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AD-A196 087

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

DTIC ELECTE JUN 03 1988 S D

- 1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED
- 1b. RESTRICTIVE MARKINGS:
- 2a. SECURITY CLASSIFICATION AUTHORITY:
- 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:
- 3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
- 4. PERFORMING ORGANIZATION REPORT NUMBER(S): R-142
- 5. MONITORING ORGANIZATION REPORT NUMBER(S):
- 6a. NAME OF PERFORMING ORGANIZATION: USAETL
- 6b. OFFICE SYMBOL (If applicable): CEETL-LO
- 7a. NAME OF MONITORING ORGANIZATION:
- 6c. ADDRESS (City, State, and ZIP Code): Fort Belvoir, VA 22060-5546
- 7b. ADDRESS (City, State, and ZIP Code):
- 8a. NAME OF FUNDING / SPONSORING ORGANIZATION:
- 8b. OFFICE SYMBOL (If applicable):
- 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:
- 8c. ADDRESS (City, State, and ZIP Code):
- 10. SOURCE OF FUNDING NUMBERS:

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

- 11. TITLE (Include Security Classification): APPLICATION OF SOIL AND VEGETATION REFLECTANCE SPECTRA TO COLOR AND COLOR INFRARED PHOTOGRAPHY
- 12. PERSONAL AUTHOR(S): MELVIN B. SATTERWHITE, J. PONDER HENLEY
- 13a. TYPE OF REPORT: RESEARCH
- 13b. TIME COVERED: FROM ______ TO ______
- 14. DATE OF REPORT (Year, Month, Day): 86 DECEMBER 15
- 15. PAGE COUNT:
- 16. SUPPLEMENTARY NOTATION:
- 17. COSATI CODES:

FIELD	GROUP	SUB-GROUP

- 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): arid region soil, vegetation remotely sensed imagery, reflectance spectra

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Characterizing arid region soil and vegetation conditions from remotely sensed imagery can be limited by the small image tonal contrast between soil and vegetation surfaces. Ground-level reflectance spectra of different soil surfaces can be highly variable over the visible-near infrared (NIR) region. Spectral differences between cheatgrass, sagebrush, shadscale, greasewood, saltgrass, and alfalfa samples resulted from pigmentation, plant structure, and phenological differences. Some soil surfaces and plant species have similar reflectances in some spectral bands but are spectrally different in other bands. This study evaluated these spectral responses and the likelihood that these surfaces would be separable on Kodak Aerochrome color or color infrared films.

Reflectance emulsion factors (REF) were calculated for each surface using the spectral sensitivity of each emulsion dye layer of the color or color infrared film and the surface's reflectance spectra. These values indicate the effect of reflected light form the sample on the film emulsion layer. Shaded soil and shaded vegetation have very similar REF values

- 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS
- 21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
- 22a. NAME OF RESPONSIBLE INDIVIDUAL: F. DARLENE SEYLER
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- 22c. OFFICE SYMBOL: CEETL-LO

DD Form 1473, JUN 86 — Previous editions are obsolete.

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Block #19

for both films, while values for dark toned gravels and medium toned soils are similar to many plant surfaces. Medium to light toned soils have REF values larger than any vegetative surface. Discriminating the surfaces with low to medium REF values depends on the film layer (s) affected, the density of the emulsion layer, and the color formed.

Proc., 11th Biennial Workshop on Color Aerial Photography & Videography in the Plant Sciences and Related Fields, 27 Apr-1 May 87, Weslaco, TX (sponsored by USAD Ag Rsch Svc Lab & Am Soc of Phtgrm & Rem Sensing)

APPLICATION OF SOIL AND VEGETATION REFLECTANCE SPECTRA TO COLOR AND COLOR INFRARED PHOTOGRAPHY

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ABSTRACT

Characterizing arid region soil and vegetation conditions from remotely sensed imagery can be limited by the small image tonal contrast between soil and vegetation surfaces. Ground-level reflectance spectra of different soil surfaces can be highly variable over the visible-near infrared (NIR) region. Spectral differences between cheatgrass, sagebrush, shadscale, greasewood, saltgrass, and alfalfa samples resulted from pigmentation, plant structure, and phenological differences. Some soil surfaces and plant species have similar reflectances in some spectral bands but are spectrally different in other bands. This study evaluated these spectral responses and the likelihood that these surfaces would be separable on Kodak Aerochrome color or color infrared films.

Reflectance emulsion factors (REF) were calculated for each surface using the spectral sensitivity of each emulsion dye layer of the color or color infrared film and the surface's reflectance spectra. These values indicate the effect of reflected light from the sample on the film emulsion layer. Shaded soil and shaded vegetation have very smiliar REF values for both films, while values for dark toned gravels and medium toned soils are similar to many plant surfaces. Medium to light toned soils have REF values larger than any vegetative surface. Discriminating the surfaces with low to medium REF values depends on the film layer(s) affected, the density of the emulsion layer, and the color formed.

INTRODUCTION

Ground-level reflectance spectra of arid-land soils and vegetation can be highly variable and over short distances many different surface conditions can be present; bare soil, gravels, precipitated salts, shadows, or plant debris. Vegetation is highly variable because of species differences in pigmentation, crown cover, growth stage, leaf area, biomass, or shadows (Satterwhite and Henley, in progress). Ground level reflectance spectra have shown many soil and vegetation surfaces are spectrally separable using discrete spectral region(s). While surfaces can be unique spectroradiometrically, many are not differentiated

on aerial color or color infrared photography, because each emulsion layer is sensitive over a much larger spectral region. This tends to mask the narrow distinctive absorption bands. Our predictions for separating various components of the soil-vegetation mosaic using aerial photographic film, could be enhanced by merging the surface spectroradiometric data with the film emulsion's spectral sensitivity data.

This paper discusses ground-level spectral measurements of semi-arid vegetation and soil surfaces and how these spectra can assist our assessments for soil and vegetation separation on color or color infrared aerial photography.

MATERIALS AND METHODS

Reflectance spectra were taken of the big sagebrush, *Artemisia tridentata*, shadscale, *Atriplex canescence*, greasewood, *Sarcobatus vermiculatus*, saltgrass, *Distichlis stricta*, alfalfa, *Medicago* sp., and the associated soil surface conditions at sample sites in northern Nevada. Most spectra represent unstressed, sunlit plant canopies. Spectra of senesced cheatgrass (*Bromus tectorum*) and alfalfa, of shaded soil, and of shaded vegetation were taken for comparison.

The reflectance spectra were recorded over the 400 to 1100 nm region in 10 nm increments using an EG&G model 555 spectroradiometer system* with a 15 degree FOV. The surfaces were viewed vertically from a height of 0.5 to 1.0 meters. The spectra were taken on clear, cloud free days. Shadow effects associated with sunlit plant canopies were minimized by acquiring the spectra between 1000 and 1400 true solar time, i.e. the solar altitude was near its daily peak and the residual shadow effect was not significant. Reflectance spectra were calculated as the ratio of the sample radiance to the radiance of a halon* reference standard (Satterwhite and Rinker, 1986).

For each surface, a reflectance emulsion factor (REF) was calculated for the yellow, magenta, and cyan emulsion layers of Kodak Aerochrome MS color film (2448) and Aerochrome infrared film (2443), both of which are reversal films* (Eq. 1). A REF value was calculated, which represents the summed REF values calculated for each 10nm bandpass over the spectral sensitivity of each emulsion layer.

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* The citation of commercially available products is not an official endorsement or approval of the use of such products.

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$$REF = \sum_{i=1}^{n} [E(i) * R(i)] \quad (1).$$

where: $E(i)$ = emulsion sensitivity in bandpass (i),
$R(i)$ = sample's reflectance in bandpass (i),
(i) = a 10nm band within the emulsion's spectral sensitivity.

The range of the emulsion's sensitivities, E(i), are shown in Table 1. These were determined from the film emulsion sensitivity curves provided by Eastman Kodak Company (1982).

Table 1.
Emulsion Sensitivities for Aerochrome Color and CIR Film

Emulsion	Color+	CIR++
Yellow	400-530nm	500-600nm
Magenta	430-600nm	500-690nm
Cyan	450-700nm	500-900nm

\+ Lower limit is set by a haze filter, Wratten HF-3.
++ Lower limit is set by the Wratten #12 filter.

DESCRIPTION OF SOIL SURFACE AND VEGETATION

The field sites are located on mid-to-lower alluvial fans, river terraces, and valley bottoms. Major soil surface conditions are bare soil, dark toned gravels, precipitated salts and salt crust. The texture of the surfaces (0-15cm depth) are sandy loam (SaLm), loam (Lm), clay loam (ClLm), silty clay loam (SiClLm), silt loam (SiLm), silty clay (SiCl), sandy clay loam (SaClLm), or clay (Cl).

Vegetation is primarily shrub and grass communities. Greasewood and saltgrass occur on low lying, wet saline soils with near surface ground water. Shadscale occurs on saline alluvial fan soils. Sagebrush is found on the non-saline soils of these fans. Cheatgrass is found on the saline and non-saline soils of the alluvial fans. Alfalfa is grown on irrigated non-saline soils on the mid to lower portions of the alluvial fans.

REFLECTANCE SPECTRA

Soil reflectance spectra are summarized in Figure 1. The percent reflectance of all soils increased directly with wavelength over the visible-NIR spectrum. Spectral differences between soils resulted from variable surface conditions. Shaded or gravel covered soils have lowest reflectances, saline soils with salt crusts have the highest, and fine gained bare soil and saline soils with darker toned silts incorporated in the crust have intermediate reflectance curves.

Vegetation reflectance spectra are summarized in Figures 2 through 7. Generally, these represent four color groups.

Gray-colored plants, characterized by rather flat spectral curves in the visible region and moderate NIR reflectance, e.g. sagebrush, shadscale, and saltgrass (Figures 2, 3, and 4). Yellow-green colored plants are slightly less reflective in the visible region and are more reflective in the NIR region, e.g., greasewood (Figure 5). Alfalfa is characteristic of green-colored plants, that have low reflectance in the blue and red regions, a small peak in the green, and high NIR reflectance (Figure 6). Senesced vegetation has moderate reflectance in the visible-NIR spectrum and reflectance varies directly with wavelength, e.g., senesced cheatgrass or alfalfa (Figure 7).

Vegetation spectra can be affected by a number of factors. Ground cover differences will vary the visible and NIR reflectance of the vegetation-soil mosaic, in accordance to the percentage of vegetation and soil in the FOV and the reflectance contrast between the vegetation and soil components. Species with near 100 percent ground cover have small differences in their visible reflectances while their NIR reflectances can vary considerably. The canopies with less than 90 percent cover, e.g., saltgrass (Figure 4), have variable visible and NIR reflectances which varies with the percentages of the vegetation and soil in the radiometer's FOV (Satterwhite and Henley, 1982).

NIR reflectance of many species is variable even for canopies with 100% cover. This had been related to canopy "green leaf area" (Asar, 1986) and soil background (Huete, 1985). The spectra of green alfalfa surfaces have essentially the same visible reflectance, indicating no difference in the ground cover, which is greater than 90 percent for each of the three spectra (Figure 6). The highest NIR reflectance is associated with an alfalfa canopy, greater than 50 cm tall, the moderate NIR reflectance with a 40 cm tall canopy and the lower NIR reflectance with an alfalfa canopy less than 30 cm tall. The NIR reflectance-plant height relation is indicative of the direct relations between NIR reflectance, leaf area, or green biomss (Tucker, et.al., 1979; and Satterwhite and Henley, 1982).

All physiologically active plants have substantial contrast between their visible and NIR reflectance, resulting from chlorophyll absorptance in the visible region. Senesced vegetation has lower visible to NIR contrast than does the "active" growing vegetation, as shown by the alfalfa spectra in Figures 6 and 7. These differences result from chlorophyll pigmentation in healthy, active plants, but which is absent in the senesced leaves. NIR reflectance can also be altered by the collapse of internal leaf structure in the senesced leaves (Gausman, 1970).

REFLECTANCE EMULSION FACTORS

The reflectance emulsion factors (REF) calculated from the soil and vegetation spectra and the film sensitivities are shown in Figures 8 and 9 for color and CIR films, respectively. Soils have large dynamic ranges of REF values (1 to 65) for all emulsion layers, while vegetation has smaller ranges (1 to 20). Shaded soil and shaded vegetation have REF values less than 3.5, while the REF values of dark toned gravels, medium toned soils (curves 1,2, and 3), and sunlit vegetation ranged from 3.5 to 26. The medium and light toned soils (curves 4, 5,6, and 7) have REF values greater than 26.

REF values indicate the relative effect of light reflected from the sample on the film emulsion layer. Although, these values do not take into account the relation between exposure and dye layer densities, these general relations are seen. The shaded soil and shaded vegetation, that have low REF values, would appear dark in a dye layer of the color or CIR film. Surfaces with high values, such as saline soils and in some emulsions vegetation, would appear bright. The large dynamic range of soil REF values indicated, that the film's exposure be set for the detail in the desired surface type, since the film latitude can not depict all soil types. Usually the film is exposed so the soil and vegetation surfaces, those with the lower REF values, are separable on the film. This causes the brighter toned soils to be "grouped" into the brightest image tones, because they "overexpose" the film emulsions. Adjusting the exposures settings to obtain detail and separation between bright toned soils would "group" those surfaces with low REF values, because the emulsions layers would be "underexposed" and dark dye layer tones are produced.

The image color of a surface depends on the emulsion layer(s) affected and the density of the dye layer formed on the film. For reversal film, the density of the dye formed is inversely related to the REF value. The exposed emulsions do not form dye layers during film development. For green alfalfa which appears red on the CIR film, the REF values must be low for the yellow and magenta emulsions, and high for the cyan. Thereby, the yellow and magenta dye layers form on the image and the cyan dye layer does not. The intersection of yellow and magenta dye layers give the red image color. Gray colored sagebrush has moderate REF values for all emulsions. The resultant CIR image color would be a "bluish" tone.

In color film, green vegetation appears green because the REF values of the yellow and cyan emulsions are low but are high for the magenta layer. Senesced vegetation appears yellowish or white because the REF values are moderate to high for all emulsions. Some soils can be distinquished by their image color if their REF values are not too high. Those with high REF values in all three emulsion layers should appear white, since none of the dye layers are formed. The image color for many soils is usually a gray tone, that varies with the intensities of the three REF values. Soils, that are highly reflective in only one spectral region, blue, green or red, would appear as a color not as a gray shade.

CONCLUSIONS

Reflectance emulsion factors (REF) calculated from soil and vegetation spectral reflectance data show the potential for discriminating certain types of vegetation and soil conditions on color and color infrared aerial photography. They also show those conditions that may not be readily identified on aerial photography. Knowing these relationships can help in the interpretation of soil and vegetation conditions.

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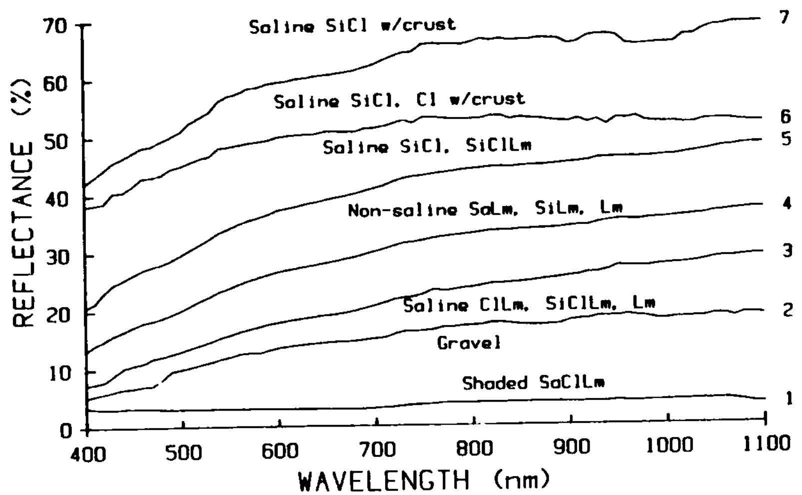

Figure 1: Spectra of Sunlit and Shaded Soils.

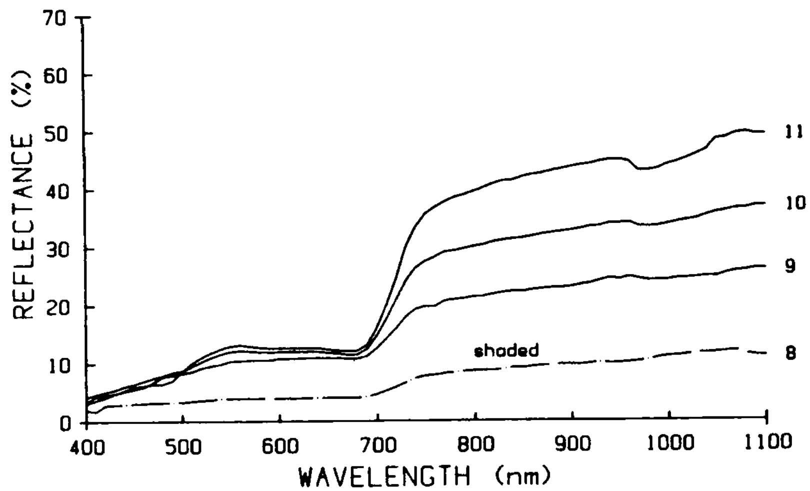

Figure 2. Spectra of Sagebrush.

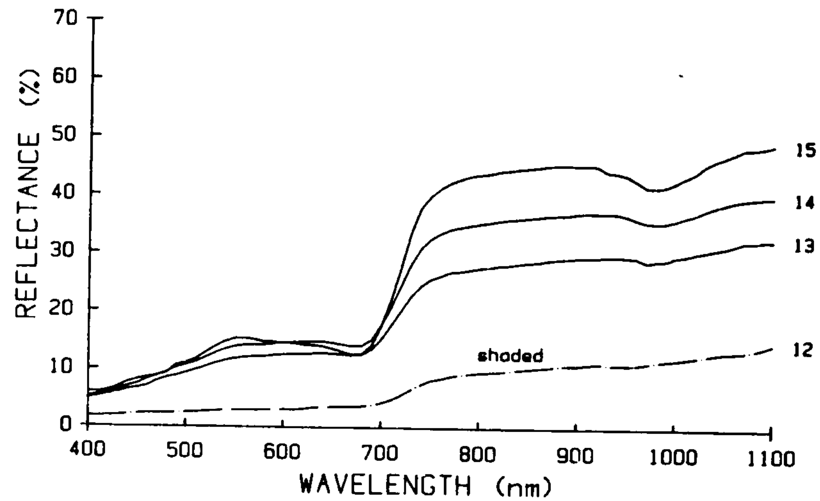

Figure 3. Spectra of Shadscale.

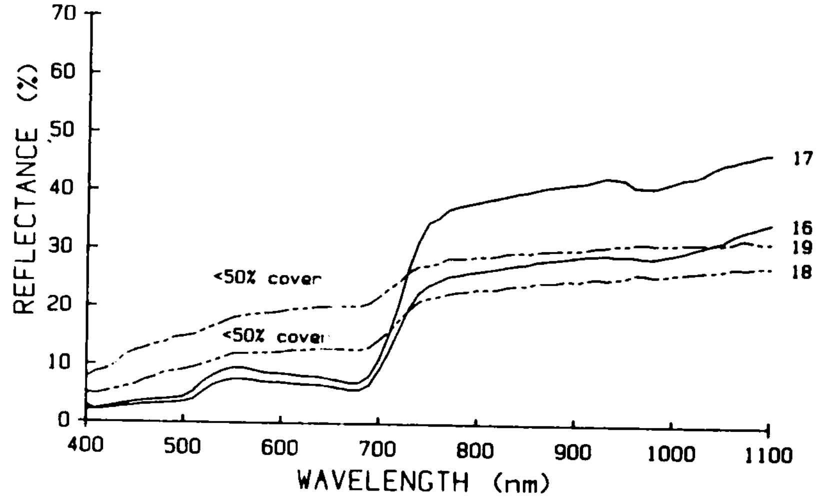

Figure 4. Spectra of Saltgrass.

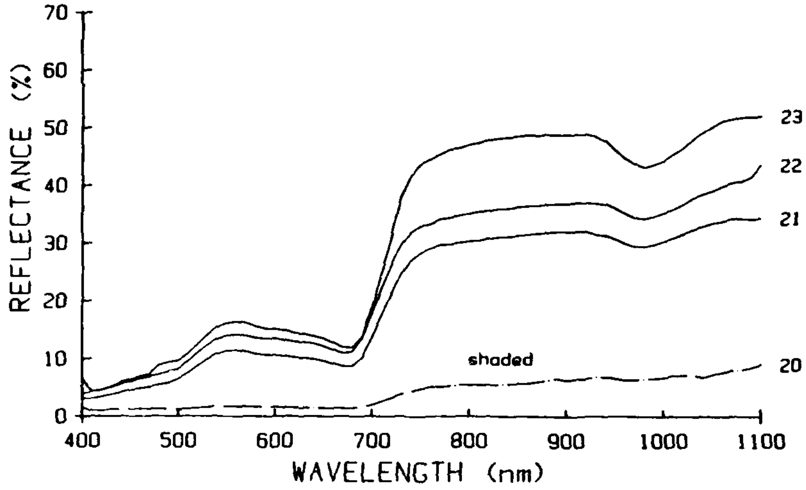

Figure 5. Spectra of Greasewood.

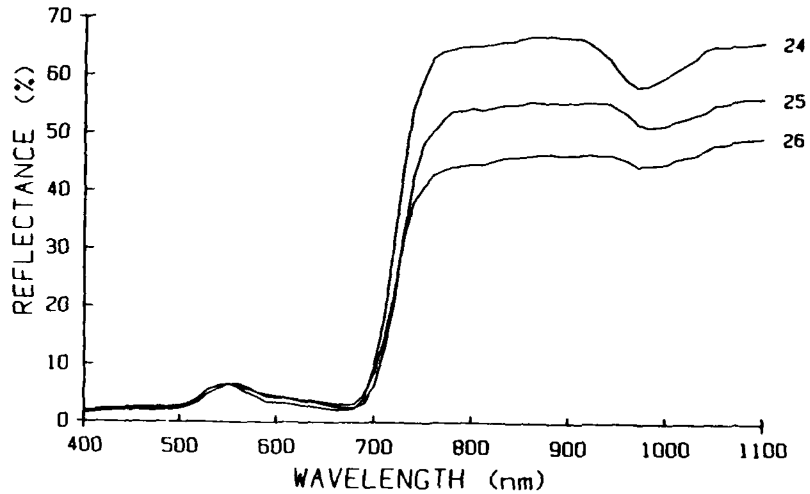

Figure 6. Spectra of Alfalfa.

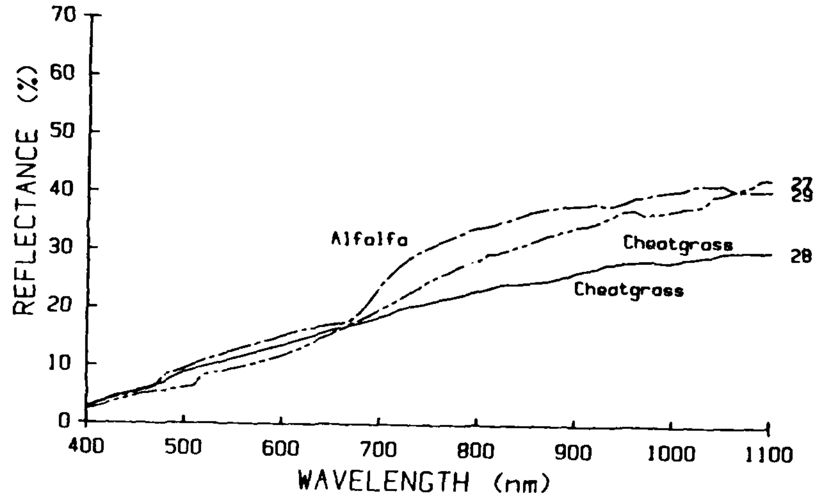

Figure 7. Spectra of Senesced Vegetation.

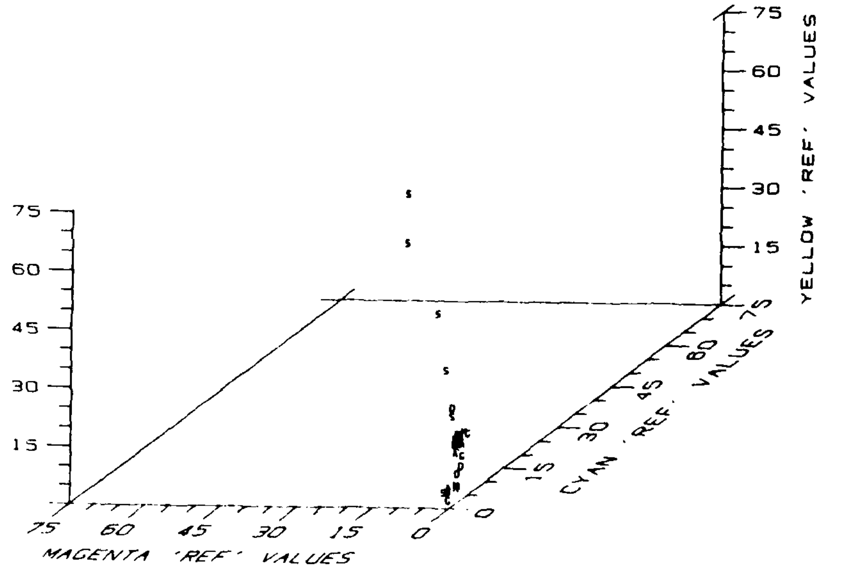

Figure 8. Sample Reflectance Emulsion Factors for Color Film Emulsion Layers.
S = soil; A = sagebrush; B = shadscale; D = saltgrass; G = greasewood; H = alfalfa; M = senesced vegetation.

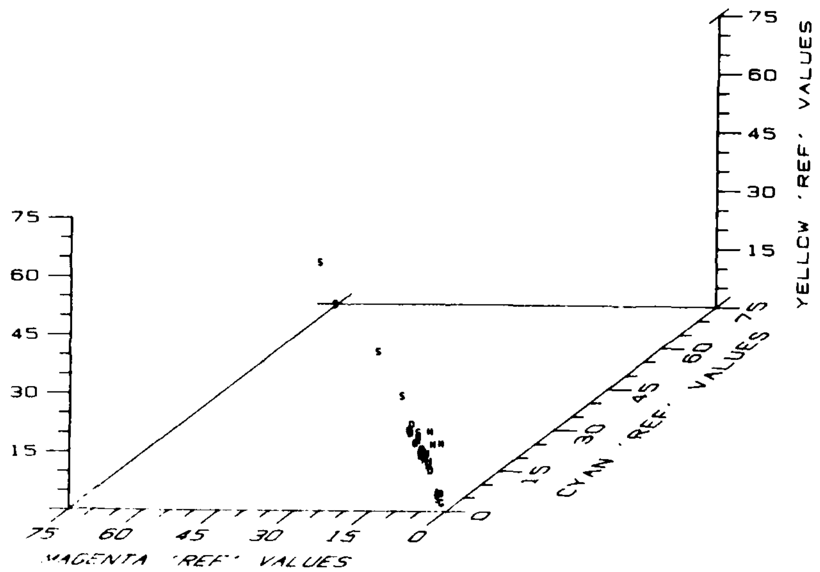

Figure 9. Sample Reflectance Emulsion Factors for Color Infrared Film Emulsion Layers.
S = soil; A = sagebrush; B = shadscale; D = saltgrass; G = greasewood; H = alfalfa; M = senesced vegetation.