BIOGRAPHICAL SKETCH

Donald T. Lauer
Forestry Remote Sensing Laboratory
School of Forestry and Conservation
University of California
Berkeley, California

Mr. Lauer was born on May 5, 1941 in Oakland, California. He is married and has two children. He received a B.S. degree in Forestry from the University of California, Berkeley in 1963 and a M.S. degree in Forestry and Remote Sensing in 1965. He is leader of the Image Interpretation and Enhancement Unit of the Forestry Remote Sensing Laboratory, University of California, Berkeley. His responsibilities include developing methodology for extracting useful resource information from remote sensing imagery -- using human photo interpreters. He is a member of the American Society of Photogrammetry and the Society of American Foresters.

TESTING MULTIBAND AND MULTIDATE PHOTOGRAPHY FOR CROP IDENTIFICATION

D.T. Lauer

Forestry Remote Sensing Laboratory
School of Forestry and Conservation
University of California, Berkeley

For several years, personnel at the Forestry Remote Sensing Laboratory have concentrated their efforts on developing techniques for extracting a maximum amount of information about vegetation resources in agricultural and wildland areas from aerial and space photos. Among the most significant research results obtained to date are our findings relating to agricultural crop surveys. Specifically, our recent investigations regarding the interpretability of photography taken in more than one spectral band and at more than one time of the year were so encouraging that we were able to attempt a semi-operational survey of the 1970 small grain crop growing in Maricopa County, Arizona. The purpose of this paper is to describe, with the aid of three case studies, the procedures used and results derived in a series of prerequisite interpretation tests that were performed on multiband and multidate photography. The results of these quantitative tests led to the selection of what was considered to be the best combination of multiband and multidate photographs for use in the Maricopa County survey.

The theoretical bases of the multiband and multidate concepts have been known for quite some time. For example, the tone or brightness with which an agricultural field or field condition is registered on a film emulsion is directly related to the amount of energy reflected from that field, through the camera lens system, to the film emulsion. Since most terrain features or conditions possess unique spectral reflectance characteristics -- depending on their atomic, molecular and physical structure -- they frequently possess unique tone signatures when viewed on photographs taken simultaneously in more than one spectral band. Consequently, multiband photography obtained in those spectral bands exhibiting the greatest differences in signatures between crops greatly facilitates the task of discriminating one crop from another. Furthermore, the reflectance characteristics of an agricultural field rapidly change throughout a growing season according to noticeable changes in plant phenology and to local or regional cropping practices. Generally, a field progresses in development as follows: unprepared bare soil, prepared bare soil (plowed, disced or diked), seedling plants, immature plants, mature plants, harvested field. Obviously, just about every agricultural crop has its own distinct life cycle, and these cycles are easily documented in a crop calendar. By studying a crop calendar for a particular region, one can predict when a crop might possess a unique tone signature when viewed on a series of photographs taken at more than one time of year. Thus, as is the case with multiband photography, multidate photography can aid the photo interpreter when trying to identify various agricultural crops. Logically, one could assume that both multiband and multidate photography, properly procured, would further enhance the interpreter's ability to perform an agricultural crop survey. The case studies presented below lend credence to this assumption -- in the form of interpretation test results.

CASE STUDIES

A. Mesa, Arizona

Our Group first became involved in crop studies at the Phoenix-Mesa Test Site (NASA Test Site #29) while preparing for the Apollo 9 S065 multispectral photographic experiment. A 16-square-mile area, near Mesa, Arizona, was chosen for intense analysis; 125 fields within the study area included most of the economically important crop types found in irrigated regions of the southwest. In addition to the Apollo multiband photography, NASA made available high-altitude aircraft multiband-multidate photography for this area, and these aircraft overflights occured sequentially at approximately one month intervals, beginning at the time of the Apollo flight. Given available multiband and multidate photography, a series of interpretation tests were devised to establish the best combination(s) of images for identifying all crop types and single crop types within the 16-square-mile area.

A large number of "test images" were presented to a group of skilled interpreters who were asked to classify each of the 125 fields within the study area into one of seven crop categories that included: barley (B), recently cut alfalfa (Ac), mature alfalfa (Am), wheat (W), sugar beets (SB), moist bare soil (BSm), and dry bare soil (BSd). Since the interpreters were not acquainted with the Mesa area, a photo interpretation key, in the form of training samples, was prepared. Individual fields from each crop category which represented a range in crop variability were selected, identified and presented to the interpreters (see figure 1). The interpreters were asked to study the appearance of each training sample, and once they became familiar with the identifying characteristics of each crop type, they attempted to correctly classify the remaining fields within the study area.

In order to minimize "familiarity" with the fields within the study area, an interpreter was asked to look at no more than five test images. Each image was examined by four different interpreters, and interpretation results were expressed as the cumulative number of fields seen by all four interpreters for each image. Table I shows actual interpretation results for eleven types of photography (i.e., various combinations of single band, multiband, single date, and multidate photography). The array of results shown in Table I were prepared in such a way as to aid the reader in comparing results derived from one image type with results from another. Note that each array includes ground truth, correct interpretations and incorrect interpretations (omission and commission errors). The correct interpretations, expressed in percent for all crops combined, have been summarized and are shown in Table II.

The interpretability of Apollo and high-flight photography (Pan-25, IR-89B, and Ekta Aero Infrared) were compared; and, in each case, the interpreters were able to identify the various crop categories field-by-field equally well on spaceborne and airborne photos.

In reference to multiband and multidate photography, note that single band photographs taken on single dates produce fairly low overall interpretation results, except for the Pan-25 image taken in May. Improved results were obtained with May photos since barley has sufficiently matured at that time allowing it to be easily discriminated from all other crops. Overall interpretation accuracies for all crops improved impressively when single date photography, including the May photos, were viewed in a multiband form (i.e., Ekta Aero Infrared photo or optically combined color composite image) and when single band photos (Pan-25) taken on two different dates were viewed in a color composite form. Higher results were obtained on multiband images because bare soil is most easily separated from vegetated fields on film containing an infrared sensitive band, and mature barley is best discriminated from sugar beets and alfalfa on film containing a red sensitive band. However, the only sure means of identifying alfalfa is by searching for its characteristic harvest pattern on sequential images. Since alfalfa is periodically mowed, changing over time from mature to recently cut to mature, a distinct pattern for that crop is readily seen on multidate photography. Consequently, multiband-multidate photography (image #1) provides the maximum amount of discriminatory information for identifying barley, bare soil, sugar beets, and alfalfa and, therefore, image #11 (three separate Ekta Aero Infrared photos taken in March, April, and May and viewed together) gave better overall interpretation results than any other form of imagery tested.

B. Imperial Valley, California

Concurrent with the Arizona study, an image interpretation experiment was being conducted in an adjacent and analogous agricultural area -- Imperial Valley, California. As in Maricopa County, agricultural cropping in the Imperial Valley is mainly on reclaimed desert land where the combination of deep rich soils, an abundance of solar energy, and available irrigation water has led to a level of agricultural productiveity equaled in only a few parts of the world.

Aircraft flights were arranged for this area during the summer of 1969 for the purpose of obtaining high quality single band, black-and-white multiband, and tri-emulsion color and false-color photographs. All photography was procured by the Science and Engineering Group at Long Island University; a boresighted multilens camera, equipped with infrared sensitive film, broad-band primary color absorption filters, and infrared cutoff filters, was used to obtain the multiband imagery. An experiment was designed, utilizing quantitative interpretation tests, to determine the usefulness of different kinds of multiband photography (flown in July) for identifying four Imperial Valley cropland categories: alfalfa, sorghum, cotton and bare soil.

Five sets of images were selected for testing -- one set of single band photos (IR-25) and four sets of multiband photos (Aerial Ektachrome, Ekta Aero Infrared, color enhancement "A", and color enhancement "B"). Color enhancement "A", a close simulation of Ekta Aero Infrared film was made by optically combining an IR-58, IR-25 and IR-89B image projected through a blue, green and red filter, respectively; while color enhancement "B" was made the same way but with the green and red filters reversed. Part of this experiment was to compare, through interpretation testing, the information content seen on enhanced black-and-white multiband photos with that seen on tri-emulsion subtractive reversal films.

Each set of imagery was examined by three interpreters, with no interpreter viewing more than one set. A set of images consisted of nine separate photos in print form, mosaiced together showing a total of 157 agricultural fields. Several fields were randomly selected within each crop category and were used as training samples by the photo interpreter.

The results of the Imperial Valley Experiment are summarized in Table III in which test results are expressed as (1) mean percent correct identifications and (2) mean percent commission error -- for each of the four crop categories and all crop categories combined. (Percent commission error for a crop category is the percent of the total number of fields identified as that type which were actually same other crop type; therefore, a low percent commission error plus high percent correct identification indicates high interpretation accuracy.)

Probably what is most evident in these results is that accuracy of identification for all crop categories combined is relatively low (80%), no matter which type of test imagery was used. These poor results are probably a function of the improper timing of the photo mission rather than the lack of information content in multiband photography, per se. An analysis of a crop calendar for this region would indicate that both cotton and sorghum are in a mature, green state of development in July -- a condition rendering tone signatures for the two crops quite similar in appearance on single band and multiband photographs. The low percent correct identifications and high percent commission errors for cotton and sorghum indicate that the interpreter continually confused the two. Furthermore, the alfalfa fields were in any of several stages of development (ranging from recently cut to mature) at this single time of year which added to the difficulty of identifying one crop type from another. Nevertheless, some very prominent trends are evident in the data derived in this series of tests: (1) the single band black-and-white images when compared to the other four kinds of multiband photography, nearly always rendered the lowest percent correct identifications and the highest percent commission errors, (2) the color enhancement "B" and Ekta Aero Infrared images tended to produce the most accurate results for each crop category and all crop categories combined, and (3) enough variability in interpretation results occurred within each group of interpreters working with a single type of imagery, that the significance of the results shown here could not be supported with statistical computations.

In summary, one might conclude from the data presented here that an accurate classification of Imperial Valley crops is not easily done on photography procured on a single day in July; however, if given the task of working with only July photos, multiband rather than single band (IR-25) photographs would be more useful for this purpose. In addition, black-and-white multiband photos properly procured and displayed as a color composite image can render as much information on crop types as conventional tri-emulsion layer color or false-color infrared films.

C. Maricopa County, Arizona

Based on the above results, it was decided that a semi-operational regional agricultural crop survey would be a logical extension of the interpretation techniques initially developed. An inventory of the 1970 small grain crop (i.e., barley and wheat) growing in Maricopa County, Arizona became the survey objective since multiband-multidate photographs were available for the entire area and reliable ground truth data had been collected by FRSL personnel during these overflights. Prior to implementing the survey, it was necessary to apply the crop calendar concept and an interpretation test to determine the best combination(s) of multiband-multidate photographs for discriminating wheat and barley from all other crops, and wheat from barley.

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 1970 small grain crop was developing in a normal manner. Thus, general conclusions based on crop calendar information which indicated that small grains are mature and most easily distinguishable from other crops during the month of May, were assumed to be applicable for 1970. However, the studies conducted within the 16-square-mile area near Mesa, Arizona indicated that although barley could be consistently identified on May 21, 1970 photos, wheat and alfalfa were sometimes confused. It was noted 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 <u>May 21</u> and <u>June 28</u> were ultimately provided for the survey.

In addition, the design of the previous tests, conducted in the Mesa area, regarding optimum film type, were not totally acceptable in terms of the survey for 1970. Since the 1970 photographs were taken at larger scales than the 1969 coverage (1/120,000 and 1/500,000 versus 1/950,000), giving better image resolution, and Aerial Ektachrome coverage was omitted in 1969, 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 identifying barley and wheat. Consequently, five types of photography were tested for information content -- three kinds of single band imagery (Pan-58, Pan-25 and IR-89B) and two kinds of multiband imagery (Aerial Ektachrome and Ekta Aero Infrared).

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 throughout the county. 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 interpretation tests:

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

Procedures used for training the interpreters were similar to those used in the Mesa and Imperial Valley studies. In this case, four additional four-square-mile plots were chosen and the fields within them were used as keys or reference materials. 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). 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 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, Aerial Ektachrome, Pan-25, and Pan-58 constituted a homogeneous sub-group of low variance, with Ekta Aero Infrared and Infrared-89B showing significantly higher variances. Thus, either Aerial 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 (Table IV). If significant differences were found, the types were to be ranked using the Duncan's new 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 in Table V. 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.

Based on the results of both the mean-of-ratio analysis and the analyses of % correct and % commission error, Aerial 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 all tests. (For a discussion of the Maricopa County survey see Draeger, et al., 1970, or Draeger, 1971).

SUMMARY AND CONCLUSIONS

The research reported upon above was designed to answer two questions; (1) can a suitable methodology of interpretation testing be developed that would allow comparisons between the information content seen on various types of aerial and space photography? and (2) are multiband and/or multidate photographs useful to the photo interpreter as he attempts to identify various agricultural crops by means of remote sensing?

Drawing on the large pool of skilled photo interpreters at the Forestry Remote Sensing Laboratory, an efficient and reliable interpretation testing procedure has been developed that would be applicable to photography taken not only of agricultural resources but of nearly any resource environment. The technique consists mainly of presenting to a group of interpreters various types of photography on which resource patterns or conditions are to be identified. A large population of resource features is required so that an interpreter never looks at a particular terrain object more than once -- during training and testing. If several interpreters evaluate each type of photography, greater reliance can be placed on their cumulative results, which can be tabulated in various ways (e.g., total correct identifications, total omission errors, total commission errors, mean correct identifications, mean omission errors, mean commission errors) or analyzed statistically (e.g., one-way classification and Duncan's new multiple range test) in order to quantitatively determine the confidence which one should have in the results.

Such testing procedures were then applied to multiband and/or multidate photography taken over agricultural lands in southern California and southern Arizona. In each of these case studies involving the identification of several important crop types, the test results indicate that multiband photography consistently yields higher interpretation accuracies than any type of single band photography; but more importantly, proper timing of photography -- taken on more than one date -- will unquestionably insure a higher level of crop identification than that attainable with photos taken at any single point in time.

SELECTED REFERENCES

Carneggie, D. M., L. R. Pettinger, C. M. Hay and S. J. Daus. 1969. An evaluation of earth resources using Apollo 9 photography -- Chapter 3. A report of research performed under Contract No. NAS9-9348 for the Office of Space Sciences and Applications, NASA, by personnel of the School of Forestry and Conservation, University of California, Berkeley.

Draeger, W. C., L. R. Pettinger and A. S. Benson. 1970. Analysis of remote sensing data for evaluating vegetation resources -- Appendix I: A semi-operational agricultural inventory using small-scale aerial photography. Annual Progress Report, Contract No. R-09-038-003, for the Office of Space Sciences and Applications, NASA, by the personnel of the School of Forestry and Conservation, University of California, Berkeley.

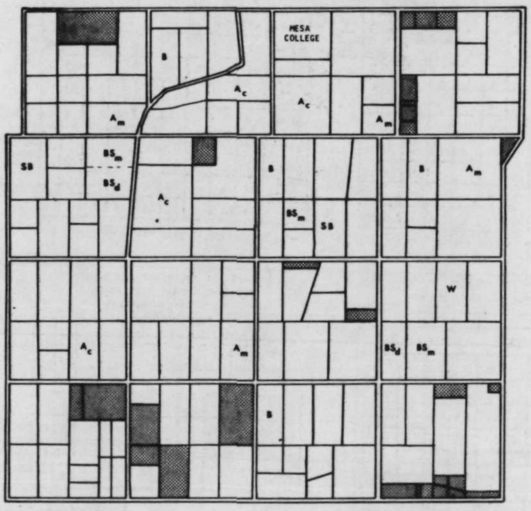
Draeger, W. C. 1971. The use of small-scale photography in a regional agricultural survey. Presented at the International Workshop on Earth Resources Survey Systems, Ann Arbor, Michigan, May 3-14, 1971.

Lauer, D. T. and G. A. Thorley. 1971. Quantitative Analysis of Multiband Photography. Presented at the 37th Annual Convention of the American Society of Photogrammetry, Washington, D.C., March 7-12, 1971.

Pettinger, L. R., et al. 1969. Analysis of earth resources on sequential high altitude multiband photography. A special report prepared for the Office of Space Sciences and Applications, NASA, by personnel of the School of Forestry and Conservation, University of California, Berkeley.

Pettinger, L.R. 1971. Field data collection - an essential element in remote sensing applications. Presented at the International Workshop on Earth Resources Survey Systems, Ann Arbor, Michigan, May 3-14, 1971.

Map With Ground Truth (March)



Map with Training Samples (March)

Figure 1: The type of reference material or "photo interpretation key" used to train the photo interpreters is shown here (bottom map). The interpreter was able to familiarize himself with the image characteristics of each crop category by studying each training sample seen on the test image. Once he was confident that he could correctly identify each field, he proceeded to annotate,on the map with training samples,the identity of the remaining fields. Accuracy of interpretation was then calculated by comparing the annotated map with the ground truth map. The symbols on the maps mean: "B" for barley, "Am" for mature alfalfa, "Ac" for cut alfalfa, "SB" for sugar beets, "W" for wheat, "BSm" for moist bare soil, and "BSd" for dry bare soil (from Carneggie, et al., 1969).

TABLE I: INTERPRETATION TEST RESULTS FOR MESA, ARIZONA STUDY AREA

IMAGE #1 PAN-25A, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	45	13	10	2	2			72	27
Am	45	34	11	15	1		1	107	73
Ac	13	5	37	3	1	12	8	79	42
SB	17	9		4				30	26
W	5	1			0			6	6
BSm	5		27			33	22	87	54
BSd	1	2	7			7	37	54	17
Total Fields	131	64	92	24	4	52	68	435	
Incorrect	86	30	55	20	4	19	31		245

Total Percentage Correct Identification: 43%

IMAGE #2 PAN 25A, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	44	17	4	2	4			71	27
Am	43	35	9	1				88	53
Ac	10	1	37	7		10	4	69	32
SB	20	11	6	10				47	37
W	5			1	0			6	6
BSm	5		18	2		22	5	52	30
BSd	3		18			20	59	100	41
Total Fields	130	64	92	23	4	52	68	433	
Incorrect	86	29	55	13	4	30	9		226

Total Percentage Correct Identification: 4[illegible]

IMAGE #3 IR-89B, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	35	13		2	4			54	19
Am	46	31	11	1				89	58
Ac	25	14	54	7		10	3	113	59
SB	18	3	7	10				38	28
W	6	2	2	1	0			11	11
BSm	1			2		22	9	34	12
BSd	1	1	17			20	56	95	39
Total Fields	132	64	91	23	4	52	68	434	
Incorrect	97	33	37	13	4	30	12		226

Total Percentage Correct Identification: 47%

IMAGE #4 IR-89B, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	43	20	2	4	4		1	74	31
Am	38	34	16	7		1	1	97	63
Ac	13	1	38	4		3	10	69	31
SB	30	3	17	6				56	50
W	7	6	2	3	0			18	18
BSm						38	17	55	17
BSd	1		17			8	39	65	26
Total Fields	132	64	92	24	4	50	68	434	
Incorrect	89	30	54	18	4	12	29		236

Total Percentage Correct Identification: 45%

IMAGE #5 PAN 25A, HIGH FLIGHT
MAY 21, 1969

Photo Interpreter's Results \ Ground Truth	B	A	SB	BS	W			Tot. seen by P.I.	Com. error
B	113	0	2	1	0			116	3
A	1	130	15	48	4			198	68
SB	0	13	0	4	0			17	17
BS	10	12	3	59	0			84	25
W	0	1	0	8	0			9	9
Total Fields	124	156	20	120	4			424	
Incorrect	11	26	20	61	4				122

Total Percentage Correct Identification: 71%

IMAGE #6 INFRARED EKTACHROME, APOLLO 9
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	66	21	1	4				92	26
Am	31	33	2	3	2			71	38
Ac	22	5	84	10			3	124	40
SB	5	3	2	6				16	10
W	7	2		1	2			12	10
BSm						43	14	57	14
BSd	1		3			9	51	64	13
Total Fields	132	64	92	24	4	52	68	436	
Incorrect	66	31	8	18	2	9	17		151

Total Percentage Correct Identification: 65%

IMAGE #7 INFRARED EKTACHROME, HIGH FLIGHT
MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	43	17	1		4			65	22
Am	38	36	6	2				82	46
Ac	24	3	72	10				109	37
SB	24	5	2	11				42	31
W	2	3		1	0			6	6
BSm						39		39	0
BSd	1		9			13	67	90	23
Total Fields	132	64	90	24	4	52	67	433	
Incorrect	89	28	18	13	4	13	0		152

Total Percentage Correct Identification: 64%

IMAGE #8 COLOR COMPOSITE-FRSL OPTICAL COMBINER
HIGH FLIGHT, MARCH 12, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BSm	BSd	Tot. seen by P.I.	Com. error
B	47	8		1	2			58	11
Am	57	51	15	8	2			133	82
Ac	23	3	57	8				91	34
SB	4		5	5				14	9
W	1	2		1	0			4	4
BSm			11			38	11	60	22
BSd			4			13	57	74	17
Total Fields	132	64	92	23	4	51	68	434	
Incorrect	85	13	35	18	4	13	11		179

Total Percentage Correct Identification: 58%

IMAGE #9 INFRARED EKTACHROME, HIGH FLIGHT
MAY 21, 1969

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BS		Tot. seen by P.I.	Com. error
B	108			3		4		115	7
Am		50	21	8				79	29
Ac	6	1	46	2	4	12		71	25
SB		9	17	8		4		38	30
W					0	4		4	4
BS	6		16	3		102		127	25
Total Fields	120	60	100	24	4	126		434	
Incorrect	12	10	54	16	4	24			120

Total Percentage Correct Identification: 72%

IMAGE #10 MULTIDATE COLOR COMPOSITE
FRSL OPTICAL COMBINER
HIGH FLIGHT, MARCH 12 & MAY 21, 1969

Photo Interpreter's Results \ Ground Truth	B	A		SB	W	BS		Tot. seen by P.I.	Com. error
B	102	1		2				105	3
A	7	113		22	3	14		159	46
			0						
SB	1	3		0				4	4
W	3	1			0	1		5	5
BS	5	34			1	112		152	40
Total Fields	118	152		24	4	127		425	
Incorrect	16	39		24	4	15			98

Total Percentage Correct Identification: 76%

IMAGE #11 MULTIBAND, MULTIDATE,
EKTA AERO INFRARED (3 IMAGES)
MARCH, APRIL AND MAY

Photo Interpreter's Results \ Ground Truth	B	Am	Ac	SB	W	BS		Tot. seen by P.I.	Com. error
B	107	1	1	2				111	4
Am	13	50	6	7	3	1		80	30
Ac	3	4	70	6		1		84	14
SB	4	9	8	8				29	21
W	1				1			2	1
BS	2		8			116		126	10
Total Fields	130	64	93	23	4	118		432	
Incorrect	23	14	23	15	3	2			80

Total Percentage Correct Identification: 81%

The array of results for each image type illustrates the cumulative results of four interpreters (data along rows for each type) along with the actual ground truth (data down the columns). For example, consider the case of barley in the upper left array (Image #1). First, reading down the column marked "B", out of a total of 131 fields known to be barley, 45 were correctly identified; however, 45 were called mature alfalfa, 13 cut alfalfa, 17 sugar beets, 5 wheat, 5 moist bare soil, and 1 dry bare soil, resulting in an omission error equal to 86. Reading across the row marked "B", out of a total of 72 fields called barley by the interpreters, 45 were correctly identified; however, 13 mature alfalfa fields, 10 cut alfalfa fields, 2 sugar beet fields and 2 wheat fields were incorrectly identified as barley resulting in a commission error equal to 27. Hence, out of a total of 131 barley fields, 45 were correctly identified yielding a percent correct equal to 43% (from Carneggie, et al., 1969 and Pettinger, et al., 1969).

TABLE II: TEST RESULTS FOR MESA, ARIZONA STUDY AREA EXPRESSED AS PERCENT CORRECT IDENTIFICATIONS FOR ALL CROP CATEGORIES

TEST NUMBER	INTERPRETATION MODE	PHOTO (S)	DATE (S)	VEHICLE	%CORRECT
1	Single Band; Single Date	Pan-25	March	Apollo 9	43%
2		Pan-25	March	High-Flight	47%
3		IR-89B	March	Apollo 9	47%
4		IR-89B	March	High-Flight	45%
5		Pan-25	May	High-Flight	71%
6	Multiband; Single date	Ekta Aero Infrared	March	Apollo 9	65%
7		Ekta Aero Infrared	March	High-Flight	64%
8*		Color Composite	March	High-Flight	58%
9		Ekta Aero Infrared	May	High-Flight	72%
10**	Single band; Multidate	Color Composite Pan-25	March and May	High-Flight	76%
11	Multiband; Multidate	Ekta Aero Infrared (3 images)	March, April and May	High-Flight	81%

* A color composite image was made with the FRSL Optical Combiner Using Pan-58, Pan-25, and IR-89B images projected through a blue, green, and red filter, respectively.

** A color composite image was made with the FRSL Optical Combiner using March Pan-25 and May Pan-25 images projected through a violet and green filter, respectively.

(From Carneggie, et al., 1969 and Pettinger, et al., 1969).

TABLE III: TEST RESULTS FOR IMPERIAL VALLEY, CALIFORNIA STUDY AREA EXPRESSED AS PERCENT CORRECT IDENTIFICATIONS AND PERCENT COMMISSION ERRORS

	ALL CROPLAND	ALFALFA		COTTON		SORGHUM		BARE GROUND	
IMAGE TYPE	% CORRECT	%COR	%COM	%COR	%COM	%COR	%COM	%COR	%COM
Enhancement B	78	86	25	51	40	60	23	84	8
Ekta Aero IR	77	77	22	70	45	44	35	94	10
Aerial Ekta	72	74	25	48	45	60	43	82	11
Enhancement A	71	73	32	45	59	35	52	93	8
IR-25	67	60	30	54	73	48	38	87	14

TABLE IV: TEST RESULTS FOR MARICOPA COUNTY, ARIZONA STUDY EXPRESSED AS PERCENT CORRECT IDENTIFICATIONS AND PERCENT COMMISSION ERRORS

	BARLEY		WHEAT	
IMAGE TYPE (MAY)	%COR.	%COM.	%COR.	%COM.
Aerial Ekta.	71.19	5.73	49.25	49.67
Ekta Aero IR	65.06	24.89	59.05	44.73
Pan-58	32.35	44.69	38.11	85.19
Pan-25	46.65	41.43	20.15	77.77
IR-89B	44.55	45.40	30.87	77.49

Note: Accuracy of interpretation of wheat is significantly improved when the analysis is performed on May photography combined with June photography.

(From Draeger, et al., 1970)

TABLE V: TYPES OF PHOTOGRAPHY RANKED (BEST AT THE TOP) AND GROUPED (WHERE SUB-GROUPS ARE SIGNIFICANTLY DIFFERENT) IN TERMS OF PERCENT CORRECT AND PERCENT COMMISSION ERROR FOR BOTH BARLEY AND WHEAT

BARLEY INTERPRETATION	
% CORRECT	% COMMISSION ERROR
Aerial Ektachrome	Aerial Ektachrome
Ekta Aero Infrared	Ekta Aero Infrared
Pan-25	Pan-25
Infrared - 89B	Pan-58
Pan-58	Infrared - 89B

WHEAT INTERPRETATION	
% CORRECT	% COMMISSION ERROR
Ekta Aero Infrared	Ekta Aero Infrared
Aerial Ektachrome	Aerial Ektachrome
Pan-58	Infrared - 89B
Infrared - 89B	Pan-25
Pan-25	Pan-58

(From Draeger, et al., 1970)