

BIOGRAPHICAL SKETCH

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THE USE OF SMALL SCALE AERIAL PHOTOGRAPHY

IN A REGIONAL AGRICULTURAL SURVEY

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INTRODUCTION

During the past year and a half, Maricopa County, Arizona has been the site of extensive NASA-sponsored research designed to investigate the potential usefulness of small-scale aerial and space photography in the inventory and evaluation of agricultural crops. Early in these investigations it became apparent that in order to fully assess the operational value of such photography, a regional approach to the research would be necessary.

One of the primary advantages of using small scale aerial or space photography is that it affords a synoptic view of the earth's surface (i.e., large areas of land can be seen in their entirety on one or a very few images), suggesting a particular potential usefulness for conducting broad regional resource analyses. Furthermore, few actual resource inventories as presently undertaken limit themselves to a small area, but rather are usually geared to larger managerial or policy-formulation units such as entire watersheds, counties or states. Thus, most remote sensing surveys, when performed operationally, would probably also be geared to fairly large areas so as to provide maximum utility to the ultimate user. Finally, while the development of remote sensing techniques on small test sites is often quite useful, especially in the early experimental stage, findings of limited tests often cannot be directly applied to the larger operational case. In addition to the obvious problems stemming from increased interpreter fatigue and data handling requirements when large areas are the subject of surveys, the phenomenon of environmental variability often becomes a major factor to be dealt with in the design of information extraction techniques.

For these reasons, it seemed that one of the most meaningful experiments which could be performed with the imagery described above would be to attempt to make an agricultural survey, for Maricopa County as a whole. By so doing, an attempt could be made to answer questions which would arise only in such a semi-operational survey and which must be solved before the full benefits which might accrue from the use of high altitude or space photography can be realized. In addition, it was hoped that such a study might provide some clues as to the procedures to be followed in evaluating synoptic imagery which will become available from the Earth Resources Technology Satellites, ERTS-A and ERTS-B, due to be launched in early 1972 and 1973, respectively, and the manned Sky Laboratory, scheduled for launch in 1973.

While certainly any number of the varied resources of Maricopa County

could be the subject of such a survey, none are more important or more amenable to the application of remote sensing techniques than agricultural crops. According to recent records, over 10 percent of the land in Maricopa County is under cultivation. The county provides roughly half of Arizona's agricultural crop production, and ranks third among all U.S. counties in gross value of such products. In addition, many of the crops grown contribute directly to the livestock and cattle feeding industry, in which Arizona ranks eighth nationally. The nature of agricultural cropland makes it especially well suited to such a study. By and large such land consists of discrete fields, each of which contains a fairly uniform stand of a particular type of vegetation that may vary quite rapidly in its phenological characteristics through a seasonal cycle. This characteristic presents an excellent opportunity for the development of techniques which could be quite valuable in their own right, and which hopefully could contribute to methods applicable to more variable wildland vegetation types. Finally, a very real need exists at the present time for inexpensive, accurate and up-to-date inventories of agricultural crops, as is evidenced by the extensive program carried out by the Statistical Reporting Service of the U.S. Department of Agriculture in cooperation with various state and county organizations.

PRELIMINARY TESTS

As has been described earlier (Lauer: Testing Multiband and Multidate Photography for Crop Identification), numerous photo interpretation tests were conducted on a 16-square-mile area within Maricopa County. These tests were intended to determine the relative value of small scale aerial photography and Apollo 9 space photography for the inventory of crops, and to evaluate the usefulness of multidate and multiband photography for these surveys.

These tests suggested that, at least for agricultural surveys in the area under study, no significant differences in identification accuracy resulted from the use of Apollo 9 and high altitude aerial photography. In addition, they emphasized the importance of the selection of specific dates for the inventory of particular crops, and the necessity for an understanding of the seasonal development of crops in a region prior to specification of optimum dates for obtaining photography.

Following these tests, a decision was made to perform the planned semi-operational survey for barley and wheat. This decision was based on the following factors: (1) small grains (of which barley and wheat are the only major varieties in Maricopa County) account for approximately 20% of the crop acreage in Maricopa County and thus are important crops for which agricultural statistics are currently prepared using conventional techniques, (2) these crops mature and are harvested within the first half of the calendar year, coincident with the time period for which monthly NASA aircraft missions were scheduled during 1970 and, (3) our previous results indicated that the highest percentage correct identification of any crop was achieved for barley (90% using Infrared Ektachrome photos and 91% using Pan-25 photos) by selecting the appropriate month (May) for conducting the test. For these reasons, it was felt that a survey for barley and wheat would provide the greatest opportunity for initial success using a previously untried technique.

Final preliminary tests were then conducted to determine the specific date or dates of photography and film/filter combinations which were optimum for the identification of barley and wheat. The results of these tests indicated that Ektachrome MS (2448) photography taken in the months of May and June should be used for the semi-operational survey.

DEVELOPMENT OF THE SEMI-OPERATIONAL SURVEY

Attempting to administer a photo interpretation survey involving an entire county, containing nearly 800-square-miles of agricultural land, immediately presented a number of problems not faced on the 16-square-mile study area. The principal questions raised were: (1) Will a sample provide a satisfactory estimate of crop acreage, or is 100% interpretation required? (2) Will stratification lead to a more accurate estimate? (3) How much ground information will be required for interpreter training and for evaluation of the interpretation? In an attempt to answer several of these questions simultaneously, the agricultural area within the county was delineated into six strata based wholly on their appearance on the Infrared Ektachrome Apollo 9 photo. Thirty-two plots, each consisting of a square, two miles on a side, were allocated to the strata on the basis of proportional area, and plot centers were located randomly (Figure 2). Maps of each plot showing field boundaries were drawn based on their appearance on earlier high-flight photography, and each plot was visited by a field crew at the time of overflights for the months of April, May and June 1970. Information gathered in this manner included the category of crop growing in each field, the condition of the crop, the percent of the ground covered by vegetation, crop height, and the direction of rows, if any.

In order to facilitate access to this information pertaining to each of the more than 2500 fields present in the thirty-two four-square-mile sample plots (comprising a total of more than 80,000 acres), field data were punched on computer cards. Programs were then written which made possible the compilation of data by stratum, cell, crop type, and date, and which provided for subdivisions or consolidations of fields over time. Thus data are available not only for each date of photography, but for the sequential changes in crop type and condition through the growing season as well.

Based on a knowledge of the distribution and variability of crop acreage thus obtained, tests were conducted regarding the value of stratification based on gross appearance on space photography, and the possibility of sampling within the agricultural areas to obtain overall crop acreages for the county. Analyses of variance indicated that no significant differences existed between strata in terms of acreages of major field crops, thus indicating that stratification would not improve acreage estimates. In addition, calculations indicated that the acreage distribution of major crops was so variable that for any plot size, extremely large samples would be necessary in order to assure acreage estimates that would satisfy accuracy requirements. For example, in order to estimate the acreage of wheat with a standard error of $\pm 10\%$ of the total acreage using a plot size of four-square-miles, a 75% sample would be necessary.

Thus, it was decided that the most efficient and realistic method of estimating crop acreage would entail a 100% photo interpretation of the agricultural areas, with ground data being gathered for thirty-two four-square-mile

plots only. In this way photo interpretation results could be compared with the ground conditions on the field plots, and the overall photo interpretation results adjusted as appropriate using standard ratio sampling procedures.

Some problems were also encountered in the development of the method of compilation of photo interpretation data. First of all, in order to make a measure of interpretation accuracy, interpretation findings must be tied to some actual unit of land area. However, the preparation of detailed field boundary maps from small-scale photos by the interpreter, while possible, would constitute an extremely time consuming task. Also, the tabulation of interpretation data on the basis of numbers of fields is not necessarily indicative of accuracy of acreage estimates which in most cases is the item of interest to the ultimate user. Furthermore, to evaluate "number of fields" data, the researcher must assign arbitrary weight to "correct", "omission error" and "commission error" values, a task which in many cases might best be left to the discretion of the ultimate user of the information.

In order to avoid these problems while still collecting data which would be as meaningful as possible, it was decided to require the interpreter merely to grid agricultural areas into regular square-mile cells (thus making possible direct comparisons with ground data on the thirty-two sample plots) and to tabulate estimates of the acreage of barley and wheat in each cell without regard to the specific location of individual fields.

The agricultural areas within Maricopa County were divided into three nearly equal portions, with one interpreter assigned to each area. The interpreters, chosen on the basis of high scores on preliminary tests, were first trained using photos and ground data maps of areas which they would not interpret later. Training included both identification of wheat and barley, and estimation of field acreage. The interpreters were then supplied with Ektachrome photos for May 21 and June 16 (scale 1/120,000) of their test areas, as well as maps indicating township boundaries. Each township (nominally a six-mile square, but not invariably so because of ground survey errors made many years ago) was located on the test photography and interpreted as a unit, section by section. For each section the interpreter recorded total acreage of wheat, barley, and all cropland. (Deductions from cropland included farmhouse-barn complexes, freeways, major canals, and general urban and developed areas, but did not include secondary service roads or local irrigation ditches.) In addition, each interpreter was asked to interpret one township in another interpreter's area, as well as to repeat the interpretation of one township in his own area without reference to his earlier results.

RESULTS

The results of the semi-operational survey were obtained in the following manner:

1. Each interpreter's estimates of acreage of barley, wheat, wheat and barley combined, and total cropland for the sample plots within his area were compared with the actual acreages for each of the plots as determined by on-the-ground surveys.
2. Ratios of actual acreages to interpretation acreages for each category were calculated for each interpreter, and this ratio was used to adjust

the results for the entire area as estimated by each interpreter by the formula

$$\hat{Y}_I = Y_{PI} \times R$$

where

\hat{Y}_I = estimate of total acreage of category within an interpreter's area

Y_{PI} = initial photo interpretation of acreage within an interpreter's area

R = the correction ratio as derived from the sample plots.

3. The category estimates for the three interpreters were summed to form a total county estimate.
4. Sampling errors were calculated for the various category estimates by each interpreter as well as for the overall county estimates in order to give an indication of the accuracy of the crop estimates. In calculating the overall county statistics, each of the three interpreters' areas was handled as an individual stratum.

A summary of the survey results is presented as a percentage figure calculated by:

$$\text{Sampling Error \%} = S_{\hat{Y}} / \hat{Y}$$

where

$S_{\hat{Y}}$ = standard error of the estimated acreage

\hat{Y} = estimated acreage.

A correction ratio greater than 1 indicates that the interpreter underestimated the acreage of that category, while a ratio less than 1 indicates that he overestimated the acreage.

ACREAGE ESTIMATES AND SAMPLING ERROR (Table 1)

CATEGORY	TOTAL ESTIMATE (ACRES)	SAMPLING ERROR
Barley	50,044	11%
Wheat	41,714	13%
Barley and Wheat	92,207	8%
All Cropland	452,000	3%

RATIO CORRECTION FACTORS (Table 2)

INTERPRETER	BARLEY	WHEAT	BARLEY AND WHEAT	ALL CROPLAND
1	1.1225	.9846	1.0481	.9913
2	1.1131	.9012	1.0352	.9809
3	1.1234	.9388	1.0309	1.0094

SAMPLING ERROR OF INTERPRETERS (Table 3)

INTERPRETER	BARLEY	WHEAT	BARLEY AND WHEAT	ALL CROPLAND
1	18%	17%	14%	5%
2	30%	32%	16%	3%
3	14%	21%	11%	6%
TOTAL AREA	11%	13%	8%	3%

INTERPRETATION TIME (Table 4)

INTERPRETER	TRAINING TIME	INTERPRETATION TIME	AVERAGE TIME/TOWNSHIP
1	8 hr. 55 min.	26 hr. 20 min.	1 hr. 20 min.
2	7 hr. 30 min.	13 hr. 40 min.	1 hr. 03 min.
3	6 hr. 30 min.	28 hr. 05 min.	1 hr. 02 min.
TOTAL	22 hr. 55 min.	68 hr. 05 min.	1 hr. 08 min.

The results of greatest interest are, of course, the estimated acreages of each category for the entire county, and their accuracies. In this case, however, there are no reliable statistics gathered in the conventional manner with which to compare these results. While the Statistical Reporting Service does publish monthly estimates of crop acreages for the U.S. as a whole and for individual states, their methods are such that no accurate estimates are available for specific counties until months after the time of harvest, and even then they are much less accurate than the state and national estimates. This, of course, only serves to emphasize the potential value of estimates obtained by means of the methods described here. It is possible, however, to discuss the accuracy of the estimates by reference to calculated measures of statistical reliability derived from the sample data.

The sampling error (standard error of the estimate expressed as a percent of the estimate) for barley was 11% and for wheat was 13%, while the figure for both barley and wheat combined was 8%, indicating that a good deal of error resulted from a confusion of the two small grain crops. This same phenomenon is evident in the correction ratio figures. In general, the interpreters underestimated barley and overestimated wheat, while they were only slightly low in their estimates of the two grains combined. These results indicate that considerable improvement in the measurements could be realized if a more definite differentiation between the two small grains could be made. Nevertheless, the accuracies as shown are quite encouraging, especially considering the rapidity with which they could be compared.

In the table listing the individual interpreter's accuracy levels (Table 3) it can be seen that one of the interpreters had a significantly higher error for both barley and wheat than the other two interpreters, but all three were nearly equal for barley and wheat combined. This indicates that while this one interpreter had more trouble differentiating between the two crops, he did nearly as

well as the others in distinguishing the two small grains from all other field conditions. Furthermore, the large differences in performance point up the importance of screening and training interpreters before undertaking operational surveys. The sampling error could have been significantly reduced if the performance of the one "inaccurate" interpreter had been equal to the other two. Also, all three interpreters indicated that their confidence in their interpretations increased as they progressed through the survey. Certainly any fully operational survey would include considerably more interpreter training than has been undertaken in this study.

CONCLUSION

The stated purpose of the experiment was to investigate the feasibility of performing inventories of agricultural resources using very small scale aerial or space photography. Further, it was hoped that by remaining cognizant at all times of the constraints that would be faced when carrying out an operational survey, findings would be more valuable than those resulting from the more usual limited-area tests.

Certainly the results to date are encouraging on two counts: (1) the questions posed initially are being answered, i.e., the very practical problems of an operational survey are being faced and solutions are being found, and (2) it would seem that a fully operational agricultural inventory using very small-scale photography is not beyond the scope of present technology.

Probably the biggest problems that will be faced in establishing a functional inventory system are those concerning logistics and data handling. For example, it will be necessary to ensure that ground crews are at the proper place at the proper time over widely scattered areas in order to provide calibration data. Imagery must be obtained at specific times to permit differentiation among various crop types, interpretation of large areas must be performed rapidly to ensure that the information is not outdated before it is available; and interpretation results must be compared with calibration data and the necessary adjustments made before distribution.

Finally, data must be provided, not at those times for those geographic units which lend themselves well to the data gathering techniques, but rather at times and for area units which are geared to user requirements as nearly as possible.

However, most of the data handling problems are not much more complex than those faced by government agencies gathering agricultural data by more conventional means at the present time. Furthermore, a number of systems are presently being developed which, it is hoped, will possess a capability to automatically extract image data from aerial or space photographs, perform crop identification functions, combine this information with other parameters keyed to the same geographic coordinate system, and produce graphical or tabular output in a wide variety of desired formats. It appears that such systems would lend themselves particularly well to agricultural surveys wherein nearly all the image interpretation is based on tone or color discrimination (a function much more accurately performed by a machine than a human interpreter) rather than complex deductive decisions. In fact, it is planned that further studies of agricultural inventory method by the Forestry Remote Sensing Laboratory will involve an

investigation of the extent to which automatic image interpretation and data handling methods can contribute to operational surveys of the type described in this paper.

LITERATURE CITED

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Figure 1: This enlargement of Apollo 9 Infrared Ektachrome frame AS9-26-3801 shows the Maricopa County test site where the agricultural inventory was performed. The city of Phoenix appears in the right center, surrounded by extensive agricultural lands and wild areas valuable as rangeland and watershed.



Figure 2: This black-and-white enlargement of an Apollo 9 space photo shows the portion of Maricopa County containing agricultural lands, and for which the semi-operational survey was performed. The location of each of the 32 4-square-mile plots selected for ground survey at the time of each NASA overflight is as indicated.