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Color-Film Densities for Soils P.I.

Color aerial films are capable of recording information which can be used to separate soil mapping units.

INTRODUCTION

Since the 1920's, when aerial photography was first suggested for soil mapping (Pasto, 1953), considerable progress has been made in both photographic materials and in photo interpretation. B&W (black-and-white) photographs were used originally, and more recently, color films were evaluated (Dominguez, 1960; St. Joseph, 1966; Anson, 1968; Parry *et al.*, 1969; Kuhl, 1970; Valentine *et al.*, 1971). However, methods of photo-interpretation developed for B&W photographs do not seem ideal for color photos. After comparative tests of B&W and color photographs, Anson (1970) pointed out that problems with the use of the latter arise in the methods to be used to acquire the color information.

The minimum color difference detectable by the human eye increases with decreasing angular subtense of the stimuli (Judd, 1930). Tests have indicated (Cihlar, 1971) that the threshold value of color difference detected between two adjacent 1.85 mm square visual fields on a color aerial transparency was approximately six times higher (average for five observers) than that achieved using a Carl Zeiss PMQ II spectrophotometer. For a larger area on the photograph, color is only one of several types of information about terrain to which the interpreter is exposed simultaneously. The three-dimensionality of color adds complications, especially if combined with lack of experience in color-photo interpretation (Kalensky, 1967). Some training in color perception can eliminate these problems. However, the threshold value of perceived color difference does not decrease (A. R. Robertson, personal communication*).

ABSTRACT: *The purpose of this study was to determine whether color aerial films contain density information usable for separating soil mapping units. Six transects crossing a total of 16 soil mapping units were located in the field and on color aerial negatives. Microdensitometric measurements of small increments along the transects on the negatives were analyzed using discriminant analysis with respect to effects of training sets, ground resolution element sizes and type of film material. The overall accuracy of identification was 39.7 percent for ideal training sets and decreased gradually if these sets were modified to suit practical requirements. Different ground resolution elements ($0.6\ m^2$ and $2.5\ m^2$) did not substantially alter the accuracy. The analysis demonstrated a marked difference between the color-negative film and a hypothetical B&W negative film. It appears that color aerial films are capable of recording information which can be used to separate soil mapping units. The capability has possible applications in soil mapping.*

More efficient use of photo colors would be made if soil interpretation were based on an accurate analysis of either color or density data (colors and densities are closely correlated). Such an application would require the condition that color or density characteristics are unique for the soil mapping units to be delineated. Therefore, our interest was in finding what information about soil mapping units is stored in the film emulsion. To

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achieve both a quantitative assessment and full use of the recorded densities, densitometric measurements were evaluated using discriminant analysis.

MATERIALS AND METHODS

The dominant landform in the study area (located in Brant County, Southern Ontario) was a dissected lacustrine plain with a surface layer of sandy material at the higher elevations. Six transects were chosen to include the range of landform features and surface materials in the area. With one exception (unit 40b, Figure 1), the transects crossed fields bare at the time of photography. Boundaries of soil mapping units (soil types and slope classes within types, Figure 1) were compiled from three different sources to reduce subjective bias introduced by individual surveyors. Soil samples were collected at 10 m intervals along transects 1, 2, 3, and 4 to a depth of 15 cm. Their colors were measured by a spectrophotometric method (Cihlar, 1971). Organic matter content was determined using the procedure of Walkley (1947). Some characteristics of the soil mapping units are listed in Tables 1, 2.

Kodak Ektachrome MS Aerographic 2448 film was exposed at two scales on May 1, 1969, when surface moisture differences were obvious. Densitometric measurements for 200×196 μm increments along the transects on color aerial negatives were made using an Automatic Scanning Microdensitometer Model 1010. Each transect was scanned three times, in the same direction, with the following filters: Kodak Wratten 92 (red, transmission peak at 700 nm), 93 (green, 540 nm) and 94 (blue, 450 nm) (Eastman Kodak Company, 1970). A high accuracy of point location made it possible to measure the same increments along the transects. The electrical responses were recorded on magnetic tape, a separate file being reserved for each combination filter-transect. Subsequently the records were transformed into optical densities by means of an IBM 360/50 computer.

The generalized form of the discriminant function was

$$Y = + a_1x_1 + a_2x_2 + a_3x_3,$$

where Y is the discriminant score, a_1, a_2, a_3 are coefficients, x_1 represents red densities, x_2 represents green densities, and x_3 the blue densities.

Because of the large number of soil mapping units, a special discriminant function was calculated for each of them (Kendall, 1965). These functions specified boundaries, in three-dimensional measurement space, between points representing various sites in such a manner as to minimize the number of misclassified points. After the functions were established on sets consisting of cases of known identity, additional points could be identified on the basis of their Y-values. Discriminant functions could be compared to photo keys (Steiner, 1970a), thus showing the similarity to the traditional method of photo interpretation.

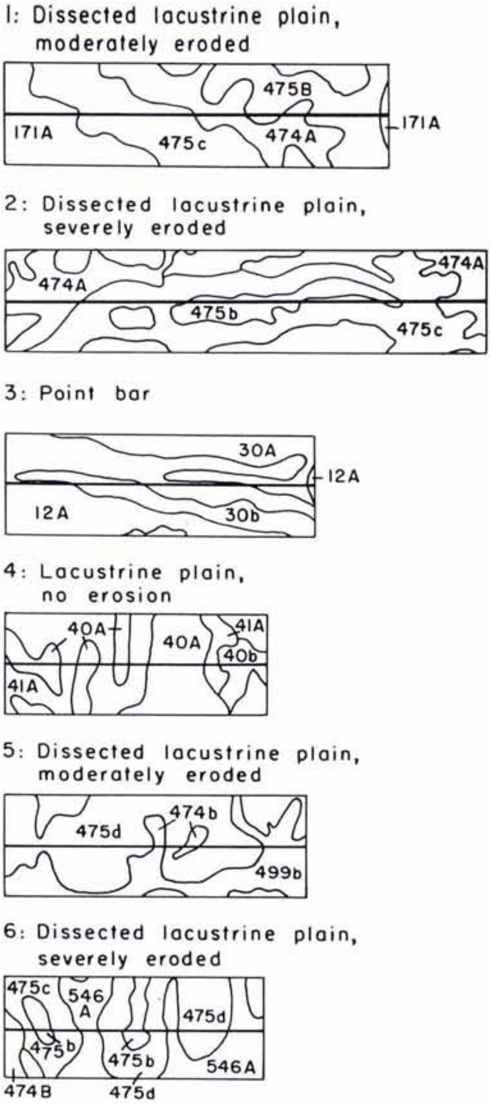

FIG. 1. Distribution of soil mapping units along transects 1 to 6. (Note. Transects are marked by the central lines.)

The computer program BMD07M used

TABLE 1. DESCRIPTION OF SOIL MAPPING UNITS*

Soil Type			*Drainage*	*Material*
No.	*Name*	*Slope Class*†		
12	Brady sandy loam	A	Imperfect	fine sand-medium sand-medium sandy loam, more than 36″ thick, with textural or color B horizon
30	Fox sandy loam	A, b	Good	(same as above)
40	none	A, b	Good	coarse sand-medium sandy loam, no Bt horizon
41	none	A	Imperfect	(same as above)
171	Berrien sandy loam	A	Imperfect	coarse sand-sandy loam, medium sand-sandy loam, fine sand-sandy loam, 12″ to 36″ thick over calcareous clayey materials
474	Beverly silt loam	A, b, B	Imperfect	silty clay loam-silty clay, brownish lacustrine material, less than 12″ overburden
475	Brantford silty clay loam	b, B, c, d	Good	(same as above)
499	none	b	Imperfect	grayish lacustrine clay
546	Toledo silt loam	A	Poor	silty clay loam-silty clay, brownish lacustrine material, less thna 12″ overburden

* From: Ontario Soil Survey (1967).

† Two simple (A, B) and three complex (b, c, d) classes were identified for the sixteen soil mapping units. Class limits were: A: 0%–3%; b, B: 3%–6%; c: 6%–12%; and d: 12%–20%.

for discriminant analysis (Dixon, 1967) was executed in a stepwise manner. At each step, one variable was entered into, or deleted from, the set of discriminating variables. At the stage of identification, each case was assigned to the group with the highest probability of including the Y-value calculated for the case. The discriminant functions and classification matrix were printed at specified steps and after the last step. The program

TABLE 2. SURFACE PROPERTIES OF SOME SOIL MAPPING UNITS

Soil Mapping Unit	*Number of Soil Samples*	*Average*				*Structure**	*Mixing of Horizons*
		Hue	*Munsell Value*	*Chroma*	*Org. M. Content (%)*		
12A	14	0.52Y	5.36	2.95	2.4	medium subangular blocky	none
30A	5	0.57Y	5.07	2.62	3.5	coarse granular to medium subangular blocky	small
30b	6	0.34Y	5.24	3.00	1.9	coarse granular to medium subangular blocky	small
40A	11	0.48Y	4.47	2.63	1.8	structureless	small
40b	4	0.50Y	4.58	2.63	2.3	structureless	small
41A	6	0.56Y	4.33	2.54	2.1	structureless	none
171A	7	0.60Y	4.84	2.58	3.1	medium to coarse granular	none
474A	16	0.56Y	5.16	2.87	3.1	coarse granular to coarse subangular blocky	none
475b eroded phase	10	0.36Y	5.98	3.03	0.75	coarse granular to very coarse subangular blocky	small
475B	9	0.57Y	5.21	2.95	3.8	coarse to very coarse subangular blocky	small
475c	30	0.24Y	5.45	3.17	2.2	coarse to very coarse subangular blocky	large

* Determined at the time of field sampling in fall of 1970, using definitions from Anonymous (1968).

TABLE 3. F-VALUES BEFORE THE FIRST STEP OF THE DISCRIMINANT ANALYSIS

Density	*Transmission Peak (nm)*	*F-Value*		
		Alternative 1	*Alternative 2*	*Alternative 3*
red	700	112.51	58.82	126.46
green	540	97.51	48.98	122.90
blue	450	113.96	58.43	142.89

operated with *variables* (densities) *cases* (increments) and *groups* (soil mapping units). Within any group, all cases could be subdivided into two parts; one for establishing the discriminant function (training set), and the other for testing the accuracy of identification (testing set).

RESULTS AND DISCUSSION

The accuracy of identification of increments representing various soil mapping units is influenced by several factors, such as the quality of training sets, size of the ground area represented by one photo density reading, and capabilities of the film materials used.

CHOICE OF TRAINING SETS

Three alternatives for establishing training sets were examined. The calculations described below were performed for data from six transects at a scale of 1:4000, with a total of 1955 cases.

Alternative 1. All cases for each soil mapping unit were included in a training set which was subsequently used as a testing set.

No appreciable difference appeared between blue and red densities with respect to their discriminatory powers. Evidently, the original ranges in spectral reflectances (approximately 25 percent at 700 nm and 6 percent at 450 nm for dry samples, and proportionally more with presence of both dry and wet soils) were modified by the logarithmic response of the emulsion. The similarity of the discriminatory powers of blue and red densities was supported by the following observations: similar *F*-values before the first step of the discriminant analysis (Table 3); dependence of the sequence of variables entered on the arrangement of training sets (i.e. the order blue density—red density for Alternative 1 was reversed for Alternative 2); overall accuracy of identification* was 15.5 percent for blue density and 30.0 percent for blue density plus red density. Green densities were entered as the last variable and the overall accuracy increased to 39.7 percent (Table 4). In contrast Wagner (1971)

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* See note below Table 4.

TABLE 4. FINAL CLASSIFICATION MATRIX, ALTERNATIVE 1

Group	*12A*	*30A*	*30b*	*40A*	*40b*	*41A*	*171A*	*474A*	*474b*	*474B*	*475b*	*475B*	*475c*	*475d*	*499b*	*546A*	*Group Accuracy (%)*
No. of Cases	*182*	*54*	*68*	*139*	*48*	*71*	*81*	*190*	*20*	*18*	*163*	*119*	*388*	*314*	*41*	*59*	
12A	89	22	6			3	17	7	5					14	8	11	49
30A	6	19	7				5	3	1					10	3		35
30b	3	4	17	1					16					13	14		25
40A				85		24				10	1		12	1	3	3	61
40b					45		2					1					94
41A		1		41	1	18	2	3		1						4	25
171A	15			1	3		54	4			1	3					67
474A	2	16	6	1	3		25	31	10	24		17	19	5	7	24	16
474b		1					1	1	17								85
474B				1						14						3	78
475b		2	1	16		1			15	1	104	3	19	1			64
475B								3			6	110					92
475c	15	6	4	56		25		1	24	22	61	2	92	2	76	2	24
475d	20	10	44	12	7	28	35	3	78	1	1	1	1	12	54	7	4
499b	1		3	1							1	1	4	1	29		71
546A						2	9			7						41	69
														Overall accuracy			39.7%

Note: Accuracy is defined as the number of correctly identified cases times 100 and divided by the number of cases to be identified. For example: Group accuracy for 12A = (89×100) ÷ 182 = 49%. Overall accuracy = (89 + 19 + ··· + 29 + 41) × (100) ÷ (182 + 54 + ··· + 41 + 59) = 39.7%.

found that green band (540 nm) was the most useful for discriminating among some soils in Kansas.

Cases from nine groups were identified with an accuracy above 60 percent and those in five groups (30b, 41A, 474A, 475c, 475d) with an accuracy below 30 percent (Table 4). The magnitude of group means for individual variables indicated that the misclassification for unit 30b occurred because of similarity of its blue densities to those from groups 474b, 475d, and 499b. Soil mapping units 41A and 40A were similar in location (Figure 1) as well as in surface characteristics (Tables 1, 2). Consequently, cases from each of these two units were classified as belonging to the other unit. The low accuracy for 474A was probably caused by a large variability of surface soil moisture content at the time of photography.

It was observed that the moisture content for this unit on transect 1 ranged from 6.4 to 46.5 percent on April 16, 1971 (Cihlar, 1971). Results for mapping units 475c and 475d were to be expected because of their surface properties. Depending on elevation and slope, surface materials were eroded and mixed with subsurface horizons during cultivation and therefore their reflectance properties encompassed those of other soil units. Further analysis (Alternative 3) indicated that the surface variability among areas contributed to the low accuracy of identification for these mapping units.

Apart from 40b, the identification of which was facilitated by surface grass cover, the high accuracy of identification for the remaining soil mapping units can be explained by the uniqueness of reflectance characteristics of those units at the time of photography.

Alternative 2. A nearly ideal selection of training sets from the accuracy-of-identification point of view is one in which a portion of data for each soil mapping unit within an area is included in a training set. This was achieved by separating cases within each mapping unit along a transect into two equal parts, and using them as training and testing sets, respectively. For example, the soil unit 474B was represented by cases 1 to 18, from which the first 9 cases were used as a training set and the rest for testing.

Group accuracies (Table 5) were greater for six groups and smaller for ten groups than those for Alternative 1, with an average loss in accuracy of 7.1 percent per group. The overall accuracy was 35.9 percent for testing sets and 39.0 percent for training sets (Table 6). Because of the nature of Alternative 2, changes in group accuracies with respect to Alternative 1 were related to spectral reflectance trends within soil mapping units. As a rule, the accuracy will be lower for testing sets and this was shown by interchanging training and testing sets. In spite of an increase in accuracy (38.7 and 46.5 percent for testing and training sets, respectively), the trend remained the same.

Alternative 3. A training set ideal from the practical standpoint is one in which numbers of both locations and cases within locations are kept to a minimum. This requirement was equivalent to using cases from one transect as

TABLE 5. FINAL CLASSIFICATION MATRIX, ALTERNATIVE 2, TESTING SETS

Group	*12A*	*30A*	*30b*	*40A*	*40b*	*41A*	*171A*	*474A*	*474b*	*474B*	*475b*	*475B*	*475c*	*475d*	*499b*	*546A*	*Group Accuracy (%)*
No. of Cases	89	26	32	65	24	33	39	89	9	9	80	59	185	153	19	30	
12A	38	4	11			2	3	6	5				1	8	8	3	43
30A	1	1	5						5					11	3		4
30b				1					13					2	16		0
40A				19		16				10	1		12	1	3	3	29
40b					24												100
41A				18		10	1	1		1						2	30
171A	26						11					2					28
474A		4	3		1		10	13	7	12		5	12	3	5	14	15
474b									9								100
474A										6						3	67
475b				5					8	1	53	2	9	2			66
475B					1						5	53					90
475c	8	1	1	11		15		1	16	18	28	1	57		26	2	31
475d	13	6	9	3		11	1	1	61		1	1	2	11	32	1	7
499b			1	2							1	1	1		13		68
546A	1					3	1			5						20	67
															Overall Accuracy		35.9%

TABLE 6. ACCURACY OF IDENTIFICATION, THREE ALTERNATIVES, TRAINING SETS

Group	*Accuracy (%)*		
	Alternative 1	*Alternative 2*	*Alternative 3*
12A	49	47	44
30A	35	46	50
30b	25	33	18
40A	61	81	65
40b	94	88	94
41A	25	34	27
171A	67	60	63
474A	16	8	3
474b	85	64	83
474B	78	89	75
475b	64	63	80
475B	93	97	98
475c	24	18	51
475d	4	1	7
499b	71	64	73
546A	70	86	69
Overall Accuracy	39.7	39.0	48.3

a training set and identifying cases at the remaining transects. Due to limited data, only five testing sets from four groups were prepared in this manner and the remaining groups were arranged according to Alternative 1. The accuracy of identification of the testing sets was 15 percent for 474A and 0 percent for each of 475b, 475c, and 475d, whereas training sets of the four groups were identified with an accuracy of 44.3 percent.

This indicated that for practical applications, an adequate choice of training sets would be a problem. Training sets for groups 475c and 475d did not represent data from the testing sets (Table 7). The degree to which variability among transects of unit 475c influenced the accuracy is apparent from a comparison of Alternatives 1 and 3 (Table 6). The reason for failure to identify cases from groups 474A and 475b is not clear as ranges, means and standard deviations for data from training and testing sets were similar within each group.

The accuracies of identification for Alternatives 1 and 2 were suprisingly high considering that: (*i*) photo colors of individual soil mapping units differed appreciably only in brightness when observed visually; (*ii*) the delineation of soil mapping units was based on soil profile properties (upper 100 cm), not on surface reflectance characteristics; (*iii*) spectral reflectances of dry soil samples were approximately proportional at wavelengths ranging from 300 nm to 800 nm; and (*iv*) Munsell hues of these samples were all in the range 9.49 YR to 0.96 Y, Munsell values between 4.20 and 6.22 and Munsell chromas ranged from 2.31 to 3.66. With increasing soil moisture content, Munsell values and chromas decreased quite strongly and Munsell hues shifted slightly toward the red part of the spectrum (Cihlar, 1971). The color film emulsion was apparently very sensitive to reflectance differences existing among surface soils in the dry state as well as among dry and wet soils.

SIZE OF THE GROUND RESOLUTION ELEMENT

To determine the effect of the ground resolution element size, densities for 200×196 μm increments from negatives at two scales were obtained along transects 1, 2, 3, and 4. A total of 1414 cases were used for the 1:4000 scale and 736 cases for the 1:8000 scale. The ground resolution elements measured approximately 0.6 m² and 2.5 m². From Table 8 it

TABLE 7. DENSITY MEANS FOR TRAINING AND TESTING SETS, ALTERNATIVE 3

Set	*Density*	*Group*			
		474A	*475b*	*475c*	*475d*
Training	*red*	0.42	0.64	0.56	0.59
	green	0.48	0.69	0.58	0.66
	blue	0.23	0.38	0.30	0.31
Testing	*red*	0.41	0.62	0.76	0.49
	green	0.48	0.68	0.82	0.53
	blue	0.25	0.34	0.39	0.25
	red			0.43	
	green			0.47	
	blue			0.22	

TABLE 8. INFLUENCE OF GROUND RESOLUTION ELEMENT SIZE ON THE ACCURACY OF IDENTIFICATION

Alternative	*Size of ground resolution element*			
	0.6 m²		*2.5 m²*	
	Training Sets, %	*Testing Sets, %*	*Training Sets, %*	*Testing Sets, %*
1*	58.1	58.1	57.1	57.1
2*	60.1	51.0	53.5	47.0
3†	42.7	4.6	80.2	1.1

* Based on 11 soil mapping units.

† Based on 2 soil mapping units.

can be seen that the accuracies of identification changed in a different manner for each scale and training set arrangement. The magnitude and sign of the differences indicated that there was no substantial decrease in accuracy due to the smaller resolution element. A further increase of the ground element size seems possible.

PERFORMANCE OF B&W AND COLOR FILM

For an evaluation of the suitability of film materials to supply information about soil mapping units, it would be helpful to know the performance of B & W and color photographs under similar conditions. As no direct measurements from B & W photos could be used, densities obtained with red, green, and blue filters on color negatives were summed for each increment along the six transects (scale 1:4,000). The sums may be considered, roughtly speaking, equivalent to B&W densities obtained under similar conditions. The overall accuracy of identification (15.2 percent, Alternative 1) matched that achieved with either red or blue densities which could be expected from the character of soil spectral reflectance curves. Although the comparison is only approximate, it does show a difference between the two film materials in their ability to supply quantitative data with a discriminatory power.

APPLICATIONS

The above results indicate that color films record some specific information about soil mapping units. This information could be utilized for soil photointerpretation provided that (*1*) areas are measured instead of transects, and (*2*) a suitable means of incorporating the information into the soil mapping procedure is developed. To satisfy the second condition, we suggest the following approaches for consideration.

Semiautomatic interpretation of soils, in the manner elaborated for crop types (Steiner, 1970b). The resulting boundaries would separate areas of uniform surface color. In instances where such boundaries coincide with those based on soil profile properties, as in some areas of California (Dominguez, 1960; R. N. Colwell, personal communication*), the results would be equivalent to a conventional soil map. The usefulness of such an approach to interpretation of soils was discussed by Wagner (1971) who conducted a similar investigation using multispectral data. Problems to be expected on the basis of our study relate to representative training sets, variability of soil surfaces and photo densities. and uniqueness of spectral reflectance characteristics for soil mapping units. The method used in this study may be refined by: (*i*) quantitative studies of the relationship between soil spectral reflectance and soil mapping units, physical properties, and chemical properties of soils in the given area; (*ii*) including near IR wavelength region; (*iii*) sequential photography; and (*iv*) alternative statistical techniques (Steiner, 1970b; Haralick *et al*., 1970).

Enhancement of images (Ross, 1969; Kalensky, 1971) to aid in human photo interpretation of soils. Such a procedure was applied to interpreting soil limitations (Frazee *et al*., 1971). Enhancement procedures, especially those capable of modifying all three emulsion layers simultaneously, should be useful in cases where subtle hue and saturation changes are masked by large differences in brightness.

Delineation of areas with color ranging within specified limits. The areas of uniform colors could be based on boundary finding algorithm (Wacker, 1969) and the printouts

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used as an aid in human soil photo interpretation.

ACKNOWLEDGMENTS

The authors wish to thank Dr. C. J. Acton for his help with problems related to mapping soils in the study area and Dr. D. Steiner who kindly reviewed a draft of this paper. The financial support of the C.D.A. Grant No. 9079 is gratefully acknowledged.

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