Estimating conservation tillage residue using aerial photography

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ABSTRACT: A new, inexpensive aerial photointerpretation technique for estimating the percentage of grain straw residue cover on field surfaces uses low-altitude, large-scale, small-format photography in conjunction with 35mm projectors and a modified light table. The 35mm reference and test frames represent subareas of fall-planted fields, which vary in previous year's residue cover, soil color, and soil texture. Ground data collected include line transects for estimating the cover percentage. Two film types, natural color and color-infrared, were acquired in 70mm film at two scales (1:4,000 and 1:12,000), then reframed in 35mm mounts for independent testing by interpreters with varying experience. Based on four residue cover classes, the 1:12,000-scale, color-infrared photographs, with an average correct value of 70.7%, were significantly better (P=0.05) than the other film types and scales. Based on two residue cover classes (<30 percent, ≥30 percent), the 1:12,000-scale, color-infrared photos again produced the highest overall correct value (91%), but the value was not significantly different from the 1:12,000 color (88.3%) or the 1:4,000 color-infrared (88.3%) photos. This method of estimating straw residue cover percentage shows promise in monitoring conservation tillage and soil exposed to rainfall erosion. The method could also substantially reduce the field time needed to ensure compliance of agricultural conservation practices in U.S. Department of Agriculture cost-sharing programs.

CALIFORNIA'S Central Coast region has been that state's leading dryland grain-producing area since the 1880s. Typically, wheat and barley are planted each year in coastal areas, and a grain-summer fallow rotation is practiced inland. The frequent diskings, used in summer-fallow to limit moisture loss to weeds, maximize the soil's susceptibility to erosion by rain and wind.

Most dryland farming in this region is practiced on uplifted sedimentary terraces and uplands with slopes up to 35%. Highly erodible soils on these steep slopes, when subjected to short, intensive rains, result in predicted annual soil losses of nearly 100 tons/acre in years with above-average rainfall (*3*).

Because of the soil's high susceptibility to erosion and the increasing cost of conventional farming techniques, conservation tillage practices are achieving acceptance. To gain experience in conservation tillage, Central Coast farmers have been working collectively with the Upper Salinas-Las Tablas Resource Conservation District, Soil Conservation Service, Agriculture Stabilization and Conservation Service and the local ASCS county committee, University of California Cooperative Extension Service, and county agricultural commissioners.

In 1980 the ASCS county committee expanded its cost-sharing program in San Luis Obispo County to include conservation tillage in Agricultural Conservation Program practices. As specified by the local ASCS committee, program participants receive payments in proportion to the residual straw cover after planting (*7*). Maximum payment is for 30% cover.

SCS is responsible for monitoring compliance with program specifications. About 17,000 acres (7,000 hectares) are cultivated under this program, most of which are scattered over the 400,000 acres (166,000 hectares) of dryland grain in San Luis Obispo and Monterey Counties (Figure 1). Seasonal monitoring of these isolated fields is time-consuming because of their inaccessibility and disbursed nature.

Study methods

Interpreting large-scale, inexpensive, small-format aerial photographs is one method to ensure compliance by participants. To reduce field staff time, the tillage monitoring system must be reliable, low cost, and simple. Here we report on a 1984-1985 trial conducted to determine the feasibility of using an aerial photographic-based monitoring system to estimate the percentage of the land surface covered by straw residue.

The decision to use a small-format camera system instead of a 9-inch-square metric mapping camera was based on several factors: (1) small-format photography is relatively inexpensive; (2) the sampling nature of the study only required coverage of selected fields; and (3) image sharpness is more important than geometric fidelity in making ocular cover estimates. Two photographic scales were selected as reasonable for compliance monitoring. The film type was an unknown, so both color and color-infrared film were tested. The film/scale combinations were then tested by photointerpretation. Results were analyzed using nonparametric statistical techniques.

Test fields were selected within the study area for diverse cover, soil properties, landform characteristic, and tillage practices characteristic of local grain land. Soils were dry, ranging from Munsel color 2.5Y7/2 to 10YR5/1. Soil textures corresponded to color: the brighter soils were sandy loams and loams, the darker soils were silty clay and clay.

In these fields 48 plots were established by SCS field office personnel. The location of the 48 field plots was determined so that (a) the range of soil color and residue cover would be represented in the photography set and (b) the plots would easily allow for field sampling coincident with the acquisition of the aerial photography.

The aerial photography was acquired on September 20, 1984. The photo mission was scheduled in late September to ensure that fields had been prepared for the upcoming planting season in compliance with ACP rules and that field office personnel would be available for coincident field sampling.

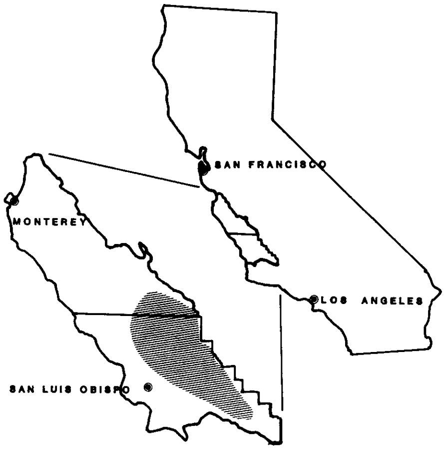

Figure 1. Location of the study area in California and the principal dryland grain production area within San Luis Obispo County.

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Table 1. Specifications of photography used for estimating grain straw residue in the San Luis Obispo County pilot study.

Camera	*Format*	*Focal Length*	*Film Type*	*Exposure*	*Filtration*	*Flying Height (feet above terrain)*	*Photo Scale*
Maurer P2	70mm	3 inch	Kodak Aerochrome MS #2448	1/500 sec. @ f6.7	Ultraviolet	1,000 3,000	1: 4,000 1:12,000
Maurer P2	70mm	3 inch	Kodak Aerochrome Infrared #2443	1/500 sec. @ f8	Wratten 12	1,000 3,000	1: 4,000 1:12,000

The vertical aerial photography was shot with two 70mm reconnaisance cameras—one containing conventional color film, the other color-infrared film. The cameras were flown at 1,000 feet and 3,000 feet above ground level to achieve the two scales of photography required. Table 1 summarizes the specifications of the photography used in our study (William Wildman, personal communication, flight log). The resulting photography was good to excellent, depending upon the surface albedo. Areas of greater straw cover exhibited a higher albedo and reduced film quality by overexposure.

Prior to and coincident with the aerial photography, field samples were collected at each of the 48 plots to verify the amount and percentage of straw residue cover. Targets were placed in the fields at each plot. The targets were biodegradable butcher paper, pre-cut into 10-foot lengths. Each was placed in an "X" pattern with one axis parallel to the flight line direction (north) and secured in place with soil clods. In a 3.7-acre (1.5-ha) area surrounding each target, percent residue cover was estimated using a line transect (bead-string) method (*4*, *8*). One cover estimate was made within 8 meters of the target center, and four were made 60 meters from the target along the direction of each axis. Data recorded at each site included percent cover, soil color (dry and moist), slope, aspect, tillage and planting practice, crop type, and residue orientation (flat or erect).

After the aerial photography had been processed to a positive transparency, the plot target was centered in a 35mm slide mount oriented to the north to standardize shadows. Each transparency accommodated only one plot. Ten subset frames of the 48 slides for each film/scale combination were loaded sequentially into a projector carousel as interpretation reference keys. These increments of 10% residue cover provided more than one example for each cover class tested. The mean percent cover was annotated on the lower corner of each transparency for easy reference.

The remaining test slides for each film/scale combination were randomly loaded into a separate projector carousel. The two projectors were placed in a rear projection device to allow an interpreter to view simultaneously and monoscopically a test slide against a reference slide. The original scales on the transparency slides were 1:4,000 and 1:12,000. When the slides were projected onto the back of an opaque viewing screen, the inpretation scales were 1:1,000 and 1:3,000, respectively.

The interpretation tests were administered to seven people with a wide range of interpretation skill, typical of the field sampling staff. There were 38 test frames per film/scale type, resulting in 1,064 interpreter responses. The responses were entered into error matrices by film/scale type for each interpreter (Table 2). The resulting 28 matrices were then aggregated to produce an error matrix based on 266 interpreter responses for each film/scale type.

Percent correct and percent commission errors were calculated for the error matrices as follows: Number of correct interpretation: percent correct = responses for a residue class ÷ total number for the residue class × 100. Number of incorrect interpretation: percent commission error = responses for a residue class ÷ total number of that residue class indicated by the interpreter(s) × 100.

In addition, for each matrix a Kappa statistic was calculated as follows:

$$\text{Kappa} = \frac{\Sigma\ \text{Diagonal}/N^2 - \Sigma\ (\text{row total x column total})/N^2}{1 - \Sigma(\text{row total x column total})/N^2}$$

where N = the total number of responses within the matrix.

The Kappa statistic, which is a nonparametric measure of agreement between ground truth and photointerpretation responses, was used to rank the individual and aggregated error matrices. The rankings were considered to be significantly different or not based on the values calculated by the following relationship:

$$Z \sim \text{Delta Kappa} = \frac{[\text{Kappa}_{(i)} - \text{Kappa}_{(j)}]}{[\text{Variance Kappa}_{(i)} + \text{Variance Kappa}_{(j)}]^{1/2}}$$

where i and j denote comparable matrices.

If the Delta Kappa calculated between

Table 2. An error matrix as constructed for 1:12,000, color-infrared photography, based on a pool of seven interpreters and four straw cover classes, and the manner in which the percent correct, percent commission error, and Kappa values are calculated.

Interpreted Results		*Field Data* 1	2	3	4	*Total*	*Percent Commission Error*
1	0-19%	38	18	1	0	57	33
2	20-29%	13	25	11	1	50	50
3	30-59%	5	6	9	23	43	79
4	60-100%	0	0	0	116	116	0
Total		56	49	21	140		
Percent Correct		68	51	43	83		

Total points = 266, Total correct = 188, Percent correct = 70.7, estimated Kappa = .567.

Table 3. Summary of film/scale type combination rankings from the San Luis Obispo photointerpretation tests.

a. Based on *four* residue cover classes: 0-19%, 20-29%, 30-59%, and 60-100%.

Rank	*Film/Scale Type*	*Kappa and Significance**	*Percent Correct* *Mean*	*Range*
1	1:12,000 cir	.567	70.7	55.3-81.6
2	1:12,000 color	.442	61.3	52.6-71.1
3	1: 4,000 cir	.429	60.2	52.6-71.1
4	1: 4,000 color	.429	59.8	50.0-71.1

b. Based on *two* residue cover classes: 0-29% and 30-100%.

Rank	*Film/Scale Type*	*Kappa and Significance**	*Percent Correct* *Mean*	*Range*
1	1:12,000 cir	.812	91.0	78.9-97.4
2	1: 4,000 cir	.761	88.3	81.6-97.4
3	1:12,000 color	.760	88.3	78.9-97.4
4	1: 4,000 color	.686	85.0	78.9-92.1

*Lines to the right of the ranked Kappa values join those film/scale combinations that are not significantly different at the 95% confidence level.

two matrices exceeded 1.96, we concluded that the Kappa values were significantly different at the 95% confidence level (as in a two-tailed F-test). If the calculated value was less than 1.96, we concluded that the Kappa values were not significantly different and the film/scale combinations represented by those matrices were equally interpretable. Table 2 provides an example of these calculations; a complete description of them can be found in the published literature (*1*, *2*).

Results and discussion

For each field plot, the mean percent cover was calculated from five replications per plot. To maximize the number of classes with the available frames and assure a 30% cover separation, the test was structured in four residue cover classes: 0-19%, 20-29%, 30-59%, and 60-100%.

The interpretation test results of the four film/scale combinations were based on the four residue cover classes (Table 3a). Based on the Kappa statistic, the 1:12,000 scale, color-infrared aerial photography was the most interpretable product, having the highest overall percent-correct (70.7%) values and lowest commission error in each of the four residue cover classes. The remaining three film/scale combinations tested had lower overall percent-correct values and higher commission errors. In most cases interpretation errors were misclassifying a field plot by one residue cover class interval. Seldom did an interpreter misclassify a field plot by two or more class intervals. In general, interpreters tended to underestimate the percentage of residue cover when the actual percentage was < 30% and overestimate the percentage of residue cover when the actual percentage was ≥ 30%.

Because the maximum payment for compliance under ACP is 30% residue cover, the four residue cover class statistics were aggregated into a two-residue cover class structure (<30% and ≥30%). Table 3b shows the ranked film/scale combinations. Assuming the results would have been similar to interpretating within a two-class test structure, the overall percent-correct values were significantly higher for all film/scale combinations. Again, the 1:12,000-scale, color-infrared photographs had the highest overall percent correct (91%) and the lowest commission errors for both classes in comparison to the other three film/scale combinations.

In a Kappa analysis by soil color for the two cover classes, dark soil (5 or less dry in Munsell color value) was interpreted significantly better when using the smaller scales for color infrared and color and the larger scale for color-infrared combinations. Soil tone was not an overwhelming parameter. In analyzing the four cover classes, the rankings of the soil tone were well mixed in film and scale combinations.

Overall, the most interpretable film/scale type combination was the 1:12,000-scale, color-infrared photography. In nearly all residue classes the smaller scale photography performed significantly better than large-scale photography, independent of film type. We believe the smaller scale photography provided a better synoptic view of the field, surface illumination conditions, distribution of residue cover, and natural soil tone variations.

In this trial the color-infrared photography was superior to the natural color photography at both scales. The consensus was that color-infrared photography provided higher contrast between residue cover and the similar tones of exposed soil than the natural color photography. At these scales individual straws were not identifiable; therefore, interpreters had to judge the amount of cover by tonal surface changes.

Conclusions

To establish compliance with conservation tillage programs, this approach, combined with a subset of field plot data for calibration and training, should provide a viable alternative to conventional ground surveys. A majority of fields, especially those greatly exceeding 30% cover, do not require field visits. Further investigation is planned to implement this system using 35mm film and verifying its accuracy under operational conditions.

In estimating the percentage of residue cover in the Central Coast dryland grain area of California, 1:12,000-scale, color-infrared, vertical aerial photography provided that most interpretable product tested. For other areas, however, the photo specifications may be very different. For example, in this study area there was an even mix of both dark and light soils. Apparently, soil color had no influence on the outcome of the film/scale combination comparisons.

If an area to be monitored differs considerably from our study area, we recommend a pilot test using similar methods. The test should be used to modify photo specifications to meet local conditions of soil color, topography, and agricultural practices. In addition, we recommend, as do others (*1*, *2*, *6*), that test results be analyzed using the Kappa statistic of agreement. We found that this statistical procedure was easy to implement and interpret, and it provided the information needed in our search for an appropriate film-scale combination.

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