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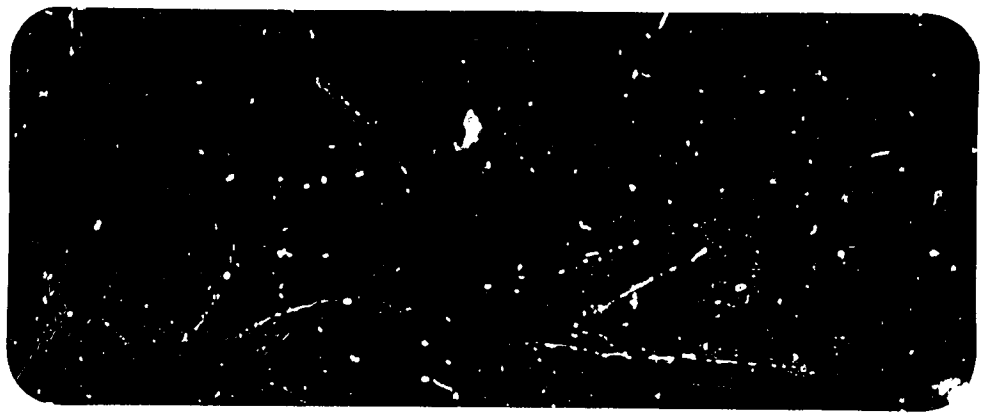

U.S. DEPARTMENT OF AGRICULTURE
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AN EVALUATION OF PHOTOGRAPHIC IMAGERY PARAMETERS RELATING TO AGRICULTURAL INVENTORIES IN THE DOMINICAN REPUBLIC

by

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ABSTRACT

An evaluation of the various imagery parameters of light aircraft 70mm photography, used to inventory major agricultural crops in the Dominican Republic, was conducted. Three film types, black-and-white panchromatic, color and color infrared of scales of 1:30,000, 1:20,000 and 1:10,000 were tested. Four interpreters with a variable degree of experience classified the test fields, based on a previously developed classification key, using monoscopic vision.

Analysis of the results indicated that the interpreter's training should preferably be accomplished using photography selected from the same imagery set used during the main interpretation phase. Results indicates that interpreter's experience played an insignificant role in the photointerpretation performance and that it was inversely proportional to the total interpretation time.

Black-and-white panchromatic photography at a scale of 1:30,000 provided a cost effective classification of the main agricultural crops in the area. "Platanos" and "cultivated land" were the cover/use categories interpreted with the highest accuracy level, both, on black-and-white and color infrared photography.

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At the time this research was conducted, Ger Schultink and Michael A. Karteris were staff members of the Department of Resource Development and Center for Remote Sensing, Michigan State University, respectively.

DISCLAIMER

This report has been reviewed by the U.S. Department of Agriculture, the Agency for International Development, and Michigan State University. Approval does not constitute endorsement or recommendation for use of the trade names of equipment and materials used or cited.

TABLE OF CONTENTS

Page

Abstract i

List of Tables vi

List of Figures. viii

Chapter

1. Introduction 1

1.1 Agricultural Inventory Needs 1

1.2 Research Objectives. 2

1.3 Description of the Study Area. 3

2. Data Acquisition 5

2.1 Imagery Acquisition 5

2.2 Ground Truth Acquisition. 8

3. Study Design and Procedures. 9

3.1 Preparation of Test Materials. 9

3.1.1 Development of the Classification Key. 9

3.1.2 Aids and Equipment Used in Interpretation 10

3.1.3 Interpreters Selection and Training 12

3.2 Interpretation Procedures 13

4. Data Analysis 13

5. Results and Discussion 26

6. Cost Considerations. 42

7. Summary and Conclusions 43

Page

Appendices

A. Classification Key 49

B. Films and Filters. 55

C. Tabulation of the interpretation, by interpreter, for results of the land cover/use categories on panchromatic film of scale 1:30,000 59

D. Correct interpretation and interpretation accuracy of the various land cover/use categories by interpreter, film type and scale (entries in percentages) 62

List of Tables

Table		Page
1.	Crop calendar Moca test site, eastern Cibao valley	6
2.	Percentages of the overall correct interpretation by interpreter, film type and scale and mean performance with standard deviation by film type and scale	15
3.	Interpretation accuracy (mean of the correct interpretation) of the land cover/use categories by film type and scale	20
4.	Illustration of data compilation and intermediate step needed to calculate omission/commission errors and interpretation accuracy for each category and mean performance for a specific film type/scale combination (example shown; panchromatic, scale 1:30,000)	24
5.	Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white panchromatic film of scale 1:30,000	27
6.	Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white panchromatic film of scale 1:20,000	28
7.	Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white panchromatic film of scale 1:10,000	29

Page

8. Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:30,000 30

9. Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:20,000 31

10. Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:10,000 32

11. Matrix with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color film of scale 1:20,000 33

12. Aggregate inventory costs for cane rust damage assessment . . . 44

13. Interpretation time for various individuals related to imagery type and approximate scale 45

14. Training time for various interpreters (minutes) 45

List of Figures

Figure		Page
1.	Location of the test site in the Moca area	4
2.	Camera side-mount for light aircraft photography, 70mm and 35mm systems installed	7
3.	Black-and-white panchromatic and color images of identical areas within the test site	11
4.	Color infrared image showing the identical area as Figure 3	12
5.	Fluctuation of the overall correct interpretation (%) of all land cover/use categories combined for four interpreters, three imagery scales and two film types	16
6.	Mean performance and associated standard deviations for all land cover/use categories and interpreters combined by imagery type and scale	17
7.	Mean performance and associated standard deviations for 1:20,000 scale imagery by film type	18
8.	Interpretation accuracy in (%) for black-and-white panchromatic film by land cover/use category and imagery scale	21
9.	Interpretation accuracy (%) for CIR film, by land cover/use category and imagery scale	22
10.	Interpretation accuracies (%) for various land cover/use categories by film type (scale 1:20,000)	23

1. Introduction

The major emphasis of this research relates to the evaluation of imagery parameters affecting agricultural and natural resources inventory capabilities using aerial survey techniques. The relative effects of film type, filter and scale combinations are determined as they relate to photo-interpretation accuracies for various crops in a test side in the Dominican Republic.

This study has been completed as part of the Comprehensive Resource Inventory and Evaluation System (CRIES) project, which major objective is to evaluate the development potential of the agricultural resources of various host countries, including the Dominican Republic. Remote sensing-based inventory procedures were an important element in the generation of the spatial information base needed to support agricultural and resource assessment efforts.

1.1 Agricultural Inventory Needs

The Dominican economy is agricultural in nature with an employment in this sector accounting for 54.6 percent of the labor force in 1970.[1] The major agricultural crops are sugar cane, coffee, cocoa and tobacco. The total agricultural production has, since 1960, expanded with an average annual rate of about 2.5 percent. This expansion resulted mostly from an increase of the area under cultivation. Since the cultivable land is presently almost completely in active agricultural production, a future growth of the agricultural output will have to originate in improved yields, as a result of improved management and appropriate

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[1]The International Bank for Reconstruction and Development/The World Bank, Dominican Republic. 1978. Latin America and the Caribbean Regional Office, Washington, D.C., U.S.A.

land use policies. Although food production, with an average annual growth of 4.2 percent over the last fifteen years, has outpaced population growth, a large deficit still exists with respect to the country's nutritional needs.

The focus of the CRIES effort was, specifically, to address the development of a spatial data base and the derived information needed to analyze the various agricultural sector policies and their associated impacts on the Dominican economy.

The generation of reliable information on the status and use of the natural resource base can be efficiently obtained using appropriate remote sensing techniques.

1.2 Research Objectives

The major objective of the evaluation of aerial imagery, as described in this report, is closely associated with a comprehensive feasibility study conducted to assess light plane survey techniques as:

a) a tool in assessing the qualitative and quantitative aspects of the natural resource base in areas at the regional level, specifically in relation to major agricultural crops;

b) a low-cost and accurate information gathering method for updating and mapping of the land cover/use status of quarterly survey sample units; and

c) a reference data acquisition method to support Landsat image interpretation for land cover/use mapping efforts.

This objective centers around the capability of light aircraft survey techniques to provide cost-effective and accurate data and the creation of an operational users' capability for imagery interpretation and mapping.

The major factors influencing the utility of photographic imagery for resource inventories are the skill level of the interpreters, the image product (PAN, COL, CIR, etc.) and the image scale.

The evaluation was, therefore, based on the comparison of these three factors and their effect on expected interpretation accuracy for a number of crops present at a selected test site in one of the major agricultural regions in the Dominican Republic.

1.3 Description of the Study Area

The test site is located in the east central portion of the Cibao Valley (Figure 1). It is an area near Moca which consists of level terraces and pediments over water deposited sediments.[2] The climate is generally moist with mean annual rainfall in the 900-1,500 millimeter range,[3] with a period from January through March considered as a distinct dry season. The mean annual temperature is 25°-27° C which is nearly uniform throughout the year. The native vegetation[4] is estimated to have consisted of savannah and subtropical broadleaf forest types. It is an extremely productive area, well suited for intensive agricultural. Major crops consist of plantains, yucca, sweet potatoes, kidney beans, coffee, tobacco and corn. The terrain is generally flat with gently slopes. Its climate can support rainfed crops, however, some irrigation can be practiced with increased yield. The topsoil

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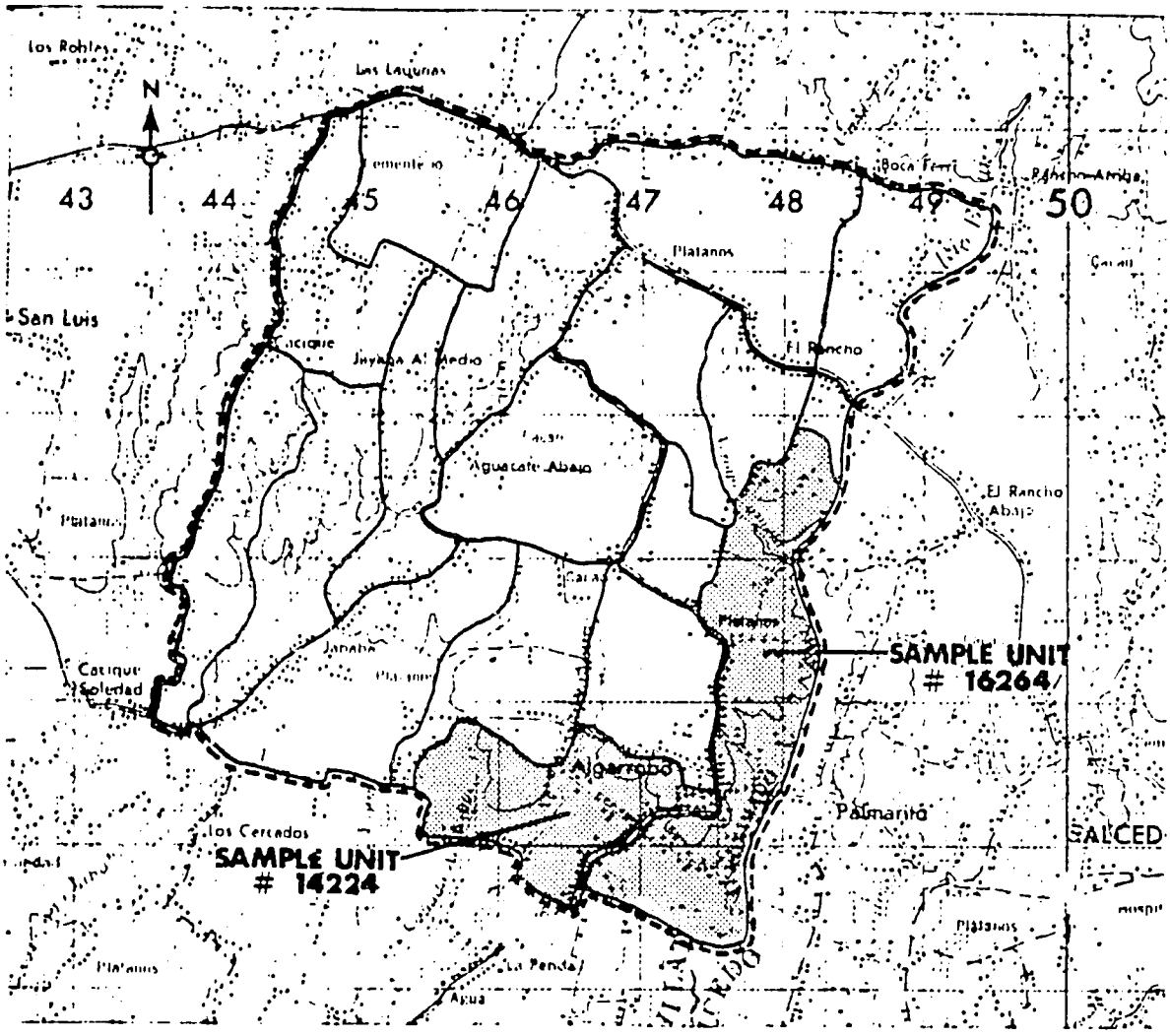
[2]Arens, P.L. et al. 1976. "Republica Dominicana: Diversificacion y Aumento de la Produccion Agricola en el Valle del Cibao. CNIECA, San Cristobal, RD.

[3]CRIES, 1977. Land Resource Base Report 77-1, USDA, AID and Michigan State University (mimeographed).

[4]Holdridge, L.R. 1967. Life Zone Ecology, Revised Edition. Tropical Service Center, San Jose, Costa Rica.



LEGEND

----- Count Unit Outline

_____ Sample Segment Outline

Sample Units for which ground survey data are obtained

0 1 KILOMETERS

Figure 1. Location of the test site in the Moca area.

is very fertile and contains a high percentage of organic matter. The planting/harvesting period for the major crops in the area are summarized (Table 1).

2. Data Acquisition

Primary data acquisition was carried out during two periods. The aerial photography and related ground truth was obtained during March, 1979 and a follow-up ground truth verification (after imagery interpretation) was done in September of that year. The main objective of the second ground survey was to verify the interpretation of certain fields for which a positive identification could not be made as a result of growing stage during the photo acquisition. This was done mainly by contacting landowners in the area.

2.1 Imagery Acquisition

Test site photography consisted of 70mm color infrared (CIR) (Kodak Aerochrome Infrared film 2443), color (Kodak Aerochrome MS 2448), and black-and-white panchromatic (Kodak Plus-X Aerographic 2402) transparencies.[5] The black-and-white imagery was in a negative form. The photography was obtained between 10 and 11:30 a.m., using two Hasselblad 500 EL/M cameras with an 80mm focal length lens.

The 70mm photographs were acquired from a T-41 aircraft provided by the Dominican Air Force. A camera platform was used, mounted on the outside of the aircraft (Figure 2) which accommodated 70mm or 35mm camera systems with a 70 to 400 exposure capability. The camera mount allowed for in-flight platform leveling using three spring-mounted screws. The actual camera orientation could

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[5]See Appendix B for a more detailed description of the various film types and filter combinations used.

Table 1. Crop calendar Moca test site, eastern Cibao valley

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. *Musa* sp.												
Platanos			———	———	———			———	———	———		
Plantains	- - -	- - -			- - -		- - -	- - -		- - -		
2. *Manihot* sp.												
Yucca		———	———	———	———		———	———		———		
Cassava	- - -	- - -	- - -				- - -	- - -	- - -			- - -
3. *Ipomoea batatas*												
Sweet potatoes		———	———	———					———	———	———	
Batata		- - -	- - -	- - -		- - -	- - -	- - -				
4. *Phaseolus vul.*												
Kidney beans	———		———	———	———			———	———	———	———	———
Habichuelas		- - -	- - -	- - -	- - -	- - -	- - -	- - -		- - -	- - -	
Red/Rojo			———	———	———		———	———				
Black/Negro						- - -	- - -	- - -		- - -	- - -	
5. *N. tabacum*												
Tobacco	———									———	———	———
tabaco	- - -	- - -	- - -	- - -	- - -	- - -						
6. *Zea mays*												
Corn			———	———	———				———	———	———	
Maiz	- - -	- - -	- - -				- - -	- - -	- - -			

——— Planting period

- - - Harvesting period

Source: Secretaria de Estado de Agricultura, 1976. Estudio del Efecto del Cambio en la Epoca de Siembra Sobre los Rendimientos e Ingresos Brutos en la Produccion de Algunos Cultivos en la Republica Domenicana. Publicaciones Administracion Rural No. 6. Santo Domingo, Republica Dominicana.

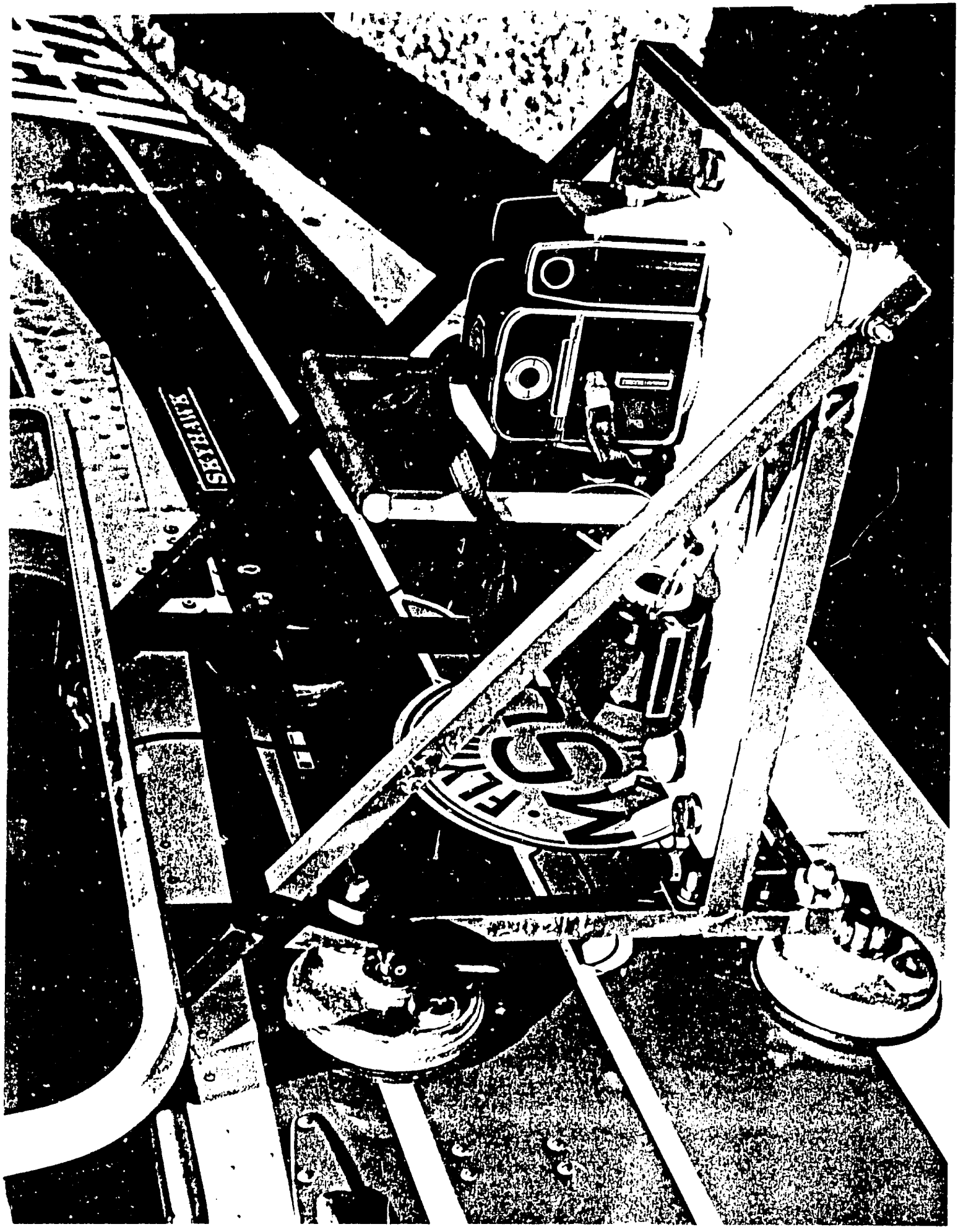

Figure 2. Camera side-mount for light aircraft photography, 70mm and 35mm systems installed.

be adjusted by rotating the cameras in the platform to offset or reduce crab, providing, therefore, better photo coverage along flight lines. The cameras were equipped with a motor driven film advance mechanism that could be controlled remotely. An intervalometer can be used to provide appropriate frame spacing and overlap to allow for stereoscopic coverage. Typical operating altitudes cary from 305m (1000') to 3050m (10,000') ASL.[6] The 70mm camera, equipped with an 80mm lens, provides a ground coverage of 105 x 105m at a scale of approximately 1:3,810 at 305m AGL;[7] and coverage of 2096 x 2096m at a scale of 1:38,099 at 3050m AGL.

2.2 Ground Truth Acquisition

During the first week of March, 1979, just prior to the photo acquisition, the Moca test site was visited. A topographic base map (scale 1:50,000) and black-and-white aerial photography (scale 1:40,000) was used to identify numerous fields and associated crops. The ground truth consisted of written descriptions of the crop (intercropping) types, stage of growth and an identifier code used to link the field information with the field boundaries delineated on a black-and-white photo mosaic covering the area. This information was later used to establish an image interpretation key for the various crops.

Following the initial photo interpretation during early summer of 1979, a second field trip was made, with Dominican counterparts, on August 29, to verify some of the interpretation.

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[6] ASL stands for Above Sea Level.

[7] ASL stands for Above Ground Level.

3. Study Design and Procedures

3.1 Preparation of Test Materials

Before the actual interpretation of the various fields included in the test, some material was prepared to aid in the interpretation process. This material contributed to the understanding of the role of various key elements in the interpretation process and their significance in discriminating between the various land cover/use categories contained within the Moca area. This understanding was particularly needed to provide the various interpreters with a basic insight in the various cropping practices and the appearance of the various categories on different imagery types and scales.

3.1.1 Development of the Classification Key

The availability of a photo interpretation key is an essential and crucial element in any crop classification procedure using aerial photography. During the development of the classification key (Appendix A) special care should be taken to identify object features like density, size, shape, assemblage, appearance, texture, tone, etc. to be used in supporting large to medium scale (1:10,000 - 1:30,000) photo interpretation. The classification elements should be well defined to ensure the use of relative easily identifiable characteristics as the basis of the classification process using various film types and imagery scales.

The development of an interpretation key was an essential part of the imagery evaluation procedure. Ancillary information such as crop calendar data, ground observations and knowledge regarding cultivation practices can provide important information to assure that the utility of the elements identified in the interpretation key is more optimal in discriminating between crop/cover types. A comprehensive photo interpretation key can compensate to a large degree for the interpreter's lack of experience.

The photo interpretation key developed, was intended for use in combination with all film types and image scales and included the primary subdivision in classes; agricultural land use and natural vegetation. Agricultural land uses were broken down by the major crops in the area; platanos (plantains), yucca (cassava), tobacco (tabaco), sweet potatoes (batatas) and two rest categories; other crops and land in cultivation. Other crops include crops of minor importance while land in cultivation refers to arable land without identifiable crop cover. The natural vegetation category comprises forest, shrub and herbaceous ground cover.

3.1.2 Aids and Equipment Used in Interpretation

A training set was developed to familiarize interpreteres with the appearance of crops on the aerial imagery and to enhance their ability to classifying fields within the test site. The training set consisted of:

a. Imagery set for an identical area within the test site consisting of transparencies of the various film types tested (the black-and-white imagery was reproduced from the original negatives) at scale 1:20,000 (Figure 3 and 4);

b. A set of 35mm color slides with examples of the appearance of the various categories obtained during the first ground truth collection;

c. A mylar overlay with delineated field boundaries and crop classification codes for all categories; and

d. A copy of the photo interpretation key for all image types.

To secure proper field identification included in the interpretation test, registered overlays were developed with field outlines and sequence codes.

To simulate a hypothetical situation with minimal photo interpretation equipment availability, it was decided to allow the use of simple, low-cost magnifiers of 7 to 10X power and a small light table. Also, interpretation was

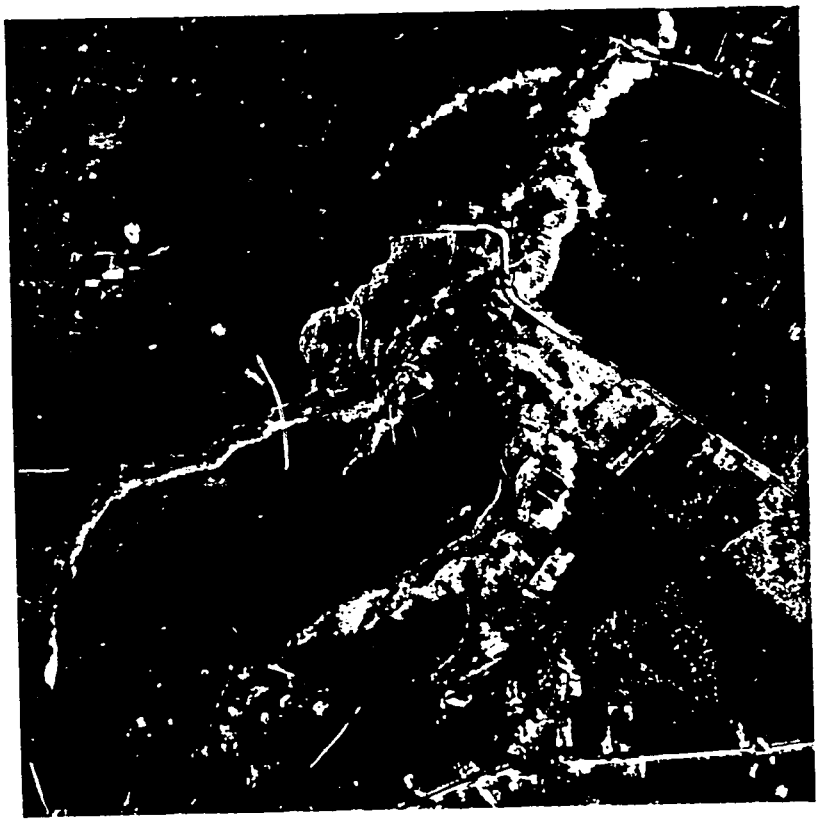

Figure 3. Black-and-white panchromatic and color images of identical areas within the test site. (original imagery in color)

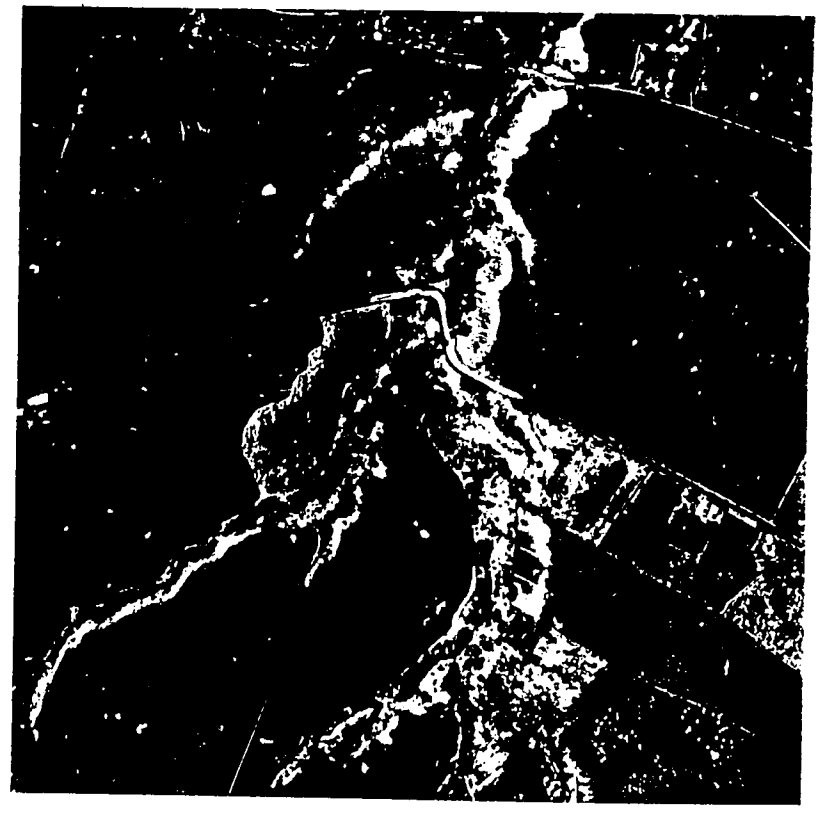

Figure 4. Color infrared image showing the identical area as Figure 3. (original image in color)

restricted to monoscopic vision. Since stereoscopic vision, which requires the acquisition of a larger number of images, appeared to contribute marginally to the improvement of the interpretation of the test site land cover/use categories.

To optimize the interpretability of 70mm imagery in this mode, a small mask restricting light transmittance to the area contained within the image frame, proved to be very useful.

3.1.3 Interpreters Selection and Training

To obtain information about the variation in interpretation results between individuals and to relate this to the level of experience, interpreters with different experience level were selected. The first interpreter (A) had, except for some minor training as indicated below, no interpretation experience. Interpreter B had

minimal experience, whereas C and D were more experienced interpreters. Interpreter D had some additional in-county exposure to the phenology of the various crops.

All four individuals were trained for 1.5 hour and were briefed on the study objectives and the relationship to on-going CRIES remote sensing activities in the Dominican Republic. The training provided mainly exposure to the appearance of all classification categories on the various film types using 1:20,000 scale imagery.

3.2 Interpretation Procedures

The interpretation was carried out according to a predefined, individual time schedule with intervals of 2-3 days. The time gap between the interpretation of the various imagery sets was intended to reduce possible bias during consecutive interpretation efforts. For the same reason, the interpretation scheduling was sequenced from small to medium to large scale imagery and from black-and-white to color to color infrared film type. This sequence was chosen to decrease the degree of assumed interpretation difficulty and to minimize the possible use of prior knowledge in the interpretation process. A time limit of two hours was set for the interpretation of all (74) fields on every imagery (type and scale combinations) tested.

4. Data Analysis

After completion of the interpretation of all imagery sets (film types and scales) a comparison was made with the initial (verified) interpretation of the same 74 fields. It was assumed that the original interpretation for all fields was 100 percent correct (especially since minor discrepancies had been resolved during the second field checking procedure).

Tables of the interpretation results were compiled (an example is given in Appendix C) for all combinations of interpreter, film type and scale, including the total number of correct/incorrect classified fields. The percentage of the overall interpretation accuracy was also calculated and included in the table. In formula:

$$\underline{\text{Overall correct interpretation}}\ (\%) = \frac{\text{total number of fields of ALL land cover/use categories correctly classified by EACH interpreter, by film type and scale}}{\text{total number of all fields subject to classification}} \times 100$$

A summary of these interpretation results (percentages) is presented including also the mean performance[8] (Table 2). Graphical presentations of Table 2 are presented in Figure 5 - illustrating the overall correct interpretation by interpreter, film type (black-and-white and CIR) and scale, Figure 6 - mean performance by film type and scale, and Figure 7 - mean performance for 1:20,000 scale imagery by film type.

The next step in the analysis was to compile information on the interpretability of the various land cover/use categories, by film type and scale. Additional tables (see example in Appendix D) were compiled from the original data to present the correct interpretation[9] of the various land cover/use categories by interpreter,

---

$$^{8}\underline{\text{Mean performance}}\ (\%) = \frac{\text{total number of fields of ALL land cover/use categories correctly classified by ALL interpreters combined, by film type and scale.}}{\text{total number of fields subject to classification X the number of interpreters.}} \times 100$$

or the mean of the interpreters' overall correct interpretations.

$$^{9}\underline{\text{Correct interpretation}}\ (\%) = \frac{\text{number of fields of a CERTAIN land cover/use category classified by EACH interpreter, by film type and scale.}}{\text{total number of fields assigned to the land cover/use category}} \times 100$$

Table 2. Percentages of the overall correct interpretation by interpreter, film type and scale and mean performance with standard deviation by film type and scale.

Interpreter	Black-and-White			Color Infrared			Color	Mean overall correct interpretation
	1:30,000	1:20,000	1:10,000	1:30,000	1:20,000	1:10,000	1:20,000	
A*	75.7	81.1	78.4	82.4	86.5	86.5	85.1	82.2
B	74.3	79.7	81.1	85.1	91.9	87.8	90.5	84.3
C	78.4	78.4	77.0	83.8	86.5	93.2	82.4	82.8
D	79.3	82.4	81.1	83.8	91.9	89.2	87.8	85.1
Mean performance	76.9	80.4	79.4	83.8	89.2	89.2	86.4	
Standard deviation	2.3	1.7	2.0	1.1	3.1	2.9	3.5	

*Experience level of interpreters increases from A to D.
A-no experience, B-medium degree of experience, C-high degree of experience, D-as C, plus additional in-country experience.

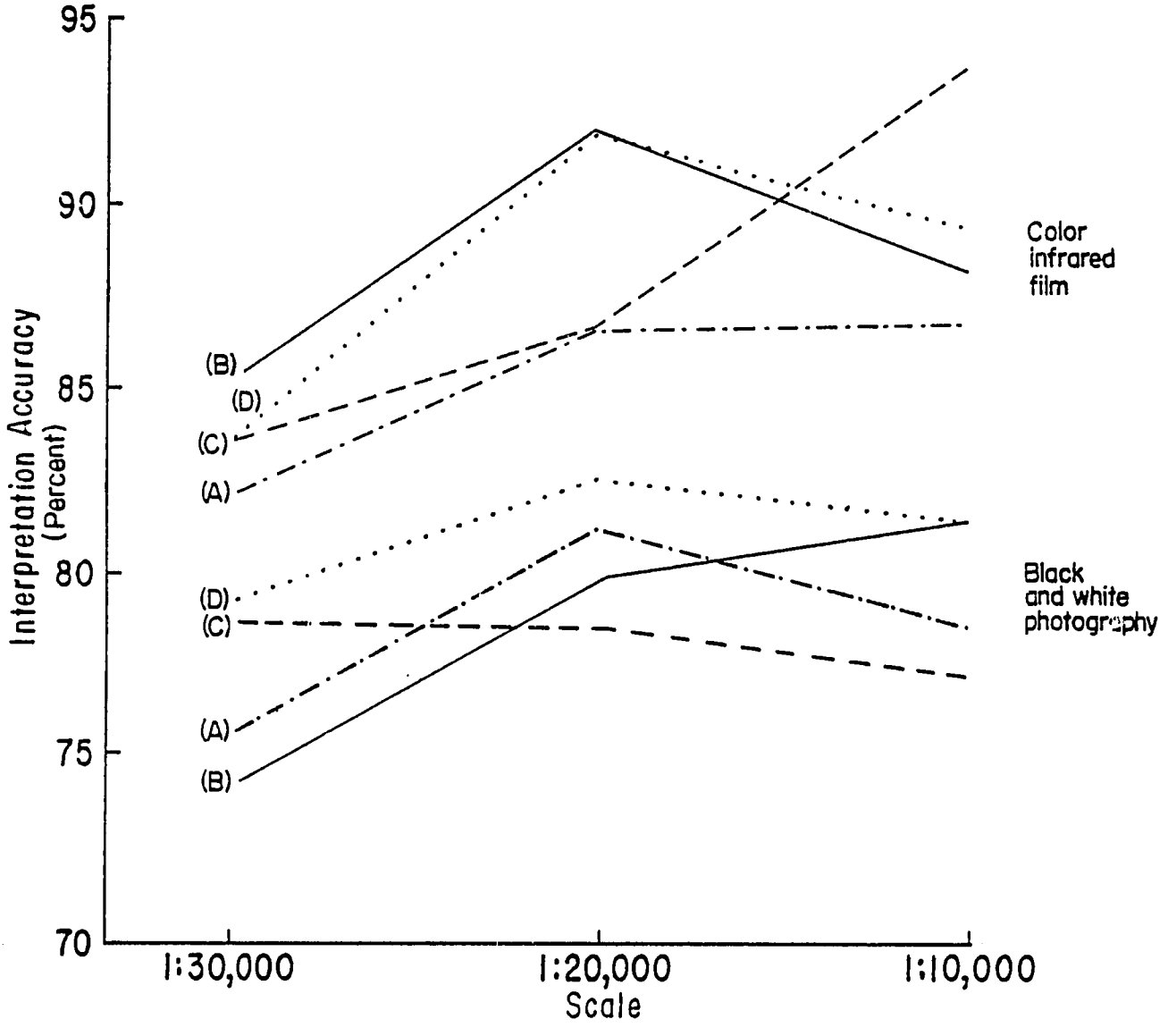

Figure 5. Fluctuation of the overall interpretation accuracy (%) of all land cover/use categories combined for four interpreters, three imagery scales and two film types.

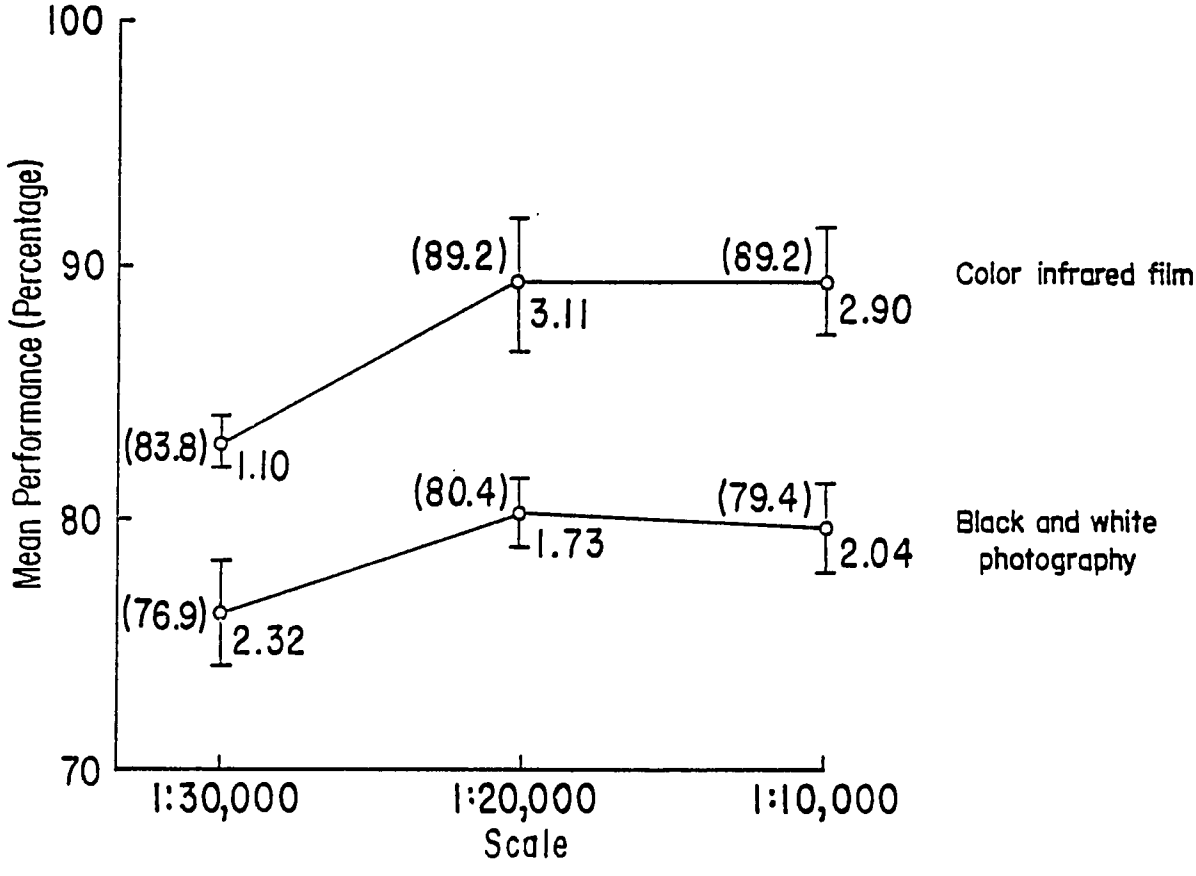

Figure 6. Mean performance and associated standard deviations for all land cover/use categories and interpreters combined by imagery type and scale.

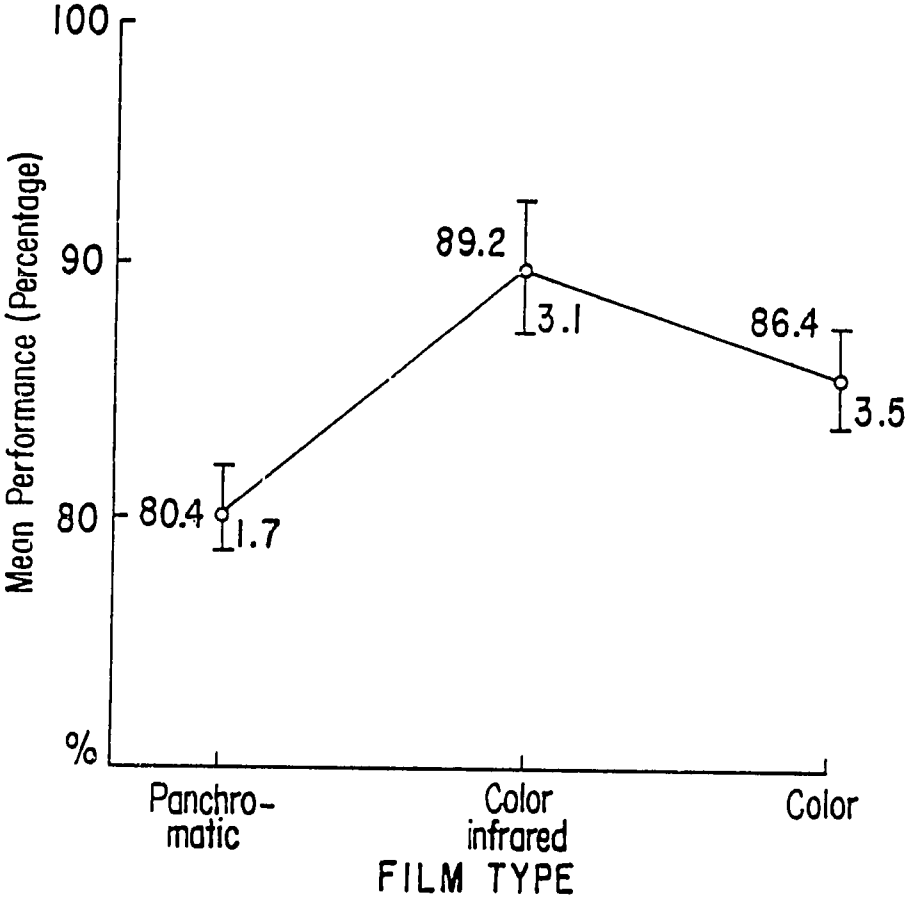

Figure 7. Mean performance and associated standard deviations for 1:20,000 scale imagery by film type.

film type and scale. The mean of the correct interpretation (also called interpretation accuracy) was also calculated. Results of the interpretation accuracies by category are summarized (Table 3).

Various graphical presentations were derived from Table 3 indicating interpretation accuracies by various crops and scales for black-and-white panchromatic (Figure 8) and color infrared (Figure 9) imagery. The next graph (Figure 10) represents the interpretation accuracies for the various land cover/use categories by film type (PAN, color and color infrared) at the identical scale (1:20,000).

Subsequently the interpretation performance relating to the classification accuracy (omission and commission errors) of the various land cover/use categories was calculated for all interpreters combined using the data of the initial tables (Appendix C). An intermediate step in this process was the compilation of tables similar to Table 4 which is shown only as an example.

The following formulas were used to calculate the factors contained in these tables:

a. Omission error for category Y (%) (Type I error) =

$$= \frac{\text{number of fields in category Y incorrectly assigned to other land cover/use categories by all interpreters combined}}{\text{total number of fields}^{10} \text{ in land cover/use category Y}} \times 100$$

b. Commission error for category Y (%) (Type II error) =

$$= \frac{\text{number of fields of other categories incorrectly assigned to category Y by all interpreters combined}}{\text{total number of fields}^{11} \text{ assigned to category Y}} \times 100$$

---

[10] Total number of fields in land cover/use category Y is known in advance (number of field in category Y times the number of interpreters) or it can be calculated as the sum of the row values of category Y (Ground total).

[11] Total number of fields assigned to category Y is calculated by adding all fields within the column for category Y (Interpretation total).

Table 3. Interpretation accuracy* (mean of the correct interpretation) of the land cover/use categories by film type and scale.

Land cover/use	Black-and-White			Color Infrared			Color
category	1:30,000	1:20,000	1:10,000	1:30,000	1:20,000	1:10,000	1:20,000
Platanos	91.7	93.5	92.0	94.4	100.0	97.0	98.1
Yucca	79.4	75.0	84.6	83.8	80.9	78.8	76.5
Tobacco	35.0	55.0	68.7	35.0	70.0	75.0	70.0
Sweet Potatoes	62.5	87.5	81.3	93.7	100.0	100.0	100.0
Other crops	68.7	68.7	75.0	56.2	56.2	81.3	69.1
Cultiv. land	72.7	84.1	68.2	97.7	100.0	100.0	90.9
Nat. vegetation	62.5	58.3	66.2	62.4	79.1	82.4	74.9

*Expressed in percent.

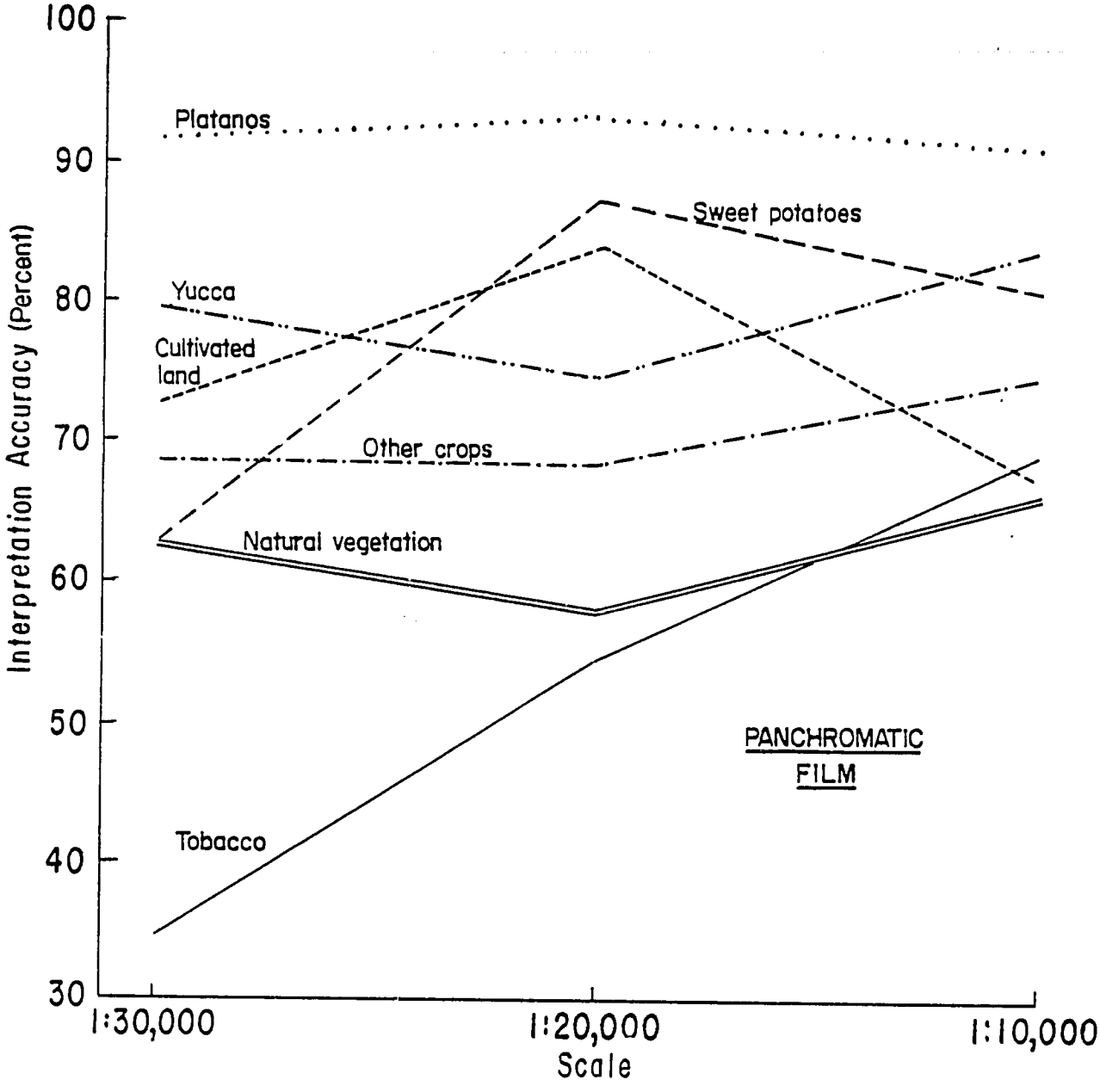

Figure 8. Interpretation accuracy in (%) for black-and-white panchromatic film by land cover/use category and imagery scale.

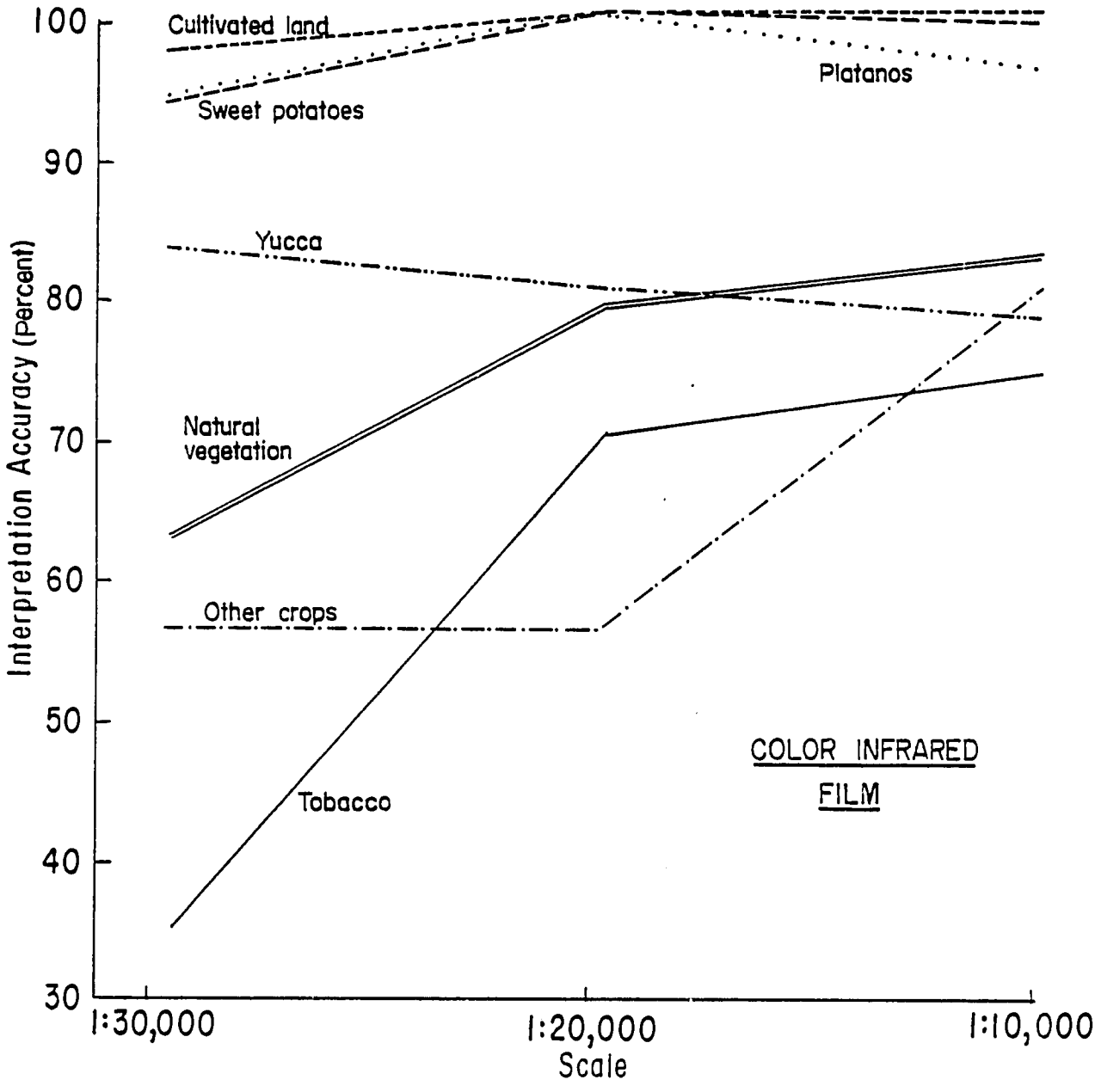

Figure 9. Interpretation accuracy (%) for Color Futra-red film, by land cover/use category and imagery scale.

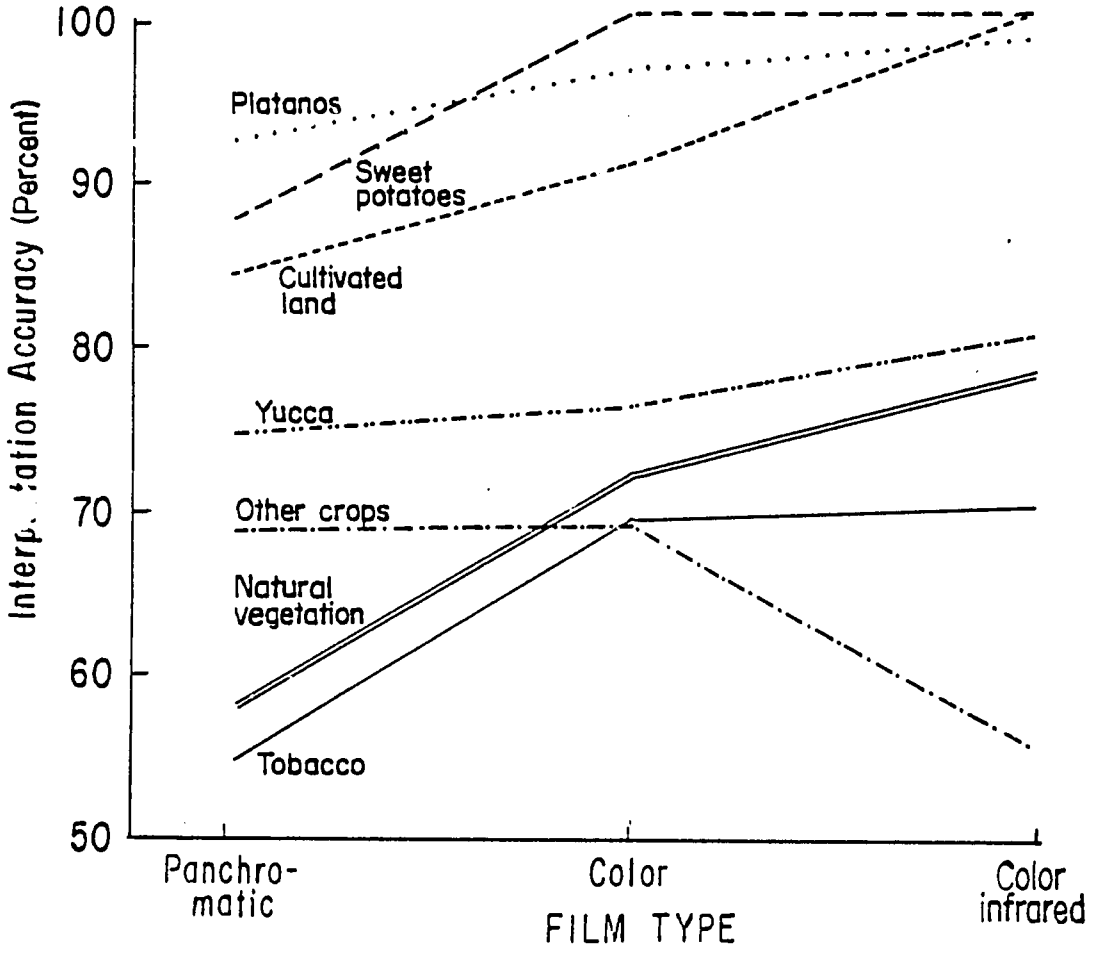

Figure 10. Interpretation accuracies (%) for various land cover/use categories by film type (scale 1:20,000)

Table 4. Illustration of data compilation and intermediate step needed to calculate omission/commission errors and interpretation accuracy for each category and mean performance for a specific film type/scale combination (example shown; panchromatic, scale 1:30,000).

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Ground Total	Omissions Absolute Values	Omissions %	Interpretation Accurary %
1A*	99		1	1	1	5	1	108	9	8.3	91.7
1B	1	54	2	2	1	8		68	14	20.6	79.4
1C	6	6	7			1		20	13	65.0	35.0
1D		1	3	10	2			16	6	37.5	62.5
1E	1	2		1	11	1	16	5	32.2	68.8	
1F		3	3	1	4	32	1	44	12	23.3	72.7
2		3		3	2	1	15	24	9	37.5	62.5
Interpretation Total	107	69	16	18	21	48	17	296			
Absolute Value	8	15	9	8	10	16	2		68		
%	7.5	21.5	56.2	44.4	47.6	32.6	12.5				
Mean Performance %	77.0										

*1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D-Sweet Potatoes, 1E=Other Crops, 1F=Cultivated Land, 2=Natural Vegetation

c. Interpretation accuracy for category Y (%) =

$$= \frac{\text{number of fields of category Y correctly interpreted by all interpreters combined}}{\text{total number of fields in land cover/use category Y}} \times 100$$

(the interpretation accuracy which is the mean value of the correct interpretation can also be found by subtracting the omission error for category Y from 100).

In Table 4 the matrix, 1A through 2, indicates the absolute total number of fields correctly classified by land cover/use category (all interpreters combined) along the diagonal (e.g. 99 fields for platanos, category 1A; 54 for yucca, category 1B, etc.). The other elements of the matrix contain the absolute values associated with the frequency of classification errors occurring for a specific category.

In order to determine the omission error (%) for a specific category (e.g. 1A), one takes the total number of fields known to be platanos (108=27 fields X 4 interpreters) and calculates the percentage of fields incorrectly assigned to different categories $\frac{9}{107} \cdot 100 = 8.3$ percent.

For commission error (e.g. category 1A); 8 fields were incorrectly assigned to this category, by all interpreters combined, from the total of 107; thus the commission error (%) is $\frac{8}{107} \cdot 100 = 7.5$ percent.

Interpretation accuracy can be calculated in two ways;

a. By dividing the correctly classified number of fields of a certain land cover/use category by the total number of fields for that category; e.g. for category 1A $\frac{99}{108} \cdot 100 = 91.7$ percent or,

b. By subtracting the omission error (percentage) from 100; e.g. for category 1A, 100 - 8.3 = 91.7 percent.

The mean performance for all interpreters combined is calculated by taking the total number of fields (74 X 4) subtracting the total (omission or commission) error, and prorating this difference to the total; $\frac{296 - 68}{296} \cdot 100 = 77.0$ percent.

The results of these calculations for various film/scale combinations are summarized (Tables 5 through 11). Diagonally the interpretation accuracies are indicated in percentages, whereas, the other matrix row locations refer to the omission errors for the various crops. The tables indicate also the commission errors for the various crops as well as the mean performance.

5. Results and Discussion

The discussion of the results was divided into two general categories. At first, the various land cover/use categories were combined. Later the categories were studied individually. The analysis was used to compile information about the interpreters' overall correct interpretation, the contribution of all possible combinations of film type and scale on the overall interpretation performance and interpretability of the various land cover/use categories, and the contribution of the various film types on these parameters. Finally, a detailed analysis of interpretation errors for each land cover/use category by film type/scale combination, was conducted.

The highest mean overall correct interpretation (85.1 percent) was obtained by the most experienced interpreter (D), whereas the lowest percentage (82.2) was obtained by the interpreter (A) without experience (Table 2). The moderately experienced interpreter (C); with no knowledge of the study area or crops obtained a score which differed by only 0.6 percent from the inexperienced interpreter. The difference of only 2.9 percent between the two extreme values of the mean overall correct interpretation, and the other small fluctuations among the interpreters' average results indicate that the interpreter's previous experience played an insignificant role in his/heer photointerpretation performance. These results suggest that after some minimal but careful training, even an unexperienced or

Table 5. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white Panchromatic film of scale 1:30,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	91.7		.9	.9	.9	4.6	.9	8.3	91.7
1B	1.5	79.4	2.9	2.9	1.5	11.8		20.6	79.4
1C	30.0	30.0	35.0			.5		65.0	35.0
1D		6.3	18.7	62.5	12.5			37.5	62.5
1E	6.3	12.3		6.3	68.8	6.3		31.2	68.8
1F		6.8	6.8	2.3	9.1	72.7	2.3	27.3	72.7
2		12.5		12.5	8.3	4.2	62.5	37.5	62.5
Commissions	7.5	21.7	56.2	44.4	47.6	32.6	12.5		
Mean Performance	77.0								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 6. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white Panchromatic film of scale 1:20,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	93.6				1.8	1.8	2.8	6.48	93.6
1B		75.0	7.3	1.5	10.3	5.9		25.0	75.0
1C	5.0	15.0	55.0		20.0	5.0		45.0	55.0
1D		6.2		87.5		6.3		12.5	87.5
1E	6.2	6.2	18.8		68.8			31.2	68.8
1F		6.8			9.1	84.1		15.9	84.1
2	4.2	4.2		12.5	12.5	8.3	58.3	41.7	58.3
Commissions	2.9	15.0	42.1	22.2	64.5	21.3	5.6		
Mean Performance	80.6								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 7. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of black-and-white Panchromatic film of scale 1:10,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	92.0		2.0		4.0	1.0	1.0	8.0	92.0
1B		84.7		1.9	9.6	1.9	1.9	15.3	84.7
1C		12.5	68.8		18.7			31.2	68.8
1D		6.2	12.5	81.3				18.7	81.3
1E	6.2	6.2	6.3		75.1		6.2	24.9	75.1
1F		3.6		21.4	10.7	64.3		35.7	64.3
2	1.5	7.3		7.3	4.4	13.2	66.3	33.7	66.3
Commissions	2.1	18.0	31.2	48.0	60.0	37.9	6.2		
Mean Performance	79.4								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 8. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:30,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	94.5		.9		.9	3.7		5.5	94.5
1B	1.5	83.8	5.9		7.4	1.4		16.2	83.8
1C		40.0	35.0	10.0	10.0	5.0		65.0	35.0
1D				93.8	6.2			6.2	93.8
1E		25.0	6.0		56.3	12.5		43.7	56.3
1F		2.3				97.7		2.3	97.7
2		8.3		4.2	8.3	16.6	62.5	37.5	62.5
Commissions	.9	20.5	42.8	16.6	55.0	21.8	0.0		
Mean Performance	83.8								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 9. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:20,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	100.0							0.0	100.0
1B		80.9	4.4	8.8	5.9			19.1	80.9
1C		10.0	70.0		20.0			30.0	70.0
1D				100.0				0.0	100.0
1E		12.4	18.7		56.2	12.5		43.8	56.2
1F						100.0		0.0	100.0
2				8.3	8.3	4.2	79.2	20.8	79.2
Commissions	0.0	6.8	30.0	11.1	57.1	15.4	0.0		
Mean Performance	89.2								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 10. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color infrared film of scale 1:10,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	97.0				2.0	1.0		3.0	97.0
1B		78.9	5.8		9.6	1.9	3.8	21.1	78.9
1C		6.3	75.0		18.7			25.0	75.0
1D				100.0				0.0	100.0
1E		6.3			81.3		12.4	18.7	81.3
1F						100.0		0.0	100.0
2		1.5	1.5	2.9	2.9	8.8	82.4	17.6	82.4
Commissions	0.0	6.8	25.0	11.1	48.0	22.2	6.6		
Mean Performance	89.0								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

Table 11. Matrix* with percentages of commission and omission errors, interpretation accuracies, and overall performance, associated with the interpretation of color film of scale 1:20,000.

Photo Interpretation Categories	1A	1B	1C	1D	1E	1F	2	Omissions	Interpretation Accuracy
1A+	98.2					.9	.9	1.8	98.2
1B		76.5	10.2		5.9	5.9	1.5	23.5	76.5
1C		30.0	70.0					30.0	70.0
1D				93.8	6.2			6.2	93.8
1E			18.7		68.8	6.2	6.3	31.2	68.8
1F				4.5	2.3	90.9	2.3	9.1	90.9
2				8.3	8.3	8.3	75.1	24.9	75.1
Commissions	0.0	10.3	41.6	21.0	42.1	16.6	18.2		
Mean Performance	86.4								

*values along the diagonal are interpretation accuracies

+1A=Platanos, 1B=Yucca, 1C=Tobacco, 1D=Sweet Potatoes, 1E=Other crops, 1F=Cultivated land, 2=Natural Vegetation

novice photointerpreter can make successful interpretation decisions and approach accuracy levels obtained by more experienced interpreters.

The highest score (93.2 percent) was obtained by interpreter using 1:10,000 color infrared transparency, whereas the lowest one (74.3 percent) was obtained by interpreter B using 1:30,000 scale, black-and-white transparencies (see Table 2 and Figure 5). The film type and scale combination, show results which, generally, could have been expected. Interpreter's experience, however, was not always consistent with the various accuracy levels obtained. Interpreters B and D obtained the same score interpreting the 1:10,000 scale, black-and-white photographs. The same accuracy was obtained by the interpreters C and D on 1:30,000 scale, CIR and A and C, and B and D on 1:20,000 scale, CIR. Moreover, other scores did not deviate much for each film type and scale combination. Interpretation accuracies were higher for CIR than for Panchromatic photographs. Also, the highest scores, with a few exceptions, were obtained when photographs of 1:20,000 scale, were interpreted. The last observation is attributed mainly to the training set materials. Actually, all interpreters commented that they encountered more difficulties when interpreting the 1:10,000 scale, photographs, as they were familiar with the appearance of the various land cover/use categories on 1:20,000 scale, photographs which was the only set included in the training materials. Generally, there was an improvement of the interpretation results for a scale reduction from 1:30,000 to 1:20,000 for black-and-white and CIR photography, although there was no consistent improvement for a further scale reduction from 1:20,000 to 1:10,000. Interpretation accuracies for color photography provided results falling within the other type and scale ranges.

Considering the mean performance of all interpreters combined, for all land cover/use categories (Table 2 and Figure 6), it is concluded that the CIR photography was consistently better for all scales than the black-and-white. The

small standard deviations indicate that all interpreters were affected similarly by the scale of the photography. For the black-and-white photography the small difference between the mean performance for the various scales, the overlapping confidence intervals (at the 80 percent probability level) and the additional cost required for image acquiring, developing, handling and interpreting more photographs associated with larger scales, indicates that the use of 1:30,000 black-and-white photography for the classification of the land cover/use categories under considerations, seems to be the best among the available scales of this film type.

For the CIR photography the situation is almost similar. The mean performance was the same for 1:20,000 and 1:10,000 photography (89.2 percent), differing slightly in standard deviations (3.1 and 2.9, respectively). The score for the 1:30,000 scale was a little lower (5.4 percent difference) than the other scales. This was, however, associated with a smaller standard deviation indicating a higher degree of consistency when interpreting land cover/use categories on the smaller scale. Furthermore, there exist an overlap of confidence intervals at the 95 percent probability level for the mean performance for the various scales.

Considering again the various factors, such as the small difference in percentage in the mean performance between the various scales, the overlapping confidence intervals, the higher degree of consistency of the interpretation at the smaller scale and the additional cost factor associated with the use of larger scale photography, it is concluded that the 1:30,000 scale CIR photography would be preferable.

The analysis to this point indicates that the smaller scale 1:30,000 photography, considering panchromatic and the CIR imagery, is preferred for the optimization of the classification accuracy for the indicated, while minimizing projection.

What film type would be preferred? The mean performance and the standard deviation of the 1:20,000 scale for all film types is illustrated (Figure 7). Interpretation of the CIR photography result generally in higher accuracies followed by color and the panchromatic film. However, in the case of color and black-and-white photography the difference of the mean performance is only 6.0 percent and overlap of the confidence intervals occurs at the 90 percent probability level. This result and the higher cost in of color and CIR film tends to favor of the use of black-and-white photography. The difference between the mean performance of the interpretation of the 1:20,000 scale, CIR and panchromatic film is 8.8 percent. This relative small percentage and the associated standard deviations do not clearly favor the choice of CIR film. As indicated before the results show that, at a smaller scale, the absolute difference in mean performance is further reduced.

In the final analysis practical considerations regarding the use of certain film types and camera systems need to be included. If the Secretariat of Agriculture (SEA) favor the development of a operational remote sensing capability to conduct applied surveys, the use of panchromatic film should be recommended initially. The film is cheaper, easier to obtain, available in greater variety of film speed ratings and roll dimensions, has a greater shelf life with less stringent storage and working temperature requirements, a greater exposure latitude and does require less specialized and sophisticated porcessing. Considering all these factors combined, panchromatic film, at a scale of 1:30,000 would be a good choice in general agricultural inventories applications in the Dominican Republic. It would allow for the initial establishment of a cost effecient, reliable inventory capability at the secretariat or related institutions.

For the next phase the interpretability of the various land cover/use categories by film type scale combinations, needs to be considered.

The results of the black-and-white photography show that platanos fields were interpreted with the highest accuracy for all scales. The interpretation accuracy was over 91.7 percent (scale 1:30,000) (Table 3). The omission and commission errors (Tables 5, 6 and 7) indicate that, in the case of omission errors, platanos fields were misinterpreted mainly as "cultivated land" at scale 1:30,000 and as "other crop" at scale 1:10,000. The first type of misinterpretation results from the very early growing stage. Very young platanos plants are not easily discernible at the smaller scale. There appears to exist no obvious explanation for the second type of misinterpretation error. The commission error for this category was 7.5 percent at the smaller scale, but dropped down to 2.9 and 2.1 at the other two larger scales, respectively. Most of these errors result from misinterpretation of the categories "other crop", "tobacco" and "natural vegetation".

The yucca fields were interpreted more accurately at the larger scale (84.7 percent), whereas for the other two subsequent scales the interpretation accuracy was less than 79.4 percent. At the smaller scale some yucca fields were misinterpreted as "cultivated land". The results from the early stage of growth made it difficult to detect young plants with the required magnification. At the medium and large scale some of these fields were misinterpreted as "other crop" because they presented a different appearance than the ones included in the training set. This was due to the various growth stages of the yucca plants at different dates of the photography. At the medium scale photography some fields were also misinterpreted as "tobacco", since at the initial stage of growth it is impossible to discriminate these two crops as a result of identical planting patterns. The commission error for this category ranged from 21.7 percent at the smaller scale to 15.0 and 18.0 percent at the medium and large scale, respectively. Except for the platanos fields all the rest land cover/use categories were misclassified as yucca fields at various frequencies.

The tobacco fields were poorly interpreted at all scales (interpretation accuracy of less than 68.8 percent). Most of the tobacco fields were misclassified as "yucca", "other crop" and some as "platanos". For the first two types of misclassification the reasons are identical to those mentioned for yucca. For the third one no explanation was found. The commission errors were also high in this category (over 31.2 percent). "Yucca", "sweet potatoes" and "other crop" were the categories which misinterpreted as tobacco. Much of the confusion during the classification happened for fields with crops of very young age.

For sweet potatoes fields had a somewhat poor interpretation accuracy resulted at the smallest scale (62.5 percent), which as improved to 87.5 and 81.3 percent respectively for the two subsequent larger scales. Omission errors were attributed to misclassification of sweet potatoes fields as "tobacco", "yucca" (in case of very young crops), "other crop" and "cultivated land" (confusion between grey tone variation and corresponding crop categories). The commission errors were fairly high. Misinterpreted "yucca", "other crop", "cultivated land" and "natural vegetation" fields attributed mainly to these high commission errors.

The interpretation accuracy of the category "other crop" was the same at both smaller scales (68.8 percent), but increased to 75.1 at the 1:10,000. These scores were attained because some "other crop" fields were wrongly classified as "yucca", "tobacco" and very few as "platanos" and "cultivated land"! The commission error was the highest of all categories at 1:20,000 and 1:10,000, 64.5 and 60.0 percent respectively, whereas at the smaller scale it was 47.6 percent, the second largest after the "tobacco" category. Again many omission errors are due to the fact that the planting pattern of some other crops like corn, is similar to the pattern of other land cover/use categories, especially at an early stage of growth. The high percentage of the commission error might have resulted from the

intention of the interpreters to classify fields as "other crop" instead of making every effort to allocate them to specific crop categories.

The "cultivated land" category was correctly classified 84.1 percent of the time at scale 1:20,000, but dropped down to 72.7 percent at the smaller scale and 64.3 percent at the larger one. The omission errors are primarily due to interpretation of fields as "sweet potatoes" and "other crop" and some as "tobacco" and "yucca". The confusion with "sweet potatoes" is easily understood, of marginal because grey tone variation between these two categories. Also, there exist no specific pattern and the texture is fine in both cases, especially at the smaller scale. The commission errors ranged from 37.9 percent at 1:10,000 scale to 21.3 percent at 1:20,000 and are mainly due to misinterpretation of fields with young crops, where the surface soil affects the grey tone rendition on the film.

For the last category, "natural vegetation", the classification was poor ranging from 58.3 to 66.3 percent. The main reason here was the misinterpretation of many rangeland fields as "sweet potatoes" or "cultivated land" and in some other cases (brush rangeland) as "other crop". The commission error was fairly low (from 5.6 to 12.5 percent) and ranked second after the "platanos" category.

Summarization of the classification results of the black-and-white film type at all scales (Figure 8) shows that the "platanos" category ranks first in interpretation accuracy followed (in decreasing order) by "yucca", "sweet potatoes", "cultivated land", "other crop", "natural vegetation" and "tobacco".

The interpretability of the land cover/use categories on <u>color infrared photography</u> is based on the information included in Tables 8, 9 and 10 and Figure 9. Platanos fields were again interpreted very accurately (over 94.5 percent). Most of the omission errors were due to misinterpretation of "platanos" as "cultivated land" which is understandable for the smaller scale and also for fields at a very early stage of growth. The commission error appeared negligible.

The interpretation accuracy of the "yucca" fields was over 78.8 percent (1:10,000). Some of the fields of this category were wrongly interpreted as "other crop", "tobacco" and "sweet potatoes". The first type of misinterpretation can be explained by the fact that some "yucca" fields, at different growth stages were rendered in a different color tone and resulting overall appearance as a result a different degree of canopy closure background soil reflectance. The second type of misinterpretation is due to the possible confusion between "yucca" and "tobacco" categories at certain growth stages. The commission error was 20.5 percent at the smaller scale but dropped down to 6.8 percent at the other two scales.

The interpretation accuracy of "tobacco" fields was less than 75.0 percent. Main contribution to the low interpretability of this category resulted from the misinterpretation of "tobacco" fields as "yucca" and "other crop". Possible explanations are the same as for "yucca". The commission error was high (25 percent).

The interpretation of "sweet potatoes" was very successful. 100.0 percent for the two larger scales and 93.8 percent for the smaller one. The commission error ranged from 16.6 (1:30,000) to 11.1 percent at the larger scales as a result or the misinterpretation of "tobacco" and "natural vegetation" (grasslands).

The "other crop" was the most poorly interpreted category, 56.3 percent interpretation accuracy was achieved at the two smaller scales and 81.3 percent at the larger one. "Other crop" fields were classified as "yucca", "tobacco" and "cultivated land". The first two misclassifications may result from a different degree of plant coverage (various stages of growth) of some yucca and tobacco fields, which appeared differently than similar categories included in the training set. The third type of classification error may be due to early stage of growth of the "other crop" category and the limitation of maximum magnification. The

commission errors were the highest for all scales. This was also caused by the tendency assign almost all questionable fields to this category.

The "cultivated land" was successfully interpreted with a 97.7 percent accuracy. However, the commission error was about 20.0 percent. This was in part because the presence of low biomass levels for some fields. The spectral reaction, texture, pattern, and other interpretation clues made this category similar to "cultivated land".

The interpretation accuracy of the "natural vegetation" increased from 62.6 percent at the smaller scale to 82.4 percent at the larger one. The gradual increase in the score was due to the successful interpretation of some "cultivated land" and "yucca" fields. The commission error was negligible.

Summarization of the color infrared photography results indicates that the sequence of the classification categories ranking in a decreasing order is "cultivated land", "sweet potatoes", "platanos", "yucca", "natural vegetation", "other crop" and "tobacco".

The 1:20,000 color photography (Table 11) interpretation accuracy results for "platanos", "cultivated land" and "sweet potatoes" fields were better than 90.0 percent. For the remaining categories the accuracies were less than 75.0 percent. The commission errors varied from 0.0 to 42.1 percent.

To provide additional information, an evaluation of the interpretation accuracy for all land cover/use categories and film types at the scale 1:20,000, was conducted (see also Table 3, and Figure 10). According to this information, the result indicate that the interpretation accuracy, almost all of the land cover/use categories, was better on the color and CIR photographs than on black-and-white. Color infrared film proved to be the best. However, a more careful examination of the results shows that the relative small gain in interpretation accuracy for the most important agricultural crop categories hardly justifies the extra expenditures,

training and facilities required to handle and process the CIR film. There was even a decrease in interpretation accuracy for the "other crop" category and slight improvement for "yucca", if comparing panchromatic and CIR film. "Platanos" and "sweet potatoes" accuracies favor, more clearly the choice of CIR film. Interpretation accuracy improvement for "tobacco" on the CIR film can be considered negligible because of the relatively small area percentage in this cultivation. Furthermore, the "cultivated land" category is not important in defining crop composition. Analysis of the "natural vegetation" category detailed analysis of the data showed that all the "forested" areas (which include the important cacao and shade cultivations for coffee) were interpreted very accurately (100.0 percent) on black-and-white film.

The results indicate that the use of black-and-white film can meet the interim requirements for a cost efficient and reliable inventory of the major agricultural areas in the country.

6. Cost Considerations

The cost associated with the classification and inventory of the land cover/use categories of the study area, when using light aircraft photography, is significantly affected by the actual time for interpretation. Interpretation time appears to be a function of several factors such as:

a. The interpreter's experience level (generally and specifically in reference to special land cover/use categories),

b. The interpreter's knowledge of ground conditions typical for the study area, cropping practices, crop calendar, intercropping, etc.,

c. The film type,

d. The image scale,

e. The individual effort in maximizing the interpretation accuracy,

f. The types of interpretation aids (influenced by image format, equipment, magnification factor) available and,

g. The availability of a well-defined interpretation key and auxilliary information.

Table 12 illustrates, for example, the relative importance of interpretation time as a cost contributing factor in crop stress analysis procedures for sugar cane in the Dominican Republic. Since interpretation time appears to be the most important factor, an effort was made to relate the time factor to film type, scale and experience level of the interpreters.

Table 13 summarizes these relationships. It is seen that the interpretation time spent by each interpreter is mostly inversely proportional to the level of experience.

Furthermore, interpretation time appears to be affected by the film type, especially for less experienced interpreters. Scale of the photographs affects interpretation time, as well. The shortest time was spent during the interpretation of 1:20,000 photographs of both film types. This is probably due to the fact that only photographs of this scale were specifically utilized in the training set, improving this scale related capability.

Table 14 summarizes the time spent by each interpreter during the intial training. Time differences result clearly from experience lives.

7. Summary and Conclusions

This study has evaluated various imagery parameters affecting agricultural inventories in the Dominican Republic. Three film types, black-and-white panchromatic, color and color infrared of scales 1:30,000, 1:20,000 and 1:10,000 (the color photography was only at a scale of 1:20,000) were tested. After an initial training, four individuals with a varying degree of experience in photointerpretation,

Table 12. Aggregate inventory costs for cane rust damage assessment.[1]

70mm System 80mm Lens	Approximate Imagery Scales					
Cost Components	1:10,000		1:20,000		1:30,000	
	Cost	% Total	Cost	% Total	Cost	% Total
Image Acquisition and Processing	6.19	7.5	1.91	5.7	0.83	4.2
Image Indexing and Plotting	14.30	17.25	4.00	12.0	1.60	8.1
Interpretation and Data Transfer	62.40	75.3	27.31	82.2	17.28	87.7
Total Cost 50 km^2	$4,144.50		$1,661.00		$905.00	
Total Cost/km^2	$ 82.89		$ 33.22		$ 19.71	

[1] G. Schultink, M.A. Karteris and R. Hill-Rowley. 1979. Cane Rust Damage Assessment in the Dominican Republic: the use of the light aircraft-small format photography in small area agricultural inventories. Third Conference on Economics of Remote Sensing, Incline Village, Nevada.

Table 13. Interpretation time for various individuals related to imagery type and approximate scale.

Film Type	Approximate Scale	Total Interpretation Time (minutes) By Interpreter* A	B	C	D	Average Time (minutes)
PAN	1:30,000	120	115	105	60	100
PAN	1:20,000	150	80	60	45	83.75
PAN	1:10,000	120	110	65	50	86.25
CIR	1:30,000	110	80	70	45	76.25
CIR	1:20,000	55	45	50	40	47.50
CIR	1:10,000	60	55	55	45	53.75
COL	1:20,000	100	60	45	30	58.75

*Interpretation experience increases from A to D.

Table 14. Training time for various interpreters (minutes).

	A	B	C	D
Collective Training	90	90	90	90
Individual Training	270	105	70	50
Total Training Time	360	255	160	140

classified test fields based on a previously developed classification key using monoscopic vision and magnification of 7 to 10 times. To reduce possible bias the interpretation was carried out according to a predefined schedule at intervals of 2-3 days, with an imagery interpretation sequence from small, medium to large scale and from black-and-white, color to color infrared photography.

The results of the interpretation were systematically analyzed resulting in the following major conclusions:

1. Interpretation experience plays an insignificant role in photointerpretation performance. Even an unexperienced photointerpreter can make successful interpretation decisions after minimal training and careful performance of the interpretation task.
2. Interpretation training should preferably be done on photographs of the same mission (scale, film type and date) as compared to those to be used in the main photointerpretation phase.
3. An optimum combination of successful classification of land cover/use categories and low cost can be achieved by using photographs of scale 1:30,000 (given the scale variation tested).
4. Color infrared photography generally provides better interpretation results. However, the low improvement of the interpretation performance of the color infrared film over the black-and-white favors the use of the latter film type for agricultural inventories in areas similar to the study area.
5. "Platanos" is the best interpreted land cover/use category on the black-and-white and color photography and "cultivated land" on the color infrared, respectively. The sequence of the other categories varies depending on the film type. Crops with a similar pattern have high probability of misinterpretation especially at an early stage of growth.

6. The interpretation accuracy of almost all of the land cover/use categories is better on color and color infrared photography. However, in the case of important agricultural crops, categories black-and-white film type can meet the requirements for a cost/efficient and reliable inventory.

7. Interpretation time spent by each interpreter is initially, inversely proportional to the level of experience. Time and cost are also affected by film type and scale.

APPENDICES

APPENDIX A

Classification Key

Introduction

Tonal variation, texture, pattern, field size and shape are the primary characteristics used in the classification key in discriminating between the various categories. The gray scale tonal variation is based on a range of twelve wedge step reflectance values of the "ANSCO DENSA-GUIDE",[1] whereas the color tonal variation was based on the ISCC-NBS system of color designations.[2] Elements related to topography and situation (degree of slope and aspect) were not included since no relevant information on crop types or distribution could be derived, especially in monoscopic analysis. Temporal information was excluded since the objective of the study was primarily to evaluate the relative accuracies of imagery interpretation procedures, rather than the generation of crop inventory data on a repetitive basis.

Before the use of the classification key in interpreter's training and applications, it was carefully checked for consistency, accuracy and completeness.

Category	Symbol
I. Agricultural Land	
A. Platanos	1A

[1]ANSCO, 1972. ANSCO Den-sa-guide, Binghamton, New York.

[2]Smith, John T. 1968. Manual of Color Aerial Photography, American Society of Photogrammetry, Falls Church, VA 22046.

B.	Yucca	1B
C.	Tobacco	1C
D.	Sweet Potatoes	1D
E.	Other Crops	1E
F.	Cultivated Land*	1F
2.	Natural Vegetation**	2

PRINCIPLES OF INTERPRETATION OF THE MAIN AGRICULTURAL CROPS

In order to classify the spectral variation recorded on black-and-white and color infrared photographs, a 12-tone gray scale ranking the classes from white tone to black, and a color variation based on the ISCC-NBS system of color designation of the National Bureau of Standards were used. Discrepancies of the tone variation of the various crops may be found, depending upon image variables like scale, angle of incidence, atmospheric conditions, etc.

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*Fields being prepared for planting/seeding during the time the photography was taken. No current vegetation cover visible.

**In this category are included:

a) forested land (more than 10% land coverage)

b) herbaceous and shrub rangeland

c) improved and permanent pasture

d) abandoned fields, fallow

In Moca area most of this natural vegetation refers to a tree cover called Guama. This cover type forms in most cases the shade tree environment needed for the cultivation of coffee and cacao.

Platanos--Plantains (*Musa* sp.)

1. Shape of field: Variable; regular or irregular polygons. Fields with curvilinear boundaries may be found conforming to various topographical features.

2. Size of field: Variable.

3. Site: Platanos are usually on level to gently undulating topography. However, they are also planted in fields of various aspects and steepness along the drainage networks.

4. Pattern: It is usually of a square and diamond type with rectangular, widely spaced rows. This type of planting pattern is the most distinguishing feature in crop identification, especially at the early stage of growth. At the mature stage and especially for fields with plants in a second or later stage of generation, the pattern becomes fuzzy and sometimes almost indistinguishable at a result of: 1) the extended foliage of the plants; and 2) the disposition of the new plants from the regularly spaced rows.

5. Shadow: In fields with plants with sparse density and intermediate stage of growth, shadow is easily identifiable and characteristic of the plant. Also, at the edge of the field, individual plant shadow may be identified.

6. Texture: In early stage of growth, a stippled texture resulting from the wide spaced planting pattern is the characteristic of the crop. This is altered to a more coarse texture as the plants mature.

7. Tone: In early stage of growth when the ground is partly covered, the tone of the fields is dominated by the spectral characteristics of the topsoil. In other stages of growth, the gray tone on black-and-white photography ranges from class 3 for low density fields to class 8 for high density fields. For fields with regenerated crops, the background has a white cast because of the litter which is concentrated on the ground after harvesting. Fields with an intermediate stage of

growth crops have a deep red (13)*, dark red (16), or dark grey red (20) tone on CIR photographs. In the mature stage, the color shifts to strong red (12), strong purplish red (255) and modeerate purplish red (258). On "true color", the predominant tone rendition is dark green (146) and very green (147).

Yucca--Cassava (Manihot sp.)

1. Shape of field: Almost rectangular to polygon shaped fields.

2. Size of field: Variable.

3. Site: It is commonly found on deep well-drained soils on level to gently undulating topography.

4. Pattern: It is planted in a relative narrowly spaced row pattern. In early stage of growth, the row pattern provide a good indication of the crop type (which, in some instances, may be confused with tobacco). In their maturity, the branches cover and obscure partly or fully the row pattern.

5. Shadow: The slight shadow of mature plants may be apparent only at the edge of the field, and then only on very large scale photography.

6. Texture: In the early stage of growth, stippled texture (as a result of the planting method) is dominant. Later on, as the plants mature, it shifts to a relatively fine (smooth or velvet-like) texture.

7. Tone: In the early stage of growth, the spectral characteristics of the soil provide the dominant tone of the field. In the intermediate and especially the mature stage, the gray tone ranges from class 3 to class 5 on black-and-white photography. On CIR photography, the crop appears, during intermediate stages of growth, gray purplish red (262) with a degree of variation depending upon the

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*The numbers in parentheses specify the color designation and are provided to aid in interpretation using the appropriate color shade in the ISCC-NBS system.

percentage of ground coverage. When the crop reaches maturity, the usual tone is dark purplish pink (251). Sometimes it may be found having a deep pink (3) or strong red (12) tone. On "true color" the tone rendition usually ranges from gray green (150) to dark green (151). Sometimes it appears light green (144) or moderate green (145).

Tobacco-Tabaco (N. tabacum)

1. Shape of field: Rectangular to irregular polygon shaped fields.

2. Size of field: Variable.

3. Site: Tobacco is usually planted on level to gently undulating topography, but is more common on level, well-drained terrain.

4. Pattern: Formed by a typically narrowly spaced row crop. The pattern is sometimes even identifiable at the mature stage of growth.

5. Shadow: Because of the size and shape of the plant, the shadow element does not contribute much as an indicator in crop idenfitication. It is, however, a more important factor in large scale photography.

6. Texture: The crop displays a coarse texture during all stages of growth because of the compactness of the plants.

7. Tone: As all row pattern crops at early stage of growth, tobacco's tone is also affected mostly by the tone of the surface soil. In the mature stage, the gray tone ranges from class 5 to class 6 on black-and-white photography. On CIR photography, during intermediate stages of growth, the tone is moderate purplish red (258) or dark red (16). During the mature stage, the predominant tone is strong red (12). On "true color" the predominant tone ranges from dark green (146) to bluish green (165).

Sweet Potatoes--Batatas (Ipomoea batatas)

1. Shape of field: Any shape, from rectangular to polygon.

2. Size of field: Variable.

3. Site: It is usually found on level to gently undulating topography.

4. Pattern: No particular pattern is evident as the plants cover the whole field uniformly. However, on very large scale photography, new crops will appear as having a row pattern.

5. Shadow: No shadow effect.

6. Texture: Very fine texture.

7. Tone: At the early stages, the tone of the field is dominated by the spectral characteristic of the surface soil. After the full coverage of the topsoil by the crop canopy, the gray tone ranges from class 4 to class 5 on black-and-white photography. On CIR photography, the tone of the field is very purplish red (254) or strong purplish red (255). On "true color", the tone rendition varies from strong green (141) to deep green (142).

APPENDIX B

Films and Filters

The selection of the appropriate film-filter combination is an essential element in remote sensing information gathering, since it determines which portion of the electromagnetic spectrum is used to high light selected features of interest.

Panchromatic (PAN) or Black-and-White Film is sensitive to the visible portion of the EMS[1] (400-700 nm) and records reflected energy in various gray tones. The use of a light yellow filter (Wratten No. 15) is recommended to reduce the effects of haze at lower flying levels (5000 feet or 1500 meters). Higher altitudes require an increased capability to reduce the blue (haze) wavelength and in those cases a red filter (Wratten No. 25) is recommended. In all cases careful consideration should be given to the filter factor in determining the required lens aperture and exposure time. A filter factor of 8,(2^3) requires that the normal f-stop setting be opened up three stops.

The general advantage of the use of PAN-film is the relative low cost of film processing, printing and reproduction, and the possibility to correct for improper film exposures during the processing and printing process.

Color Film offers a great advantage in aerial applications compared to B/W film, since the tonal range of natural color is of distinct benefit in photo interpretation. Color film consists of three emulsion layers sensitive to blue, green and red light and is therefore sensitive to the complete visible light range (400-700 nm) of the EMS. This means also that variation in atmospheric conditions (haze and pollution) affects the quality of the photo image to a great extent, limiting the

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[1]EMS stands for Electromagnetic Spectrum.

period of data collection to good or excellent flying weather. Only for low altitude applications (2000 feet or 600 meters) can reasonable results be expected if the visibility is in the 7-15 miles range. The sensitivity of haze conditions of color film requires the use of an ultraviolet (UV) filter. For visibilities better than 7 miles, a Wratten 1A is recommended. Flying altitudes over 5000 feet with visibilities less than 7 miles require a Wratten 2B or an HF-3 aerial filter.

It is important to distinguish between negative and positive (or reversal) color film. Negative color film has the advantage of a great degree of control over the color balance and the density variation, to be exercised during the printing process. Color negative film has a greater exposure latitude and versatility than reversal film. Negative color film can be used to produce color and B/W prints, slide or large transparencies. Positive color film produces transparencies or slides and allows for contrast enhancement by means of making an internegative. This requires special processing facilities but can "save" a mission flown under bad (haze) condition. Film availability generally does not pose any problems, especially for 35 mm cameras. Color film for 70 mm cameras (120) has to be special ordered for use in 15-foot camera cassettes (e.g., Ektachrome MS 5256).

Color Infrared Film (CIR) combines, to some extent, the advantages of infrared and color film. It consists, like color film, of 3 layers sensitive to green-red light and to reflected infrared radiation (700-900 nm). The resulting images display therefore false natural colors, recording healthy vegetation (large chlorophyll concentrations) as red, red as green and green as blue. The CIR film is an invaluable data recording tool in vegetation studies, crop stress monitoring, pollution detection and land cover/use mapping efforts at a regional scale. CIR-films have to be exposed with a yellow ("minus-blue") filter to eliminate the blue light scattered by the atmosphere, especially during hazy conditions. A Wratten 12 filter is recommended and exposure charts should be developed for different flying

conditions. It is important to consider the variation in reflected radiation of various surface features and ground cover, especially for flying altitudes below 2000 feet. As a reference, exposure times of 1/500 seconds at f5.6 - f-stop. produce excellent results, for visibility conditions better than 15 miles and flying altitudes above 2000 feet, using standard small format cameras and lenses. The exposure latitude of CIR-film is f½ f-stop. If an exposure meter is used, the recommended ASA or DIN setting gives an indication of the variation in radiation. But, again, remember that one is photographing a different portion of the EMS than the light meter is capable of measuring. If one is not sure of the exact exposure time/f-stop combination it pays off to fly (a small site) with 3 f-stop settings, exposing below, on, and above the assumed correct aperture setting. This additional cost is often easily offset by the improved potential for image analysis. CIR film is generally available in 20 exposure rolls for 35 mm cameras. Bulk film for large 35 mm backs requires a special order (minimum approximately $1,900). For 70 mm cameras it is available in 100-foot rolls Kodak Aerochrome 2443 (ESTAR base) which can, however, easily be loaded into 15-foot camera cassettes in the darkroom.

Processing

PAN-film processing is universally available. Special end-products specifications or large volumes might prove it useful to shop around for a qualified processing facility improving data collecting time and cost during image interpretation.

Color and CIR film can be processed using the standard Ektachrome processing practices. If a specific false color rendition is required, mechanical processors (E-4) can be used if the Aerochrome CIR 2443 film is exposed with a

Wratten 15 filter or a Wratten 12 plus a Kodak Color Compensating Filter CC 10 M. Self processing is possible using appropriate Ektachrome kits.

The processing of 70 mm film requires the services of more specialized processing laboratories.

APPENDIX C

Tabulation of the interpretation, by interpreter, for results of the land cover/use categories on panchromatic film of scale 1:30,000.

Interpreter A

Land cover/use category	1A	1B	1C	1D	1E	1F	2	Total	Interpretation correct	Interpretation incorrect
1A	24				*	*	*	27	24	3
1B		15				**		17	15	2
1C	***	*	1					5	1	4
1D		*	**	0	*			4	0	4
1E					3	*		4	3	1
1F		*	**			8		11	8	3
2			·	*			5	6	5	1
						Total		74	56	18

Percent overall correct interpretation 75.7

Interpreter B

Land cover/use category	1A	1B	1C	1D	1E	1F	2	Total	Interpretation correct	Interpretation incorrect
1A	24		*			*		27	24	3
1B		14	*			**		17	14	3
1C	**	*	2					5	2	3
1D			*	3				4	3	1
1E	*	**			1			4	1	3
1F			*	*		9		11	9	2
2	***					*	2	6	2	4
						Total		74	55	19

Percent overall correct interpretation 74.3

Interpreter C

Land cover/use category	1A	1B	1C	1D	1E	1F	2	Total	Interpretation correct	Interpretation incorrect
1A	25			*		*		27	25	2
1B	*	12		*	*	**		17	12	5
1C	*	**	2					5	2	3
1D				4				4	4	0
1E				*	3			4	3	1
1F		**			*	8		11	8	3
2				**			4	6	4	2
						Total		74	58	16

Percent overall correct interpretation 78.4

Interpreter D

Land cover/use category	1A	1B	1C	1D	1E	1F	2	Total	Interpretation correct	Interpretation incorrect
1A	26				*			27	26	1
1B		13	*	*	**			17	13	4
1C		**	2			*		5	2	3
1D				3	*			4	3	1
1E					4			4	4	0
1F					***	7	*	11	7	4
2					**		4	6	4	2
						Total		74	59	15

Percent overall correct interpretation 79.3

APPENDIX D

Correct interpretation and interpretation accuracy of the various land cover/use categories by interpreter, film type and scale (entries in percentages).

Inter-preter \ Scale	Black-and-White 1:30,000	Black-and-White 1:20,000	Black-and-White 1:10,000	Color Infrared 1:30,000	Color Infrared 1:20,000	Color Infrared 1:10,000	
			Platanos				
A	88.9	96.3	92.0	96.3	100.0	96.0	
B	88.9	92.6	88.0	92.6	100.0	96.0	(Correct
C	92.6	92.6	92.0	92.6	100.0	100.0	interpretation)
D	96.3	92.6	96.0	96.3	100.0	96.0	
$\bar{X}$	91.7	93.5	92.0	94.4	100.0	97.0	(Interpretation
S_x	3.54	1.85	3.27	2.14	0.0	2.0	accuracy)
			Platanos				
A	82.4	82.4	100.0	88.2	82.4	84.6	
B	70.6	76.5	76.9	88.2	76.5	92.3	(Correct
C	88.2	64.7	76.9	76.5	82.4	69.2	interpretation)
D	76.5	76.5	84.6	82.4	82.4	69.2	
$\bar{X}$	79.4	75.0	84.6	83.8	80.9	78.9	(Interpretation
S_x	6.56	7.42	10.9	5.6	2.9	11.5	accuracy)

Interpreter \ Scale	Black-and-White 1:30,000	Black-and-White 1:20,000	Black-and-White 1:10,000	Color Infrared 1:30,000	Color Infrared 1:20,000	Color Infrared 1:10,000	
				Tobacco			
A	40.0	60.0	100.0	20.0	100.0	100.0	
B	40.0	60.0	50.0	40.0	20.0	75.0	(Correct
C	20.0	20.0	50.0	40.0	60.0	25.0	interpretation)
D	40.0	80.0	75.0	40.0	100.0	100.0	
$\bar{X}$	35.0	55.0	68.7	35.0	70.0	75.0	(Interpretation
S_x	10.0	25.2	23.9	10.0	38.3	35.3	accuracy)
				Sweet Potatoes			
A	75.0	75.0	50.0	100.0	100.0	100.0	
B	100.0	100.0	100.0	100.0	100.0	100.0	(Correct
C	0.0	100.0	75.0	100.0	100.0	100.0	interpretation)
D	75.0	75.0	100.0	75.0	100.0	100.0	
$\bar{X}$	62.5	87.5	81.3	93.7	100.0	100.0	(Interpretation
S_x	43.3	14.4	20.7	12.5	0.0	0.0	accuracy)
				Other Crops			
A	25.0	50.0	75.0	75.0	50.0	75.0	
B	75.0	75.0	75.0	75.0	75.0	75.0	(Correct
C	75.0	75.0	75.0	50.0	25.0	75.0	interpretation)
D	100.0	75.0	75.0	25.0	75.0	100.0	
$\bar{X}$	68.7	68.7	75.0	56.2	56.2	81.3	(Interpretation
S_x	31.5	12.5	0.0	23.9	23.9	12.5	accuracy)

Interpreter \ Scale	Black-and-White 1:30,000	Black-and-White 1:20,000	Black-and-White 1:10,000	Color Infrared 1:30,000	Color Infrared 1:20,000	Color Infrared 1:10,000	
	Cultivated Land						
A	81.8	81.8	71.4	90.9	100.0	100.0	
B	72.7	72.7	57.1	100.0	100.0	100.0	(Correct
C	72.7	100.0	71.4	100.0	100.0	100.0	interpretation)
D	63.6	81.8	57.1	100.0	100.0	100.0	
$\bar{X}$	72.7	84.1	68.2	97.7	100.0	100.0	(Interpretation
S_x	7.43	11.4	8.25	4.5	0.0	0.0	accuracy)
	Natural Vegetation						
A	33.3	33.3	58.8	66.6	83.3	70.6	
B	66.6	50.0	70.6	33.3	83.3	88.2	(Correct
C	83.3	83.3	70.6	66.6	83.3	88.2	interpretation)
D	66.6	66.6	64.7	83.3	66.6	88.2	
$\bar{X}$	62.5	58.3	66.2	62.4	79.1	82.4	(Interpretation
S_x	20.9	21.5	5.6	20.9	8.35	8.29	accuracy)

Color (1:20,000)

Inter-preter \ Category	Platanos	Yucca	Tobacco	Sweet Potatoes	Other Crops	Cult. Land	Nat. Vegetation
A	100.0	82.3	80.0	100.0	100.0	81.8	83.3
B	96.3	76.5	40.0	100.0	75.5	90.9	50.0
C	96.3	82.3	60.0	100.0	25.5	90.9	83.3
D	100.0	64.7	100.0	100.0	75.5	100.0	83.3
$\bar{X}$	98.15	76.5	70.0	100.0	69.1	90.9	74.9
S_x	2.1	8.3	25.8	0.0	31.3	7.4	16.6