REFLECTANCE AND TEMPERATURE CHARACTERISTICS OF SEMIARID RANGELAND SURFACES

by

Georgia Reavis Turner

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Donald F. Post
D.F. Post
Professor of Soil Science

5/3/84
Date

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ABSTRACT

Spectral and surface temperature measurements were made of various rangeland surface conditions using a hand-held radiometer and an infrared thermometer. Three different soil series, each with three plots with varying surface conditions,were studied. T-tests, simple-linear regression analysis, and principal components analysis were used to relate rangeland surface features to spectral and thermal measurements.

Vegetation was the feature that had the most effect on surface temperature under dry conditions, and vegetated plots had a lower percent change in daily temperature than bare plots. Under wet conditions, there were no significant differences in temperature between plots with differing surface conditions.

Correlation coefficients showed that the hue of the soil was highly correlated with the percent reflectance in all four spectral bands, and the green grass cover decreased the reflectance in bands one, two and three.

There were high correlation levels among the spectral bands showing an overlap of spectral information.

INTRODUCTION

Semiarid rangelands cover over 490 million acres in the western United States, and of this area, 230 million acres are classified as being in fair to poor condition (U.S.D.A., 1974; Forest Service, 1980). The disappearance of native grasslands, increased arroyo (gully) cutting, and accelerated sheet erosion was recorded over 100 years ago in southern Arizona (Hastings and Turner, 1965). Today, shrubby plants dominate areas that were grasslands before 1880 (Cox et al., 1983). This rangeland deterioration mandates better land-use management decisions based on detailed natural resource surveys. However, these surveys can be very time consuming and costly if conventional ground-based methods are used for data collection and mapping.

The Landsat satellites developed by the National Aeronautics and Space Administration have the potential to aid in the collection of rangeland resource information. Remotely sensed data can provide information to soil scientists for the identification and distribution of soils (Kornblau and Cipra, 1983), and can delineate problem areas, such as eroded and/or overgrazed areas, for range managers (Robinove, Chavez, and Gehring, 1981; Morrison and Cooley, 1973).

One of the problems associated with analyzing remotely sensed data is collecting representative ground-truth information to be used in interpreting satellite images. To overcome this problem, there has been an increase in the use of hand-held radiometers to provide detailed ground-based information on the spectral properties of various surfaces (Jackson et al., 1980).

The objectives of this thesis were to study the relationship between semiarid rangeland surface features and their reflectance and temperature characteristics. Three major rangeland features were studied: vegetative cover, erosion pavement, and varying soils. The spectral and thermal properties of these features were measured by using a hand-held radiometer and an infrared thermometer that sensed electromagnetic radiation in bands which are identical to five of the seven bands found on the Landsat 4 Thematic Mapper instrument.

LITERATURE REVIEW

This section of the thesis summarizes previous research on uses of remote sensing for rangeland resource management. Research on factors which affect the relative reflectance and temperature of semiarid rangeland surfaces are also presented.

Uses of Remote Sensing for Rangeland Resource Management

Changes in relative reflectance values in the 0.5-to-1.1μm portion of the electromagnetic spectrum, which includes green, red and near infrared light, have been used by several workers to monitor land degradation and reduced rangeland productivity (Walker and Robinove, 1981; Robinove, Chavez, and Gehring, 1981). These reflectance values were digitally recorded by multispectral scanners placed in Landsat satellites and reproduced into images.

Robinove et al. (1981) used Landsat multispectral digital data to calculate Landsat albedo changes of arid terrain in Utah. Albedo difference images were produced showing the annual percent change in reflectance, with the reflectance measurements being the sum of the four spectral bands (0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1μm). They reported that in most cases decreased density of vegetation, increased erosion, and movement and deposition of windblown materials tended to increase the reflectance. Exceptions to this may occur where grasses and forbs are replaced by shrubs having higher density crown cover, resulting in an increase in reflectance (Warren and Hutchinson, in press). It was suggested that precipitation data should also be considered because increased soil moisture in wet years will decrease reflectance (Robinove et al., 1981).

Morrison and Cooley (1975) used high altitude aerial photos taken from 62,000 ft. (18,902m) above the ground to provide a basis for assessing satellite information to produce maps showing the distribution of erosion features in southern Arizona. They found that the 0.6-0.7μm portion of the spectrum (red) was best for detecting arroyos (gullies) due to the high contrast of dark vegetation against the light arroyos, and soils of former floodplains that were denuded of vegetation.

Temperature changes have also been observed as a result of overgrazing and land degradation. Otterman (1974) reported that soils denuded of vegetation by overgrazing had higher reflectance and were cooler than vegetated soils. These findings, however, were refuted by Jackson and Idso (1975) and by Dixon and Simanton (1980). They found that denuded surfaces had elevated mean daytime temperatures in comparison to vegetated surfaces.

Dixon and Simanton (1980) had preliminary results which suggest that temperature observations can be used to monitor desertification reversal. Portions of a creosote bush (Larrea divaricata) infested area of the Santa Rita Experimental Range in southeastern Arizona were revegetated using herbicide and/or a land imprinter. The revegetated areas had significantly lower air temperatures one meter above the soil surface than the natural creosotebush condition.

Extensive research has been done in the use of Landsat digital data as an aid for soil mapping and survey. Most of this work, however, has been done in the Midwest. Kornblau and Cipra (1983) and Thompson, Hass, and Milford (1980) were some of the few researchers to work in a semiarid area.

Kornblau and Cipra (1983) studied the ability of the Landsat satellite to provide information on the location and distribution of soils in semiarid regions with low to moderate amounts of range vegetation. Landsat satellite data was found to have 46.5% agreement with field collected information. Satellite computer classified maps showed that some soil boundaries might be more accurately located using satellite data than using only standard field mapping methods.

Thompson et al. (1980) collected Landsat data from three overpass dates from a Prairie-Post Oak savanna landscape in Brazos County, Texas. They evaluated this data for its possible use and relative accuracy in separating soils on vegetated landscapes. Particle sizes in control sections, most of which were fine or fine-loamy, and soil moisture regimes were separable using Landsat digital data from June and October. Soils with argillic horizons could be separated from soils without argillic horizons.

Spectral and Thermal Properties of Vegetation

In the visible portion of the electromagnetic spectrum (0.50-0.75μm), vegetation plant pigments such as chlorophyll and xanthophyll absorb radiation. In the 0.75 to 1.1μm wavelength region, the internal structure of the leaf results in low absorptance and high reflection. A slight peak of reflectance occurs at 0.54μm, in the green region, due to slightly higher reflectance by chlorophyll (Sinclair, Hoffer, and

Schreiber, 1971). Workers have also found a high negative correlation between spectrophotometric plant reflectance and plant moisture, which may also be a result of plant pigments (Johannsen, 1969). Reflectance values of vegetation and different land cover types are pesented in Figure 1, along with wavelength channels for three satellite systems. SPOT is a French satellite scheduled to be launched in 1985.

The spectral reflectance of leaves undergoes changes throughout the growing season. Young leaves have low reflectance in the visible bands and very strong reflectance in the near infrared region. As leaf morphology and pigmentation change, the leaf's reflective characteristics also change. Siegal and Goetz (1977) noted that vegetation varies in brightness as it changes from the growing stage (dark green) to the dormant stage (tan, yellow). They reported that dry vegetation lacks the strong adsorption band in the red portion of the spectrum and high reflectance in the near infrared, making the reflectance of dead or dormant vegetation similar to soils.

Gates (1970) reported that up to 15% vegetative cover appears as soil, while vegetative cover of over 40% masks the soils' spectral reflectance. However, Huete, Post, and Jackson (1984) showed that if the reflectance of individual soils, rather than a mean soil reflectance for an area, is used when determining vegetation densities, then accuracy with a low vegetative cover can be increased.

With respect to thermal properties, three basic processes contribute to the energy budget of a plant and affect its temperature: solar radiation, free and forced convection, and transpiration. According to Gates (1970) studies of energy budgets of green vegetation show that a dark dry loam in full sunlight may have a surface temperature of

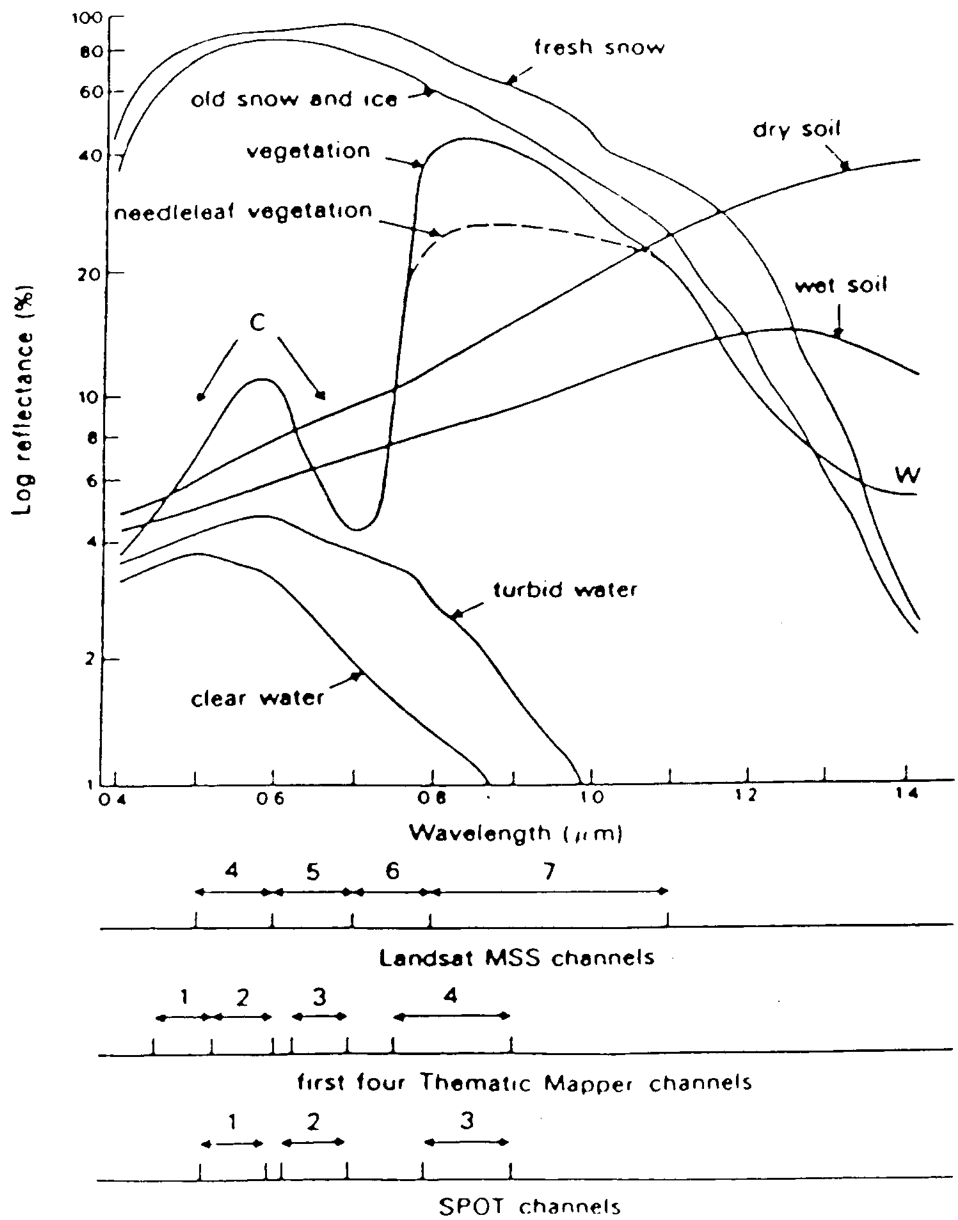

Figure 1. Reflectance values of different land cover types at different wavelengths (Townshend, 1981).

50°C, while a stand of vegetation nearby will have temperatures of 30°C. The cooler temperatures of fully sunlit leaves are a result of plant transpiration and the low absorption in the near infrared portion of the spectrum.

Spectral and Thermal Properties of Soils and Land Surfaces

Bare soils and coarse fragments on the soil surfaces make up a large portion of the spectral response from arid and semiarid rangelands. Soil reflectance values generally increase in the 0.5-to-1.1μm portion of the electromagnetic spectrum. This is generally true for both wet and dry soil conditions, but wet soils have reduced reflectance throughout the spectrum (Condit, 1970). Spectral reflectance varies among different soil types and has been shown to be affected by the following: surface moisture content, color, organic matter content, particle size distribution, soil mineralogy, soil structure, surface roughness, and crusting (Bowers and Hanks, 1965; Stoner and Baumgardener, 1981). The relative reflectance of individual soils can be graphically shown as a "soil line", which is the ratio of reflectance in the red band (0.63-0.69μm) to reflectance in the near infrared band (0.76-0.90μm). The soil line has been accepted as being useful for interpretation and analysis of multispectral data (Jackson et al., 1980; Wiegand and Richardson, 1982).

Osborn, Simanton, and Renard (1977) reported that erosion pavements predominate on many rangelands due to extensive sheet erosion which exposes coarse fragments from the subsurface horizons of the soil. Horvath (1981) performed a laboratory study using a hand-held radiometer to determine if there is a significant difference in reflectance of three different size fractions of coarse fragments (erosion pavement) collected from an Arizona rangeland. He found that the <2mm fraction of the soil had reflectance values that were significantly different from fine gravel (2-13mm) and coarse gravel (13-76mm), but fine gravel and coarse gravel reflectance values did not differ significantly.

Lucas (1980) studied the spectral response of soil and coarse fragments on rangelands in southeastern Arizona and found decreasing values for relative reflectance associated with increasing area of cobble (7.5-25cm). However, he found that the percent cover of particles <2mm in diameter and percent cover of particles 0.2-7.5cm in diameter did not correlate with any of the four spectral bands (0.5-1.1μm).

Thermal properties of soils are interrelated with their spectral properties, which is expressed by the following equation of radiation balance: $R = Q-S-U$ where R is the net radiation retained by the soil, Q is the total solar radiation at the top of the atmosphere, S is reflected solar radiation, and U is effective radiation. Soil radiation emitted and soil surface temperatures are related by the Stefan-Boltzman equation: $\varepsilon\sigma T^4 = q(\text{watts } m^{-2})$ where q is the rate at which electromagnetic waves are emitted in watts/meter^2, T is surface temperature in degrees Kelvin, σ is the Stefan-Boltzman constant (wm^2K^{-4}), and ε is the emissivity which equals one for black bodies (perfect emitters), while for less efficient emitters ε is less than one (Gates et al., 1970).

Factors that affect diurnal, seasonal, and annual temperature changes are as follows: surface aspect and slope, latitude, soil color, soil moisture, soil-air humidity, evapotranspiration, soil porosity, size of soil particles, and vegetative cover. The most important of these factors affecting soil thermal properties are soil moisture and soil-air humidity. Soil moisture and humidity increase the thermal conductivity of soil. Water film between soil particles not only improves the thermal contact between particles but also replaces air in the soil pore space with water, which has approximately 20 times the thermal conductivity of air (Baver, Gardner, and Gardner, 1972).

Topography

Temperature

Changes in the position of the sun, along with latitude, varying slope, and aspect, greatly influence the amount of net radiation received by soil. Incoming radiation is highest at lower latitudes and decreases rapidly at latitudes above 30 degrees due to the decreasing elevation of the sun. The closer the sun's rays are to forming a right angle with the soil surface, the greater the amount of heat received per unit area. The slope and aspect also affect the angle between the sun's rays and soil surface (Baver et al., 1972).

The effect of slope, aspect, and latitude on soil temperature is illustrated by a study by Alter (1912). He found that a one-degree slope in Idaho facing north had the same solar radiation as a level field at a latitude which was one degree farther north. A five-degree slope in Idaho with a southern aspect had the same solar radiation as a level field in southern Utah, which was a five-degree change in latitude.

Reflectance

It may be assumed that the soil acts as a lambertian reflector for high sun angle in the 0.5-to-1.1μm spectral region. Thus, relative reflectance should be independent of aspect (Reeves, Anson, and Landen, 1975). However, spectral reflectance is affected by the combination of slope and aspect. Reflectance decreases on north and south aspects as the slope increases from 0 to 30 degrees. Reflectance increases on east aspects as the slope increases from 0 to 30 degrees, while on west aspects reflectance decreases as the slope increases (Buffo, Fritschen, and Murphy, 1973).

The interaction of sun angle and azimuth with slope angle and aspect in causing variations in surface illumination is given by an incidence value: incidence value = $\cos\alpha + \sin\alpha \cot\beta \cos\theta$ where β = solar elevation from the horizontal, α = slope angle, θ = the difference between slope, aspect, and solar azimuth (Monteith, 1973).

DESCRIPTION OF STUDY AREA

Rainfall simulator erosion plots, located on the Walnut Gulch Watershed near Tombstone, Arizona were used for this study. These plots were set up for an erosion study by the Southwest Rangeland Watershed Research Center of the Agricultural Research Service, U.S. Department of Agriculture.

The Walnut Gulch Watershed is a topographic basin in the Basin and Range Province on an undulating alluvial fan with a shrub and grass cover. There is evidence that most of the watershed was grassland 75 years ago but now two-thirds of it is shrub with varying amounts of native grasses. The area has a warm, semiarid climate with a mean annual temperature of 17°C with 60% of the annual precipitation occurring during the months of July, August, and September. April, May, and June contribute 6% of the mean annual precipitation, while the rest of the annual precipitation is evenly distributed over the remaining months (U.S.D.A., Soil Conservation Service, August, 1970).

The study plots are located on three major soil series: Bernardino, Hathaway, and Cave (see Table 1). The plots, measuring 35 ft. (10.7m) by 10 ft. (3.1m), had the following treatments on each soil: one plot with the vegetation and erosion pavement removed, one plot with the vegetation removed and erosion pavement left undisturbed, and a control plot with natural range vegetation and erosion pavement. Terms which will be used to represent these erosion plots in this thesis are given in Figure 2. The Bernardino soil site had one additional plot

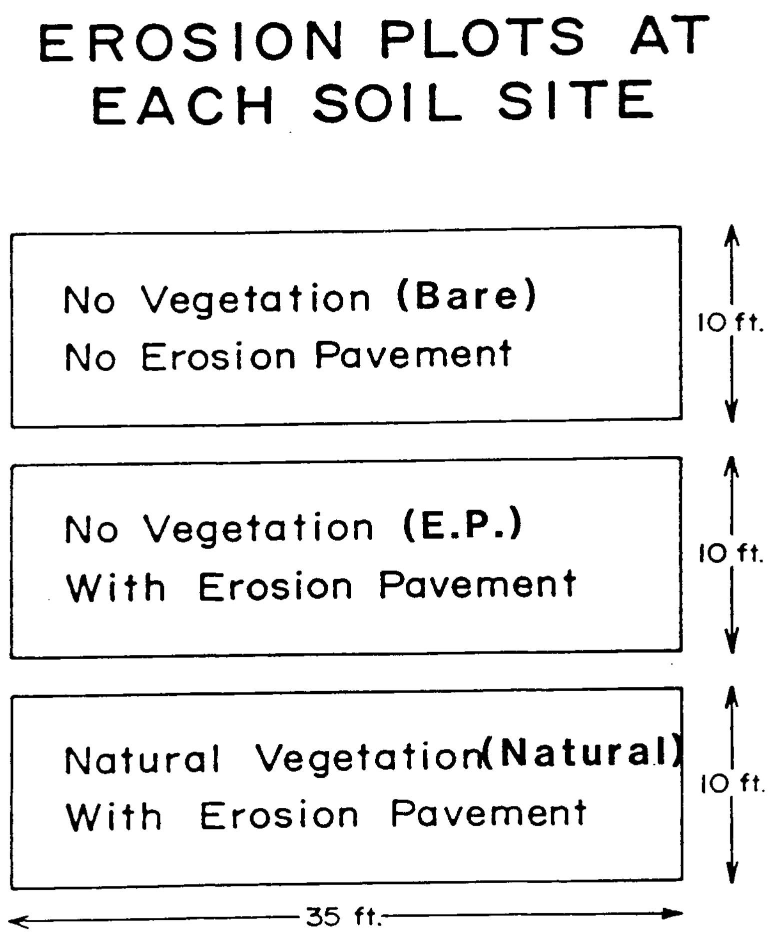

Figure 2. Terms, in parentheses, used to represent plots.

Table 1. Soil Information on Three Soil Series

Soil Series	Texture %sand	%silt	%clay	%Organic Matter	Taxonomic Classification	Munsell Color (Dry)	Munsell Color (Moist)
Bernardino	84	11	5	.93	Fine, mixed, thermic	7.5YR 4/4*	7.5YR 3/2*
					Ustollic Haplargids	7.5YR 4.2/3.5**	7.5YR 3/2.9**
Cave	64	27	9	1.87	Loamy, mixed,	7.5YR 5/2*	7.5YR 4/2*
					thermic, shallow	7.5YR-10YR	7.5YR-10YR
					Typic Paleorthids	5.1/2.0**	3.7/2.1**
Hathaway	74	17	9	1.67	Loamy-skeletal,	10YR 5/2*	10YR 4/2*
					mixed, thermic,	7.5YR-10YR	7.5YR-10YR
					Aridic Calciustolls	5.1/2.0**	3.7/2.1**

* Nearest Chip
** Average of 10 soil scientists

(USDA-Soil Survey Staff, 1970)

which is a control plot.

The term erosion pavement, as defined for this thesis, refers to coarse rock fragments that are greater than 5mm in diameter and are exposed on the surface of the soil. It is assumed that these fragments are exposed because of past sheet and wind erosion (Shaw, 1927).

The three soils on which the erosion plots are located have widely varying amounts of erosion pavement and varying amounts and types of vegetation (see Table 2). The Bernardino averaged 71% vegetative crown cover in June and 87% in November which was a mixture of grass and forbs; the Hathaway soil had 38% vegetative crown cover in June and 67% in November which was predominately grass; and the Cave soil had 27% vegetative crown cover in June and 51% in November which was mostly shrub.

All plots are on six to eight degree slopes with northwest aspects at the Bernardino and Hathaway soil sites and a southeast aspect at the Cave soil site. The elevation of the plots ranges from 1356m to 1509m.

Table 2. Plot Characteristics - June and November, 1983

Soil	Plot	Month	%Rock >2cm	%Gravel 5mm-2cm	%Soil <5mm	%Litter	%Base	%Shrub Crown	%Grass Crown	%Forb Crown	Azimuth (Degrees)	Slope %	Elevation (meters)
			June, November, 1983										
BERNARDINO	Bare	June	4.5	6.1	88.6	0.8	--	--	--	--	328	11.7	1356
		Nov.	4.2	--	95.7	--	--	--	--	--			
	Natural 1	June	22.2	13.5	62.9	0.6	0.8	5.1	39.8	27.1	320	11.1	1356
		Nov.	19.8	12.2	65.5	2.1	--	16.5	70.6	1.8			
	Natural 2	June	20.8	21.0	56.7	0.6	0.8	22.0	35.1	13.3	324	11.5	1356
		Nov.	21.2	19.8	58.2	--	--	44.9	37.6	2.9			
	E.P.*	June	21.2	31.2	46.7	0.8	--	--	--	--	317	10.8	1356
		Nov.	20.6	27.9	51.2	--	--	--	--	--			
HATHAWAY	Bare	June	4.9	2.9	90.8	1.4	--	--	--	--	301	9.9	1509
		Nov.	6.3	--	93.7	--	--	--	--	--			
	Natural	June	21.2	28.4	46.3	2.7	1.2	6.5	31.2	--	300	10.2	1509
		Nov.	19.2	25.1	53.1	--	2.2	18.9	46.9	1.0			
	E.P.*	June	24.7	33.7	41.2	0.4	--	--	--	--	295	12.1	1509
		Nov.	30.4	30.4	39.2	--	--	--	--	--			
CAVE	Bare	June	5.2	3.9	90.0	0.8	--	--	--	--	117	10.8	1372
		Nov.	7.1	4.9	87.1	1.2	--	--	--	--			
	Natural	June	17.5	28.7	51.0	2.6	0.2	17.7	3.8	5.5	112	9.9	1372
		Nov.	22.5	18.9	56.1	2.0	--	28.3	18.5	4.3			
	E.P.*	June	20.4	27.6	49.6	2.4	--	--	--	--	116	10.4	1372
		Nov.	15.9	32.2	49.4	1.2	--	--	--	--			

*E.P. - Erosion Pavement

METHODS AND MATERIALS

Collection of Reflectance Data

Reflected incident radiation was measured from the erosion plots in June and November of 1983. These reflectance measurements were collected with a portable Exotech Model 100A, four-channel radiometer with the following bandwidths: 0.4-0.52μm, 0.52-0.60μm, 0.63-0.69μm, and 0.76-0.90μm. These bandwidths are in the blue, green, red, and near-infrared portions of the spectrum (see Fig. 3), and are identical to four of the seven spectral bands used on the Landsat 4 Thematic Mapper instrument developed by the National Aeronautics and Space Administration. Ten reflectance readings were taken along each long side of the plots at designated 3.5 ft. (1.1m) intervals for a total of 20 readings per plot, and the mean of these 20 readings was used in the data analysis.

The radiometer was vertically hand-held at one meter above the soil surface using a one-degree circular field-of-view lens for the June data, and a 15-degree circular field-of-view lens for the November data. Measurements were taken of the plots under dry and wet conditions from June 13 to 21 between the hours of 0830 and 1030 (mountain standard time) at sun angles ranging from 50 to 26 degrees zenith and 40 to 64 degrees elevation. Dry reflectance readings were also taken on November 5 between 0930 and 1100 (mountain standard time) at sun angles of 60 to 50 degrees zenith and 30 to 40 degrees elevation. The soil was wetted by adding 2.5cm of water in approximately 20 minutes with a rainfall simulator.

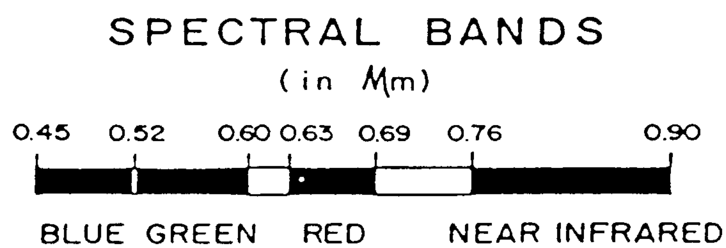

Figure 3. Spectral bandwidths used in this study.

All reflectance readings were collected during cloudless times to minimize error due to scattering of light rays by clouds.

Irradiance (incoming radiation) was measured at approximately ten-minute intervals from a barium sulfate reference plate. These plate readings were used to standardize the reflectance readings taken at changing sun angles to give relative percent reflectance. Standardization was calculated according to the equations:

$$L = ER$$

$$\%R(\text{target}) = L(\text{target})/E(\text{plate}) \cdot R(\text{plate}) \cdot 100$$

L = radiation reflected, R = reflectance, and E = irradiance. These equations make the percent reflectance of the target independent of the irradiance and viewing angles (Jackson et al., 1980). Reflectance values of plates used are given in Appendix A.

Collection of Temperature Data

Temperature data was collected concurrently with the June reflectance data from June 13 to June 21. Weather data from these days are given in Appendix B. A hand-held Everest infrared thermometer with a three-degree field-of-view was used for collecting surface temperatures. The thermometer was held vertically at a height of one meter above the soil surface. Twenty readings were taken per plot, twelve times per day when dry temperatures were collected between the hours of 0500 and 1600 and the wet temperatures were collected from 1100 to 1600 hours. Morning temperature data for the moist soil was not gathered because mornings were occupied with wetting the soil with the rainfall simulator and obtaining wet spectral reflectance data.

Collection of Surface Feature Data

Vegetative and surface properties were measured on each plot by J.R. Simanton of the U.S.D.A.-A.R.S. These measurements were taken during April and November of 1983 and consisted of the following: % rock covering the surface (>2cm in diameter), % gravel (5mm-2cm), % soil exposed (<5mm), % vegetative litter covering the surface, % grass crown cover, % forb crown cover, % shrub crown, % vegetative base, and grams of sediment runoff after application of water with the rainfall simulator (see Table 2). Major vegetative species growing on the natural plots are listed in Table 3. These surface properties were obtained by taking ten transects across the width of each plot at 3.5 ft. (1.1m) intervals. The Munsell colors were acquired for each soil by sending samples of the soil to ten Arizona Soil Conservation Service scientists, and the average of their soil notations was used.

Table 3. Major Vegetative Species on Natural Plots

Type of Vegetation	Common Name	Scientific Name
Bernardino		
grass	Sideoats gramma	Bouteloua curtipendula
grass	Three-awns	Aristida species
grass	Black gramma	Bouteloua eriopoda
forb	Desert zinnia	Zinnia pumila
shrub	Snake weed	Gutierrezia sarothrae
shrub	False mesquite	Calliandra eriophylla
Hathaway soil		
grass	Sideoats gramma	Bouteloua curtipendula
grass	Three-awns	Aristida species
grass	Black gramma	Bouteloua eripoda
grass	Fluff grass	Tridens pulchellus
shrub	False mesquite	Calliandra eriophylla
shrub	White thorn	Acacia constricta
Cave soil		
grass	Black gramma	Bouteloua eripoda
forb	Desert zinnia	Zinnia pumila
shrub	White thorn	Acacia constricta
shrub	Mariola	Parthenium incanum
shrub	Creosote	Larrea divaricata

STATISTICAL PROCEDURES

Statistical methods used to determine the relationship of spectral and thermal data with surface features are presented below.

Basic distribution information was obtained for all reflectance and temperature measurements which included the means and coefficients of variation for each set of twenty readings per plot (see Appendices C and D).

T-tests were performed to determine whether the means of the spectral and thermal responses were significantly different between the plots on each soil. Twelve temperature means of the plots, taken from 0500 to 1600 hours, were used for the thermal T-tests. The percent reflectance in the four spectral bands from each of the plots was used for the spectral T-tests.

A multiple-linear regression was attempted with temperature and reflectance measurements as dependent variables and surface features as independent variables. One of the assumptions required for the use of multiple-linear regression is that the independent variables are linearly independent of each other; however, several of the independent variables were highly correlated with each other which invalidated use of the multiple-linear regression (Little and Hills, 1978).

Simple-linear regression was used on all variables, which included thermal and spectral measurements and surface features, to generate a Pearson's product moment correlation matrix. This simple-linear regression indicates the correlation between two variables, disregarding any other variables that are varying simultaneously (Little and Hills, 1978).

Principal components analysis was used to analyze the relationship of reflectance and temperature data with surface characteristics of the study plots. The first step in principle components analysis is the preparation of a correlation matrix, followed by a rearrangement and reduction of the data to a smaller set of components. New variables (components) are defined as exact mathematical transformations of the original correlation coefficients. These components are the best linear combination of variables that account for variance in the data and are uncorrelated to each other. The first component is the single best summary of linear relationships, while the second component is the second best linear combination after the effect of the first component is removed from the data. Eigenvalues associated with each component represent the amount of total variance accounted for by the component (Nie et al., 1975). Three principal components were used for spectral and thermal data under dry conditions, but principal components were not used for wet conditions due to the lack of significant differences between the plots when wet.

RESULTS AND DISCUSSION OF TEMPERATURE STUDY

Comparison of Temperatures Between Plots

Ranges of percent coefficient of variation for the 20 measurements taken from each plot are given in Table 4. Under both dry and wet conditions the bare plots had the lowest coefficients of variation while the natural plots had the highest.

Graphs of surface temperatures versus time for each of the soils under dry and wet conditions are given in Figures 4, 5, and 6. Only five temperature measurements were made on the Cave soil under wet conditions due to adverse weather (clouds and rain) which would have affected the validity of the measurements. Similar temperature patterns were found on all three soil sites. During early morning hours the surface temperatures were nearly equal, making the plots indistinguishable from one another, while the highest temperature contrast between the plots occurred at their maximum temperatures from 1300 to 1400 hours.

Histograms of peak temperatures for each of the plots were also constructed (see Fig. 7). At maximum temperatures, the natural (control) plots had the lowest temperatures when both dry and wet; thus, on all three soils the vegetated plots could be distinguished from the non-vegetated plots when at their maximum temperature. This is in agreement with results of temperature studies done by Jackson et al. (1975) and Dixon (1979, see Lit. review). On the Bernardino and Hathaway soils, the bare plots had higher temperatures than the erosion pavement plots; but on the Cave soil, the erosion pavement plot had the highest temperature.

Table 4. Ranges of Percent Coefficient of Variation of 20 Temperature Measurements per Plot at Selected Times

Dry Temperatures in °C

Plot	Time of Day (hours)		
	0500	1330	1600
Bare	3%-7%	2%- 6%	3%
Natural	5%-9%	14%-18%	12%-14%
Erosion Pavement	3%-8%	2%- 5%	3%

Wet Temperatures in °C

	1130	1300	1600
Bare	2%-5%	3%- 7%	4%-7%
Natural	7%-8%	6%-10%	8%-9%
Erosion Pavement	4%-5%	3%- 5%	5%-6%

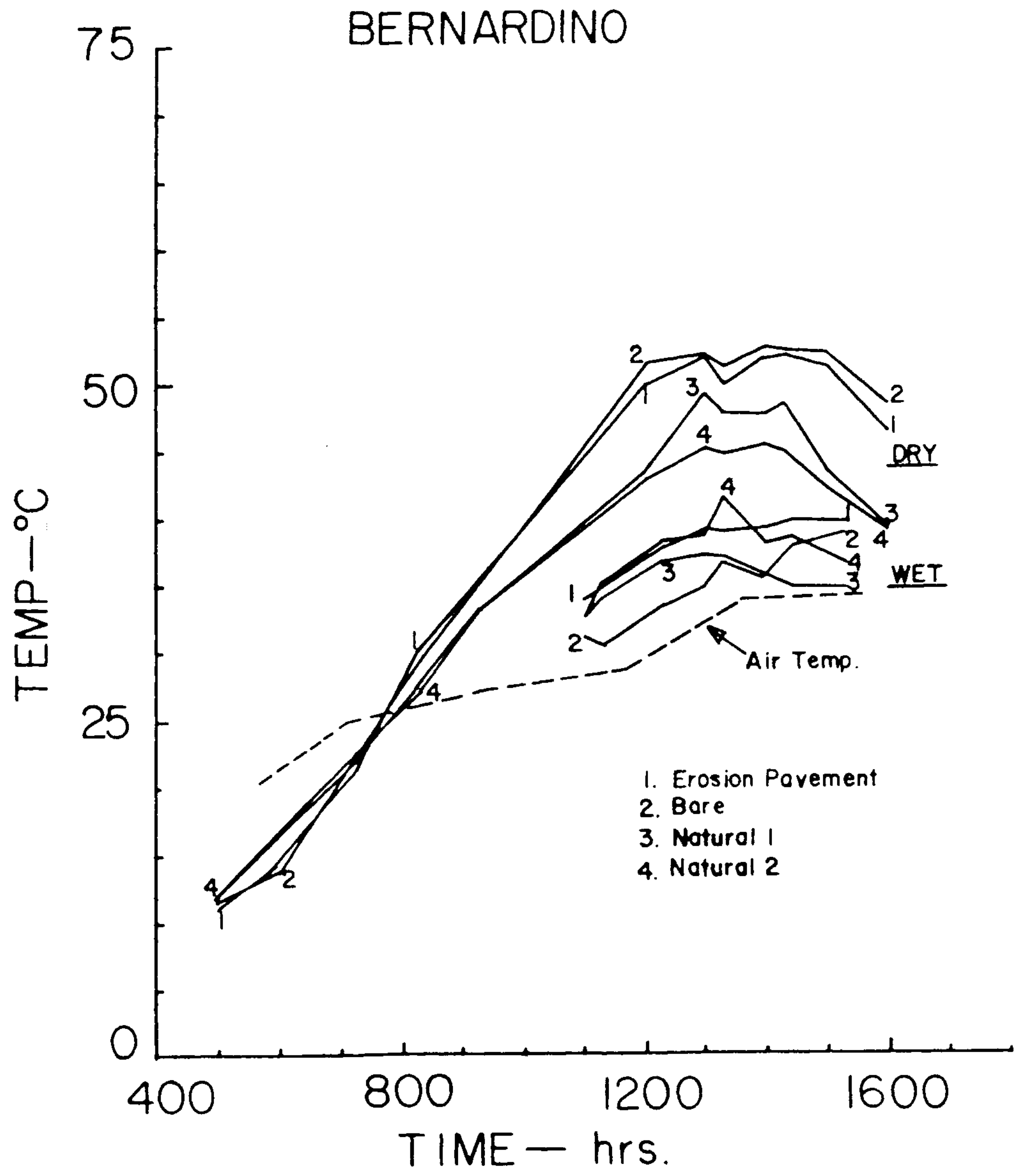

Figure 4. Temperature versus time for plots on the Bernardino soil, June 1983.

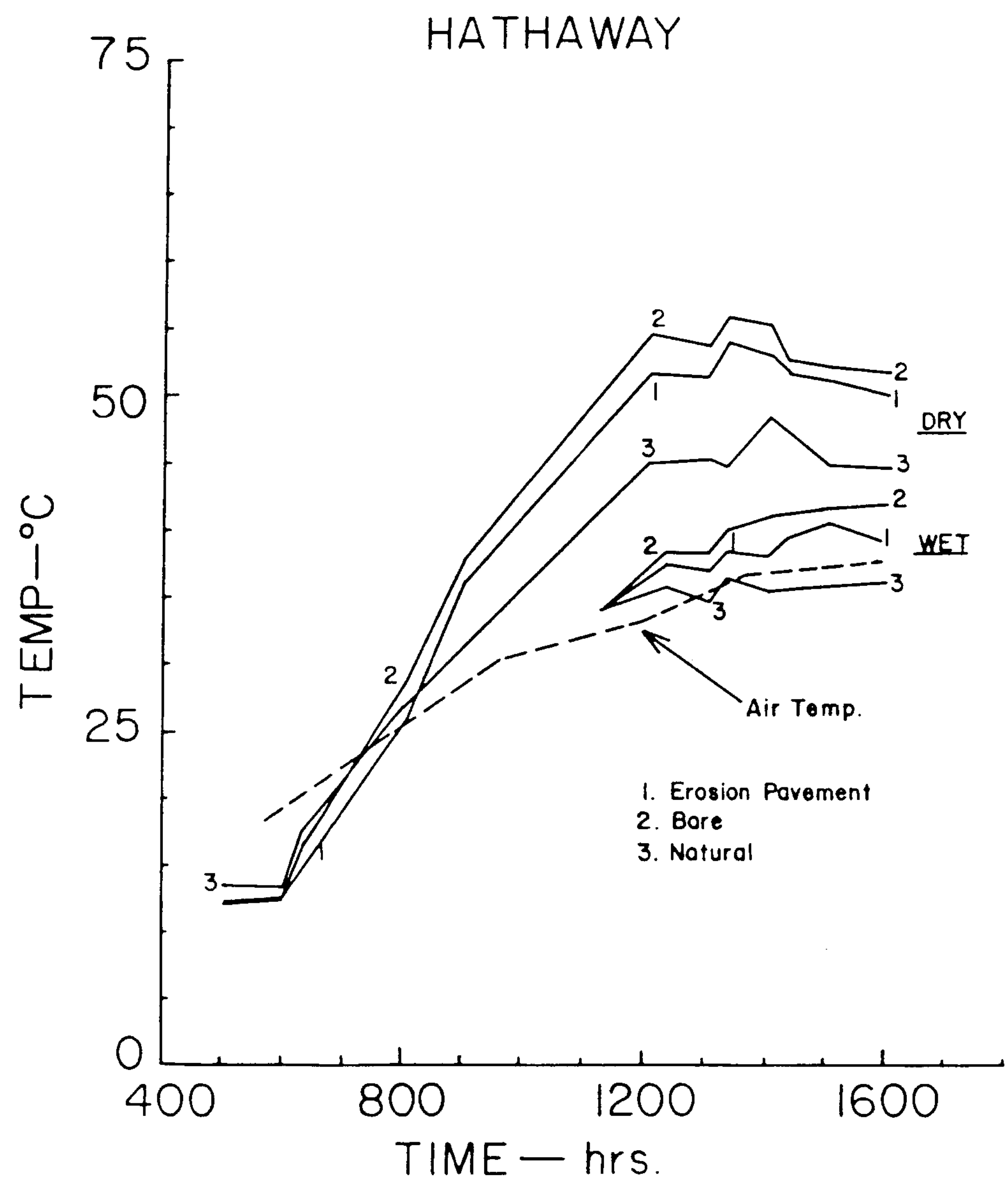

Figure 5. Temperature versus time for plots on the Hathaway soil, June 1983.

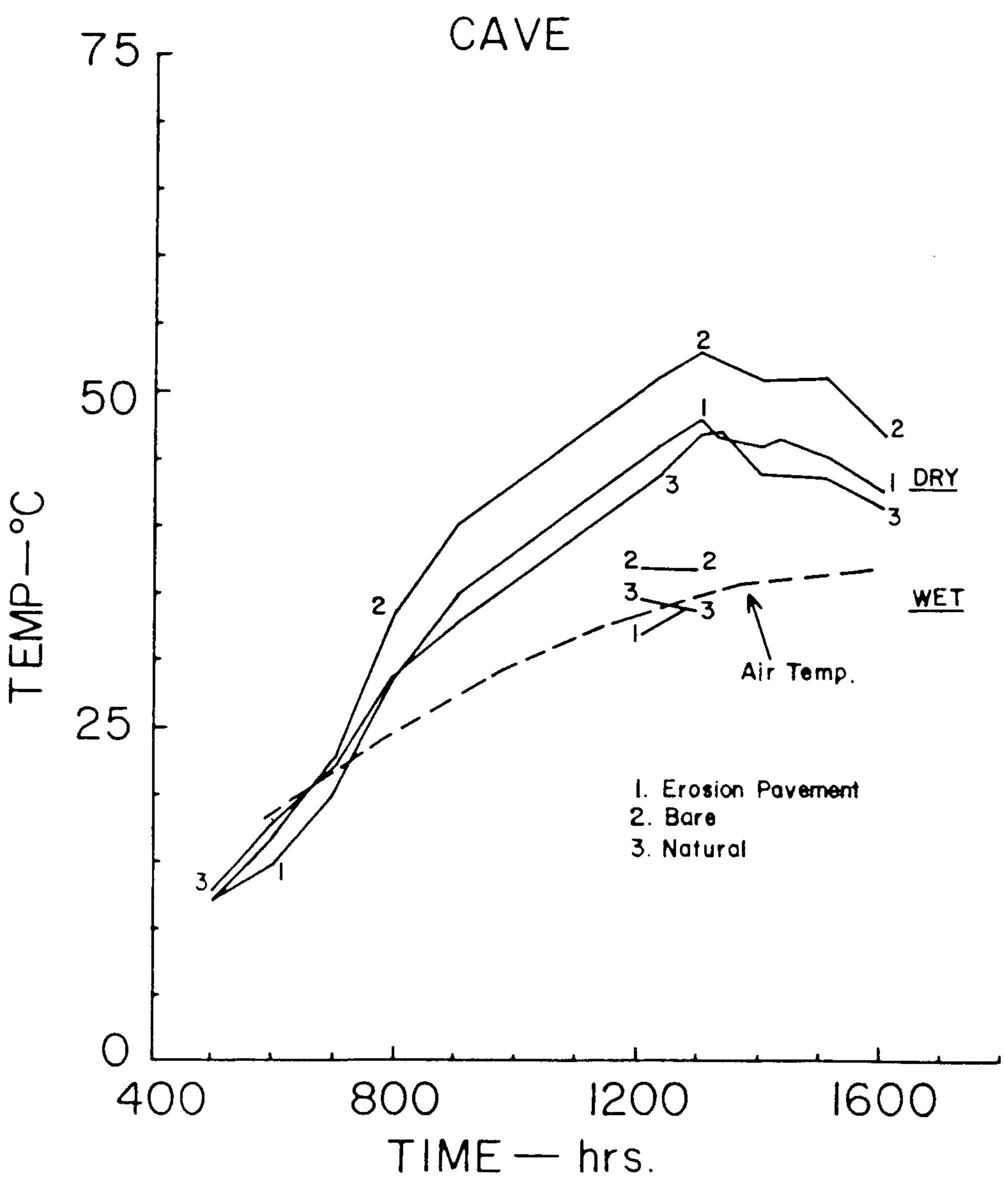

Figure 6. Temperature versus time for plots on the Cave soil, June 1983.

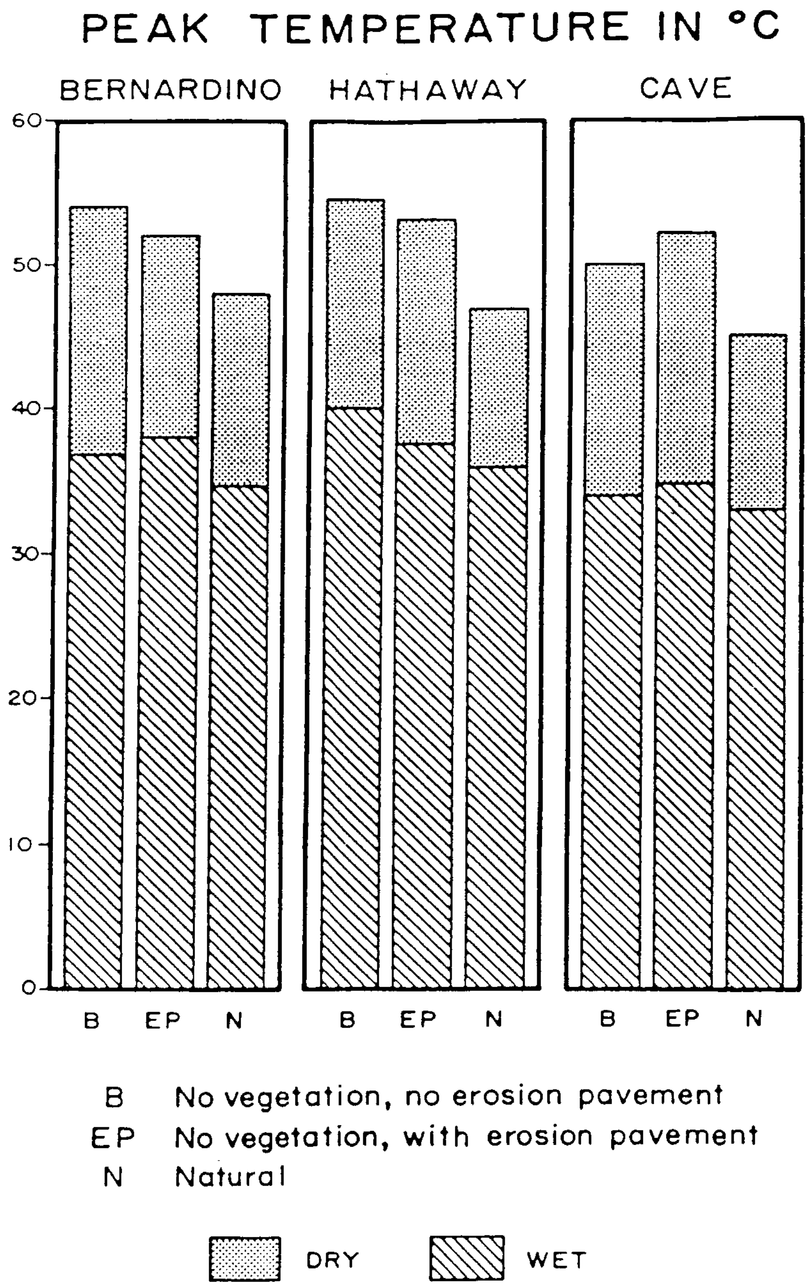

Figure 7. Maximum temperature of plots.

This may be due to the fact that the erosion pavement on the Cave site is predominately dark gray limestone which would absorb more heat. The erosion pavement on the other soils tended to be lighter in color than on the Cave soil. The lack of temperature trend for these plots would make it difficult to separate the erosion pavement plots from the bare plots based on their temperatures.

T-tests of Surface Temperatures Between Plots

T-tests were performed to determine if there was a significant difference in surface temperature between the plots on each soil series. This was completed by using 12 temperatures from throughout the day under dry conditions and eight to five temperatures for wet conditions. When the soil was dry, all plots had significantly different temperatures from other plots at the same soil. Under wet conditions, one pair of plots had significantly different temperatures on the Bernardino and Cave soils, while all the plots on the Hathaway soil were significantly different (see Table 5). Thus, soils should be dry for the maximum contrast in peak temperature between varying rangeland surfaces. No comparisons were made between plots on different soils because the soils were at different aspects and temperatures were taken on different days.

Correlations of Surface Features with Temperature

Simple-linear regression was used to produce a correlation matrix of temperature and surface-feature data when the soil was dry. The matrix showed that the surface features which had the most effect on the temperature of the plots varied with the time of day (see Table 6 and Appendix E). During early morning hours, from sunrise at 0500 to 0800

Table 5. T-Tests Between Pairs of Temperature Means

Soil	Pairs of Plots	Significant Difference at 95% Confidence Level: Dry (T-value)	Wet (T-value)
BERNARDINO	Bare vs. Natural 1	Yes (5.33)*	No (0.03)**
	Bare vs. Natural 2	Yes (7.38)	No (1.46)
	Bare vs. Erosion Pavement	Yes (2.50)	No (1.73)
	Erosion Pavement vs. Natural 1	Yes (5.87)	Yes (4.42)
	Erosion Pavement vs. Natural 2	Yes (8.22)	No (1.28)
HATHAWAY	Bare vs. Natural	Yes (8.41)	Yes (5.67)
	Bare vs. Erosion Pavement	Yes (9.12)	Yes (4.35)
	Erosion Pavement vs. Natural	Yes (5.43)	Yes (4.35)
CAVE	Bare vs. Natural	Yes (15.17)	No (1.29)***
	Bare vs. Erosion Pavement	Yes (6.12)	No (0.09)
	Erosion Pavement vs. Natural	Yes (24.21)	Yes (6.75)

* T-value for 11 degrees of freedom is 2.20.
** T-value for 7 degrees of freedom is 2.36.
*** T-value for 4 degrees of freedom is 2.78.

Table 6. Correlation Coefficients for
Selected Surface Features vs. Surface Temperature

0500 hours	0900 hours	1230 hours	1330 hours	1600 hours
Value - 0.70	Shrub - -0.56	Shrub - -0.64	Shrub - -0.66	Shrub - -0.64
Chroma - -0.70	Grass - -0.73	Grass - -0.77	Grass - -0.77	Grass - -0.72
Hue - 0.72		Forb - -0.62	Runoff - 0.53	Forb - -0.70

hours, soil color, including hue, value, and chroma, was the most important factor affecting surface temperature. The 0500 temperature had correlation levels of 0.70 with the value of the soil color, and -0.70 with chroma. At 0600 and 0800 hours the hue had a high correlation with temperature at levels of 0.72 and 0.76, respectively. From 0900 to 1600 the factor which had the most significant correlation levels ($|r|>0.50$) with temperature was vegetation, including grass, shrubs, and forbs. Vegetation had negative correlation values ranging from -0.56 to -0.77 from 0900 to 1600 hours. Grams of sediment removed by runoff during rainfull simulation were correlated with temperature at 1330 hours with a level of 0.53.

The results of this study, which show that soil color is the surface feature which has the most effect on dry soil surface temperature during early morning hours, may be due to a combination of low sun angles, low vegetative transpiration rates, and the lack of shading by the vegetation.

Principal Components Analysis of Temperature and Surface Feature Data

Principal components analysis was used to determine which surface features accounted for the most variance in temperature between the plots. Three principal components were extracted from the data and are presented in Table 7. Forty-four percent of the soil temperature variance was explained by the first component, which is a vegetative component due to the heavy loading of % shrub, % grass, and % forb crown cover onto this component. The negative correlation coefficients of the vegetation show that vegetative cover decreased the surface temperatures. The second

Table 7. Principal Components of Surface Temperature

Variables	Correlation Coefficients Component 1	Component 2	Component 3
Shrub	-.65	*	*
Grass	-.71	*	*
Forbs	-.51	-.59	*
Hue	*	.85	*
Value	*	.87	*
Chroma	*	-.87	*
Soil	*	*	-.99
Gravel	*	*	.96
Rocks	*	*	.93
% of Variation	44%	17%	16.5%

$* < |.50|$

principal component, which is a color component composed of hue, value, and chroma of the soil, explained 17% of the variance. The third component, which is an earth materials component, consisting of % soil, % rock, and % gravel, explained 16% of the variance. These three components account for 77% of the temperature variance of the plots. This principal components analysis suggests that the vegetative cover had the most effect on surface temperature, followed by the color of the soil, and finally by earth materials (soil, gravel, rocks).

By correlating surface features with variations in temperature between the plots in the above discussion it was assumed that soil physical properties, such as soil moisture content, volumetric heat capacity and organic matter contents were constant among the plots at each soil.

Comparison of Percent Change in Temperature Between Plots

The percent change in temperature from 0500 to 1330 hours is given in Table 8. The natural plots, with the exception of natural plot 1 on the Bernardino soil site, had the lowest percent change in temperature, while the bare plots and the erosion pavement plots had nearly equal percent changes in temperature.

Discussion

The results of this study show that vegetation decreases the surface temperature of this semiarid rangeland. Therefore, it would seem that surface temperature could be used to delineate areas which had been denuded of vegetation; however, vegetation was not significantly correlated with temperature throughout the whole day. Therefore, it may be

Table 8. Change in Dry Temperature from 0500 to 1330 Hours

Soil	Plot	Change in °C	% Change in* °C
Hathaway	Bare	43.7	78.2
	Erosion Pavement	41.8	77.4
	Natural	31.3	69.9
Cave	Bare	38.6	76.3
	Erosion Pavement	40.3	76.9
	Natural	34.2	72.6
Bernardino	Bare	39.7	77.8
	Erosion Pavement	40.6	78.8
	Natural 1	35.7	75.0
	Natural 2	32.7	73.3

$$^{*}\ \%\ \text{Change} = \frac{\text{1330 Temp. - 0500 Temp.}}{\text{1330 Temp.}} \times 100$$

that only after the soil has absorbed a certain level of radiation and the plants begin to actively transpire could there be a separation of vegetated areas from non-vegetated areas based on temperature.

A single temperature reading from mid-afternoon, when there is a high temperature contrast between vegetated and denuded areas, may be an effective way to distinguish different surface coverings from a site with one slope and aspect. But using a single temperature reading would not be practical for remotely sensed rangelands where a variety of slopes and aspects exist. In addressing this problem, comparison of the percent change in temperature, from the minimum daily temperature to the maximum daily temperature may be useful for delineating denuded areas from vegetated areas due to the dampening effect of vegetation on mid-day temperatures. In order for this technique to be used, at least two thermal readings would have to be taken per day, preferrably at times of maximum and minimum temperature.

RESULTS AND DISCUSSION OF REFLECTANCE STUDY

Comparison of Reflectance Between Plots

Table 9 shows the percent coefficients variation of the 20 reflectance measurements per plot. The plots with the lowest coefficients of variation were the bare plots while the plots with the highest coefficients of variation were the natural plots.

Histograms of the sum of the percent reflectance in the four spectral bands for each of the plots from the June and November data are presented in Figures 8 and 9. For all three soils, the plots with the highest percent reflectance under dry conditions were the bare plots, while the plots with the least percent reflectance were the natural plots. These trends in reflectance were the same for both June and November measurements; however, the November percent reflectance was one-third to one-half lower than the June reflectance data. The lower reflectance in November was probably due to the use of a different standard barium sulfate plate in November which had lower reflectance values than the plate that was used in June (see Appendix A for reflectance values of standard plates).

In June when the plots were wet, the erosion pavement plots had the highest percent reflectance, while the natural and bare plots had nearly equal percent reflectance on the Hathaway and Cave soils. On the Bernardino soil, the natural plots had higher reflectance than the bare plot, which was probably because there was less wet soil exposed. The Bernardino soil which had approximately 70% vegetative crown cover would

Table 9. Ranges of Percent Coefficient of Variation of 20 Reflectance Measurements per Plot in Four Spectral Bands

Plots	Band One	Band Two	Band Three	Band Four
Dry Reflectance, June 1983				
Bare	15%-20%	9%-16%	11%-15%	8%-16%
Natural	43%-47%	31%-37%	24%-27%	28%-38%
Erosion Pavement	18%-31%	15%-25%	12%-28%	8%-23%
Wet Reflectance, June 1983				
Bare	14%-42%	17%-35%	12%-21%	13%-17%
Natural	44%-51%	24%-48%	23%-34%	24%-45%
Erosion Pavement	25%-53%	27%-37%	17%-31%	15%-22%
Dry Reflectance, November 1983				
Bare	10%-16%	8%-17%	9%-14%	8%-17%
Natural	36%-42%	26%-36%	39%-40%	18%-29%
Erosion Pavement	11%-16%	10%-13%	12%-16%	11%-14%

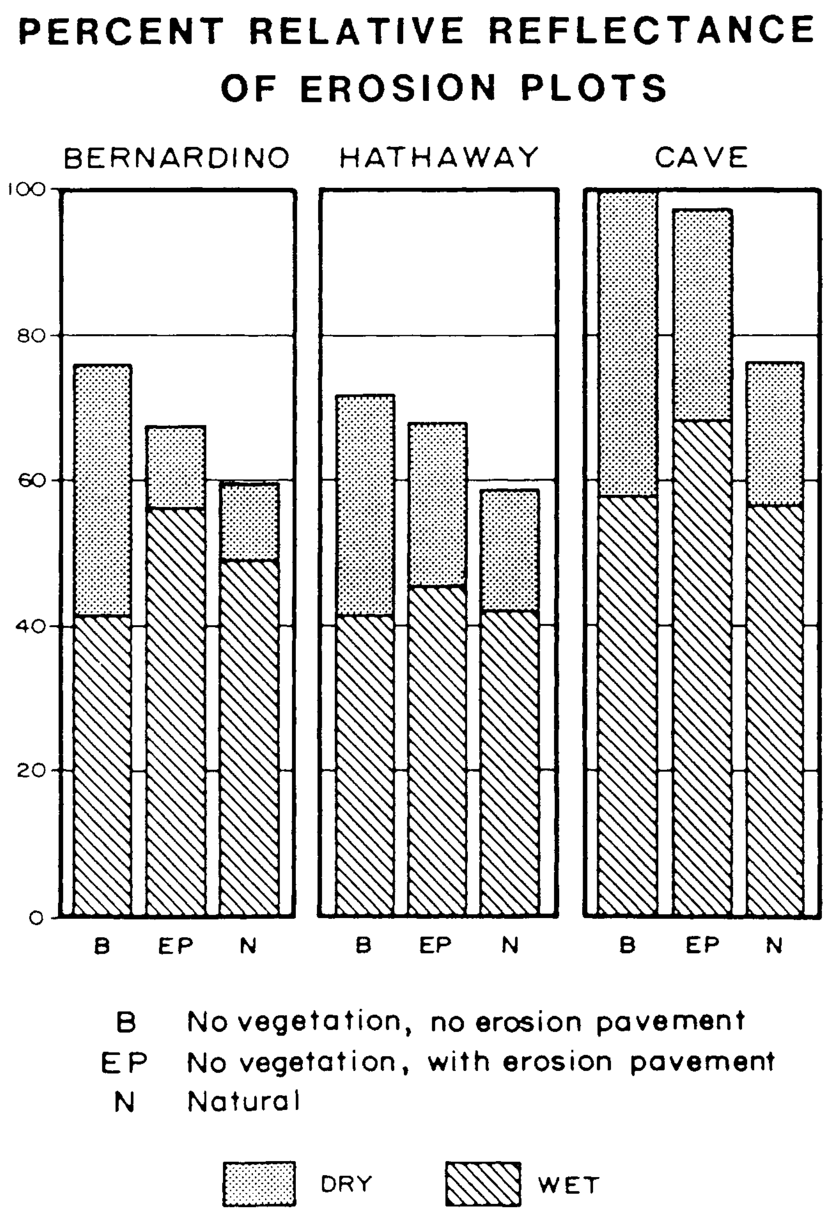

Figure 8. Sum of percent relative reflectance in the four spectral bands, June 1983.

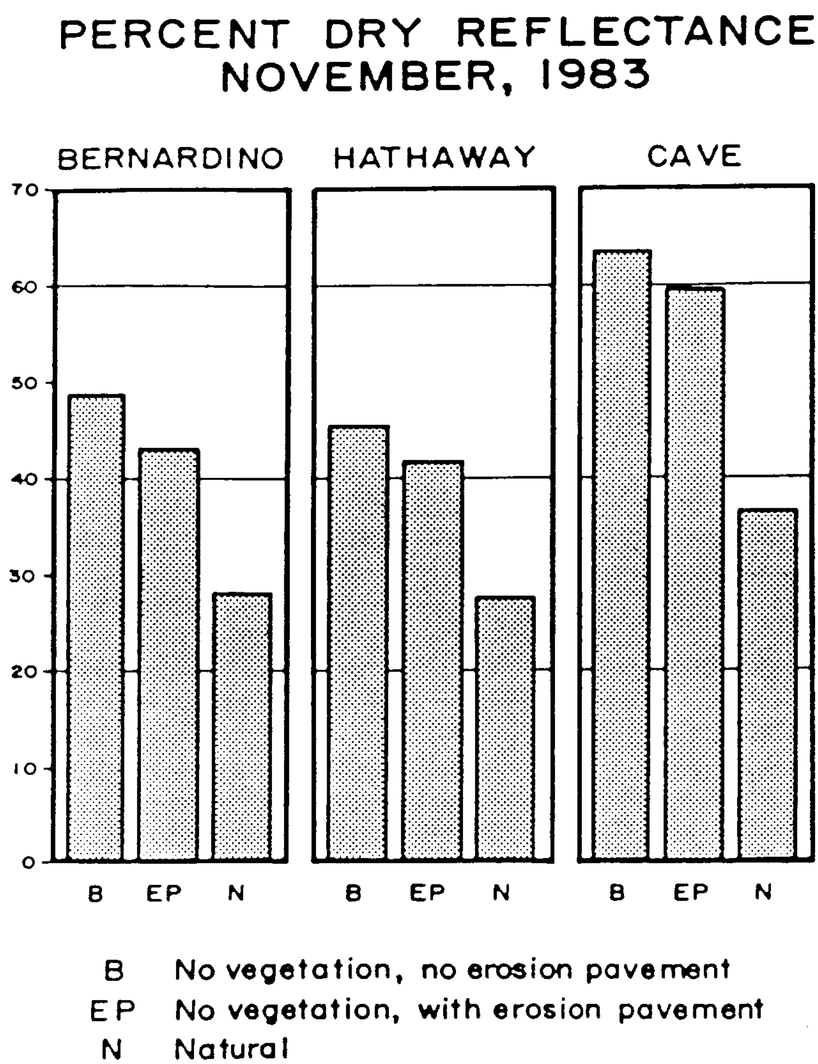

Figure 9. Sum of percent reflectance in the four spectral bands, November, 1983.

have had a higher relative reflectance than the Hathaway and Cave sites, which had 40% and 30% vegetative cover, respectively. The erosion pavement plots probably had the highest percent reflectance because the coarse fragments covering the surface dried more quickly than the soil or vegetation, giving those plots a lighter color and higher reflectance than the bare plots.

T-tests of Reflectance Between Plots

T-tests were performed to determine if there were significant differences in reflectance in the four spectral bands between the plots on each soil (see Tables 10 and 11). Results of the T-tests revealed that there were significant differences, at the 95% confidence level, in reflectance between the bare plots and the natural plots on each of the soils under dry conditions. Only on the Bernardino soil was there a significant difference between the bare plot and the erosion pavement plot in June, and in November there were significant differences between the bare and erosion pavement plots on all soils. The reflectance differences in November may have been due to lower sun angles, which caused the erosion pavement to cast shadows. These results show that, based on reflectance, denuded plots without erosion pavement could be distinguished from vegetated plots, but denuded plots with erosion pavement could not always be successfully distinguished from non-erosion pavement plots or from vegetated plots.

When the plots were wet, the T-tests showed that none of the erosion plots had significantly different reflectance in the four spectral bands. The lack of a reflectance trend in the plots under wet

Table 10. T-tests Between Pairs of Spectral Bands
June 1983

Soil	Pairs of Plots	Significant Difference at 95% Confidence Level Dry (T-value)	Wet (T-value)
Bernardino	Bare vs. Natural 1	Yes (3.73)*	No (-0.98)*
	Bare vs. Natural 2	Yes (3.50)	No (0.73)
	Bare vs. Erosion Pavement	Yes (7.44)	No (-3.39)
	Erosion Pavement vs. Natural 1	No (-0.63)	No (-1.23)
	Erosion Pavement vs. Natural 2	No (-0.68)	No (0.73)
Hathaway	Bare vs. Natural	Yes (5.23)	No (0.18)
	Bare vs. Erosion Pavement	No (-1.20)	No (2.31)
	Erosion Pavement vs. Natural	No (2.50)	No (-2.14)
Cave	Bare vs. Natural	Yes (-3.23)	No (-0.21)
	Bare vs. Erosion Pavement	No (0.80)	No (-7.71)
	Erosion Pavement vs. Natural	No (-2.59)	No (-3.15)

* T-value for three degrees of freedom is 3.18.

Table 11. T-tests Between Pairs of Spectral Bands
November 1983

Soil	Pairs of Plots	Significant Difference at 95% Confidence Level Dry (T-value)	Wet (T-value)
Bernardino	Bare vs. Natural 1	No (2.73)*	No wet data
	Bare vs. Natural 2	Yes (3.57)	" " "
	Bare vs. Erosion Pavement	Yes (6.10)	" " "
	Erosion Pavement vs. Natural 1	No (-1.92)	" " "
	Erosion Pavement vs. Natural 2	No (-2.79)	" " "
Hathaway	Bare vs. Natural	Yes (7.70)	" " "
	Bare vs. Erosion Pavement	Yes (9.08)	" " "
	Erosion Pavement vs. Natural	No (-5.48)	" " "
Cave	Bare vs. Natural	Yes (7.20)	" " "
	Bare vs. Erosion Pavement	Yes (3.62)	" " "
	Erosion Pavement vs. Natural	No (-7.42)	" " "

* T-value for three degrees of freedom is 3.18.

conditions suggest that it is best to make reflectance interpretations when the soils have a low moisture content.

Correlations of Surface Features with Reflectance

Simple-linear regression was used to produce a correlation matrix of reflectance and surface-feature data when the soil was dry. A correlation matrix was not made for wet reflectance data due to the lack of significantly different reflectance measurements between the plots. Table 12 presents the correlation coefficients of selected surface features with dry reflectance in the four spectral bands. The entire correlation matrix is in Appendix F.

For dry reflectance from June and November, spectral bands one (blue) and two (green) were significantly ($|r|>.50$) correlated with hue and value, and negatively correlated with % grass cover with nearly equal correlation coefficients for both dates. Band three (red) was negatively correlated with % grass in November, but in June was highly correlated with hue, and negatively correlated with % shrub cover and % rock cover. These results show that reflectance in bands one and two was decreased by grass cover in both June and November. Band four (near infrared) had a high level of correlation with hue in both June and November.

The difference in results for band three between the two dates may be due to the fact that in June there was less grass cover than in November and some of the grass in June was senescent, so there was less absorption in the red band (band three). This makes the grass reflectance similar to the soil reflectance in June (Siegal and Goetz, 1977), and it may cause surface features such as hue, % rock cover, and

Table 12. Correlation Coefficients of Selected Surface Features with Spectral Bands, Under Dry Conditions

June 1983

Band One		Band Two		Band Three		Band Four	
Hue	.68	Hue	.82	Hue	.72	Hue	.93
Value	.60	Value	.60	%Shrub	-.60		
Chroma	-.60	Chroma	-.60	%Rock	-.52		
%Grass	-.61	%Grass	-.65				
		%Forb	-.50				

November 1983

Band One		Band Two		Band Three		Band Four	
Hue	.70	Hue	.63	%Grass	-.70	Hue	.65
Value	.58	%Grass	-.64				
Chroma	-.58						
%Grass	-.60						

% shrub cover to have more effect on the reflectance in June. The % gravel covering the surface was correlated with band three at a level of -.52 in June; otherwise the % gravel, % rock, and % soil exposed at the surface was not significantly correlated with any of the bands, which is in agreement with the results reported by Lucas (1980, see Lit. review).

Correlations Among Spectral Bands

Spectral bands were highly correlated with each other with the lowest correlation level at 0.60 between bands one and four from the June data, and the highest correlation level at 0.98 between bands one and two in November. Table 13 shows the redundancy of spectral information among the four spectral bands.

In humid areas with dense vegetation there is often low reflectance in the red spectral band and high reflectance in the infrared spectral band, making the ratioing of the red band to the infrared band a useful technique for separating vegetation from soils (Townshend, 1981). However, in arid and semiarid areas the redundancy of spectral information in spectral bands makes the sum of the reflectance in the bands more useful for analyzing spectral data than ratioing or analyzing the bands separately (Robinove et al., 1981).

Principal Components Analysis of Reflectance and Surface Feature Data

Principal components analyses were used to determine which features accounted for the variance in the dry reflectance data between the plots by extracting three components from the data. These three

Table 13. Correlation Matrices of Spectral Bands

June 1983 Data

	Band One	Band Two	Band Three	Band Four
Band One	1.000	0.955	0.893	0.602
Band Two		1.000	0.915	0.768
Band Three			1.000	0.750
Band Four				1.000

November 1983 Data

	Band One	Band Two	Band Three	Band Four
Band One	1.000	0.980	0.890	0.741
Band Two		1.000	0.959	0.798
Band Three			1.000	0.749
Band Four				1.000

components accounted for approximately 83% of the variance in between the plots.

In June the first component, according to Table 14, accounted for 44% of the variance in the data. This first component appears to represent brightness due to the fact that the four spectral bands were heavily loaded onto this component, along with the hue of the soil. The second component accounted for an additional 23% of the data independent of the first component. This component seems to be a vegetative component because of its loading of % grass, % forb, and % shrub cover. Chroma was positively correlated with the second component, but value and bands one and two were negatively correlated suggesting that vegetation masks the value of the soil and decreases the reflectance in bands one and two. Component three, which is an earth materials component, explained an additional 12.5% of the variance but was not correlated with reflectance in any of the spectral bands.

In November the first component explained 40.5% of the variance in the data and again appeared to be a brightness component due to heavy loading of the four spectral bands (Table 14). Hue and value of the soil were positively correlated with the first component while chroma and % grass cover were negatively correlated. Percent grass cover was probably loaded onto the first component in November but not in June because there was less grass cover, some of which was senescent in June. Earth materials, along with bands three and four, composed the second component which accounted for 21.8% of the variance. Band four was nearly equally distributed between component one (brightness) and component two (earth materials). Component three is a vegetative component

Table 14. Principal Components of Reflectance

Data	Component One		Component Two		Component Three	
	Variable	Correlation Coefficient	Variable	Correlation Coefficient	Variable	Correlation Coefficient
June 1983	Band One	0.74	Band One	-0.52	%Rock	0.90
	Band Two	0.84	Band Two	-0.50	%Soil	-0.96
	Band Three	0.86	Value	-0.81	%Gravel	0.93
	Band Four	0.94	Chroma	0.81		
	Hue	0.89	%Shrub	0.69		
			%Grass	0.75		
			%Forb	0.85		
	% Variation	44%	% Variation	23%	%Variation	12.5%
Nov. 1983	Band One	0.94	Band Three	0.52	%Grass	0.65
	Band Two	0.88	Band Four	0.62	%Shrub	0.79
	Band Three	0.73	%Soil	0.93	%Forb	0.94
	Band Four	0.61	%Gravel	-0.92	%Litter	0.85
	Hue	0.82	%Rock	-0.82		
	Value	0.74				
	Chroma	-0.74				
	%Grass	-0.55				
	% Variation	40.5%	% Variation	21.8%	% Variation	19.8%

explaining 19.8% of the variance, which was not correlated with any of the spectral bands. This is in agreement with the simple-linear regression which showed that the % shrub, % forb, and % litter cover were not correlated with any of the four spectral bands in November.

These results, according to simple-linear regression and principal components analyses, show that the hue of the soil is highly correlated with reflectance in all four bands and the % green grass cover decreases the reflectance in bands one, two, and three. Other variables, such as earth materials and % shrub and % forb cover, affected the reflectance but did not have a predictable trend.

Discussion of Reflectance Results

Up to this point, the discussion of the reflectance results has been of comparisons between plots on the same soil, but, if the reflectance of these plots were remotely sensed, then surface features from various soils would be sensed simultaneously. In comparing the reflectance of the erosion plots between soil sites, it would be difficult to distinguish between plots with different surface features. For instance, there was very little difference in reflectance between the erosion pavement plot on the Bernardino and Hathaway soils from the natural plot on the Cave soil. However, reflectance information from semiarid rangelands may be useful for monitoring change in vegetative cover and surface conditions from one year to the next.

CONCLUSIONS

The following conclusions can be made from this reflectance and surface temperature study of a semiarid rangeland.

Vegetative cover decreased the surface temperatures during the warmest time of day under dry conditions and dampened the percent change in daily temperature. During early morning hours soil color was the important property affecting soil temperature. The presence of erosion pavement slightly decreased the percent change in daily temperature.

T-tests showed that, based on percent reflectance in the four spectral bands, denuded plots without erosion pavement could be distinguished from vegetated plots; however, denuded plots with erosion pavement could not always be distinguished from non-erosion pavement plots or from vegetated plots.

Using simple-linear regression to analyze the spectral bands separately under dry conditions, the hue of the soil was highly correlated with all four spectral bands with correlation coefficients ranging from 0.63 to 0.93. The percent grass cover decreased the reflectance in bands one, two, and three, while value and chroma of the soil correlated with band one at levels of 0.60 and -0.60, respectively. The % shrub, % forb, and earth materials (soil, gravel, and rocks) did not have a predictable effect on spectral reflectance in any of the four bands.

The four spectral bands were highly correlated with each other with correlation levels of 0.60 to 0.98, showing the redundancy of spectral information among the bands. This overlapping of spectral information makes the sum of the percent reflectance in the bands more useful for analyzing spectral data than ratioing of spectral bands.

APPENDIX A

REFLECTANCE OF $BaSO_4$ PLATES USED FOR STANDARDIZATION

Sun Angle (Zenith)	Reflectance of Plate in 4 Thematic Mapper Bands TM-1	TM-2	TM-3	TM-4
June 1983, Plate #1				
50	.78	.83	.85	.85
26	.86	.89	.92	.93
November 1983, Plate #2				
60	.70	.69	.68	.70
40	.74	.72	.70	.74

APPENDIX B

WEATHER DATA FROM TEMPERATURE STUDY, JUNE 13-21, 1983

Soil	Date	Minimum °C	Maximum °C	Relative Humidity	Wind	Pan Evaporation
Bernardino-Dry	June 13	15	32	25-48%	19.9	0.40"
Bernardino-Wet	June 14	17	35	26-45%	25.9	0.38"
Hathaway-Dry	June 16	17	35	24-48%	19.2	0.38"
Hathaway-Wet	June 17	17	35	27-50%	20.1	0.38"
Cave-Dry	June 20	18	35	20-38%	36.6	0.89"
Cave-Wet	June 21	18	34	24-42%	11.4	0.34

APPENDIX C

SURFACE REFLECTANCE DATA

Table C.1. Dry Measurements - June 1983

Bernardino Soil Site - June 13, 1983

	PLOT											
	Bare			Natural 1			Natural 2			Erosion Pavement		
Band	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)
1	.0673	15	10.11	.0429	43	6.44	.0604	30	8.50	.0573	31	8.07
2	.2349	9	16.32	.1683	31	11.69	.1882	28	12.36	.1865	25	12.25
3	.1008	14	21.85	.0723	26	15.67	.0884	28	17.71	.0934	16	18.71
4	.4570	16	27.06	.4372	38	25.89	.4628	20	25.90	.4207	23	23.54
	Hathaway Soil Site - June 16, 1983											
1	.0764	20	12.19	.0520	45	7.91	***	***	***	.0758	31	12.44
2	.2269	12	15.97	.1757	37	12.37				.2135	25	16.27
3	.0868	11	19.38	.0717	27	15.77				.0742	28	17.45
4	.3934	8	24.31	.3783	36	22.87				.3610	18	22.97
	Cave Soil Site - June 20, 1983											
1	.1146	15	17.47	.0600	47	9.52	***	***	***	.1163	18	17.73
2	.3164	16	22.14	.2346	36	16.99				.3237	15	22.66
3	.1262	15	27.16	.0838	24	18.84				.1205	12	26.36
4	.5420	12	32.86	.5082	28	32.00				.5178	8	31.39

* Mean of 20 readings/plot - Watts/meter^2
** Coefficient of Variation
*** No Natural 2 Plot

Table C.2. Wet Measurements - June 1983

	PLOT											
	Bare			Natural 1			Natural 2			Erosion Pavement		
Band	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)
Bernardino Soil Site - June 14, 1983												
1	.0353	19	5.39	.0342	49	5.22	.0480	34	6.67	.0516	50	7.07
2	.1303	18	6.32	.1228	24	5.96	.1739	34	11.24	.1921	37	12.19
3	.0601	13	13.12	.0625	30	13.60	.0799	24	15.77	.0771	21	15.06
4	.2808	16	16.69	.3941	31	23.43	.4621	29	25.40	.3865	22	21.82
Hathaway Soil Site - June 17, 1983												
1	.0430	14	6.38	.0475	51	4.70	***	***	***	.0564	53	8.04
2	.1426	35	9.95	.1410	48	8.20				.1495	27	9.99
3	.0551	12	11.15	.0702	34	11.54				.0647	30	13.30
4	.2718	17	14.85	.3210	45	18.12				.2669	15	15.03
Cave Soil Site - June 21, 1983												
1	.0648	42	9.52	.0593	44	7.76	***	***	***	.0778	25	11.44
2	.1817	17	12.05	.1908	43	11.65				.2300	31	15.43
3	.0793	21	16.45	.0865	23	16.09				.0899	17	18.53
4	.3578	13	20.27	.4261	24	22.16				.3911	15	22.46

* Mean of 20 readings/plot - Watts/meter^2
** Coefficient of Variation
*** No Natural 2 Plot

Table C.3. Dry Measurements - November 5, 1983

	PLOT											
	Bare			Natural 1			Natural 2			Erosion Pavement		
Band	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)	Spectral Value* (W/m^2)	C.V.** (%)	Reflectance (%)
	Bernardino Soil Site											
1	.0269	11	4.76	.0093	39	1.65	.0091	40	1.60	.0226	16	3.98
2	.1203	8	10.28	.0652	26	5.57	.0608	29	5.19	.1070	13	9.08
3	.1581	10	14.83	.0672	39	6.30	.0626	30	5.74	.1434	14	13.16
4	.2208	8	18.08	.2086	18	17.08	.1856	30	15.11	.2010	11	16.37
	Hathaway Soil Site											
1	.0360	16	6.13	.0148	41	2.52	***	***	***	.0353	16	5.31
2	.1259	17	10.18	.0713	26	5.76				.1129	11	9.25
3	.1432	14	12.51	.0741	39	6.47				.1244	12	11.65
4	.2002	17	15.64	.1541	25	12.04				.1754	11	14.35
	Cave Soil Site											
1	.0667	10	9.54	.0305	42	4.36	***	***	***	.0647	11	9.25
2	.2108	9	14.64	.1153	36	8.00				.1994	10	13.84
3	.2429	9	17.46	.1106	40	8.02				.2207	16	16.00
4	.3432	11	21.73	.2514	29	15.92				.3221	14	20.40

* Mean of 20 readings/plot - Watts/meter^2
** Coefficient of Variation
*** No Natural 2 Plot

APPENDIX D

SURFACE TEMPERATURE DATA

Table D.1. Dry Temperatures - June 1983

Time	Bare		Natural 1		Natural 2		Erosion Pavement	
	°C*	C.V.** (%)	°C*	C.V.** (%)	°C*	C.V.** (%)	°C*	C.V.** (%)
Bernardino Soil Site - June 13, 1983								
5:00	11.3	4	11.9	10	11.9	7	10.9	4
6:00	13.7	9	16.1	8	16.3	8	14.1	8
8:00	29.4	7	27.4	9	26.9	11	30.0	8
9:00	35.6	8	32.6	13	33.1	10	34.4	6
12:00	51.3	5	43.2	14	42.7	14	49.6	3
13:00	52.0	5	48.8	12	45.0	14	51.8	4
13:30	51.0	4	47.6	16	44.6	17	51.5	7
14:00	52.5	5	47.5	17	45.3	13	51.8	6
14:30	52.3	3	48.3	15	44.7	13	51.9	3
15:00	52.1	3	43.2	16	41.7	12	51.1	3
16:00	48.3	4	39.0	13	38.8	13	46.2	6
Hathaway Soil Site - June 16, 1983								
5:00	12.0	6	13.5	5	***	***	12.2	3
6:00	12.6	7	13.3	3			12.4	5
8:00	28.5	8	26.8	12			25.5	12
9:00	37.9	6	31.9	11			35.9	7
12:00	54.6	2	45.0	12			51.7	4
13:00	53.7	3	45.3	12			51.5	3
13:30	55.9	2	44.8	16			54.0	3
14:00	55.3	3	51.2	15			53.0	4
14:30	53.3	3	50.2	12			51.7	5
15:00	52.2	3	47.4	13			51.2	3
16:00	51.8	3	44.7	12			50.1	3
Cave Soil Site - June 20, 1983								
5:00	12.0	6	12.9	8	***	***	12.1	8
6:00	16.3	10	17.8	10			16.8	8
8:00	33.5	5	29.1	9			33.8	5
9:00	40.8	4	34.8	12			41.7	4
12:00	49.6	3	43.8	19			51.1	3
13:00	50.6	4	46.9	18			53.0	4
13:30	50.6	3	47.1	18			52.4	4
14:00	50.2	4	44.0	15			51.0	4
14:30	50.4	3	44.0	16			51.0	4
15:00	49.4	3	43.8	17			51.3	2
16:00	45.2	3	41.1	13			46.9	3

* Mean of 20 readings per plot in °C

** Coefficient of Variation

*** No Natural 2 Plot

Table D.2. Wet Temperatures - June 1983

Time	Bare		Natural 1		Natural 2		Erosion Pavement	
	°C*	C.V.** (%)	°C*	C.V.** (%)	°C*	C.V.** (%)	°C*	C.V.** (%)
Bernardino Soil Site - June 14, 1983								
11:30	30.3	2	33.9	8	35.0	7	35.0	4
12:30	33.4	4	36.6	9	38.2	9	37.6	5
13:00	34.8	4	37.2	10	38.6	11	38.9	5
13:30	36.6	7	37.0	10	41.4	7	38.9	5
14:00	35.6	8	35.5	9	38.0	8	39.1	5
14:30	37.8	10	34.7	9	38.4	8	39.7	5
15:00	38.8	8	34.6	9	36.5	9	39.6	6
16:00	35.9	7	31.8	4	30.8	6	33.3	4
Hathaway Soil Site - June 17, 1983								
11:30	34.3	3	34.2	8	***	***	34.4	5
12:30	38.4	6	35.9	7			37.5	4
13:00	38.4	6	34.7	8			37.0	4
13:30	40.1	3	36.5	9			38.5	3
14:00	41.1	5	35.5	7			38.1	5
14:30	41.3	4	35.7	8			39.5	4
15:00	41.7	5	35.9	8			40.6	5
16:00	42.0	4	36.3	8			39.1	4
Cave Soil Site - June 21, 1983								
12:00	35.1	5	34.7	8	***	***	37.0	4
13:00	37.0	7	33.8	8			36.9	4
13:30	30.9	7	30.3	6			31.5	4
14:00	30.9	6	30.3	4			31.7	4
15:00	27.6	7	27.6	3			27.9	4

* Mean of 20 readings per plot in °C
** Coefficient of Variation
*** No Natural 2 Plot

Appendix E. Correlation Coefficients of Dry Surface Temperatures and Surface Features - June 1983

	Hue	Value	Chroma	%Soil	%Gravel	%Rock	%Shrub	%Grass	%Forb	%Litter	Runoff	T-5:00	T-6:00	T-8:00	T-9:00	T-12:30	T-13:00	T-13:30	T-14:00	T-14:30	T-15
Hue																					
Value	.53																				
Chroma	-.53	-1.00																			
%Soil	.04	-.06	.06																		
%Gravel	.02	.13	-.13	-.98																	
%Rock	-.16	-.10	.10	-.95	.87																
%Shrub	-.33	-.42	.42	-.18	.07	.32															
%Grass	-.43	-.41	.41	-.22	.04	.44	.76														
%Forb	-.31	-.57	.57	-.64	-.15	.33	.51	.79													
%Litter	.15	.23	-.23	-.35	.32	.28	.04	.21	-.19												
Runoff	-.06	.32	-.32	.75	-.71	-.75	-.28	-.36	-.27	-.35											
T-5:00	.23	.70	-.70	-.01	-.63	-.01	.08	.26	-.14	.47	.12										
T-6:00	.72	-.06	.06	.08	-.13	-.01	.22	.15	.32	.08	-.29	.06									
T-8:00	.76	.20	-.20	-.02	.11	-.14	-.40	-.50	-.33	.14	-.06	-.26	.47								
T-9:00	.49	.40	-.41	-.06	.17	-.12	-.56	-.73	-.49	-.12	.22	-.33	-.04	.75							
T-12:00	.03	.34	-.34	.08	.06	-.26	-.64	-.77	-.62	-.20	.45	-.36	-.55	.36	.83						
T-13:00	.06	.11	-.11	.11	-.02	-.21	-.71	-.72	-.34	-.25	.37	-.55	-.36	.45	.81	.90					
T-13:30	.05	.36	-.36	.16	-.07	-.25	-.66	-.72	-.41	-.34	.53	-.31	-.46	.25	.79	.93	.92				
T-14:00	-.29	.15	-.15	-.01	.10	-.11	-.55	-.55	-.43	-.17	.39	-.38	-.76	.13	.64	.93	.86	.86			
T-14:30	-.22	.03	-.03	-.08	.17	-.04	-.61	-.55	-.36	-.16	.23	-.52	-.64	.26	.68	.90	.90	.82	.97		
T-15:00	.01	.21	-.21	.02	.12	-.21	-.70	-.80	-.63	-.11	.31	-.49	-.54	.39	.79	.97	.92	.87	.92	.93	
T-16:00	-.12	.42	-.42	.08	.05	-.27	-.64	-.72	-.70	-.06	.49	-.13	-.73	.11	.63	.94	.77	.86	.92	.84	.92

APPENDIX F

CORRELATION COEFFICIENTS OF DRY

PERCENT REFLECTANCE AND SURFACE FEATURES

Table F.1. Correlation Coefficients of Dry Spectral Reflectance and Surface Features - June 1983

	Band 1	Band 2	Band 3	Band 4	Hue	Value	Chroma	%Soil	%Gravel	%Rock	%Shrub	%Grass	%Forb	%Litter
Band 1														
Band 2	.96													
Band 3	.89	-.91												
Band 4	.60	.77	.75											
Hue	.68	.82	.72	.93										
Value	.60	.60	.30	.29	.53									
Chroma	-.60	-.60	-.30	-.29	-.53	-1.0								
%Soil	.28	.29	.44	.27	.04	- .06	.06							
%Gravel	-.20	-.20	-.35	-.23	.02	.13	-.13	-.98						
%Rock	-.37	-.41	-.52	-.34	-.16	-.10	.10	-.95	.87					
%Shrub	-.40	-.49	-.38	-.22	-.33	-.42	.42	-.18	.07	.32				
%Grass	-.61	-.65	-.60	-.33	-.43	-.41	.41	-.22	.38	.44	.75			
%Forb	-.51	-.50	-.43	-.13	-.31	-.57	.57	-.04	-.15	.33	.51	.79		
%Litter	.18	.15	.18	.01	.15	.23	-.23	-.34	.32	.27	.04	.21	-.19	
Runoff	.32	.24	.23	-.03	-.06	.32	-.32	.75	-.71	-.75	-.28	-.36	-.27	-.35

Table F.2. Correlation Coefficients of Spectral Reflectance and Surface Features - November 1983

	Band 1	Band 2	Band 3	Band 4	Hue	Value	Chroma	%Soil	%Gravel	%Rock	%Shrub	%Grass	%Forb
Band 1													
Band 2	.98												
Band 3	.89	.96											
Band 4	.74	.80	.75										
Hue	-.70	.63	.43	.65									
Value	.58	.44	.25	-.00	.53								
Chroma	-.58	-.44	-.25	.00	-.53	-1.00							
%Soil	.30	.38	.44	.45	-.02	- .12	.12						
%Gravel	-.30	-.37	-.42	-.47	.09	- .15	-.15	-.97					
%Rock	-.28	-.35	-.39	-.38	-.13	.03	-.03	-.93	.81				
%Shrub	-.30	-.37	-.46	-.11	-.06	- .24	.24	-.27	.14	.39			
%Grass	-.60	-.64	-.70	-.27	-.30	- .33	.33	-.20	.06	.31	.65		
%Forb	.03	-.04	-.16	.19	.19	- .10	.10	-.25	.09	.40	.88	.53	
%Litter	.11	.08	-.01	.39	.22	- .10	.10	-.11	-.06	.28	.39	.56	.70

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