A SEMI-OPERATIONAL AGRICULTURAL INVENTORY USING SMALL-SCALE AERIAL PHOTOGRAPHY

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INTRODUCTION

The photographic experiment performed by the Apollo 9 astronauts in March, 1969 provided the scientific community for the first time with high quality multiband space photography. These photos were obtained specifically for the purpose of developing improved capabilities for the inventory and evaluation of earth resources. One of the principal test sites for this experiment is Maricopa County, Arizona, chosen on the basis of its geographic location (proximity to existing remote sensing research centers and low latitude, which made vertical photography possible from the spacecraft), and the presence of numerous earth resources presenting intriguing possibilities for evaluation on small-scale imagery. The test site contains the urban complex comprising the city of Phoenix, extensive agricultural lands, and varied semi-arid desert and mountainous regions valuable as rangeland and watershed areas (see Figure 1).

In addition to the Apollo 9 photography, the site has been the subject of regular high altitude (60,000-70,000 feet flight altitude) multispectral aerial photographic missions made possible through the NASA Earth Resources Survey Program (Tables 1 and 2). These missions, the first of which coincided with the Apollo 9 experiment, have been flown at approximately monthly intervals during the ensuing year and a half.

It became apparent at the outset of the experiment that the nature of the photography which would be available -- i.e., broad aerial coverage on very small scale photos at regular intervals through a variety of seasonal conditions --

would make possible and, in fact, almost demand a regional-operational approach to the research. 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 a survey of a particular resource 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. Thus it was decided that, at least initially, research efforts would be concentrated on the agricultural resources of the county.

PRELIMINARY TESTS

Detailed field studies were begun in two areas south of Mesa, Arizona in March, 1969 at the time of the Apollo 9 overflight. A 16 square-mile area containing more than 125 individual fields was chosen as the primary study area. This site was chosen because (1) it was contiguous, (2) it was easy to reach for gathering crop data on a field-by-field basis, (3) it contained many of the important crop types found in the Phoenix area, and (4) it was imaged clearly on the Apollo 9 imagery as well as on most of the photos taken during subsequent aircraft missions. Additional data were also gathered during 1969 for another area of some 22 square miles (more than 250 fields) located in the same general region.

These two areas, totaling over 24,000 acres of agricultural land, were monitored at the time of each photo mission so that distribution and variability of crop type, crop development patterns, and crop signature could be adequately assessed. Coincident with each aircraft mission, each field was visited on the ground and notes were collected regarding crop type, condition, height of stand, and approximate percentage of ground cover.

An interpretation test was devised to establish whether crop type could be determined with greater accuracy using small scale Nikon aircraft photography than with Apollo 9 Hasselblad space photography. It was determined that overall interpretation results for crop identification were quite similar for both types of photographs (Carneggie, et al., 1969). Although the resolution of the high altitude photographs was greater than that of the space photographs of the same area, the improvement was not sufficient to permit detection of image detail which is necessary for increased accuracy of crop identification. For this reason, it is believed that valid inferences regarding the interpretation of crop type on space photography of Apollo 9 quality can be drawn from the conclusions based on studies of high altitude <u>aircraft</u> photography.

The most serious limitation to developing useful crop identification techniques lies in the variability of crop type and cropping practices. Any factor which affects the distribution, development and vigor of a crop will affect its photographic signature, and thus may influence the success with which that crop can be consistently identified. Thus some <u>a priori</u> knowledge or assumptions regarding these factors is necessary before practical interpretation techniques can be developed. Our conclusions regarding these factors were as follows:

1. Crop type and distribution. It is generally true that agricultural practices in an area are relatively stable and that totally foreign crops are rarely introduced. For this reason, interpretation keys can be devised for particular crops in a specific area with little fear that certain crops will totally disappear or that new crops will suddenly be introduced in large number. These generalizations were found to be valid for the main crops grown in Arizona during a recent 4-year period.

2. Seasonal development. Documentation of the seasonal development of crops is important for determination of optimum times of the year for crop type discrimination. Both within-season and between-season variability will affect the specification of optimum dates for obtaining photography. Knowledge of crop sequences and of the variations which affect these sequences must be understood. For agricultural areas, the cyclic changes and the approximate dates when they occur are best summarized in a table or chart known as a "crop calendar." Tone values of individual fields (as seen on photographs of a given date) can be related to the stage of maturity of the crops on that date, as summarized in the crop calendar. The calendar can then be used to determine either (1) at what single date a particular crop type has a unique signature that could be discriminated from signatures of all other crops, or (2) what combination of dates for sequential photography would best permit identification of that crop type.

3. Crop signature. Since little field detail is discernible at the scale and resolution of the high altitude Nikon photographs which were studied during 1969, Photographic tone or color became the critical factor for identification. Either unique spectral signatures must exist at one date so that

individual crop type can be identified, or else sequential patterns of tone or color must exist such that crop type can be distinguished on the basis of changing patterns (i.e., bare soil to continuous cover crop to bare soil) at particular dates throughout the year.

Interpretation tests were administered to determine the value of multidate and multiband photography obtained during 1969 for crop identification. The following conclusions are suggested by the results of these tests: (1) similar results were obtained from Apollo 9 and high altitude photographs, (2) better results were generally obtained from Infrared Ektachrome photos than from Panchromatic-25 photos, (3) improvement in percent correct identification resulted from the selection of specific date(s) for particular crops (e.g., May for identifying barley), and (4) the concurrent identification of crop types using March 12, April 23 and May 21 Infrared Ektachrome photographs produced the most substantial improvement in overall identification.

DEVELOPMENT OF THE SEMI-OPERATIONAL SURVEY

A. Determination of Film-Filter Combinations

As discussed earlier, and based on the above results, it was decided that a semi-operational countywide inventory of one or more particular crops would provide the most logical extension of the techniques initially developed for only one small portion of Maricopa County. The decision to perform this survey for barley and wheat was made for the following reasons: (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. Plans for similar surveys for the other major crops will be undertaken in the future when the technique has been refined.

Previous studies of multiband high altitude Nikon aerial photographs of the Phoenix area (Carneggie, et al., 1969; Pettinger, et al., 1969) indicated that, of the 1969 photo dates available (March 12, April 23 and May 21), May photographs were best for identifying small grains; also, of the film/filter combinations available -- Infrared Ektachrome (8443)/15, Panatomic-X (3400)/25, Panatomic-X (3400)/58, and Infrared Aerographic (5424)/89B -- Infrared Ektachrome/15 and Panatomic-X/25 produced the best photo interpretation results. The following table summarizes the interpretation results obtained for the identification of barley in the 1969 study which used high altitude photography taken in March, April and May, 1969 (there were not enough wheat fields in the test area to design a valid test for that crop):

PHOTO INTERPRETATION TEST RESULTS FOR BARLEY IDENTIFICATION ON HIGH ALTITUDE PHOTOGRAPHY (1969)[1]

	Panatomic-X/25			Infrared Ektachrome/15		
	March 12	April 23	May 21	March 12	April 23	May 21
Percent Correct	34	31	91	33	57	90
Percent Commission	38	44	3	34	24	6

[1]Carneggie, et al., 1969.

In the table above, percent correct data indicate the percentage of actual barley fields in the test area that were corrently identified by the interpreters. Percent commission data indicate the percentage of the total number of fields identified as barley which were actually some other crop type.

Studies of crop development patterns during early 1970 (data collected from FRSL field surveys and extracted from Arizona Crop and Livestock Reporting Service newsletters) indicated that the small grain crop was developing in a normal manner. Thus general conclusions based on crop calendar information, which indicate that small grains are mature and most easily distinguishable from other crops during the month of May, were held to be applicable for 1970.

Although barley could be consistently identified on May 21, 1970 photos, wheat and alfalfa were sometimes confused. It was discovered that the identity of fields in question usually could be established by noting the appearance of these same fields on June 28, 1970 photos. For this reason, photos taken on May 21 and June 28 were ultimately provided for the survey.

Previous conclusions regarding optimum film type were not totally acceptable in terms of the 1970 survey. In addition to the four film types tested using high altitude photos in 1969, a color film, namely Ektachrome MS (2448), was also available which had not previously been evaluated. Also, the scales of the RC-8 photos (1/120,000) and Hasselblad photos (1/500,000) which were to be used in the survey were different from the Nikon photos (1/950,000) obtained in 1969; the resolution of the 1970 imagery was also improved. Because of these differences, it was felt that a new test should be made, based primarily on May 21, 1970 photos, to determine the optimum film/filter combination for the identification of various types of crops.

The following film/filter combinations were tested:

CAMERA	FILM/FILTER	SCALE
RC-8	Ektachrome MS Aerographic (2448)	1/120,000
RC-8	Infrared Ektachrome (SO117)/15	1/120,000
Hasselblad	Plus-X Aerographic (2402)/25	1/500,000
Hasselblad	Plus-X Aerographic (2402)/58	1/500,000
Hasselblad	Infrared Aerographic (2424)/89B	1/500,000

It was realized at the outset that the scale differences between RC-8 and Hasselblad imagery would probably affect the success with which crop types could be distinguished. However, imagery at these two scales represented all that was available. The scale difference was accepted as another constraint within which the test must be administered.

Fifteen photo interpreters of equal ability were randomly placed in one of five three-man photo interpretation groups. Five four-square mile test plots were chosen from thirty-two sample plots located in the area (Figure 3). The photo interpretation tests were administered so that (1) each interpreter group would interpret each of the five film/filter types, (2) each test plot would be interpreted using each of the five film/filter types, and (3) no interpreter group would interpret a test plot more than once. Thus each plot was interpreted fifteen times for a total of seventy-five photo interpretation tests.

$$5 \text{ Test Plots} \times \frac{5 \text{ F/F Types}}{\text{Test Plot}} \times \frac{1 \text{ Interp. Group}}{\text{F/F Type}} \times \frac{3 \text{ Interpretations}}{\text{Interp. Group}} = 75$$

Four additional plots were chosen which would provide training and reference materials. These plots were selected from different parts of the test site and represented a sample of the variability which would be encountered during the test as well as during the semi-operational survey. These training plots were presented to the interpreters in pairs, so that one plot in each pair could be studied with ground data, for familiarization, and the second could be used as a "practice test" (without reference to ground data for that plot). Each interpreter corrected each of his own practice tests, thus learning where correct and incorrect identifications had been made. In each of the training plots, the identity of the crop type in each field was made known so that the interpreters could determine which other crop types were likely to be mistaken for barley and wheat. It is to be emphasized that all of the interpreters used in

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this experiment were skilled photo interpreters who previously had worked with tests of this type. Hence each of them was asked to study the training material provided and decide for himself which criteria would be used for crop identification.

After each interpreter had trained himself to interpret a particular film/filter combination, he began the interpretation of the test plot assigned to him for that combination (each interpreter examined each of the five test plots on a different film/filter combination). Sample test results appear in Figure 2. That figure also contains (1) photo examples of each of the film/filter combinations, (2) the interpretation results for one of the three interpreters in the group assigned to the Ektachrome image, and (3) the correct identification of the fields in that plot.

For each of the five test plots, a map showing field boundaries was provided. Although a measure of the consistency with which interpreters can estimate field acreage would be needed to evaluate results from the semi-operational survey, it was decided that tests for identification would be separated from tests for acreage estimation. In addition, prior field delineation makes possible more rapid evaluation of crop identification <u>per se</u>, for the interpreter is interested only in identity of fields and not their measurement. Training in these two tasks would be given once the final team of interpreters (only three out of fifteen who took the tests) had been chosen for the semi-operational survey.

In order to ascertain the optimum film/filter combination for inventorying wheat and barley, the results of the tests were analyzed in three ways: (1) mean-of-ratio variance analysis, (2) analysis of variance for % correct, and (3) analysis of variance for % commission error.

<u>Mean-of-Ratio Test</u>: In the actual crop survey, the acreage estimates by the photo interpreters were to be adjusted by using a mean-of-ratio estimator.

This estimator is defined as:

$$R = \frac{\text{actual acreage of wheat (or barley)}}{\text{interpretation acreage estimate for wheat (or barley)}}$$

This estimator is calculated for each of the thirty-two sample plots, the mean of the ratios calculated, and the acreage estimation for the entire survey area adjusted by multiplying by this mean. The optimum film/filter type, therefore, is that in which the variance of ratios is lowest, (e.g., if the interpreter consistently interprets 60% correct, the adjusted total will be more accurate than if he fluctuates between 70% and 90%.

Variances of the ratios using each of the five film/filter types under consideration were tested at the 95% level of significance. No differences were found between the ratio variances for barley. For wheat, however, Ektachrome, Pan-25, and Pan-58 constituted a homogeneous sub-group of low variance, with Infrared Ektachrome and Infrared-89B showing significantly higher variances. Thus, either Ektachrome, Pan-25 or Pan-58 would be optimum for the operational survey under this criterion.

% Correct and % Commission Error Analyses: Analyses of variance were run to ascertain whether there were differences (at the 95% level of significance) between the film/filter types in terms of % correct acreage and % commission error. If significant differences were found, the types were to be ranked using the New Duncan's Multiple Range Test.

The film/filter types proved to be different in terms of both % correct and % commission error for both barley and wheat, and hence were ranked. The results are illustrated below. Percent correct is ranked with highest values at the top and % commission error with lowest values (and hence "best") at the top. However, types which are included within the same bracket are not significantly different according to Duncan's test at the 95% level of significance.

BARLEY INTERPRETATION

% Correct	% Commission Error
Ektachrome	Ektachrome
Infrared Ektachrome	Infrared Ektachrome
Pan-25	Pan-25
Infrared-89B	Pan-58
Pan-58	Infrared-89B

WHEAT INTERPRETATION

% Correct	% Commission Error
Infrared Ektachrome	Ektachrome
Ektachrome	Infrared Ektachrome
Pan-58	Infrared-89B
Infrared-89B	Pan-25
Pan-25	Pan-58

Based on the results of both the mean-of-ratio analysis and the analyses of % correct and % commission error, Ektachrome film was chosen as the film/filter type to be used for the operational survey. Although in some cases it was not significantly superior to other film types, it was the only type which was at least in the superior group in <u>all</u> tests.

B. Field Data and Sampling Rationale

Attempting to administer a photo interpretation survey involving the entire county 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 3). 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 (see Figures 4 and 5). The crop category code which was used, and which appears in Appendix II of this report, is an adaptation of a coding system originally developed by the U. S. Government for categorizing land use (U. S. Urban Renewal Administration, 1965) and subsequently refined for specific use in agricultural land use mapping by researchers at the University of California, Riverside (Johnson, et al., 1969).

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 ± 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 <u>numbers of fields</u> is not necessarily indicative of accuracy of <u>acreage</u> 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 below (Tables 3 through 6). Note that sampling error is presented as a precentage 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.

INTERPRETATION TIME

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.

Table 6

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 the data were produced, the relatively large area interpreted, and the lack of any other reliable estimates with which they could be compared.

In the table listing the individual interpreter's accuracy levels (Table 5) 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 space 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 and 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 report.

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SENSOR PLATFORM	APOLLO 9	HIGH ALTITUDE AIRCRAFT	NASA RB57F AIRCRAFT
ALTITUDE	126 NAUTICAL MILES	60,000 FEET	60,000 FEET
CAMERA SYSTEM DATE	<u>70mm Hasselblad Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations (S065 Experiment)	<u>35mm Nikon Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations <u>70mm HyAc Cameras</u>: Pan-25 and IR Ektachrome-15 film-filter combinations	<u>70mm Hasselblad Cameras</u>: Pan-25, Pan-58, IR-89B, and IR Ektachrome-15 film-filter combinations <u>RC-8 Cameras</u>: Ektachrome-HF3, and IR Ektachrome-15 film-filter combinations
<u>1969</u>			
March 8-12	X	X*	
April 23		X	
May 21		X	
July 15		X	
August 5		X	
September 30		X	
November 4		X	
December 6			X
<u>1970</u>			
January 13			X
February 6-8			X
March 16			X
April 22			X
May 21			X
June 16			X
July 28			X

* 70mm Mitchell-Vinten cameras were substituted for 35mm Nikon cameras on this date only.

Table 1. Tabulation of the types of imagery obtained through the NASA Earth Resources Survey Program for the Phoenix test site during 1969 and 1970.

MISSION/DATE	Zeiss (1/60,000)	RC - 8 (1/120,000)				Hasselblad (1/500,000)					
	IR EKTA-15	EKTA	IR EKTA-15	IR-89B	PAN	PAN-25	PAN-58	IR-89B	EKTA-HF3	IR EKTA-15	OTHER F
116/Dec. 6	S0117/D	S0278/2E	----	----	2402/12	3400	3400	----	2448/UV-17	S0180/15	----
118/Jan. 13	S0117/D	2448/HF-3	----	S0246	----	3400	3400	2424	2448/UV-17	S0180/15	----
120/Feb. 6-8	S0117/D (also S0278/2E)	S0278/2E	S0117/15	S0246	2402/12	3400	3400	2424	S0278/2E	S0180/12	3400/[illegible]
123/Mar. 16	S0117/D	2448/HF-3	----	S0246	----	2402	2402	2424	----	S0117/15 S0117/15 +CC30B	----
127/Apr. 22	S0117/D	2448/HF-3	----	S0246	----	2402	2402	2424	----	S0117/15	----
129/May 21	S0117/B	2448/HF-3	S0117/15	----	----	2402	2402	2424	S0278/3	S0117/15	----
131/Jun. 16	S0117/B	2448/HF-3	S0117/15	----	----	2402	2402	2424	S0278/3	S0117/15 S0117/15 +CC30B	----
139/Jul. 28	2443/15	S0-397/2E	2443/15	----	----	2402	2402	2424	S0168/2E	S0117/15 S0117/15 +CC30B	----

Table 2. Detailed Summary of NASA RB57F Imagery (by film-filter combination) Obtained Between December 1969 and July 1970 for the Phoenix, Arizona Test Site.

ACREAGE ESTIMATES AND SAMPLING ERROR

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%

Table 3

RATIO CORRECTION FACTORS

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

Table 4

SAMPLING ERROR OF INTERPRETERS

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%

Table 5

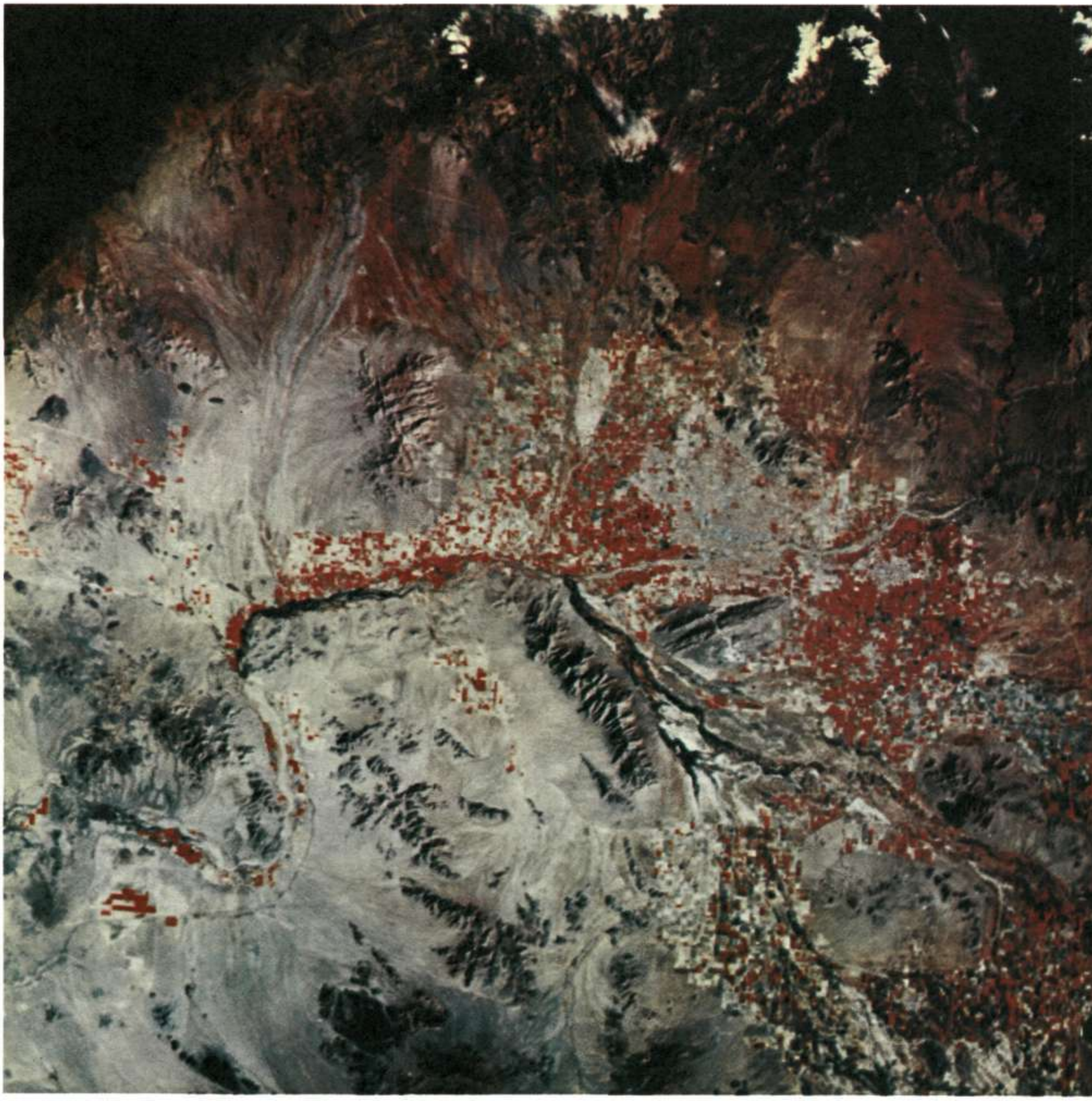
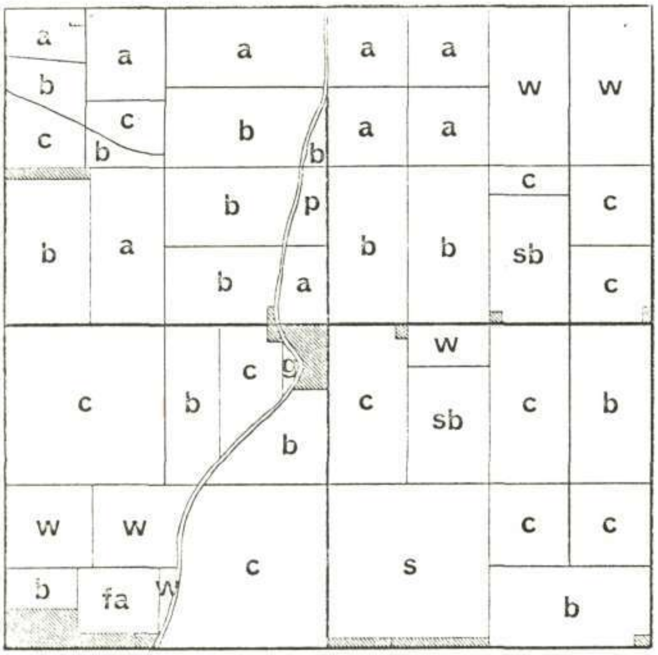


Figure 1. This enlargement of Apollo 9 Infrared Ektachrome frame AS9-26-3801 shows the Phoenix test site where the semi-operational agricultural inventory was performed. The city of Phoenix appears in the right center, surrounded by extensive agricultural lands and wildlands valuable as rangeland and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



Crop Type Map: Phoenix Plot 2-1
Date: May 22, 1970

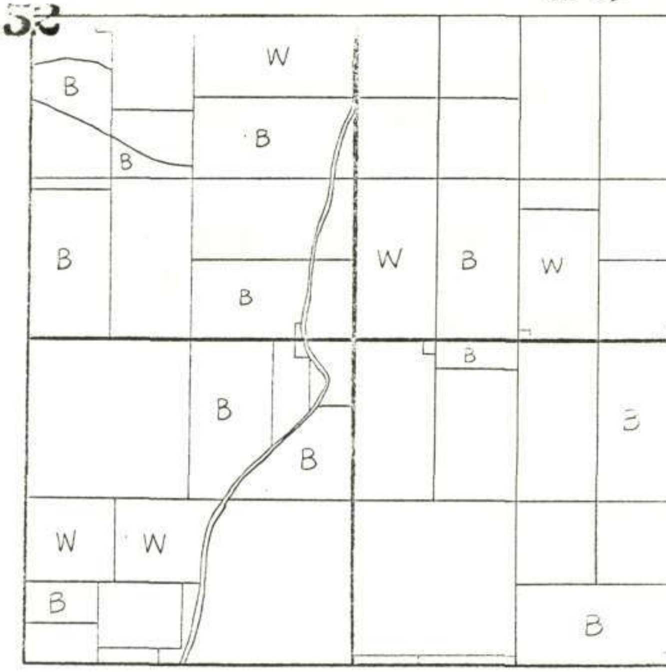


Photo Interpretation Answer Sheet
Phoenix Plot 2-1

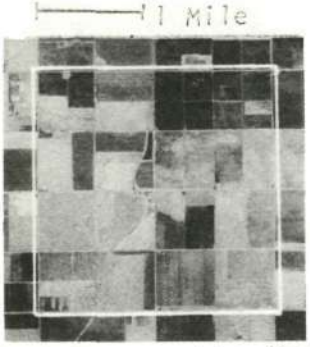
CROP SYMBOL KEY

a = Alfalfa
b = Barley
c = Cotton
fa = Fallow
g = Grass
p = Pond
sb = Sugar Beet
w = Wheat

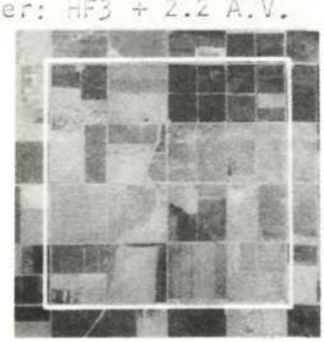
Ektachrome MS (2448)
Filter: HF3 + 2.2 A.V.

Infrared Ektachrome (SO117)
Filter: Wratten 15

1 Mile



Plus-X Aerographic (2402)
Filter: Wratten 25

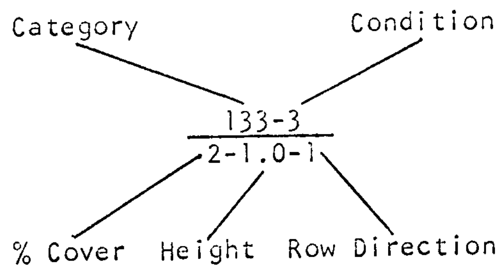


Plus-X Aerographic (2402)
Filter: Wratten 58

Infrared Aerographic (5424)
Filter: Wratten 89B

Figure 2. Appearing in this figure are test images (obtained May 21, 1970), ground data, and sample interpretation test results for one 4-square-mile test plot. Ground data, top left, were collected in conjunction with the high altitude photo mission. The Ektachrome and Infrared Ektachrome photos above are reproduced at the same scale as the original transparencies. The black-and-white photos have been enlarged from their original scale (1/500,000) to match the color photos. Each of the test images was interpreted by a group of three photo interpreters. Results from the Ektachrome plot, as obtained by one interpreter (top right), are as follows (based on number of fields): barley - 85% correct, 8% commission; wheat - 40% correct, 33% commission.

Figure 3. This black-and-white enlargement of an Apollo 9 space photo shows the portion of Maricopa County for which the semi-operational survey was performed (compare with Figure 1). The location of each of the 32 4-square-mile plots selected for ground survey at the time of each NASA overflight is indicated on the overlay.



Condition Code

1 seeded
2 young
3 mature
4 dry (not harvested)
5 cut back (e.g., alfalfa)

% Cover Code

1 80-100%
2 50-80%
3 20-50%
4 5-20%
5 0-5%

Height: Indicate average crop height in feet and tenths.

Row Direction Code

1 N-S |
2 E-W —
3 NW-SE \
4 NE-SW /

Figure 4. This coded fraction represents a typical field code as recorded by field crews gathering information pertaining to the sample plots. Field category codes appear in Appendix II of this report, while the coding system used for recording other field parameters is described above. The example shown here represents a mature alfalfa field one foot in height, with 50-80% ground cover and rows running in a north-south direction.

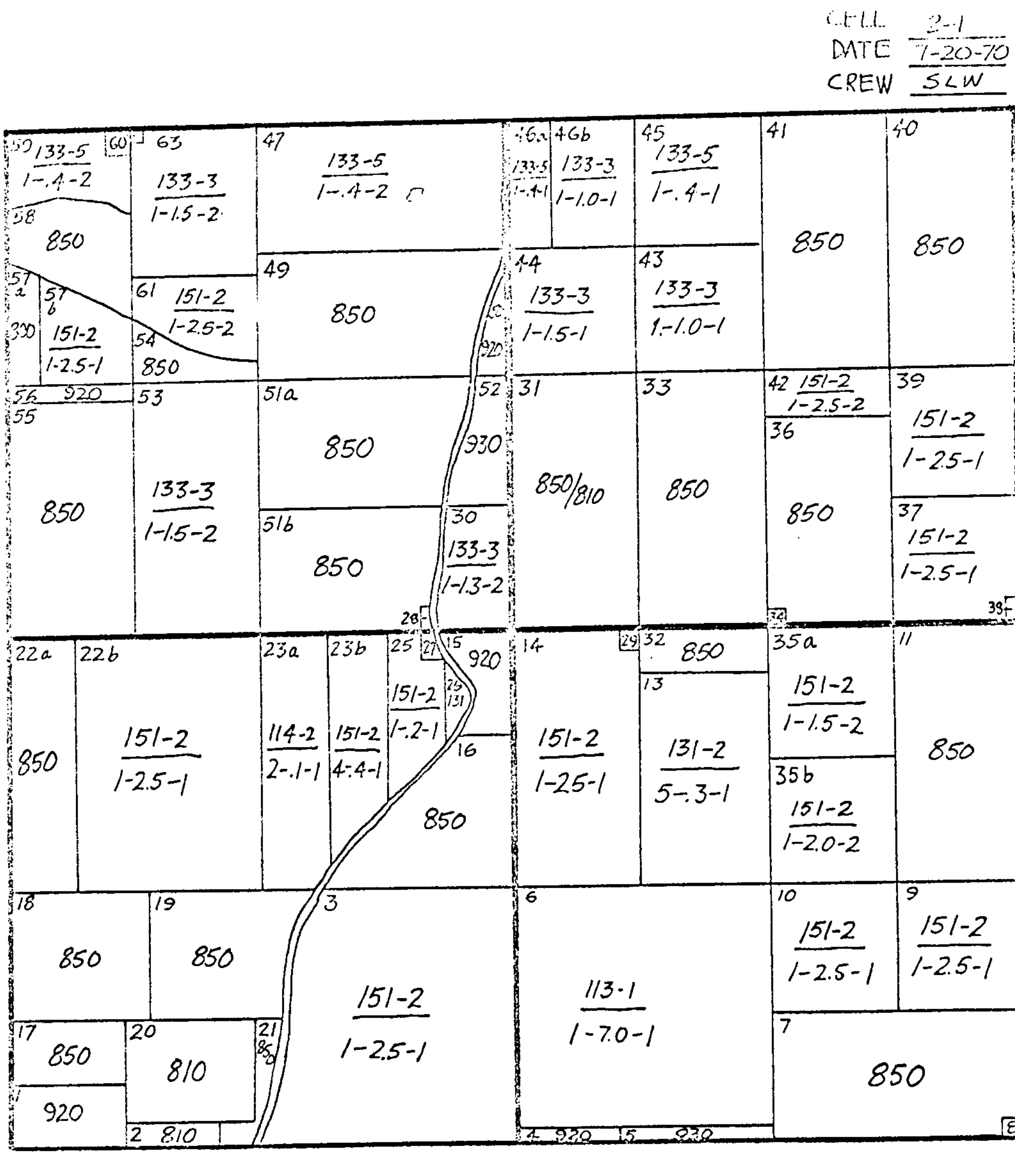


Figure 5. This map contains field data collected for one of the 4-square-mile plots in Maricopa County at the time of a NASA high altitude overflight. The coded fraction in each field is explained in Figure 4 (and a complete listing of the field category codes appears in Appendix II). Representative high altitude aerial photographs of this cell appear in Figure 2. Computer storage of survey data collected at the time of each flight on a field-by-field basis facilitates sequential analysis of crop patterns as well as evaluation of photo interpretation test results.