AgRISTARS

"Made available under NASA sponsorship
in the interest of early and wide dis-
ssemination of Earth Resources Survey
Program information and without liability
for any use made thereof."

Supporting Research

Technical Report

Characteristic Variations in
Reflectance of Surface Soils

by E.R. Stoner and M.F. Baumgardner

Purdue University
Laboratory for Applications of Remote Sensing
West Lafayette, Indiana 47907

E82-10396
SR-P2-04301
NAS9-15466

A Joint Program for
Agriculture and
Resources Inventory
Surveys Through
Aerospace
Remote Sensing
May 1982.

https://ntrs.nasa.gov/search.jsp?R=19820024942 2018-11-03T01:19:31+00:00Z
CHARACTERISTIC VARIATIONS IN REFLECTANCE
OF SURFACE SOILS

E.R. Stoner and M.F. Baumgardner

Purdue University
Laboratory for Applications of Remote Sensing
West Lafayette, IN 47907

May 1982
Surface soil samples from a wide range of naturally occurring soils were obtained for the purpose of studying the characteristic variations in soil reflectance as these variations relate to other soil properties and soil classification. A total of 485 soil samples from the U.S. and Brazil representing 30 suborders of the 10 orders of Soil Taxonomy was examined. Spectral bidirectional reflectance factor was measured on uniformly moist soils over the 0.52 to 2.32 um wavelength range with a spectroradiometer adapted for indoor use.

Five distinct soil spectral reflectance curve forms were identified according to curve shape, the presence or absence of absorption bands, and the predominance of soil organic matter and iron oxide composition. These curve forms were further characterized according to genetically homogeneous soil properties in a manner similar to the subdivisions at the suborder level of Soil Taxonomy. Results indicate that spectroradiometric measurements of soil spectral bidirectional reflectance factor can be used to characterize soil reflectance in terms that are meaningful to soil classification, genesis, and survey.
Characteristic Variations in Reflectance of Surface Soils

E. R. STONER AND M. F. BAUMGARDNER

ABSTRACT

Surface soil samples from a wide range of naturally occurring soils were obtained for the purpose of studying the characteristic variations in soil reflectance; these variations relate to other soil properties and soil classification. A total of 485 soil samples from the U.S. and Brazil representing 30 suborders of the 10 orders of Soil Taxonomy was examined. Spectral bidirectional reflectance factor was measured on uniformly moist soils over the 0.52 to 2.32 µm wavelength range with a spectroradiometer adapted for indoor use.

Five distinct soil spectral reflectance curve forms were identified according to curve shape, the presence or absence of absorption bands, and the predominance of soil organic matter and iron oxide composition. These curve forms were further characterized according to genetically homogeneous soil properties in a manner similar to the subdivisions at the suborder level of Soil Taxonomy. Results indicate that spectroradiometric measurements of soil spectral bidirectional reflectance factor can be used to characterize soil reflectance in terms that are meaningful to soil classification, genesis, and survey.

Additional Index Words: remote sensing, spectroradiometry, bidirectional reflectance factor, soil taxonomy.


MODERN COMPREHENSIVE soil classification (Soil Survey Staff, 1975) utilizes visible soil reflectance, or color, as a differentiating characteristic for many classes as an essential part of the definition of certain diagnostic horizons. Unlike other differentiating characteristics such as particle size distribution or base saturation, which are verifiable by established laboratory procedures, soil reflectance is determined solely by visual comparison with standard color charts. Quantitative measurements of visible as well as infrared reflectance spectra of soils are possible using spectroradiometric techniques developed to simulate the geometry of remotely sensed data (Stoner et al., 1980b).

Soil reflectance is a cumulative property which derives from inherent spectral behavior of the heterogeneous combination of mineral, organic, and clay matter that comprises mineral soils. Numerous studies have described the relative contributions of soil parameters such as organic matter, soil moisture, particle size distribution, soil iron oxide content, soil mineralogy, and parent material to reflectance of naturally occurring soils (Angstrom, 1925; Baumgardner et al., 1970; Bowers and Hanks, 1965; Bowers and Smith, 1972; Da Costa, 1979; Hoffer and Johannsen, 1969; Karmanov, 1970 Lindberg and Snyder, 1972; Mathews et al., 1973; Montgomery, 1976; Myers and Allen, 1968; Obukhov and Orlov, 1964; Peterson et al., 1979; Plane, 1970; Schreiber, 1977; Shields et al., 1968; Stoner, 1979).

Extensive literature exists describing the characteristic variations in visible and near-infrared reflectance of minerals and rocks (Hunt, 1977; Hunt and Salisbury, 1970, 1971, 1976a, 1976b; Hunt et al., 1971a, 1971b, 1973a, 1973b, 1973c, 1974a). Hunt's studies reveal the intrinsic spectral features that appear in the form of bands and slopes in the bidirectional reflectance spectra of minerals as caused by a variety of electronic and vibrational processes. Reflectance measurements of 160 soil samples from 36 states are the basis for an investigation by Condit (1970, 1972) that classifies all soil spectra into three general types with respect to their curve shape. However, Condit does not discuss the three general soil spectral curve types in relation to soil characteristics or soil classification. Cipra et al. (1971) conducted field spectroradiometric studies and described the properties and classification of seven soil series in terms of Condit's spectral curve types.

Five soil reflectance curve forms are described here from examination of 485 bidirectional reflectance spectra of surface soils from 39 states and Brazil. Characteristic variations in the reflectance of these laboratory measured soils are discussed in terms of reflectance-related soil properties and soil taxonomy.

MATERIALS AND METHODS

Surface soil samples representing 246 soil series were collected from 481 sites within 39 of the 48 contiguous states of the U.S. and 4 sites within the state of Paraná, Brazil (Fasolo, 1978). 2For 239 U.S. soil series, duplicate samples were obtained: one from a site near the type location for the current official series, and another at a site from 1 to 30 km distant from the first site in a different mapping delineation of the same series. Soil series were selected at random within climatic strata from among a list of more than 1,300 benchmark U.S. soil series of large geographic extent and widely applicable characteristics (Soil Survey Staff, 1972). Climatic strata followed the soil temperature regimes defined in Soil Taxonomy (Soil Survey Staff, 1975) and moisture zones based on the Thornthwaite (1948) moisture stress index. The resulting collection of soil samples covers a well-distributed pattern encompassing 17 continental U.S. climatic zones including soils from 28 suborders of 9 soil taxonomic orders.

The standard sieved soil fraction < 2 mm in diameter was used for laboratory determination of chemical, physical, and spectral properties. Organic carbon was determined by the modified Walkley-Black procedure, while free iron was measured by the Na citrate-bicarbonate-dithionite extraction procedure (Franzmeier et al., 1977). Reflectance measurements were made on uniformly moist soils equilibrated for 24 hours at one-tenth bar moisture tension on asbestos tension tables (Stoner et al., 1980b). This procedure expedited the establishment of a standardized moisture condition for a very large number of samples (over 500) held in large (10 cm in diameter) sample holders, while avoiding the fluctuating, uncontrolled environmental conditions of air-dry soil samples. Bowers and Hanks (1965) and Peterson et al. (1979) confirmed the predictable increase in reflectance of soil samples on dry.
RESULTS AND DISCUSSION

Examination of soil spectra from 485 individual soil samples revealed the existence of five distinct soil reflectance curve forms identified by curve shape and the presence or absence of absorption bands. In addition, these five soil spectral reflectance curve forms could be distinguished as having in common certain differentiation characteristics pertaining mainly to the organic matter content and iron oxide content of these soils.

Reflectance spectra representative of the five curve forms are illustrated for five mineral soil samples (Fig 1). Characteristics of these specific surface soils are detailed for comparison of reflectance-related soil properties (Table 1). The first three curve forms are identical to those described by Condit (1970, 1972) as Types 1, 2, and 3 but here are renamed to express the distinguishing soil characteristics. The organic-dominated form (Condit Type 1) exhibits a low overall reflectance with a characteristic concave curve shape from 0.5 to 1.3 μm. Strong water absorption bands are present at 1.45 and 1.95 μm in this and most other curve forms. The broadness of these bands indicates the presence of water molecules in relatively unordered sites, probably as water films on soil particle surfaces (Angstrom, 1925; Hunt and Salisbury, 1970).

The minimally altered form (Condit Type 2) is characterized by overall high reflectance and a characteristic convex curve shape from 0.5 to 1.3 μm. In addition to the strong water absorption bands at 1.45 and 1.95 μm, weak water absorption bands may be present at 1.2 and 1.77 μm. These weak absorption bands correspond to the absorption bands observed in transmission spectra of relatively thick water films of the type that may be expected to fill the voids between fine sand grains (Lindberg and Snyder, 1972).

The Type 3 curve form of Condit is identified here as the iron-affected form, being distinguished by a slight ferric iron absorption band at 0.7 μm together with the stronger 0.9 μm iron absorption band (Hunt et al., 1971a). The 2.2 μm hydroxyl absorption band can be seen in this specific sample, but does not exhibit a consistent relationship with any particular curve form or soil property.

A fourth curve type, labeled the organic-affected form, typically has a higher overall reflectance than the organic-dominated form. It exhibits a concave shape.
Table 2 — Differentiating characteristics of 5 soil spectral reflectance curve forms.

<table>
<thead>
<tr>
<th>Differentiating characteristics</th>
<th>Organic-dominated</th>
<th>Minimally altered</th>
<th>Iron-affected</th>
<th>Organic-dominated</th>
<th>Iron-dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetational effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral soils†</td>
<td>High organic matter content</td>
<td>Low organic matter content</td>
<td>Low organic matter content</td>
<td>High organic matter content</td>
<td>Varied organic matter content</td>
</tr>
<tr>
<td>Organic soils</td>
<td>Fully decomposed organic fibers</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Iron oxide content‡</td>
<td>Low</td>
<td>Fine to moderately fine textured soils</td>
<td>Medium</td>
<td>Medium to coarse textured soils</td>
<td>Fine-textured</td>
</tr>
<tr>
<td>Texture</td>
<td>Poor to good Commonly montmorillonitic</td>
<td>Good Mixed</td>
<td>Poor to good Good</td>
<td>Commonly kaolinitic</td>
<td></td>
</tr>
<tr>
<td>Natural drainage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineralogy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Low organic matter content = 0 to 2%, high = 2 - 5%.
‡ Low iron oxide content = 0 to 1%, medium = 1 to 4%, high = 4 - 10%.
§ Soils with low iron oxide contents occurring as coatings on coarse-textured soil particles exhibit the same curve form.

Fig. 2 — Representative reflectance spectra for organic soils with: (a) minimally (fibric), (b) partially (hemic), and (c) fully (sapric) decomposed organic fibers (Table 3).

from 0.5 to 0.75 μm with a convex shape from 0.75 to 1.3 μm.

The fifth curve type, the iron-dominated form, is unique in that reflectance actually decreases with increasing wavelength beyond 0.75 μm. In some soils such as the one shown here, absorption in the middle infrared wavelengths is so strong that the 1.45 and 1.95 μm water absorption bands are almost obliterated.

Soil parameters characteristic for specific reflectance properties serve to differentiate soil spectral reflectance curve forms (Table 2). Mineral soils with the organic-dominated curve form have high organic matter contents (> 2%) well dispersed as coatings on the fine to moderately fine soil grains. In the case of organic soils, the decomposition state of plant remains determines the reflectance curve form. Fully decomposed organic fibers reflect in the manner of the organic-dominated form, while well-preserved fibers exhibit the higher reflecting organic-affected form. The high reflectance of fibric soil materials in the infrared region resembles the infrared reflectance of senesced leaves (Gauman et al., 1975). This increased infrared reflectance has been attributed to tissue morphology in which an increased number of air voids provide more air-cell interfaces for enhanced reflection. Reflectance spectra for three organic soil samples illustrate these differences for fibric, hemic, and sapric soil materials (Fig. 2, Table 3).

The organic-dominated curve form is often associated with montmorillonitic clay mineralogy, while soils with the iron-dominated curve form have been seen to exhibit kaolinitic mineralogy. Inherent spectral properties of clay minerals are not responsible for the character of soil reflectance curves (Lindberg and Snyder, 1972), but mineralogy is interrelated with organic matter content, iron oxide content, and texture which directly affect soil reflectance.

Soils with the minimally altered curve form are characterized by low organic matter content, low iron oxide content, and good drainage. Texture and mineralogy are seen to vary for these soils.

Medium iron oxide contents (from 1 to 4%) distinguish soils with the iron-affected curve form from those with the minimally altered form. Soils with the iron-dominated curve form have high iron oxide contents (> 4%) which appear capable of masking even the effects of high organic matter contents.

Mineral soils with the organic-affected curve form differ from those with the organic-dominated form principally because of coarser soil textures. Coarse soil grains uncoated by organic material were evident from the appearance of samples of these soils. Lower moisture contents of the coarser textured soils would...
Table 4—Identity according to reflectance curve forms for 485 surface soil samples representing 30 suborders of the 10 orders of Soil Taxonomy (Soil Survey Staff, 1975).  

<table>
<thead>
<tr>
<th>Reflectance curve form</th>
<th>Organic-dominated</th>
<th>Minimally altered</th>
<th>Iron-affected</th>
<th>Organic-dominated</th>
<th>Iron-affected</th>
<th>Total samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquaf</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Boraf</td>
<td>3</td>
<td>9</td>
<td>21</td>
<td>5</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>Udalf</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>Alfisol</td>
<td>6</td>
<td>15</td>
<td>35</td>
<td>21</td>
<td>4</td>
<td>81</td>
</tr>
<tr>
<td>Ardig</td>
<td>27</td>
<td>3</td>
<td>2</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthol</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eriodol</td>
<td>35</td>
<td>2</td>
<td>3</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquent</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flurent</td>
<td>12</td>
<td>3</td>
<td>1</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthent</td>
<td>8</td>
<td>2</td>
<td>8</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudent</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entisol</td>
<td>13</td>
<td>37</td>
<td>7</td>
<td>21</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>Hemiset</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seprast</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Histosol</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aqupekt</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ochrept</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Umbrept</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Inceptisol</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arbol</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquoll</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boroll</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udoll</td>
<td>14</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ustoll</td>
<td>34</td>
<td>8</td>
<td>2</td>
<td>20</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Xeroll</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mollisol</td>
<td>95</td>
<td>16</td>
<td>2</td>
<td>35</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>Humrox</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthox</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxisol†</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquox</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthox</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>14</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Eriodol</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Aqucult</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humult</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udtl</td>
<td>2</td>
<td>10</td>
<td>20</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultisol</td>
<td>2</td>
<td>10</td>
<td>20</td>
<td>8</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>Udrt</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ustert</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertisol</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Grand total 485

† From Brazil.

also explain the higher reflectance of the organic-affected curve form.

Soil spectral reflectance curve forms were identified for all 485 surface soil samples and were tabulated according to soil suborder (Table 4). All Vertisol soil samples and a majority of Mollisol soil samples exhibited the organic-dominated curve form. Aquic moisture regime soils of the Alfisol, Entisol, Inceptisol, Mollisol, Spodosol, and Ultisol orders show a predominance of organic-dominated and organic-affected curve forms. A majority of Aridolls and nonaquetic Entisols have a minimally altered curve form. Among Alfisols and Ultisols with a humid moisture regime a majority exhibit the iron-affected curve form. Although the iron-dominated curve form is typical of Oxisol soil samples, two Boralfs and two Udalfs also revealed this curve form.

The differentiating characteristics used to describe the five soil spectral reflectance curve forms are similar in nature to those used to define the genetically homogeneous subdivisions at the suborder level of Soil Taxonomy (Buol et al., 1973). These subdivisions are based on the presence or absence of properties associated with wetness, soil moisture regimes, parent material, and vegetational effects, including organic fiber decomposition stage in Histosols. Although the soil samples in this study represent only the soil surface as it might be viewed by remote sensors, the characteristic variations in the reflectance of these soils can be interpreted in terms of soil properties diagnostic for the higher categories in Soil Taxonomy.

SUMMARY

The diversity of soil reflectance among a wide range of naturally occurring surface soils has been represented by five characteristic soil spectral reflectance curve forms. These curve forms are identified by curve shape and the presence or absence of absorption bands. Soil properties associated with each curve characterize soil reflectance in a manner which facilitates comparison with higher categories of Soil Taxonomy. Spectroradiometry provides both comparison with remotely sensed data from nonvegetated soils and a laboratory tool for quantitative characterization of visible as well as infrared soil reflectance. Controlled laboratory reflectance measurements serve to define the extent to which intrinsic spectral information is available from soils as a consequence of their composition. Characterization of soil reflectance has important implications for soil genesis, classification, and survey.

ACKNOWLEDGMENTS

The authors acknowledge with gratitude the contributions of the following persons: soil scientists of the Soil Conservation Service who provided samples from 39 states; B. F. Robinson and L. L. Blehl for assistance with the spectroradiometric measurements; L. M. Nash for laboratory analysis; and Drs. D. P. Franzmeier, J. B. Peterson, L. F. Silva, and R. A. Weismiller for project support.

LITERATURE CITED


ORIGINAL PAGE IS
OF POOR QUALITY