A. Karim Batchily
Donald F. Post
R. B. Bryant
Donald J. Breckenfeld

Spectral Reflectance and Soil Morphology Characteristics of Santa Rita Experimental Range Soils

Abstract: The Santa Rita Experimental Range (SRER) soils are mostly transported alluvial sediments that occur on the piedmont slope flanking the Santa Rita Mountains in Arizona. The major geomorphic land forms are alluvial fans or fan terraces, but there are also areas of residual soils formed on granite and limestone bedrock, basin floor, stream terraces, and flood plains. The soils range in age from recent depositions to soil material one to two million years of age. We sampled A and B horizons of soil series from different geomorphic surfaces, and measured the dry spectral reflectance (0.4 to 2.5 μm wavelength) on the sieved less than 2-mm-size fraction. Soil color (measured with a Chroma Meter), texture, organic carbon, calcium carbonate content, and effervescence properties were determined and correlated to spectral reflectance in selected wavelengths. The Munsell soil color value component was most positively correlated to reflectance. Soil effervescence and calcium carbonate content, percent sand and clay, and the Munsell soil color hue component and redness rating were also significantly correlated to soil reflectance. Energy reflected from soil surfaces represents the interaction between many soil properties, and soil color is an integrated expression of many soil properties. It is the best soil morphology property to measure to predict the spectral reflectance of soils, particularly in the visible and near infrared parts of the electromagnetic spectrum.

Acknowledgments: The Soils Map GIS data for the Santa Rita Experimental Range (SRER) were completed by Debbie Angell and Dr. M. McClaran, and the manipulation of this data to prepare the geomorphic land form map was prepared by Dawn Browning and Mamadou Niane, University of Arizona, School of Renewable Natural Resources (SRNR). The SRNR Advanced Resource Technology (ART) Laboratory facilities were utilized to create the geomorphic land form map of the SRER. Special thanks are extended to Mary Kay Amistadi and Dr. Jon Chorover, Department of Soil, Water and Environmental Science, University of Arizona, for determining the organic carbon and calcium carbonate content of the SRER soils. We also thank Dr. M. S. Moran, the USDA Agricultural Research Service, Tucson, AZ, for allowing us to use her Analytical Spectral Device to measure spectral reflectance.

Introduction

Jenny (1941, 1980) presents a soil formation equation that states a soil is a product of the interaction of the five "Factors of Soil Formation," namely climate, biota, parent material, time, and topography. Within the Santa Rita Experimental Range

A. Karim Batchily is a Research Specialist in the Department of Soils, Water and Environmental Science (SWES) at the University of Arizona. He received a B.S. degree in agronomy from the Agronomic Institute Nicolae Balcescu, Buchurest, Romania, in 1982, and an M.S. degree in soil science from the University of Arizona in 1991. He has more than 10 years of experience in soils and remote sensing. Donald F. Post is Professor Emeritus of soil science from the Soil, Water and Environmental Science Department, University of Arizona; e-mail: postdf@ag.arizona.edu. He joined the University of Arizona faculty in 1967 and has taught classes in basic soils, soil morphology and classification, and soil and water conservation from 1967 until the present. His research has been in soil morphology and classification, and in using remotely sensed data to map soils and other natural resources. R. B. Bryant is a research specialist employed by the USDA Agricultural Research Service in Tucson, AZ. He has a B.A. degree in geology from Colorado College, and he completed an M.S. degree in soil and water science from the University of Arizona in 1990. Donald J. Breckenfeld is a Major Land Resource Area Soil Survey Leader with the USDA Natural Resources Conservation Service at the Tucson Soil Survey in Tucson, AZ. He has a B.S. degree in soil science from the University of Arizona. He started working with the Soil Conservation Service as a Soil Scientist making soil surveys in 1979.

In: McClaran, Mitchel P.; Ffolliott, Peter F.; Edminster, Carleton B., tech. coords. Santa Rita Experimental Range: 100 years (1903 to 2003) of accomplishments and contributions; conference proceedings; 2003 October 30–November 1; Tucson, AZ. Proc. RMRS-P-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

(SRER) all factors are important; however, the time and parent material factors are particularly important. Most SRER soils are formed in alluvium of mixed origins, derived from igneous and sedimentary rocks (mostly granite and limestone), and these materials then experienced different time periods for soil development to occur. It is particularly useful to identify what are called "geomorphic surfaces" (Ely and Baker 1985; McAuliffe 1995 a,b; Peterson 1981), as they are closely related to soil characteristics.

A "geomorphic surface" is a mappable landscape element formed during a discrete time period, which has distinctive geologic materials, topographic features, and soil profiles. From this definition, it can be inferred that each stable surface will have a soil developed upon it, which has properties that are in part a function of the time since erosion and/or deposition has ceased. Quantifying pedogenic properties of soils on different geomorphic surfaces provides a means to compare the age of surfaces. On the SRER, soil texture, the color (amount of reddness) of the soil, presence or absence of carbonates in the parent material, and soil horizons distinguish the soil series mapped on the SRER

Significant relationships between soil properties and the spectral reflectance of soils in the visible and near-infrared portions of the electromagnetic spectrum (Baumgardner and others 1985; Condit 1970; DaCosta 1979; Shields and others 1968; Stoner 1979; Stoner and Baumgardner 1981) show it is possible to use remote sensing techniques to quantify soil properties. These researchers emphasized how the soil components of organic carbon, iron oxides, texture, water, and salts affect spectral reflectance. Correlations with Munsell hue, value, and chroma were also presented, but the color measurements were made using only the visual comparison procedure (Soil Survey Division Staff 1993). Escadafal and others (1988, 1989) investigated the relationships between Munsell soil colors and Landsat spectral response, especially on arid landscapes, and reported that the Munsell color parameters of hue, value, and chroma were significantly correlated with Landsat data. Post and others (1994) and Horvath and others (1984) concluded that the reflectance of radiant energy from sparsely vegetated arid rangelands is determined by the characteristics of the soil and geologic material on the land surface. They also concluded colorimeters to accurately quantify the color of earth surface features are very important for evaluating remotely sensed data. Other researchers (Bowers and Hanks 1965; Cipra and others 1980; Huete and Escadafal 1991; Weismiller and Kaminsky 1978; Westin and Lemme 1978) report how remotely sensed spectral data can be used to characterize and map soils.

There is a keen interest in understanding how incoming solar radiation from the sun is absorbed at the earth's surface. The ratio of the energy reflected back to the atmosphere is called the albedo of that surface. When discussing albedo the spectral wavelength must be identified, and commonly an integration of the amounts of energy reflected between 0.3 to 2.8 μm is used. Post and others (2000) described how albedo of soils can be predicted from soil color and spectral reflectance and how the albedo of SRER soils will be evaluated.

The objectives of this paper were to (1) collect samples of soil series mapped on different geomorphic surfaces with different kinds of alluvial parent materials and measure their spectral reflectance, (2) measure the morphological properties of these soils, and (3) correlate soil reflectance in selected spectral bands to soil properties. Identification of basic spectral curves of the soil series found on the SRER would be useful for improved interpretation of remotely sensed data acquired by airborne sensors and orbiting satellites.

Materials and Methods

Thirty soil samples were collected from 16 different locations from six SRER geomorphic surfaces. The A and B horizons were sampled for mature soils; however, only the A horizon was collected from the Holocene age soils, except for one site where a C horizon was also collected. The samples were selected to encompass the range of soil reflectances that are found on the SRER. Multiple sample sites were selected for three soil series because these soils had a wider range of soil physical properties within these soil series.

All samples were air dried and passed through a 2-mm sieve, and all analyses were completed with the less than 2-mm soil fraction. Soil color was measured using a Model 200 Chroma Meter (Minolta Company) as follows: the samples were evenly distributed on a flat surface to provide a thickness of about 2 mm, the measuring head was rested in a vertical position on the soil surface, and a color reading was taken. A detailed description of this procedure and how the hue color notation was converted to a number for statistical analyses is described by Post and others (1993). The three Munsell color components were also converted into a redness rating as follows (Torrent and others 1980):

$$\text{Redness} = \frac{(10 - hue)\, x\, chroma}{Value}$$

where the chroma and value are numerical values of each, and the hue is the notation number preceding the YR in the Munsell color notation system. Organic and inorganic carbon (C) contents were measured using a dry combustion method (TOC-VCSH, Total Carbon Analyser, made by Shimadzu Corporation, Columbia, MD). The samples were heated to 300 and 800 ^{o}C, and the CO_2 evolved at these two temperatures were measured by an infrared detector. The percent C released was converted to percent Organic Carbon (O.C.) and percent calcium carbonate ($CaCO_3$) found in each soil. Soil texture characteristics were determined by the "Field or Feel Method" (Thien 1978) by two field soil scientists, a mean percent clay and sand was calculated, and then the textural class was identified. Also, how the soil reacts when 10 percent HCL is applied to the sample (Soil Survey Division Staff 1993) was observed and recorded. The amount of effervescence refers to the amount of bubbles (CO_2) released, and terms like "slight," "strong," and "violent" are used to describe the reaction.

The reflectance spectra of these soils were recorded between the 0.4 to 2.5 μm wavelengths region at one nanometer increments using an Analytical Spectral Device full range hyperspectral system with a 15^{o} field of view. Smooth soil surfaces were viewed vertically from a height of 0.5 m, and the reflected energy was referenced to a calibrated standard reflectance plate. The spectra were measured on a clear, cloud-free day in Tucson, AZ, between 11:00 and 11:30 a.m. on April 16, 2003. Reflectance data of special interest to us were the Landsat Thematic mapper (TM) bands, namely TM1 (blue, 0.45 to 0.52 mm), TM2 (green, 0.52 to 0.60 mm), TM3 (red, 0.63 to 0.69 mm), TM 4 and 5 (near infrared [NIR] 0.76 to 0.90 and 1.55 to 1.75 mm), and TM 7 (middle infrared [MIR], 2.08 to 2.35 mm). A mean reflectance factor for each band was computed for the following wavelengths: blue = 0.485 mm, green = 0.560 mm, red = 0.660 mm, NIR = 0.830 mm, near short wave infrared = 1.650 mm, and middle infrared = 2.180 mm. These reflectance factors were correlated with the soil morphology properties for the 16 A horizons, 13 B horizons, and one C horizon for a total of 30 samples. The correlation coefficient (r value) was computed and reported (Gomez and Gomez 1984).

Results and Discussion

The Soil and Ecological Site Map of the SRER prepared by Breckenfeld and Robinett (these proceedings) was the basic map used to prepare a general geomorphology map of the SRER and to determine where soil samples were to be collected. Figure 1 is a map outlining seven geomorphic surfaces on the SRER, and table 1 defines the terms that

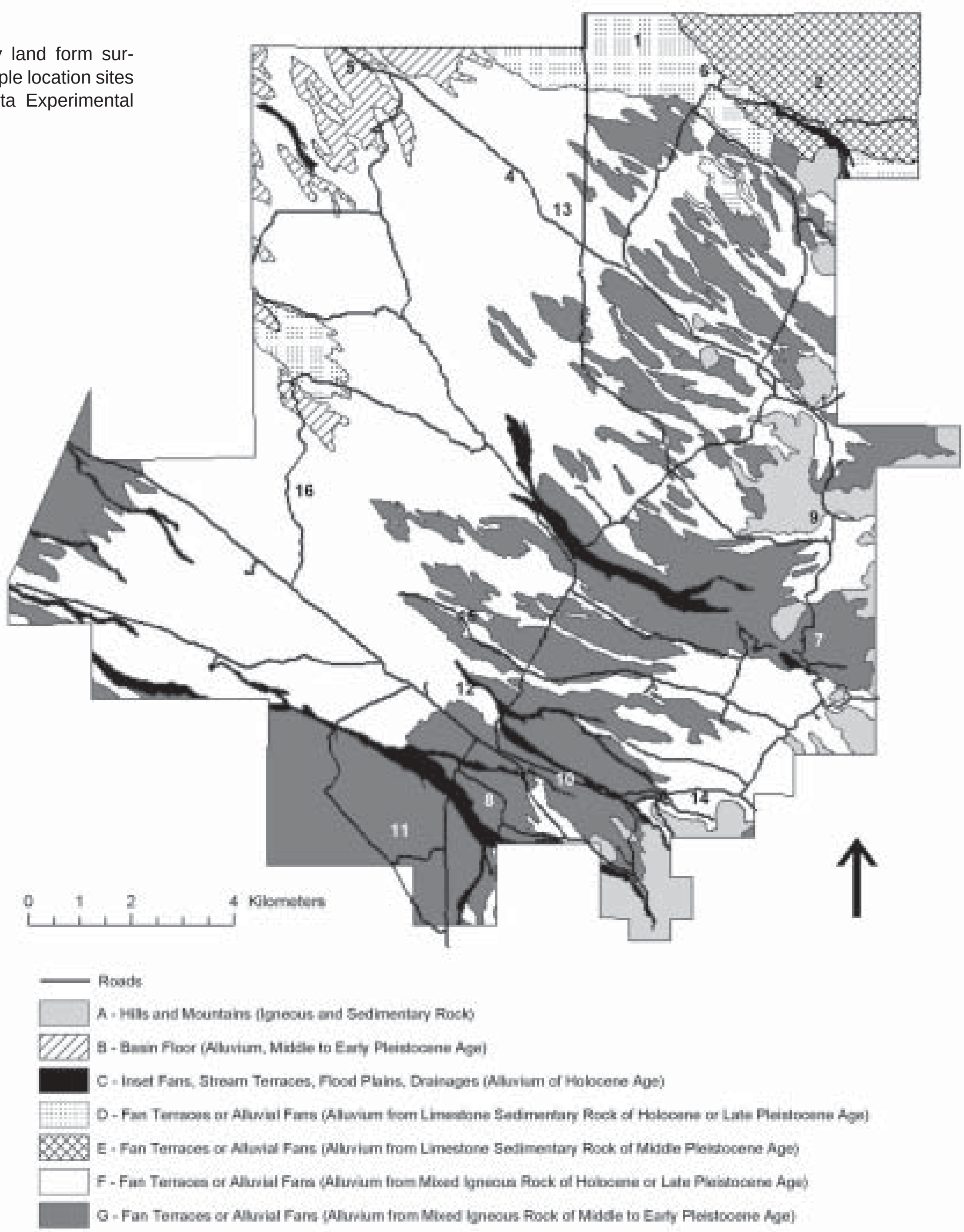

Figure 1—Geomorphology land form surfaces map and the soil sample location sites collected on the Santa Rita Experimental Range.

Table 1—Description of the geomorphic land form surfaces and geologic terms to define their age as identified on the SRER listed in alphabetical order.

Geomorphic surfaces	
Alluvial fan	A low, outspreading mass of loose soil and rock material, commonly with gentle slopes that are shaped like an open fan or a segment of a cone, deposited by water at the place where it issues from mountains.
Basin floor	A general term for the nearly level, lower most part of intermontane basins. The floor includes all the alluvial, eolian, and erosional land forms below the piedmont slope.
Fan terrace	A general term for land forms that are remaining parts of older fan B land forms, such as alluvial fan (fan remnant is another term used to describe this land form).
Flood plain	The nearly level A plain that borders a stream and is subject to inundation under flood-stage conditions (unless it is protected artificially).
Hills and mountains	A hill is an area of land surface, rising as much as 300 m above the surrounding lowlands, whereas a mountain rises more than 300 m.
Inset fan	An ephemeral stream flood plain rather broad in area incised in alluvial fans or fan terraces; a barren channel covers a minor portion of its surface, but its breadth is rather extensive.
Piedmont slope	The dominant gentle slope at the foot of a mountain that grades to a basin floor or alluvial flood plains.
Stream terraces	One of a series of levels in a stream valley that mostly parallels the stream, but it no longer floods.
Geologic terms to define the age of geomorphic surfaces	
Holocene	The geologic time period extending from the end of the Pleistocene (Ice Age) Epoch from10,000 to 12,000 years before present.
Pleistocene	The epoch of geologic time referred to as the Quaternary Period with a geologic time from approximately 2 million to 10,000–12,000 years before present.
Late Pleistocene	10,000–12,000 to 25,000 years before present.
Middle Pleistocene	25,000 to 300,000 or 400,000 years before present.
Early Pleistocene	300,000 or 400,000 to 1,000,000–2,000,000 years before present.

describe these surfaces. Figures 2 and 3 present the spectral curves for representative A and B horizons, respectively. Table 2 lists the mean reflectance values for the 30 soils for six of the Thematic Mapper (TM) wavelength bands, and table 3 lists the soil morphology characteristics for the 30 soils.

Stoner (1979) and Stoner and Baumgardner (1981) describe in great detail the spectral characteristics for many soils. They explain that moisture content, organic matter, iron content, and presence of minerals such as calcium carbonate most determine soil color. The SRER soils have a

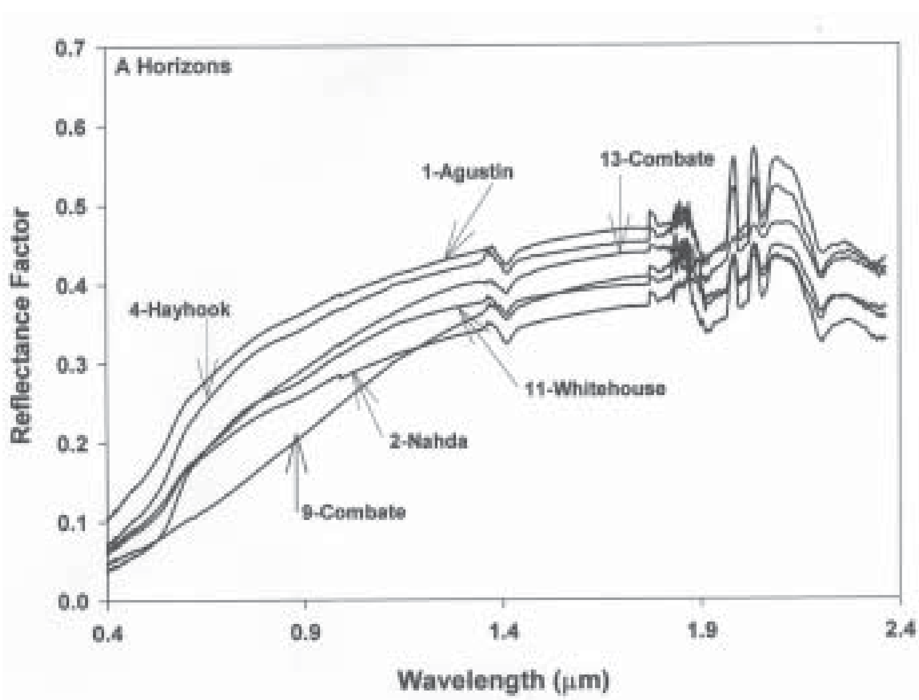

Figure 2—Spectral curves for A horizons of representative Santa Rita Experimental Range soils.

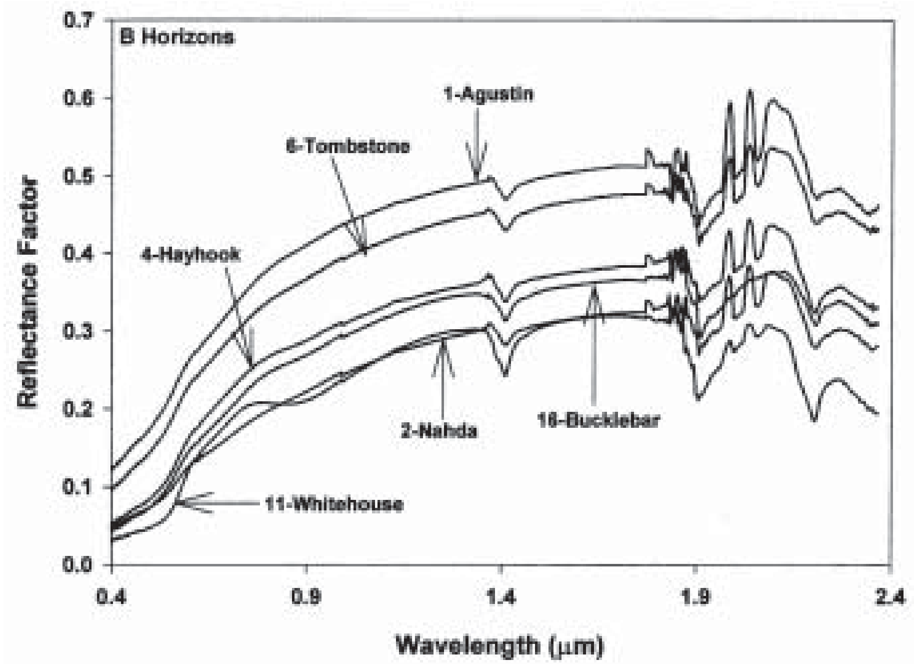

Figure 3—Spectral curves for B horizons of representative Santa Rita Experimental Range soils.

Table 2—Percentage of reflected energy in six selected wavelengths corresponding to the Landsat Thematic Mapper (TM) bands.

Soil ID	Soil names and horizons	Blue (0.485 μm)	Green (0.560μm)	Red (0.660μm)	NIR (0.830μm)	MIR (1.650μm)	MIR (2.179μm)
1	Agustin (A)	0.1521	0.2126	0.2823	0.3474	0.4634	0.4814
1	Agustin (Bk)	.1678	.2264	.2999	.3888	.5086	.5181
2	Nahda (A)	.0912	.1336	.1891	.2441	.3645	.3747
2	Nahda (Btk)	.0707	.1027	.1485	.2047	.3203	.3237
3	Sasabe (A)	.0803	.1283	.2008	.2650	.4021	.4197
3	Sasabe (Bt)	.0619	.0976	.1597	.2247	.3544	.3536
4	Hayhook (A)	.1110	.1718	.2565	.3278	.4464	.4611
4	Hayhook (Bw)	.0802	.1267	.1999	.2724	.3796	.3782
5	Tubac (A)	.0947	.1492	.2303	.3021	.4205	.4288
5	Tubac (Bt)	.0681	.1129	.1954	.2633	.3582	.3364
6	Tombstone (A)	.1326	.1875	.2549	.3262	.4612	.4734
6	Tombstone (Bk)	.1381	.1940	.2658	.3465	.4716	.4792
7	Whitehouse (A)	.0950	.1581	.2549	.3246	.4466	.4435
7	Whitehouse (Bt)	.0522	.0856	.1592	.2211	.3335	.2962
8	Caralampi (A)	.1060	.1572	.2307	.2966	.3760	.3861
8	Caralampi (Bt)	.0779	.1204	.1887	.2496	.2927	.2794
9	Combate (A)	.0667	.0880	.1187	.1833	.3995	.4017
10	Whitehouse (A)	.0625	.1001	.1561	.2089	.3563	.3512
10	Whitehouse (Bt)	.0501	.0879	.1730	.2427	.3885	.3156
11	Whitehouse (A)	.0620	.1100	.1963	.2625	.3933	.3949
11	Whitehouse (Bt)	.0456	.0808	.1617	.2072	.3178	.2524
12	Combate (A)	.0832	.1189	.1640	.2326	.4265	.4244
12	Combate (C)	.1088	.1541	.2069	.2749	.4502	.4443
13	Combate (A)	.0970	.1392	.1955	.2684	.4323	.4416
14	Baboquivari (A)	.1023	.1567	.2304	.3131	.4560	.4376
14	Baboquivari (Bt)	.0759	.1179	.1815	.2567	.3953	.3620
15	Bucklebar (A)	.1053	.1646	.2514	.3301	.4393	.4374
15	Bucklebar (Bt)	.0798	.1249	.1962	.2656	.3520	.3429
16	Bucklebar (A)	.1027	.1603	.2373	.3167	.4465	.4369
16	Bucklebar (Bt)	.0696	.1136	.1778	.2523	.3628	.3465

Table 3—Soil morphology characteristics of the thirty soils sampled on the Santa Rita Exerimental Range.

Soil ID	Geomorphic Surface[a]	Soil names and Horizons	Munsell soil color Hue	Hue	Value	Chroma	Redness rating	Organic carbon	$CaCO_3$	Clay	Sand	Effer[b]	Albedo
								. . . . percent	. . . .				
1	D	Agustin (A)	9.5 YR	4.8	6.1	3.6	0.3	0.49	13.7	10	73	3.2	0.31
1	D	Agustin (Bk)	9.0 YR	4.6	6.0	3.2	.5	.59	19.4	18	69	3.8	.30
2	E	Nahda (A)	8.7 YR	4.5	4.8	3.4	.9	.71	.0	18	63	.0	.22
2	E	Nahda (Btk)	8.2 YR	4.3	4.2	3.2	1.4	.92	.7	32	50	.4	.18
3	G	Sasabe (A)	7.2 YR	3.9	4.8	4.4	2.6	.48	.0	13	67	.0	.22
3	G	Sasabe (Bt)	6.0 YR	3.4	4.2	4.3	4.0	.46	.0	30	57	.2	.18
4	F	Hayhook (A)	8.0 YR	4.2	5.5	4.4	1.6	.34	.0	10	75	.0	.27
4	F	Hayhook (Bw)	7.5 YR	4	4.6	4.1	2.3	.32	.0	16	70	.0	.20
5	B	Tubac (A)	7.5 YR	4	5.2	4.5	2.2	.29	.0	9	78	.0	.24
5	B	Tubac (Bt)	5.5 YR	3.2	4.5	4.9	5.0	.21	.0	42	41	.0	.19
6	D	Tombstone (A)	9.7 YR	4.9	5.5	3.4	.2	.80	7.6	12	68	3.8	.27
6	D	Tombstone (Bk)	8.7 YR	4.5	5.7	3.5	.8	.52	7.8	15	69	3.8	.28
7	G	Whitehouse (A)	7.0 YR	3.8	5.2	4.7	2.7	.52	.0	8	76	.0	.24
7	G	Whitehouse (Bt)	4.2 YR	2.7	3.8	4.7	7.2	.94	.0	47	30	.0	.15
8	G	Caralampi (A)	8.2 YR	4.3	5.2	3.8	1.3	1.00	.0	9	67	.0	.24
8	G	Caralampi (Bt)	6.7 YR	3.7	4.2	3.9	3.0	.71	.0	35	52	.0	.18
9	F	Combate (A)	9.7 YR	4.9	3.9	1.9	.1	.89	.0	5	87	.0	.16
10	G	Whitehouse (A)	7.2 YR	3.9	4.2	3.9	2.6	.84	.0	17	69	.0	.18
10	G	Whitehouse (Bt)	4.0 YR	2.6	4.1	5.3	7.7	.68	.0	48	40	.0	.17
11	G	Whitehouse (A)	5.7 YR	3.3	4.4	4.9	4.9	.92	.0	14	58	.0	.19
11	G	Whitehouse (Bt)	3.2 YR	2.3	3.9	5.2	9.1	.69	.0	53	25	.0	.16
12	C	Combate (A)	10.0 YR	5	4.6	2.7	.0	.62	.0	7	85	.0	.20
12	C	Combate (C)	10.0 YR	5	5.1	3.0	.0	.43	.9	5	89	1.5	.23
13	F	Combate (A)	9.0 YR	4.6	4.8	3.2	.7	.38	.0	8	85	.0	.22
14	F	Baboquivari (A)	9.0 YR	4.6	5.3	3.9	.7	.80	.0	8	76	.0	.25
14	F	Baboquivari (Bt)	7.7 YR	4.1	4.6	3.8	1.9	.53	.0	25	64	.0	.20
15	F	Bucklebar (A)	7.7 YR	4.1	5.4	4.3	1.8	.49	.0	9	72	.0	.26
15	F	Bucklebar (Bt)	7.0 YR	3.8	4.8	4.0	2.5	.32	.0	15	70	.0	.22
16	F	Bucklebar (A)	8.7 YR	4.5	5.2	4.0	1.0	.99	.0	12	71	.0	.24
16	F	Bucklebar (Bt)	8.0 YR	4.2	4.5	3.9	1.7	.30	.0	25	63	.0	.19

[a] Refer to figure 1 and table 1 for descriptions of geomorphic surfaces.
[b] Effervescence: 0 = none, 1 = slight, 2 = moderate, 3 = strong, 4 = violent.

low organic matter. Content and the older land surfaces, particularly the Whitehouse soil series, are very red, indicating the presence of iron oxide in the soil. It also has a clay texture which occurs as soils get older. Although we did not measure the iron content of the SRER soils, we did compute the redness index, which is indicative of the iron content (particularly Fe_2O_3 – ferric iron) in a soil.

The spectral curves for the A horizons show that Combate (9) has the lowest reflectance factor in the 0.4 to 1.0 μm wavelength range (fig. 2). This soil also has a color value of 3.9, the lowest of all soils. The Agustin (1) soil has the highest reflectance factor, and it also has the highest Munsell color value of 6.1. The Agustin soil has about 14 percent $CaCO_3$, which contributes to the lighter color and higher Munsell value. Other representative soil curves for the Hayhook, Whitehouse, Nahda, and a second Combate sample are shown to illustrate the range in spectral characteristics of the A horizons mapped on the SRER.

Figure 3 presents the spectral curves for the B horizons. The Agustin soil is the most reflective, and the Tombstone soil has the next highest reflectance. Both of these soils are formed from alluvium derived from limestone parent materials. The Whitehouse Bt horizon is very red (redness rating of 9.1), and the shape of the spectral curve shows the presence of iron in this soil. The iron absorption occurs in the 0.5 to 0.9 μm band width. The Bucklebar and Hayhook soils have intermediate spectral reflectance characteristics. The Nahda Btk horizon reflectance is similar to the Whitehouse Bt horizon, but the curve shape is different because the Nahda soil is less red and likely has a lower iron content.

The spectral curves for both the A and B horizons from 1.0 μm to 2.5 μm show very strong absorptions at about 1.9 μm, and a less pronounced absorption band at 1.4 μm. There are striking other differences in reflected energy in the 1.0 to 2.5 μm bands, which are mostly water or hydroxyl absorption bands. Spectral data in the visible and NIR are commonly used to classify the reflectance properties of land surfaces because orbiting satellites collect data in these wavelengths, and this is of most interest to us.

Table 4 lists the linear relationships, expressed as the correlation coefficient > r value =, for the mean reflectances of six TM bands and soil morphology properties. The correlations were determined for the A and B horizons, and all 30 samples including one C horizon sample. The significance of each correlation is noted in the table for $P \leq 0.05$ and $P \leq 0.01$, with one and two asterisks, respectively.

Table 4—Correlations between Landsat Thematic Mapper wavelengths and soil morphology properties for the A, B, and all horizons combined.

	Blue (0.485)	Green (0.560)	Red (0.660)	NIR (0.830)	MIR (1.650)	MIR (2.180)
A horizons (n = 16). P £ 0.05[a] (r > 0.5) and P £ 0.01[b] (r > 0.62)						
Redness rating	–0.50[a]	–0.29	0.02	–0.01	–0.35	–0.36
Percent organic carbon	–0.26	–0.30	–0.32	–0.32	–0.36	–0.48
Percent calcium carbonate	0.76[b]	0.66[b]	0.48	0.43	0.45	0.57
Percent clay	–0.17	–0.12	–0.05	–0.14	–0.52[a]	–0.47
Percent sand	0.0	–0.12	–0.26	–0.19	0.35	0.30
Hue	0.43	0.21	–0.10	–0.06	0.35	0.35
Value	0.93[b]	0.99[b]	0.95[b]	0.94[b]	0.69[b]	0.75[b]
Chroma	0.02	0.27	0.56[a]	0.54[a]	0.09	0.08
Effervescence	0.73[b]	0.63[b]	0.46	0.42	0.47	0.57[a]
B Horizons (n = 13). P £ 0.05[a] (r > 0.55) and P £ 0.01[b] (r > 0.68)						
Redness rating	–0.70[b]	–0.69[b]	–0.53	–0.58[a]	–0.46	–0.69[b]
Percent organic carbon	–0.14	–0.20	–0.26	–0.30	–0.23	–0.28
Percent calcium carbonate	0.92[b]	0.90[b]	0.89[b]	0.87[b]	0.83[b]	0.84[b]
Percent clay	–0.68[b]	–0.70[b]	–0.59[a]	–0.63[a]	–0.54	–0.73[b]
Percent sand	0.65[a]	0.67[a]	0.57[a]	0.63[a]	0.55[a]	0.71[b]
Hue	0.75[b]	0.74[b]	0.59[a]	0.63[a]	0.53	0.74[b]
Value	0.97[b]	0.98[b]	0.95[b]	0.96[b]	0.88[b]	0.95[b]
Chroma	–0.70[b]	–0.66[a]	–0.47	–0.49	–0.39	–0.62[a]
Effervescence	0.93[b]	0.91[b]	0.89[b]	0.87[b]	0.85[b]	0.88[b]
All Horizons (n = 30). P £ 0.05[a] (r > 0.36) and P £ 0.01[b] (r > 0.46)						
Redness rating	–0.67[b]	–0.62[b]	–0.38[a]	–0.41[a]	–0.57[b]	–0.72[b]
Percent organic carbon	–0.13	–0.17	–0.22	–0.24	–0.15	–0.16
Percent calcium carbonate	0.79[b]	0.73[b]	0.64[b]	0.63[b]	0.57[b]	0.56[b]
Percent clay	–0.57[b]	–0.57[b]	–0.43[a]	–0.46[b]	–0.66[b]	–0.80[b]
Percent sand	0.52[b]	0.50[b]	0.32	0.37[a]	0.65[b]	0.75[b]
Hue	0.67[b]	0.60[b]	0.35	0.38[a]	0.61[b]	0.73[b]
Value	0.95[b]	0.98[b]	0.94[b]	0.94[b]	0.82[b]	0.86[b]
Chroma	–0.39[a]	–0.25	0.06	0.03	–0.28	–0.40[a]
Effervescence	0.79[b]	0.72[b]	0.62[b]	0.60[b]	0.59[b]	0.59[b]

[a] Correlation significance P £ 0.05.
[b] Correlation significance P £ 0.01.

For all three groups, there was a very significant correlation with Munsell value, and the r values ranged from 0.93 to 0.99 for the visible and NIR bands. For the middle NIR and the MIR bands the r values were lower, and they ranged from 0.69 to 0.95, and were lowest for the A horizons. For the A horizons, the percent $CaCO_3$ and effervescence had the next strongest correlations to reflectance in the blue and green bands, but they were less important in the other bands. Munsell chroma was significantly correlated in the red and NIR bands.

There were many significant correlations identified for the B horizons and for all 30 samples. Munsell value, percent $CaCO_3$, and effervescence were again most strongly correlated, but other soil morphology properties like Munsell hue and chroma, redness rating, and percent clay and sand were also significantly correlated. The only soil morphology property that was not correlated to reflectance was percent organic carbon. Organic carbon is a very important factor in other soils, but the low percent of organic carbon in SRER soils showed that it did not significantly affect reflectance.

Post reported that soil albedo in the 0.3 to 2.8 mm can be computed using the Munsell color value as follows: Soil Albedo = 0.069 (color value) – 0.114. Using this equation the albedos of SRER soils (A horizon) would range from 0.155 for the Combate (9) to 0.307 for the Agustin, and are presented in table 3.

Summary

The range of spectral characteristics of the SRER soils were presented, and these data will be useful as researchers complete remote sensing projects on the SRER. The geomorphology map compiled from the basic soils and ecological site map helps us to better understand the soil-forming factors responsible for the formation of the SRER soils. What soil morphology characteristics determine the reflectance characteristics of SRER soils have been identified, and the Munsell color value component is the most important, particularly in the 0.4 to 1.0 mm wavelengths. The range of soil properties for the A and B horizons have been measured, and these data will be helpful in understanding the biophysical conditions that exist on the SRER.

References

Baumgardner, M. F.; Silva, L. F.; Biehl, L. L.; Stoner, E. R. 1985. Reflectance properties of soils. Advance Agronomy. 38: 1–44.

Bowers, S. A.; Hanks, R. J. 1965. Reflection of radiant energy from soils. Soil Science. 100: 130–138.

Cipra, J.; Franzmeier, D. P.; Bauer, M. E.; Boyd, R. K. 1980. Comparison of multispectral measurements from some nonvegetated soils using Landsat digital data and a spectroradiometer. Soil Science Society of America Journal. 44: 80–84.

Condit, H. R. 1970. The spectral reflectance of American soils. Photogrammetric Engineering. 36: 955–966.

DaCosta, L. M. 1979. Surface soil color and reflectance as related to physico-chemical and mineralogical soil properties. Columbia: University of Missouri. Dissertation Abstract 80-24350.

Ely, L. L.; Baker, V. R. 1985. Geomorphic surfaces in the Tucson Basin, Arizona. Field guidebook for workshop on global mega-geomorphology, January 1985. University of Arizona, Deptartment of Geosciences.

Escadafal, R.; Girard, M. C.; Courault, D. 1988. Modeling the relationship between Munsell soil color and soil spectral properties. International Agrophysics. 4(3): 249–261.

Escadafal, R.; Girard, M. C.; Courault, D. 1989. Munsell soil color and soil reflectance in the visible spectral bands of Landsat MSS and TM data. Remote Sensing of Environment. 27: 37–46.

Gomez, K. A.; Gomez, A. A. 1984. Statistical procedures for agricultural research. 2d ed. Wiley-Interscience Publications. 680 p.

Horvath, E. H.; Post, D. F.; Kelsey, J. B. 1984. Relationships among Landsat digital data and the properties of Arizona rangelands. Soil Science Society of America Journal. 48: 1331–1334.

Huete, A. R.; Escadafal, R. 1991. Assessment of biophysical soil properties through spectral decomposition techniques. Remote Sensing of Environment. 35: 149–159.

Jenny, Hans. 1941. Factors of soil formation. New York: McGraw-Hill. 281 p.

Jenny, Hans. 1980. The soil resource-origin and behavior. New York: Springer-Verlag. 270 p.

McAuliffe, J. R. 1995a. Landscape evolution, soil formation, and Arizona desert grass lands. In: McClaran, M. P.; Van Devender, T. R., eds. The desert grassland. Tucson: University of Arizona Press.

McAuliffe, J. R. 1995b. Landscape evolution, soil formation, and ecological patterns and processes in Sonoran Desert bajadas. Ecological Monographs. 64: 111–148.

Peterson, F. F. 1981. Land forms of the Basin and Range Province defined for soil survey. Tech. Bull. 28. Reno: University of Nevada, Nevada Agriculture Experiment Station.

Post, D. F.; Levine, S. J.; Bryant, R. B.; Mays, M. D.; Batchily, A. K.; Escadafal, R.; Huete, A. R. 1993. Correlations between field and laboratory measurements of soil color. In: Bigham, J. M.; Ciolkosz, E. J., eds. Soil color. Spec. Publ. 31. Madison, WI: SSSA: 35–49.

Post, D. F.; Lucas, W. M.; White, S. A.; Ehasz, M. J.; Batchily, A. K. 1994. Relations between soil color and landsat reflectance on semiarid rangelands. Soil Science Society of America Journal. 58: 1809–1816.

Post, D. F.; Fimbres, A.; Mathias, A. D.; Sano, E. E.; Accioly, L.; Batchily, A. K.; Ferreira, L. G. 2000. Predicting soil albedo from soil color and spectral reflectance data. Soil Science Society of America Journal. 64: 1027–1034.

Shields, J. A.; Paul, E. A.; St. Arnaud, R. J.; Head, W. K. 1968. Spectrophotometric measurement of soil color and its relationship to moisture and organic matter. Canada Journal of Soil Science. 48: 271–280.

Soil Survey Division Staff. 1993. Soil survey manual. USDA-SCS Agric. Handb. 18. Washington, DC: U.S. Government Printing Office.

Stoner, E. R. 1979. Atlas of soil reflectance properties. Result Bull. 962. West Lafayette, IN: Purdue University, Agriculture Experiment Station.

Stoner, E. R.; Baumgardner, M. F. 1981. Characteristic variations in reflectance of surface soils. Soil Science Society of America Journal. 45: 1161–1165.

Thien, S. J. 1978. A flow diagram for teaching texture-by-field analysis. Journal of Agronomic Ed: 54–55.

Torrent, J.; Schwertmann, U.; Schulze, D. G. 1980. Iron oxide mineralogy of some soils of two river terrace sequences in Spain. Geoderma. 23: 191–208.

Weismiller, R. A.; Kaminsky, S. A. . 1978. Application of remote sensing technology to soil survey/research. Journal of Soil and Water Conservation. 33: 287–289.

Westin, F. C.; Lemme, G. D. 1978. Landsat spectral signatures: studies with soil associations and vegetation. Photogrammetric Engineering and Remote Sensing. 44: 315–325.