Interpretability of Advanced SPOT Film Products for Forest and Agricultural Survey

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ABSTRACT: A series of interpretation tests was given to a pool of 26 image analysts using simulated SPOT-1 imagery and proposed film products from future SPOT systems. The objective of these tests was to determine which of the products was best for discriminating selected forest and agricultural resource categories in California. Based on the statistical analysis of the 15,600 analyst responses from these tests, we concluded that the best film products for interpreting renewable resources in both environments would be those which contained spectral bands sensitive to red, photographic infrared, mid-reflectance infrared, and far-reflectance infrared energy.

INTRODUCTION

SOUND LAND MANAGEMENT requires timely and accurate information about the type, amount, availability, and condition of renewable resources being produced. For 13 years, the experimental Landsat satellite systems have provided the means for collecting spectral data over large land areas in support of renewable resource inventory and monitoring needs. To be operationally successful, Earth observation satellite systems must implement robust data acquisition, management, and marketing strategies to insure (1) timeliness of data acquisition, (2) availability and consistency of high quality data products, and (3) data products competitively priced with respect to products derived from other Earth observation systems. The Earth observation satellite system which employs the necessary technological advances and marketing strategies will be in a strong position to provide direct benefits to the world resource survey community.

In an effort to advance the technology of Earth observations from space, the French government is developing an Earth observation satellite system called SPOT (Systeme Probatoire d'Observation de la Terre). The major attribute of the first satellite of this system (SPOT-1), which was successfully launched in February 1986 and is presently transmitting high quality data, includes a three-band high resolution linear array sensor that can, upon command, be pointed $\pm 27°$ from the vertical (CNES, 1984; Chevrel, 1981). Currently, experiments are being conducted to evaluate the utility of additional spectral bands which will be onboard the SPOT-3 and -4 satellites.

BACKGROUND

During 1983, simulated SPOT-1 and future SPOT system data were acquired for selected sites on a global basis in order to (1) enable users to evaluate SPOT data within their application field, (2) provide the value-added industry an opportunity for product development, and (3) serve as an aid to SPOT IMAGE Corporation in perceiving and responding to the needs of the potential user community. The United States SPOT Simulation Campaign acquired multispectral and panchromatic data over 61 sites nationwide using the Daedalus AADS1268 multispectral scanner mounted on-board a Learjet 25-C platform. Simultaneous acquisition of stereo aerial photography was accomplished for each site using a Zeiss RMK A 15/23 metric camera with a 153-mm (6-in.) focal length lens which produced 1:42,000-scale Kodak Aerochrome Infrared 23 by 23-cm. (9 by 9-in.) prints. The results of this campaign can be found in American Society of Photogrammetry (1984).

OBJECTIVES

On the basis of an initial qualitative analysis of simulated SPOT imagery by DeGloria (1984, 1985), the SPOT Image Corporation (SICORP) sponsored a research investigation with these authors to study the interpretability of current and proposed SPOT imagery for forestry and agricultural applications. Specifically, the following objectives were addressed in this study (DeGloria and Benson, 1985):

- determine the capability of SPOT film products to discriminate selected forestry and agricultural resource categories;
- determine the comparative worth to future SPOT systems of two reflectance infrared bands, 1.55 to 1.75μm and 2.08 to 2.35μm, for discriminating resource categories; and
- perform statistical analyses of error matrices in order to assess the interpretation errors within and common to the film products.

METHODS

To evaluate the capability of future SPOT film products for discriminating selected agricultural and forest resource categories, quantitative interpretation tests were conducted using five film products provided by SICORP. These tests were applied in mixed conifer forest and irrigated agricultural study sites in northern California.

FILM PRODUCTS TESTED

The spectral specifications of the five film products tested are listed in Table 1 and briefly described below.

- *Image B1-B2A-B3* was similar to color composite images that are available from the SPOT-1 and Landsat multispectral scanner and thematic mapper sensors. This film product simulated the spectral sensitivity of most false color infrared aerial films.
- *Image B2A-B3-SWIR1A* was a composite of visible, photographic infrared, and mid-reflectance infrared energy. Because this image was not sensitive to blue or green radiant energy, we expected the image to exhibit less atmospheric scattering than Image B1-B2A-B3. This product simulated the most interpretable three-band composite derived from Landsat-4 Thematic Mapper data (Benson and DeGloria, 1985).
- *Image B2A-B3-SWIR2* was similar to Image B2A-B3-SWIR1A, but in this case the longer wavelength SWIR2 was substituted for SWIR1A in order to determine the effect of SWIR1A versus SWIR2 on interpretation accuracy
- *Image B1-B2A-SWIR1A* was similar to Image B1-B2A-B3 except that a mid-reflectance infrared band was used in place of the photographic infrared band (B3) to determine the effect on interpretation accuracy of using a film product which was not sensitive to photographic infrared energy.
- *Image B3-SWIR1A-SWIR2* was an all infrared band. This image allowed us to evaluate the effect on interpretation accuracy of using a film product which was not sensitive to visible radiant energy.

The methods used to generate these film products are described in the appendix.

THE PLUMAS FORESTRY AND DAVIS AGRICULTURAL STUDY SITES

During the 1983 U.S. SPOT Simulation Campaign, SICORP acquired airborne multispectral scanner data over two areas in

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TABLE 1. CHARACTERISTICS OF SIMULATED SPOT IMAGERY EVALUATED IN FORESTRY AND AGRICULTURAL TEST SITES IN NORTHERN CALIFORNIA (SPOT IMAGE CORPORATION, 1983).

Nominal Film Product Scale = 1:24,000
Film Format = 21 by 53cm
Area Imaged = 5 by 12km
Nominal Ground Resolution = 10 metres (B2A)
20 metres (SWIR1A)

Product	Spot Band/Filtration Blue	Green	Red	Spectral Region
1	B1	B2A	B3	Green, Red, Photo IR
2	B2A	B3	SWIR1A	Red, Photo IR, Mid-Reflectance IR
3	B2A	B3	SWIR2	Red, Photo IR, Far-Reflectance IR
4	B1	B2A	SWIR1A	Green, Red, Mid-Reflectance IR
5	B3	SWIR1A	SWIR2	Photo IR, Mid-Reflectance IR, Far-Reflectance IR

Spot Band		Spectral Sensitivity (μm)
B1	Green	0.50 - 0.59
B2A	Red	0.61 - 0.68
B3	Photo IR	0.79 - 0.89
SWIR1A	Mid-Refl. IR	1.55 - 1.75
SWIR2	Far-Refl. IR	2.08 - 2.35

California which were of interest to these investigators (Figure 1). The Plumas Forestry Site (#74) is located in Plumas County approximately 330 kilometres northeast of San Francisco; the Davis Agricultural Site (#76) is located in Yolo County, adjacent to and including the city of Davis, approximately 120 kilometres northeast of San Francisco.

The Plumas Forest Study Site has been defined as part of the Sierra Nevada Mixed Conifer Forest cover type by the Society of American Foresters (1980). The site contains a diversity of commercially important tree species occurring as pure stands of red and white fir (*Abies magnifica* and *A. concolor*, respectively) and stands of mixed conifers dominated by ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and/or sugar pine (*P. lambertiana*). Several other resource categories are also prevalent and include low density Jeffrey pine (*P. jeffreyi*) stands, hardwood stands on wet and dry slopes, dense shrub fields, wet and dry meadows, bare soil, granitic rock outcrops, and large water bodies.

FIG. 1. Location of the Plumas Forestry and Davis Agricultural SPOT Simulation sites in California, U.S.A.

The simulated SPOT data of the Plumas Forestry Site were acquired on 25 June 1983. In addition to these data, aerial oblique photography, ground photography, and ground data were acquired at selected sites previous to and coincident with the overpass.

The Davis Agricultural Study Site is characterized by the intensive cultivation of a variety of crops on highly productive soils. This area was selected for study because of the diverse cropping practices and small field sizes. In this area, there are wide variations in percent plant cover, irrigation practices, field boundary conditions, and field size. Major resource categories present when the simulated SPOT data were acquired included tomatoes, corn, alfalfa, irrigated pasture, orchards and vineyards, mature grain and harvested grain residue (stubble), and bare soil.

The simulated SPOT data of the Davis Agricultural Study Site were acquired on 24 June 1983. In support of this acquisition, ground data were collected for a number of fields in the overpass area on 1 July 1983. Aerial oblique photography was also acquired on 16 June 1983 from a light aircraft using 35-mm color film to assist in identifying ground-cover conditions of areas not surveyed by ground crews.

QUANTITATIVE EVALUATION OF SIMULATED SPOT IMAGERY FOR RESOURCE CATEGORY DISCRIMINATION

To evaluate the interpretability of the five film products, 60 test points were allocated to each film product for the six resource categories of interest that were present in the scenes. After referring to image interpretation keys and written descriptions of the categories, image analysts determined which of the resource categories were represented at each point. This testing procedure generated a total of 7800 interpreter responses per test site. The analyst responses were subjected to statistical analyses and summarized using error matrices. The Kappa statistic was used to determine if significant differences existed *between* image types based on the discrimination of the six resource categories (Congalton and Mead, 1983; Congalton *et al.*, 1983). Percent correct and commission error values were used to assess the interpretability of individual image types for discriminating selected resource categories.

Six resource categories were selected in each study site. In

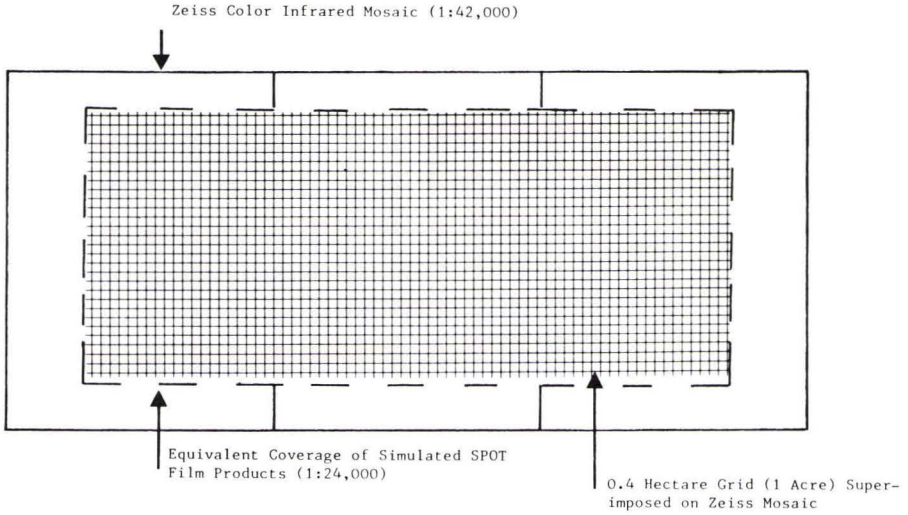

FIG. 2. Example of the sampling grid used in both the Forestry and Agricultural sites for randomly selecting interpretation test plots.

the Plumas Study Site, the categories were conifer, low-density conifer, hardwood, brush, snow, and non-vegetated. In the Davis Study Site the categories were grain, grain stubble, alfalfa, tomato, bare soil, and non-agriculture. These particular categories were selected because they (1) represented important resources of the study sites, (2) were present in sufficient abundance to allow for both training and testing on the five image types without causing undue interpreter bias, and (3) represented the range of spectral variability characteristic of each study site.

Selective photointerpretation keys were constructed for the five film products. These keys, developed for each of the six resource categories in each study site, were used to train a pool of photointerpreters prior to testing.

As defined by the Interservice Commission on Photo Interpretation Keys, a photointerpretation key is reference material designed to facilitate the rapid and accurate identification of features from an examination of their photographic images (Colwell, 1952). All photointerpretation keys are based upon the diagnostic features (tone, color, texture, etc.) of the objects or conditions to be identified as they appear on the photos. Depending on the manner in which the features are organized, two general types are recognized: (1) selective keys are arranged so that the photointerpreter simply selects the example corresponding to the image type he is trying to identify, and (2) elimination keys are arranged so that the photointerpreters follow a step-by-step process that leads to the elimination of all items except the one that he is trying to identify.

We developed selective keys for the five SPOT images of each site because (1) association and location are important image characteristics that the human interpreter must use to identify forest and agricultural categories because of the relatively low spatial resolution of satellite imagery (and simulated satellite imagery); and (2) the primary use of these keys was to familiarize both skilled and unskilled interpreters with the expected spectral responses of the categories on the different image types. The characteristics and ranges of spectral response can be presented most effectively by using selective keys.

For both the Plumas and Davis Study Sites, ten test plots (0.4 hectare) were allocated to each of the six resource categories; this resulted in 60 plots per image type. The 60 plots were randomly located on each image using a a 0.4-hectare (1-acre) sampling grid (Figure 2) in order to minimize "interpreter recall" from image to image. The ground reference data label was assigned to the test plots, and was determined by assessing a combination of ground data and large scale aerial oblique photography, collected within a week of acquisition of the simulated SPOT data, and 1:42,000-scale color infrared aerial photography, collected coincident with the acquisition of simulated SPOT data. To efficiently test and utilize of the original image products, the test plots were transferred to 7.6- by 12.7-cm contact copy prints of each image type and were renumbered in consecutive order.

A pool of 26 semi-skilled and skilled image interpreters from the University of California - Berkeley were given the image interpretation tests over a one-week period. The interpreter pool was divided into five groups, and the sequence in which the images were to be interpreted was randomized with the restriction that all images would be interpreted at each step of a sequence and that all analysts would interpret all image types (Table 2). This randomization process was performed so as to minimize the bias associated with the analysts' increased interpretation skill at later stages of the test.

After the testing was completed, the answer sheets were corrected and error matrices were constructed for each interpreter by film product. The resulting 130 matrices were then aggregated to produce an error matrix for each product (Table 3) with 1560 analyst responses per image type.

Percent correct, percent omission error, and percent commission error were calculated for the error matrices for all cover types and individual cover types as follows:

$$\text{Percent Correct} = \frac{\text{number of correct interpretation responses for a resource category}}{\text{total number of that resource category present in the sample}} \times 100$$

$$\text{Percent Ommission Error} = 1 - \text{Percent Correct}$$

$$\text{Percent Ommission Error} = \frac{\text{number of incorrect interpretation responses for a resource category}}{\text{total number of that resource category indicated by the interpreter(s)}} \times 100$$

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

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

where N = total number of interpreter responses.

The Kappa statistic, which is a non-parametric measure of agreement between the reference data ("ground truth") and image interpretation labels, was used to rank the error matrices. The rankings were considered to be significantly different, or

TABLE 2. METHOD OF ALLOCATING IMAGE ANALYSTS TO IMAGE INTERPRETATION SEQUENCES.

Analyst Numbers	Group Number	Film Product Number	Simulated Spot Bands
1- 6	1	I	B1-B2A-B3
7-11	2	II	B2A-B3-SWIR1A
12-16	3	III	B2A-B3-SWIR2
17-21	4	IV	B1-B2A-SWIR1A
22-26	5	V	B3-SWIR1A-SWIR2

Plumas Forestry Study Site						Davis Agriculture Study Site					
	Image interpretation Sequence						Image interpretation sequence				
Group	1	2	3	4	5	Group	1	2	3	4	5
1	II	IV	III	I	V	1	I	III	II	V	IV
2	III	II	V	IV	I	2	II	IV	III	I	V
3	IV	V	I	III	II	3	III	II	V	IV	I
4	V	I	IV	II	III	4	IV	V	I	III	II
5	I	III	II	V	IV	5	V	I	IV	II	III

TABLE 3. EXAMPLE OF AN ERROR MATRIX FROM THE DAVIS AGRICULTURAL STUDY SITE FOR SIMULATED SPOT IMAGE B2A-B3-SWIR2.

	Reference Data						Total	Percent Commission Error
P.I. Results	1	2	3	4	5	6		
1. Grain	256	6	5	1	11	3	282	9
2. Grain Stubble	0	249	0	0	0	15	264	6
3. Alfalfa	1	0	250	14	0	4	269	7
4. Tomatoes	0	0	5	226	19	3	253	11
5. Bare Soil	0	5	0	19	225	6	255	12
6. Non-agriculture	3	0	0	0	5	229	237	3
Total	260	260	260	260	260	260	1560	
Percent Correct	98	96	96	87	87	88		
Percent Omission Error	2	4	4	13	13	12		

Total Correct = 1435
Total Error = 125
Estimated Kappa = .904

Total Percent Correct = 92.0
Total Percent Error = 8.0
Estimated St. Dev. = .008

not, based on the values obtained through the use of the following relationship:

$$Z \sim \text{Delta Kappa} = \frac{|[\text{Kappa}_i - \text{Kappa}_j]|}{[\text{Variance Kappa}_i + \text{Variance Kappa}_j]^{1/2}}$$

for which Delta Kappa approaches the normal Z distribution. If the Delta Kappa calculated between two matrices exceeded 1.96, we concluded that the Kappa values were significantly different at the 95 percent confidence level; if the calculated values were less than 1.96, we concluded that the Kappa values were not significantly different and that the image types represented by those matrices were equally interpretable.

RESULTS AND DISCUSSION

Summaries of the test results for the Plumas Forestry Study Site and the Davis Agriculture Study Site are given in Tables 4 and 5, respectively. In Tables 4 and 5, the results are summarized on the basis of the six resource categories combined (a) and on the individual resource categories for each study site (b). The vertical lines to the right of the image rank number(s) in these tables indicate those image groups that are not significantly different at the 95 percent confidence level based on the Kappa statistic.

PLUMAS FORESTRY STUDY SITE

The two best film products were Images B2A-B3-SWIR1A and B2A-B3-SWIR2, which did not differ statistically. These results are similar to those of Benson and DeGloria (1985), where the best Landsat Thematic Mapper image for this study site was sensitive to the same three spectral regions as Image B2A-B3-SWIR1A. Image B2A-B3-SWIR1A was significantly more interpretable for the conifer and shrub categories, while Image B2A-B3-SWIR2 was more interpretable for the hardwood category. The relatively high percent correct identification (75.8 and 74.4, respectively) and low percent error (24.2 and 25.6, respectively) must be considered as excellent results, particularly when one considers the complexity and diversity of the mixed conifer forest type.

The third best product was Image B1-B2A-SWIR1A, which was sensitive to green, red, and mid-reflectance infrared energy. The major confusions that the interpreters experienced with this product were between similar forest categories: conifer versus low-density conifer; low-density conifer versus non-vegetated; and hardwood versus shrub. By reexamining those test plots for which interpretation errors were high, we discovered that these were the plots that could only be identified reliably from the high resolution Zeiss photography, because they represented transition areas, admixtures, or isolated areas of one category within another.

The lowest ranking film products were Images B3-SWIR1A-SWIR2 and B1-B2A-B3 which were sensitive, respectively, to photographic infrared, mid-reflectance infrared, and far-reflectance infrared; and to green, red, and photographic infrared. These two images were significantly less interpretable than the other three images, both in terms of low percent correct identification (55.1 and 53.1, respectively) and high percent errors (44.9 and 46.9, respectively). These results are contradictory to our experiences with the Landsat-4 Thematic Mapper imagery (Benson and DeGloria, 1985). Although we had expected that Image B3-SWIR1A-SWIR2 would do poorly, because it lacked sensitivity to visible radiant energy, we had expected that Image B1-B2A-B3 would be competitive with Images B2A-B3-SWIR1A and B2A-B3-SWIR2. We suspect that the poor interpretability

TABLE 4. SUMMARY OF FILM PRODUCT RANKINGS FROM THE PLUMAS FORESTRY STUDY SITE SIMULATED SPOT IMAGE INTERPRETATION TESTS. THE VERTICAL LINES TO THE RIGHT OF THE RANK NUMBER(S) INDICATE SIGNIFICANT GROUPINGS OF FILM PRODUCT TYPES AT THE 95 PERCENT CONFIDENCE LEVEL BASED ON THE KAPPA STATISTIC.

a. Based on *six* forest resource categories: (1) conifer, (2) low density conifer, (3) hardwood, (4) brush, (5) snow, and (6) non-vegetated.

Rank	Product Type	Kappa and Significance	Percent Correct -Range-	Percent Correct -Mean-	Percent Error -Mean-
1	B2A-B3-SWIR1A	0.709	60.0 - 90.0	75.8	24.2
2	B2A-B3-SWIR2	0.692	55.0 - 88.3	74.4	25.6
3	B1-B2A-SWIR1A	0.579	53.3 - 85.0	64.9	35.1
4	B3-SWIR1A-SWIR2	0.462	38.3 - 71.7	55.1	44.9
5	B1-B2A-B3	0.438	15.0 - 75.0	53.1	46.9

b. Based on *individual* forest resource categories.

Rank		%C/%CE*	Rank		%C/%CE*
	Conifer			Low Density Conifer	
1	B2A-B3-SWIR1A	79/27	1	B2A-B3-SWIR1A	63/40
2	B1-B2A-SWIR1A	76/30	2	B1-B2A-SWIR1A	59/43
3	B2A-B3-SWIR2	72/40	3	B2A-B3-SWIR2	55/42
4	B3-SWIR1A-SWIR2	45/51	4	B1-B2A-B2	50/41
5	B1-B2A-B3	52/64	5	B2-SWIR1A-SWIR2	53/48
	Hardwood			Brush	
1	B2A-B3-SWIR2	92/12	1	B2A-B3-SWIR1A	67/27
2	B2A-B3-SWIR1A	72/21	2	B2A-B3-SWIR2	48/32
3	B1-B2A-SWIR1A	40/47	3	B1-B2A-SWIR1A	60/51
4	B3-SWIR1A-SWIR2	35/59	4	B3-SWIR1A-SWIR2	58/56
5	B1-B2A-B3	22/56	5	B1-B2A-B3	48/61
	Snow			Non-Vegetated	
1	B2A-B3-SWIR2	97/ 3	1	B2A-B3-SWIR2	82/24
2	B2A-B3-SWIR1A	95/ 3	2	B2A-B3-SWIR1A	79/26
3	B1-B2A-SWIR1A	95/ 4	3	B2-SWIR1A-SWIR2	78/27
4	B1-B2A-B3	92/15	4	B1-B2A-SWIR1A	59/34
5	B2-SWIR1A-SWIR2	63/25	5	B1-B2A-B3	55/39

*%C/%CE = Percent Correct/Percent Commission Error.

TABLE 5. SUMMARY OF FILM PRODUCT RANKINGS FROM THE DAVIS AGRICULTURAL STUDY SITE SIMULATED SPOT IMAGE INTERPRETATION TESTS. THE VERTICAL LINES TO THE RIGHT OF THE RANK NUMBER(S) INDICATE SIGNIFICANT GROUPINGS OF FILM PRODUCTS AT THE 95 PERCENT CONFIDENCE LEVEL BASED ON THE KAPPA STATISTIC.

(a) Based on *six* agricultural resource categories: (1) grain, (2) grain stubble, (3) alfalfa, (4) tomatoes, (5) bare soil, and (6) non-agriculture.

Rank	Product Type	Kappa and Significance	Percent Correct -Range-	Percent Correct -Mean-	Percent Error -Mean-
1	B2A-B3-SWIR2	0.904	83.3 - 100.0	92.0	8.0
2	B2A-B3-SWIR1A	0.792	66.7 - 93.3	82.6	17.4
3	B1-B2A-B3	0.787	65.0 - 95.0	82.2	17.8
4	B3-SWIR1A-SWIR2	0.728	55.0 - 90.0	77.3	22.7
5	B1-B2A-SWIR1A	0.648	46.7 - 85.0	70.7	29.3

b. Based on *individual* agricultural resource categories.

Rank		%C/%CE*	Rank		%C/%CE*
	Grain			Grain-Stubble	
1	B2A-B3-SWIR2	98/ 9	1	B2A-B3-SWIR2	96/ 9
2	B2A-B3-SWIR1A	96/14	2	B2A-B3-SWIR1A	92/ 9
3	B1-B2A-SWIR1A	87/ 5	3	B1-B2A-SWIR1A	92/10
4	B3-SWIR1A-SWIR2	68/10	4	B3-SWIR1A-SWIR2	90/ 9
5	B1-B2A-B3	63/10	5	B1-B2A-B3	94/16
	Alfalfa			Tomatoes	
1	B2A-B3-SWIR2	96/ 7	1	B2A-B3-SWIR2	87/11
2	B1-B2A-B3	81/ 4	2	B1-B2A-B3	84/21
3	B2A-B3-SWIR1A	87/14	3	B2A-B3-SWIR1A	66/24
4	B3-SWIR1A-SWIR2	92/39	4	B3-SWIR1A-SWIR2	57/30
5	B1-B2A-SWIR1A	67/38	5	B1-B2A-SWIR1A	44/52
	Bare Soil			Non-Agriculture	
1	B2A-B3-SWIR2	87/12	1	B2A-B3-SWIR2	88/ 3
2	B3-SWIR1A-SWIR2	83/29	2	B1-B2A-B3	82/ 9
3	B1-B2A-B3	89/35	3	B3-SWIR1A-SWIR2	7/4 4
4	B2A-B3-SWIR1A	81/32	4	B2A-B3-SWIR1A	74/ 8
5	B1-B2A-SWIR1A	58/50	5	B1-B2A-SWIR1A	76/13

*%C/%CE = Percent Correct/Percent Commission Error.

TABLE 6. RANKING OF ALL FILM PRODUCTS BASED ON TEST SEQUENCE. THE VERTICAL TO THE RIGHT OF THE TEST SEQUENCE NUMBERS INDICATE THOSE SIGNIFICANT GROUPINGS OF SEQUENCES AT THE 95 PERCENT CONFIDENCE LEVEL BASED ON THE KAPPA STATISTIC.

	Plumas Forestry Study Site			Davis Agricultural Study Site		
Rank	Test Sequence	Percent Correct	Estimated Kappa	Test Sequence	Percent Correct	Estimated Kappa
1	4	65.5	0.586	5	82.2	0.787
2	5	65.3	0.583	3	81.7	0.781
3	3	65.3	0.583	4	80.4	0.769
4	2	64.9	0.578	1	80.3	0.764
5	1	62.4	0.549	2	79.8	0.758

of Image B1-B2A-B3 was not due to the spectral sensitivity of the bands used nor the lack of information content, but to the enhancement algorithm and subsequent photographic processing which resulted in a dark image product with very low contrast.

DAVIS AGRICULTURAL STUDY SITE

The most interpretable film product for this agricultural area was Image B2A-B3-SWIR2 with an overall percent correct identification of 92. This product was so interpretable that two of the skilled analysts identified all 60 test plots correctly. Without exception, Image B2A-B3-SWIR2 was significantly more interpretable than all others for all of the six agricultural resource categories tested. The largest error that occurred with this product, as with all other image types, was the discrimination between emerging tomato fields and bare soil fields because of the subtle distinction between these two resource categories on all images. In fact, reliable identification of tomatoes could only be made from the interpretation of our large-scale color oblique photography and the Zeiss color infrared vertical photography, and, in some cases, only from the field data.

The second most interpretable group of film products contained Images B2A-B3-SWIR1A and B1-B2A-B3 with overall percent correct identifications of 82.6 and 82.2, respectively. The only significant differences between these two were that Images B2A-B3-SWIR1A was better for interpreting grain and that Image B1-B2A-B3 was better for interpreting tomatoes.

The fourth most interpretable product was Image B3-SWIR1A-SWIR2 with an overall percent correct identification of 77.3 percent. The major confusion that occurred with this film product was between the alfalfa and grain categories. This had not been a major problem with the preceeding three images, each of which had contained a band sensitive to visible red energy.

The poorest image for interpreting these six agricultural categories was Image B1-B2A-SWIR1A with an overall percent correct identification of only 70.7. Just as in the forestry site, the reason for the poor interpretability of this product was the lack of a band sensitive to photographic infrared energy. As with all other product types, the major confusion was between bare soil fields and tomato fields; but, without the photographic infrared sensitivity, the confusion was even greater.

TEST SEQUENCE

The rankings for all film products based on test sequence are given in Table 6 for both test sites. These results show that the order in which the interpreters viewed the image products had no statistically significant effect on their performance. What is of particular importance is that interpreter performance did not *decrease* as the testing progressed. This situation often occurs when the tests are too long and the interpreters become fatigued, or when the imagery being tested is of such poor quality that the interpreters no longer interpret but simply guess. These results, therefore, indicate that the tests were properly designed and conducted and that the imagery was of sufficient quality that the interpreters felt they were able to make conscious decisions concerning the label given to each plot.

FILM PRODUCT EXAMPLES

Plate 1 shows three examples of the simulated SPOT film products compared to the simultaneously acquired aerochrome infrared 2443 aerial photography (far left). Two significant features are annotated at points "A" and "B." The appearance of the alfalfa field at "A" remains unchanged when viewing the film products containing either SWIR1A or SWIR2 spectral bands; the appearance of the golf course at "B," however, changes significantly. By closely examining the color infrared aerial photograph and the film product at the far right of Plate 1, which contains SWIR2 but not the photographic-infrared band (B3), the apparent color difference in the golf course is a result of differential absorption of the mid-reflectance infrared energy and not the photographic infrared energy. There is high reflectance of both photographic *and* mid-reflectance infrared energy from the golf course vegetation, as indicated by the red color on both the aerochrome infrared photo and the B1-B2A-SWIR1A image and the yellow color on the B2-B3-SWIR1A. Though not measured on the ground when the images were acquired, the apparent canopy moisture is higher in the alfalfa field than in the golf course, resulting in the difference in color between the two features on the B2A-B3-SWIR1A image. Due to similarities in plant vigor and growth, however, the reflectance of photographic infrared energy is nearly the same, resulting in the red color for both features on the aerochrome infrared photography.

CONCLUSIONS

As a result of the total 15,600 analyst responses from the forestry and agricultural tests, we conclude that the best film product for interpreting renewable resources in both environments would be Image B2A-B3-SWIR2 or Image B2A-B3-SWIR1A. These two products, which are sensitive to red, photographic infrared, and mid- or far-reflectance infrared energy, produce data from which skilled analysts can extract useful information on a consistent basis. We must stress that photographic infrared must be used in conjunction with either of the longer infrared wavelength bands, for without sensitivity in the 0.79- to 0.89-μm region, the resulting image would be of significantly poorer quality.

In summary, the image analysts were able to accurately discriminate selected forest and agricultural resource categories on simulated SPOT film products, as indicated by the upper ranges of percent correct values achieved in the interpretation tests. If the actual SPOT film products are produced with the same degree of quality, they should prove to be very useful to those organizations which do not have the computer capability for image processing and must rely on image analysis for mapping or stratifying natural resources for inventory and monitoring purposes.

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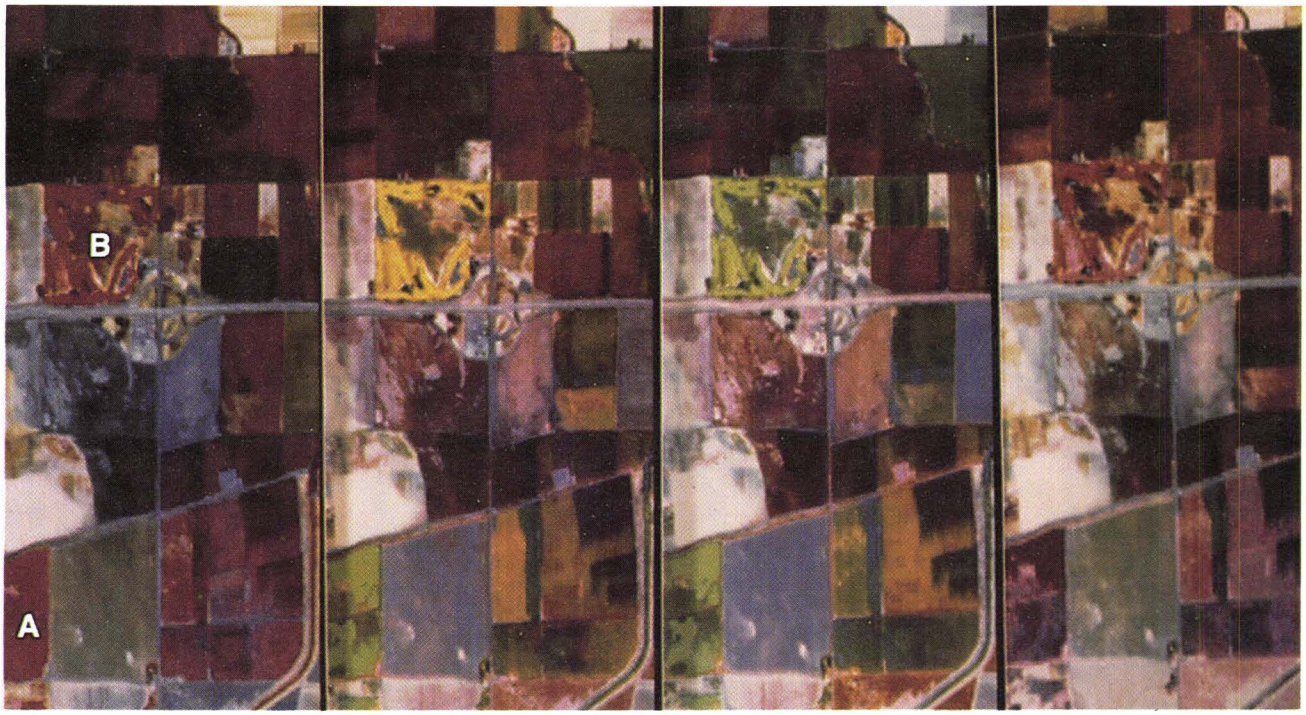

SPECTRAL BANDS:	.500-9.10μm (Aerochorme Infrared)	B2A-B3-SWIR1A	B2A-B3-SWIR2	B1-B2A-SWIR2
FILTRATION:	Wratten 15	(B) (G) (R)	(B) (G) (R)	(B) (G) (R)

PLATE 1. Example of three SPOT film products in comparison to simultaneously acquired aerochrome infrared aerial photography (left). Points "A" and "B" indicate two features which differ in the reflectance of photographic and mid-reflectance infrared energy as a result of plant vigor, growth, and moisture characteristics (see text).

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APPENDIX

Processing Specifications for the Simulated SPOT Film Products

This appendix briefly describes the processing techniques used to create the simulated SPOT film products used in our image interpretation tests. The composite film products containing the best radiometric characteristics ($Ne\Delta p = 0.005$) of the red band, B2A, and the middle reflectance infrared band, SWIR1A, were used for the interpretation testing. All film products were processed by the Laboratoire d'Etudes et de Recherche en Teledetection Spatiale (LERTS), Centre National d'Etudes Spatiales (CNES), Toulouse, France using the following specifications (Podaire, 1985):

- Resampling of the original image to 10 m according to the attitude coefficients provided with the Daedalus AADS1268 multispectral scanner simulator data:
- Generation of 20-m pixels for bands B1(Green), B2(Red), B3(Photo IR), SWIR1, and SWIR2 by averaging the surrounding 2 by 2 pixel array;
- Generation of a 10-m red band (B2A) with an MTF equivalent equal to 15 m and radiometric resolution, $Ne\Delta p$, estimated at 0.005;
- Generation of a 20-m mid-reflectance infrared band (SWIR1A) with $Ne\Delta p = 0.005$;
- Resampling with a coefficient of 0.625 using a cosine law interpretation equaling 6.25 m and 12.5 m for the 10-m and 20-m bands, respectively;
- Tridimensional decorrelation with an exponential coefficient equalizing the variance of all components;
- Application of an isopopulation correspondence law to the decorrelated channels where the distribution function is divided into four areas of equal population with the application of the linear law to these four areas; and
- Photorecording individual spectral bands using a linear density stretch calculated so that 2.5 percent of the pixels fall beyond either extreme of the 0.4 to 2.3 density interval.

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