an enlarged negative print from the original color infrared transparency.

number of crowns, tree densities, and stand volumes from aerial photographs (Spurr, 1960). Aldred and Hall (1975) developed a method whereby the aforementioned parameters, when determined from random samples, can be used in a model to automatically produce forest inventories. Morris (1970) developed a method whereby number of logs within and depth of forest slash can be determined from low-altitude aerial photographs.

Thomas *et al.* (1966) found that plant height and per cent cover for cotton were highly correlated with film optical density of color infrared aerial photographs. Unni *et al.* (1974) found that a direct relationship existed between number of fields (crops) correctly identified on aerial photography and percent vegetative cover. Hoffer *et al.* (1966) found a high correlation between per cent vegetative cover and signal strength detected by a remote sensor.

MATERIALS AND METHODS

PHOTOGRAPHY

Missions were flown near Weslaco, Texas, over six flight lines, totaling approximately 64 km, on April 13, May 13, June 6, and July 9, 1969, at altitudes of 640, 488-640, 610-1067, and 1219 meters AGL, respectively. The flight lines were photographed on each date with a Zeiss RMK A 15/23 camera* containing Kodak Ektachrome Infrared Aero 8443 film, 9-inch format; KLF, 15G, CC 30 M filters were used.

*Mention of product names is for the convenience of the reader and does not imply endorsement of or preference for such products by the USDA over others that might be available.

GROUND SURVEY

Observations were made within three days of the flight dates at sites about 15 meters into crop stands from borders, adjacent to paved roads. The observations recorded included crop identity, per cent crop cover, plant height, stage of maturity, row spacing, row orientation, type of tillage, soil surface moisture condition (wet or dry) and any symptoms of nutrient deficiency or disease that might affect the response of airborne sensors. Among 537 field sites observed, the crop type and number of fields of each were, respectively: cantaloupe, 15; citrus, 84; corn, 62; cotton, 182; forage sorghum, 16; grain sorghum, 167; and onion, 11.

The procedure used to determine the per cent of ground covered by the plant canopies depended on whether the crop plants produced a solid canopy (bare soil exposed only in the inter-row area) or an open canopy (bare soil visible through the canopy as well as in the inter-row area). For solid canopy crops, such as cotton and thick stands of corn and sorghum, the bare soil width (*BW*) and row spacing (*RS*) were measured in cm. Bare soil width (*BW*) is the distance between the leaf canopies of adjacent crop rows, and *RS* is the average distance between mid-point of adjacent rows. For the solid canopy the per cent crop cover was calculated from these measurements using

$$\left(\frac{RS - BW}{RS}\right) 100 = \quad \% \text{ cover} \qquad (1)$$

For open canopy crops such as onion, immature cantaloupe, and sparse population corn and sorghum, the above formula was also used to first determine a preliminary calculation of per cent cover. Then a visual estimate was made of the per cent open spaces in the leaf canopy by looking downward on them and this percentage was subtracted from the formula calculation to obtain an estimate of actual cover.

In fields with apparent uniform ground cover conditions, observation sites were selected at random. In fields with obvious nonuniform ground covers, measurements were made of each major cover condition.

FILM ANALYSIS

For the photographic determination of per cent ground cover, the same general areas used for ground observations were located on the transparencies. Measurements of *BW* and *RS* were made on the transparencies using a Bausch and Lomb micrometer and zoom 70 Power Pod with single aperature 2× lens and 0.7 and 3.0 magnifications mounted on a Richards light table Model MM221100. Figure 1 shows the image for a cotton canopy as viewed through the Power Pod. The per cent covers of the solid canopies were calculated by Equation 1. For open canopies an estimate of the percentage of soil background visible through the plant canopy was made, and the solid canopy calculation was reduced by that amount as had been done in the case of the direct ground observations.

The photographic estimates of ground cover were made by a single observer, different from the ground observers, and without knowledge of their data. To check the accuracy and consistency of the photographic observer's measurements, some photographs were selected at random and examined by another individual; the ground cover estimates by the two observers agreed within ±3 per cent.

Standard statistical simple correlation and linear regression analyses of the paired corresponding observations of ground and transparency estimates of ground cover were made.

Results and Discussion

The simple correlation of the photographic and ground observer estimates of per cent ground cover for cotton and grain sorghum, and the best fit linear regression lines, are presented in Figure 2. Points that were superimposed are displayed only once in the figure. The high correlation coefficients for both cotton and grain sorghum suggest a best linear fit was very close to a 1:1 line and, thus, statistically both methods gave the same estimates. Individual pairs, however, deviated considerably in some cases. Experience in this study indicated that there is a tendency to overestimate per cent ground cover on aerial photographs for corn, grain sorghum, and forage sorghum because the magenta color appears solid on the film when there are actually openings in the plant canopy. These plants typically display their long curved leaves in umbrella fashion with the broadest part of the leaf canopy near the top of the plant.

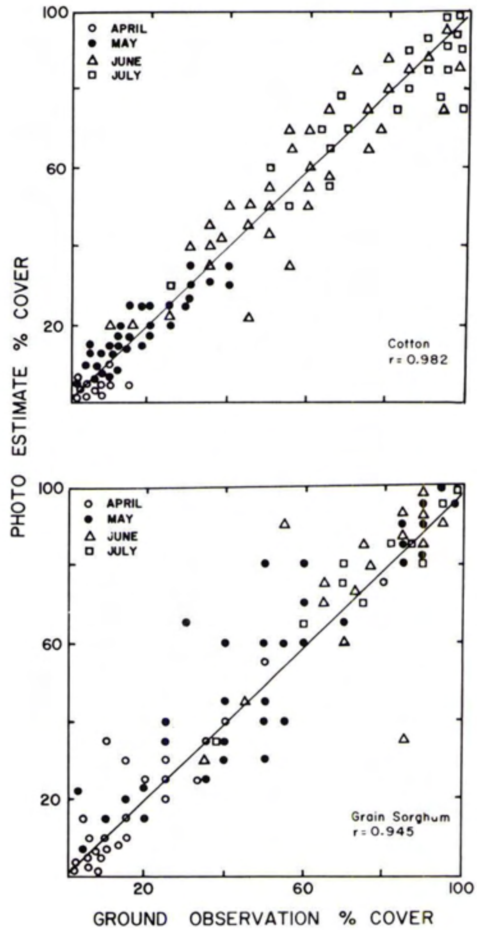

FIG. 2. The correlation of per cent ground cover by cotton and grain sorghum from ground observations with photographic estimates of per cent ground cover for four sampling dates.

Cotton plants, on the other hand, grow in a form with the leaves near the base of the plants extending furthest from the central stem and upper leaves cast shadows on lower level foliage (Gerbermann *et al.*, 1970); the shadows reduce foliage reflectance and give the appearance on film of less than 100 percent ground cover even though the lower leaves on the plants from adjacent rows are touching or interpenetrating. An understanding of plant geometry, therefore, aids in photographic interpretation. The simple correlations, r, of 0.982 and 0.945 between photographic and ground observer estimates of plant cover for cotton and grain sorghum indicate that despite differences in growth habit, reliable photographic estimates of ground cover can be made.

The data for cantaloupe, citrus, corn, and onion are displayed in Figure 3. Data for forage sorghum are not displayed since they are very similar to that of grain sorghum. Onion has an open canopy as viewed from above even when closely planted because of the few tubular and erect leaves it possesses. It is a fall-planted crop in South Texas and thus had reached its near-maximum growth in April when this study was initiated. Hence, the range of ground cover estimates for onion in Figure 3 largely represents differences in plant population. The simple correlation between the two ground cover estimates for onion is relatively low at 0.805 which reflects the difficulty of estimating the ground cover of this crop either photographically or by ground observation.

The photointerpreter can more easily determine the per cent cover of citrus than the ground observer since his result can integrate many trees whereas the ground observer gets only a partial view of the orchard at any one time. The ground observer can make estimates at several locations in an orchard but that is time consuming.

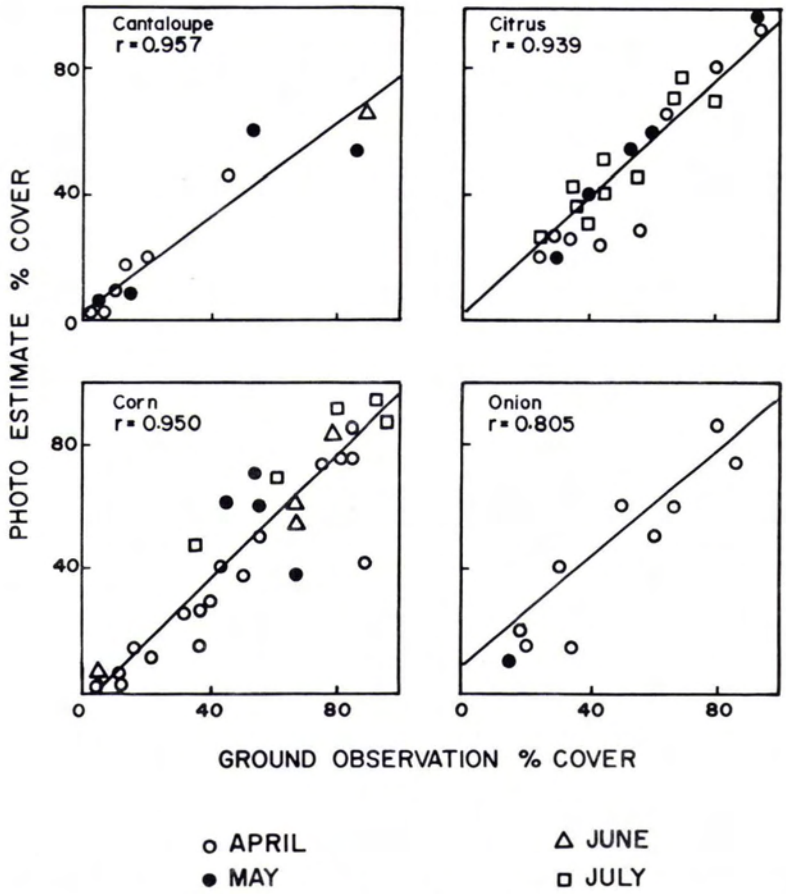

FIG. 3. The correlation of per cent ground cover by cantaloupe, citrus, corn, and onion from aerial photographs and ground observations.

TABLE 1. LINEAR EQUATIONS EXPRESSING PER CENT GROUND COVER (*GC*) IN TERMS OF THE PHOTOGRAPHIC ESTIMATE (*PE*) FOR SEVEN CROPS ALONG WITH STANDARD ERROR OF THE GROUND COVER ESTIMATE, s_{GC}; THE STANDARD ERROR OF THE SLOPE, $s_{b_{GC \cdot PE}}$; THE CORRELATION COEFFICIENT r, AND THE COEFFICIENT OF DETERMINATION r^2.

Crop	Equation	s_{GC}	$s_{b_{GC \cdot PE}}$	r	r^2
Cantaloupe	$GC = -0.814 + 1.217$ (PE)	± 9.10	0.102	0.958	0.917
Citrus	$GC = 4.710 + 0.956$ (PE)	6.60	0.039	0.935	0.874
Corn	$GC = 8.593 + 0.903$ (PE)	9.74	0.038	0.951	0.904
Cotton	$GC = -0.347 + 1.024$ (PE)	7.33	0.015	0.982	0.964
Forage sorghum	$GC = 6.561 + 0.967$ (PE)	10.72	0.079	0.956	0.913
Grain sorghum	$GC = 1.518 + 0.931$ (PE)	11.32	0.025	0.945	0.893
Onion	$GC = 8.205 + 0.760$ (PE)	17.33	0.186	0.807	0.651

Cantaloupe is a vine crop that differs in growth habit from all the other crops studied. The correlation of 0.957 is very satisfactory but the data included only four fields of greater than 40 per cent ground cover. In May and June, the cantaloupe were at harvest stage and some of the older leaves on the vines had already died. Thus some disagreement can be expected between the ground observer, who tends to distinguish between live and dead vegetation in making his estimate, and the photointerpreter, who bases his estimate on the magenta image of the live vegetation and ignores the greenish image for bare soil and dead vegetation.

The difficulty in estimating the ground cover of row crops increased as the altitude of the flights increased because of film resolution restrictions or the need for higher magnifications of the image to distinguish inter-row bare areas from the vegetation of the crop rows. The flights of this study were made at altitudes of 488, 610, 640, 762, 1,067, and 1,219 meters. Use of the micrometer and the magnification of the stereoscope enabled ground cover estimates to be made from all photographic altitudes.

In Figures 2 and 3, the photographic estimates of ground cover are presented as the dependent variable because the traditional ground observations served as the standard against which to judge those estimates. The high correlations obtained indicate that photographic estimates of ground cover can be used to replace the tedious and time consuming observations made by ground survey teams. To this end, linear regression equations of the lines in the figures are presented for each crop in Table 1, along with the standard error of the ground cover estimate, s_{GC}; the standard error of the slope, $s_{b_{GC \cdot PE}}$; the correlation coefficient r, and the coefficient of determination r^2. Except for onion, the standard errors of the ground cover estimate are 11 per cent or less, and r^2 values indicate that between 87 and 96 per cent of the variation in ground cover estimates are explained by the photographic estimates. Thus the regression equation can be used for satisfactorily predicting percent ground cover (*GC*) from the photographic estimates (*PE*).

The equations of Table 1 show that the intercepts of the regression line on the *GC* axis vary from −0.8 per cent to +8.6 per cent and the slopes expressed by the coefficients of *PE* in the equations are, except for cantaloupe and onion, within 0.10 of unity. Thus, except for onion, the ground cover can be estimated within 10 per cent from the photographic estimates.

Ground observers tend to overestimate the per cent ground cover as ground cover approaches 100 per cent. It is also difficult for the ground observer to estimate the ground cover of tall vegetation, such as mature corn, that he cannot look down upon. In such cases the estimates from aerial photographs should be more accurate than ground observations.

In summary, results of this study indicate that low-altitude aerial photography, 488 to 1,219 m, can be used to provide reliable estimates of row crop ground cover. Such information is needed to relate signals from aerial cameras and other remote sensors to the stage of development, help establish spectral categories for vegetation, separate signals for vegetation from those of the soil background, judge the vigor of crops, and indicate plant stresses. The extensive and rapid coverage capabilities of aircraft makes the estimation of ground cover from aerial photography attractive for very large areas (e.g., 25,900 square kilometers), for correlations with reflectance and film density patterns on ERTS-1 and SKYLAB imagery.

ACKNOWLEDGMENT

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