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FINAL REPORT

DEVELOPMENT OF REMOTE SENSING TECHNIQUES CAPABLE OF DELINEATING SOILS AS AN AID TO SOIL SURVEY

ACARS

Alabama Center for Application of Remote Sensing
Alabama A&M University
Huntsville, Alabama

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Development of Remote Sensing Techniques Capable of Delineating Soil as an Aid to Soil Survey

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Abstract

Eighty-one benchmark soils from Alabama, Georgia, Florida, Tennessee, and Mississippi were evaluated to determine the feasibility of spectrally differentiating among soil categories. Relationships among spectral properties that occur between soils and within soils were examined, using discriminant analysis. Soil spectral data were obtained from air-dried samples using an Exotech Model 20C field spectroradiometer (0.37 to 2.36 μm). Differentiating among the orders, suborders, great groups, and subgroups using reflectance spectra achieved varying percentages of accuracy. Six distinct reflectance curve forms were developed from the air-dried samples based on the shape and presence or absence of adsorption bands. Iron oxide and organic matter content were the dominant soil parameters affecting the spectral characteristics for differentiating among and between these soils. The reflectance response of Alfisols, Inceptisols, and Entisols is predominantly influenced by iron oxide. These soils have a concave character in the 0.5 - 0.8 μ m region and a higher reflectance throughout the 0.5 - 1.8 μ m region. The Ultisols and Mollisols are predominately affected by organic matter content. The reflectance response is lower and they have a concave character in the 0.5 - 0.8 μ m region. The Spodosols show evidence of organic matter influence in the 0.5 - 0.8 μ m region and the characteristic water adsorption bands are almost indistinguishable in these soils.

INTRODUCTION

The general objective of this study was to develop time-saving and cost-effective remote sensing techniques capable of delineating soils in a manner which would serve to expedite the preparation of soil surveys. This general objective was to be addressed through four specific objectives, which were as follows:

1. Identify soil parameters of importance in soil mapping unit delineation which can be correlated with spectral soil properties.
2. Quantify the extent to which field conditions (surface roughness, vegetation cover, moisture difference, etc.) alter the spectral response of surface soils.
3. Determine the effect of wave band selection, wave bandwidth, and wave band on the correlation of spectral reflectance with soil parameters.
4. Provide a body of knowledge and interpretive skills which will render remote multispectral sensing a more valuable tool for soil survey.

These objectives were to be accomplished via a three-phase approach: Phase 1-Laboratory study: Phase II-Field Study: and Phase III-Correlation Studies with Satellite Imagery. However, as a result of budget cuts and a change in the research objectives of the funding agency this project was terminated after the first year of funding and phases II and III could not be completed.

This report is a summary of the work that was completed and discussed in the annual report (ACARS CONTRACT REPORT #013186) and in a manuscript entitled "Assessment of spectral characteristics for differentiating among soil categories in the southeastern United States. The manuscript has been submitted to the Soil Science Society of American Journal and is currently under review.

MATERIALS AND METHODS

Eight-one soil samples, representing the surface horizon of eighty-one benchmark soils from the southeastern United States were utilized in this study (Soil Survey Staff, 1972). The soils were randomly selected from the pool of benchmark soils of the southeastern U. S., which resulted in samples from six soil orders and several suborders, great groups, and subgroups (Table 1). The standard sieved soil fraction ($\leq$ 2mm) was used for laboratory determination of the spectral properties. Reflectance measurements were made on air-dried samples held in large (10-cm diam) sample holders. Spectral bidirectional reflectance factors (Nicodemus et al., 1977) were measured with an Exotech Model 20C spectroradiometer (Leamer et al., 1973) adapted for indoor use with a reflectometer equipped with an artificial illumination source, transfer optics, and sample stage. Spectral readings were taken in 0.01 increments over the 0.45 to 2.36 m wavelength range. A 1,000 watt tungsten-iodide coiled filament lamp and paraboloidal mirror provided highly collimated incident irradiation similar to that of solar illumination. Pressed barium sulfate was used as a calibration standard to account for fluctuations in intensity of the illumination source (Robinson and Biehl, 1979). The spectral data were separated into seventeen wavelength intervals or band widths, which coincided with the band widths of the Thematic mapper (TM) and SPOT Satellites.

Table 1. Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Decatur	Alabama	Clayey, Kaolinitic, Thermic Rhodic Paleudult
Dothan	Alabama	Fine-loamy, Siliceous, Thermic Plinthic Paleudult
Hartsells	Alabama	Fine-loamy, Siliceous, Thermic Typic Hapludult
Red Bay	Alabama	Fine-loamy, Siliceous, Thermic Rhodic Paleudult
Sumter	Alabama	Fine-silty, Carbonatic, Thermic Rendollic Eutrochrept
Troup	Alabama	Loamy, Siliceous, Thermic Grossarenic Paleudult
Vaiden	Alabama	Very-fine, Montmorillontic, Thermic Vertic Hapludalf
Blanton	Florida	Loamy, Siliceous, Thermic Grossarenic Paleudult
Gainesville	Florida	Hyperthermic, Coated Typic Paleudult
Lakeland	Florida	Thermic, Coated Typic Quartizipsamment
Leon	Florida	Sandy, Siliceous, Thermic Aeric Haplaquod
Lynchburg	Florida	Fine-loamy, Siliceous, Thermic Aeric Paleaquult
Norfolk	Florida	Fine-loamy, Siliceous, Thermic Typic Paleudult
Orangeburg	Florida	Fine-loamy, Siliceous, Thermic Typic Paleudult
Paola	Florida	Hyperthermic, Uncoated Spodic Quartizipsamment

Table 1. Continued Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Rains	Florida	Fine-loamy, Siliceous, Thermic Typic Paleaquult
Red Bay	Florida	Fine-loamy, Siliceous, Thermic Rhodic Paleudult
Tifton	Florida	Fine-loamy, Siliceous, Thermic Plinthic Paleudult
Americus	Georgia	Sandy, Siliceous, Thermic Rhodic Paleudult
Appling	Georgia	Clayey, Kaolinitic, Thermic Typic Hapludult
Bayboro	Georgia	Clayey, Mixed, Thermic, Umbric Paleaquult
Bladen	Georgia	Clayey, Mixed, Thermic Typic Albaquult
Cecil	Georgia	Clayey, Kaolinitic, Thermic Typic Hapludult
Eustis	Georgia	Sandy, Siliceous, Thermic Psammentic Paleudult
Faceville	Georgia	Clayey, Kaolinitic, Thermic Typic Paleudult
Gwinnett	Georgia	Clayey, Kaolinitic, Thermic Typic Rhodudult
Leefield	Georgia	Loamy, Siliceous, Thermic Arenic Plinthaquic Paleudult
Madison	Georgia	Clayey, Kaolinitic, Thermic Typic Hapludult
Ocilla	Georgia	Loamy, Siliceous, Thermic Aquic Arenic Paleudult
Pelham	Georgia	Loamy, Siliceous, Thermic Arenic Paleaquult

Table 1. Continued Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Georgeville	Georgia	Clayey, Kaolinitic Thermic Typic Hapludult
Bude	Mississippi	Fine-silty, Mixed, Thermic Glossaquic Fragiudalf
Falkner	Mississippi	Fine-silty, Siliceous, Thermic Aquic Paleudalf
Atwood	Mississippi	Fine-silty, Mixed, Thermic Typic Paleudalf
Sumter	Mississippi	Fine-silty, Carbonatic, Thermic Rendollic Eutrochrept
Vaiden	Mississippi	Very-fine, Montmorillonitic, Thermic Vertic Hapludalf
Savannah	Mississippi	Fine-loamy, Siliceous, Thermic Typic Fragiudult
Prentiss	Mississippi	Coarse-loamy, Siliceous, Thermic Glossic Fragiudult
Stough	Mississippi	Coarse-loamy, Siliceous, Thermic Fragiaquic Paleudult
Ora	Mississippi	Fine-loamy, Siliceous, Thermic Typic Fragiudult
Pheba	Mississippi	Coarse-silty, Siliceous, Thermic Glossaquic Fragiudult
Providence	Mississippi	Fine-sitly, Mixed, Thermic Typic Fragiudalf
Memphis	Mississippi	Fine-silty, Mixed, Thermic Typic Hapludalf
Grenada	Mississippi	Fine-silty, Mixed, Thermic Glossic Fragiudalf

Table 1. Continued Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Loring	Mississippi	Fine-silty, Mixed, Thermic Typic Fragiudalf
Alligator	Mississippi	Very-fine, Montmorillonitic, Acid, Thermic Vertic Haplaquept
Dundee	Mississippi	Fine-silty, Mixed, Thermic Aeric Ochraqualf
Dubbs	Mississippi	Fine-silty, Mixed, Thermic Typic Hapludalf
Alcoa	Tennessee	Clayey, Oxidic, Thermic Rhodic Paleudult
Armour	Tennessee	Fine-silty, Mixed, Thermic Ultic Hapludalf
Baxter	Tennessee	Fine, Mixed, Mesic Typic Paleudult
Bosket	Tennessee	Fine-loamy, Mixed, Thermic Mollic Hapludalf
Calloway	Tennessee	Fine-silty, Mixed, Thermic Glossaquic Fragiudalf
Collins	Tennessee	Coarse-silty, Mixed, Acid, Thermic Aquic Udifluvent
Cumberland	Tennessee	Fine, Mixed, Thermic Rhodic Paleudalf
Decatur	Tennessee	Clayey, Kaolinitic, Thermic Rhodic Paleudult
Dekoven	Tennessee	Fine-silty, Mixed, Thermic Fluvaquentic Haplaquoll
Dellrose	Tennessee	Fine-loamy, Mixed, Thermic Humic Hapludult
Dickson	Tennessee	Fine-loamy, Siliceous, Thermic Glossic Fragiudult

Table 1. Continued Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Dunmore	Tennessee	Clayey, Kaolinitic, Mesic Typic Paleudult
Forestdale	Tennessee	Fine, Montmorillonitic, Thermic Typic Ochraqualf
Fullerton	Tennessee	Clayey, Kaolinitic Thermic Typic Ochraqualf
Greendale	Tennessee	Fine-loamy, Siliceous, Mesic Fluventic Dystrochrept
Grenada	Tennessee	Fine-silty, Mixed, Thermic Glossic Fragiudalf
Guthrie	Tennessee	Fine-silty, Siliceous, Thermic Typic Fragiaquult
Henry	Tennessee	Coarse-silty, Mixed, Thermic Typic Fragiaqualf
Holston	Tennessee	Fine-loamy, Siliceous, Thermic Typic Paleudult
Huntington	Tennessee	Fine-silty, Mixed, Mesic Fluventic Hapludoll
Landisburg	Tennessee	Fine-loamy, Mixed, Mesic Typic Fragiudult
Lawerence	Tennessee	Fine-silty, Mixed, Mesic Aquic Fragiudalf
Leadvale	Tennessee	Fine-silty, Siliceous, Thermic Typic Fragiudult
Lexington	Tennessee	Fine-silty, Mixed, Thermic Typic Paleudalf
Minvale	Tennessee	Fine-loamy, Siliceous, Thermic Typic Paleudult
Pembroke	Tennessee	Fine-silty, Mixed, Mesic Mollic Paleudalf

Table 1. Continued Soil Series, State, and Classification of the Soils used in this study.

SOIL SERIES	STATE	CLASSIFICATION
Seqnoia	Tennessee	Clayey, Mixed, Mesic Typic Hapludult
Silerton	Tennessee	Fine-silty, Mixed, Thermic Typic Hapludult
Tunica	Tennessee	Clayey over loamy, Montmorillonitic, Nonacid, Thermic Vertic Haplaquept
Waynesboro	Tennessee	Clayey, Kaolinitic, Thermic Typic Paleudult
Bodine	Tennessee	Loamy-skeletal, Siliceous, Thermic Typic Paleudult
Allen	Tennessee	Fine-loamy, Siliceous, Thermic Typic Paleudult

The spectral data were organized in a databank and analyzed statistically using discriminant analyses (Ray, 1982). The discriminating variables (wavelength intervals or band widths) are used directly in the analysis or a select number of the variables are used as determined through a stepwise method. The soil samples of the Ultisols and Alfisols soil order were later divided into databanks containing suborders, great groups, and subgroups such that the discriminant functions could be applied to each category individually.

RESULTS AND DISCUSSION

Six distinct reflectance curve forms were produced from the air-dried samples, based on the shape and presence or absence of water and iron oxide absorption bands (Fig. 1). The curve forms are considered characteristic of the six soil orders used in this study. The sharpness or broadness of the water adsorption bands (1.4 μm and 1.9 μ m) is attributed to the presence or absence of hydoscopic moisture around the soil aggregates. The Aflisols, Inceptisols, and Entisols are primarily affected by the iron oxide content and are similar to the iron-affected and minimally altered curve forms of Stoner and Baumgardner (1981). The reflectance responses of the soils shows a convex character in the 0.5 - 0.8 μm region. They also have a higher response throughout the 0.5 - 1.8 μm region. The Mollisols and Ultisols are predominantly affected by organic matter content and are similar to the organic-dominated and organic-affected curve forms of Stoner and Baumgardner (1981). They have a concave character in the 0.5 - 0.8 μ m region. The Ultisols have considerably lower reflectance than the other orders throughout the 0.45 - 2.4 μm region. The Spodosols show evidence

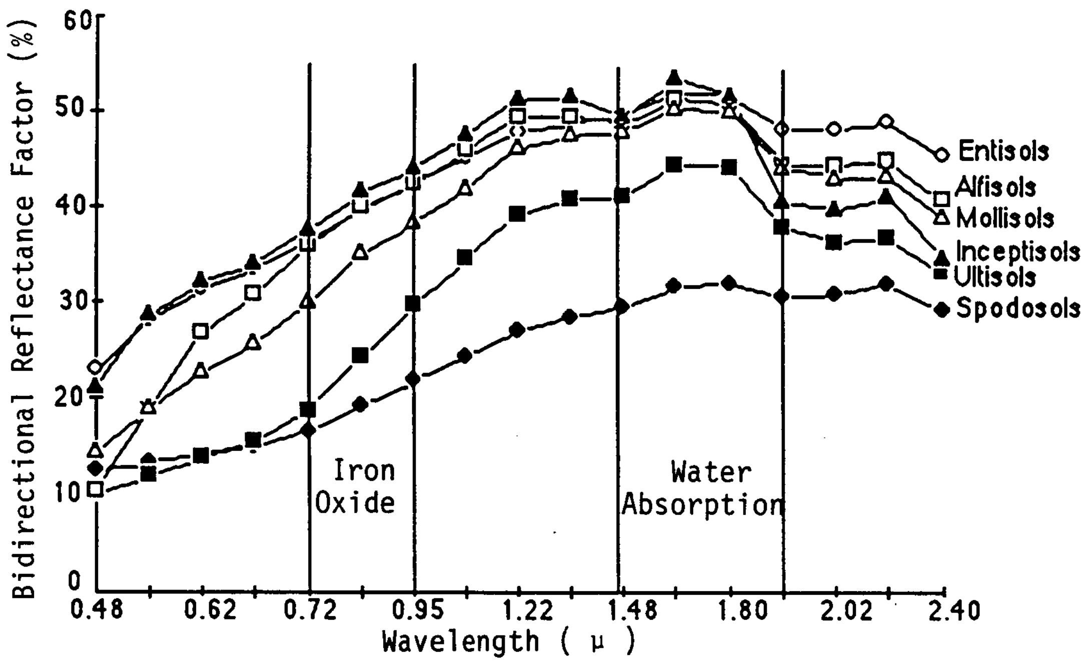

Figure 1. Representative reflectance spectra of six soil orders obtained from air-dried soil samples.

of organic matter influence in the 0.5 - 0.8 μm region and the water absorption bands of these soils are almost indistinguishable. These findings infer that spectral properties from air-dried soils are adequate for separating soils; however, quantitative data, not visual data is more useful in a classification scheme. The Mollisols and Spodosols were accurately differentiated (100%) based on their spectral properties, while the Inceptisols, Entisols, Alfisols, and Ultisols were differentiated at levels of 80%, 75%, 68%, and 55%, respectively (Fig. 2). The low percentage levels achieved with the Alfisols and Ultisols were attributed to the varying percentages of organic matter they contained.

The ability of the spectral properties to differentiate Alfisols and Ultisols increased when the samples were compared and analyzed separately from the other orders (Fig. 3). The Ultisols were differentiated at 98% which is an increase of 45%. The Alfisols increased 12% from 68% to 80%. The Ultisols and Alfisols were used to assess the ability of the spectral properties in differentiating among soil samples at lower categories of the taxonomic scheme. These two orders were used because they represented the largest group of samples within each category that could be used for statistical comparison.

The classification performance for the suborders is given in (Fig.4). The Aqualfs were accurately differentiated (100%), while the Udults, Udalfs, and Aquults were differentiated at levels of 88%, 71%, and 67%, respectively. The classification performance of the great groups is given in Figure 5. The Paleaquults and Ochraqualfs were correctly differentiated (100%). The Fragiudalfs, Hapludults, Paleudalfs, Hapludalfs, Paleudults, and Fragiudults were differentiated at levels of 84%, 69%, 59%, 49%, 44%, and 44%, respectively.

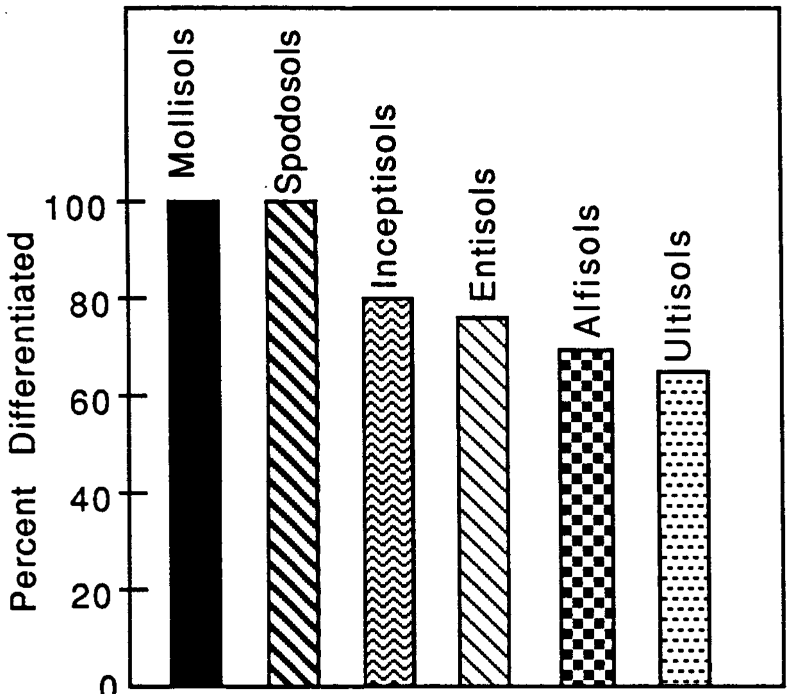

Figure 2. Percentage of samples accurately differentiated at the order level.

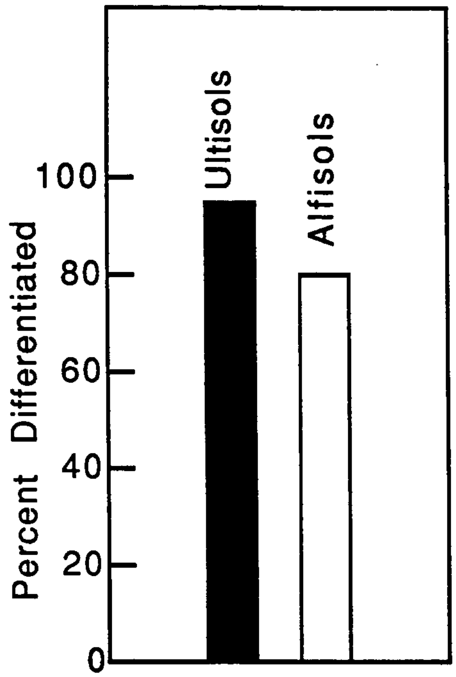

Figure 3. Percentage of Ultisols and Alfisols accurately differentiated.

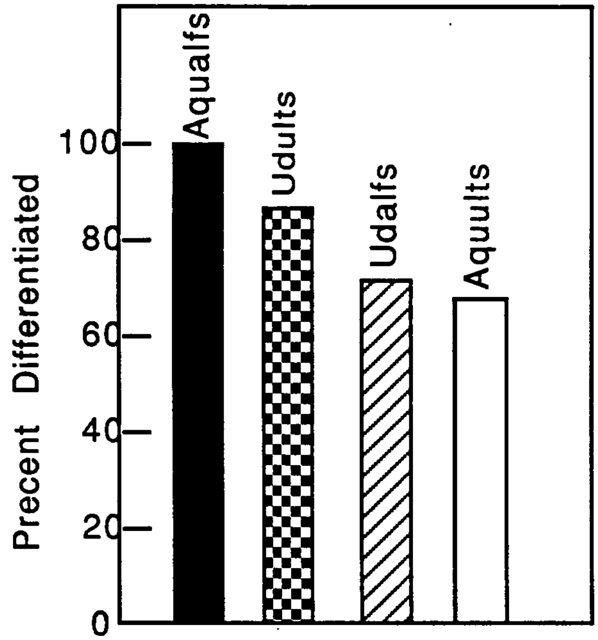

Figure 4. Percentage of samples accurately differentiated at the suborder level.

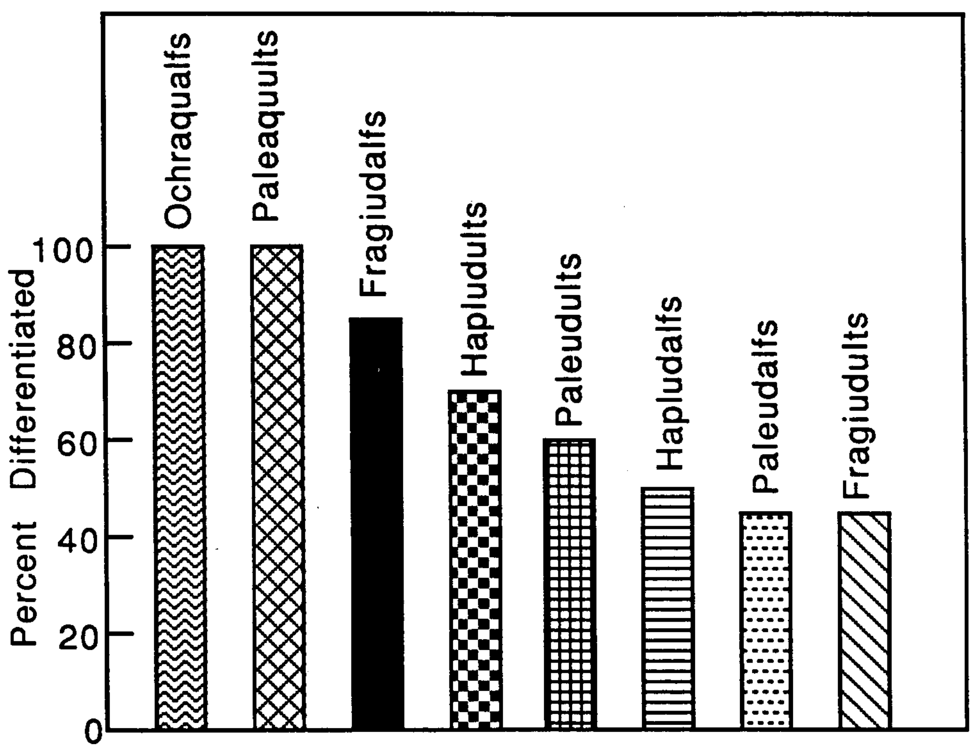

Figure 5. Percentage of samples accurately differentiated at the great group level.

The spectral properties were better in differentiating among the subgroups base on the number of samples that were correctly identified in comparison to the other categories (Fig. 6). The Grossarenic and Plinthic Paleudults, Typic Fragiudults, Typic and Vertic Hapludalfs, and Typic Paleudalfs were accurately differentiated (100%). The Rhodic Paleudults, Typic Paleudalfs, and Typic Hapludults were differentiated at levels of 85%, 69% and 59%, respectively.

Table 2 contains results of a stepwise discriminant analysis procedure for selecting the best wavelength bands for differentiating among the six soil orders and the suborders, great groups, and subgroups of the Alfisols and Ultisols. Soil orders are best differentiated using wavelength intervals 0.60 - 0.63 μm, 0.76 - 0.90 μm and 1.85 - 1.95 μm. The suborders of the Alfisols and Ultisols are best differentiated using wavelength intervals 0.60 -0.63 μm, 0.63 - 0.69 μm, and 0.76 - 0.90 μm. The great groups of the Alfisols and Ultisols are best differentiated using wavelength intervals 0.60 - 0.63 μm and 0.63 - 0.69 μm. The subgroups are best differentiated using wavelength intervals 0.45 - 0.52 μm, 0.63 - 0.69 μm, 0.69 - 0.76 μm, and 0.90 - 1.00 μm.

The increase in the accuracy, at lower levels of the classification scheme, by which the spectral properties were able to differentiate among the soil samples is a good indication of the potential use of spectral soil properties in identifying soils. This increase in accuracy maybe attributed to the number and/or section of the spectrum from which the spectral bands or wavelength intervals used in the algorithum were selected. Except for the great group category the number and/or wavelength interval changed at each level. The bandwidths are also narrower in most cases which may result in less interference from atmospheric variables, such as CO_2 and water.

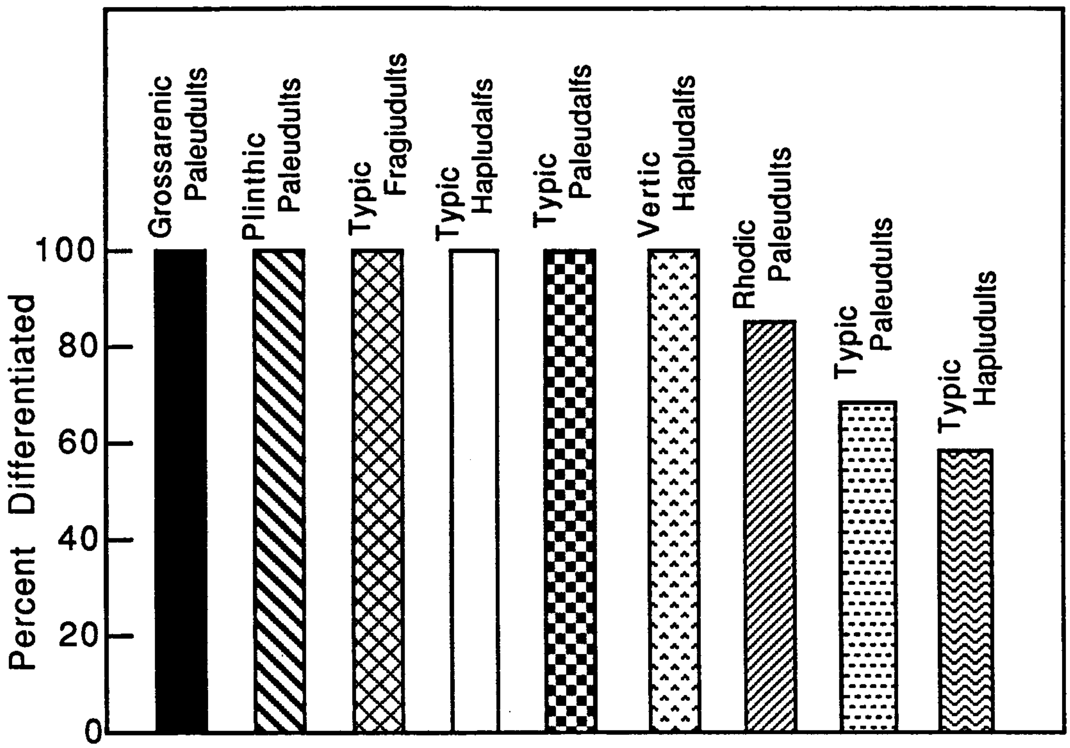

Figure 6. Percentage of samples accurately differentiated at the subgroup level.

Table 2. Results from stepwise discriminant analysis for selecting the best portion of the spectrum in differentiating among soils.

Taxonomic Category	Wavelength Intervals Entered (μm)	Wilks Lambda[1]	F	Prob F
Order	0.60-0.63 0.76-0.90 1.85-1.95	0.6798	5.167	0.0264
Suborder	0.60-0.63 0.63-0.69 0.76-0.90	0.5771	2.840	0.0315
Great Group	0.60-0.63 0.63-0.69	0.3764	1.475	0.1577
Subgroup	0.45-0.52 0.52-0.60 0.62-0.63 0.63-0.69	0.0057	2.054	0.0240

[1]Wilks Lambda is close to 0 if the groups are well separated.

SUMMARY

The spectral data and curve-forms presented here were generated from air-dried samples, whereas the findings presented by previous investigators were generated using uniformly moist soil samples. The most frequently occurring natural condition of the surface soil is closer to an air-dry state and not a uniformly moist state. Moisture tends to reduce reflectance in all wavelength bands and will result in a biassed indicator of true soil reflectance. The characteristic adsorption bands that are commonly used in distinguishing spectral curve-forms, water and iron oxide, are still recognizable using the air-dried samples.

The accuracy achieved utilizing soil reflectance spectra in differentiating among soil groups, as tested using discriminant analysis, proved that spectral properties of air-dried soils are useful for differentiating among soil orders, suborders, great groups, and subgroups; however, the accuracy achieved at each taxonomic level was variable. The increase in the accuracy at lower levels of the taxonomic scheme can be attributed to the increase in the number of bands entered into the algorithm and the section of the spectrum they represent. The greatest asset of using spectral properties in studing soils lie in the ability to acquire reliable information about the soil which may speed-up the classification process of an uncharted area. Knowing how dry conditions affect the spectral properties are important in supplying needed information to the classifier. This study has attempted to address that issue inorder to more fully utilize all of the tools available for classifying soils.

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LITERATURE CITED

Baumgardner, M. F., S. J. Kristof, C. J. Johannsen, and A. L. Zachary. 1970. Effect of organic matter of the multispectral properties of soils. Agricultural Experiment Station Journal. No. 3939. West Lafayette, Indiana.

Cipra, J. E., M. F. Baumgardner, E. R. Stoner, and R. B. MacDonald. 1971. Measuring radiance characteristics of soil with a field spectroradiometer. Soil Sci. Soc. Am. Proc. 35:1014-1017.

Condit, H. R. 1970. The spectral reflectance of American soils. Photogramm. Eng. 36:955-966.

Condit, H. R. 1972. Application of characteristic vector analysis of the spectral energy distribution of daylight and the spectral reflectance of American soils. Appl. Opt. 11:74-86.

Kaminsky, S. A., R. A. Weismiller, and B. O. Blair. 1979. An investigation of analysis techniques of LANDSAT MSS data designed to aid soil survey. Laboratory for Application of Remote Sensing Technical Report 080879.

Kristof, S. J. 1971. Preliminary Multispectral studies of soils. J. Soil Water Conserv. 16:15-18.

Kristof, S. J. and A. L. Zachary. 1971. Mapping soil types from multispectral scanner data. LARS Information Note 061471. Laboratory for Application of Remote Sensing. Purdue University. West Lafayette, Indiana.

Latz, K., R. A. Weismiller, G. E. Van Scoyoc, and M. F. Baumgarder. 1984. Characteristic variations in spectral reflectance of selected eroded alfisols. Soil Sci. Soc. Am. J. 48:1130-1134.

Leamer, R. W., V. I. Meyers, and L. F. Silva. 1973. A spectroradiometer for field use. Rev. Sci. Instrum. 44:611-614.

Montgomery, O. L., M. F. Baumgardner, and W. A. Weismiller. 1972. An investigation of the relationship between spectral reflectance and the chemical, physical and genetic characteristics of soils. LARS Information Note 082776.

Nicodemus. F. E., J. C. Richmond, J. J. Hsia, I. W. Ginsberg, and T. Limperis. 1977. Geometrical considerations and nomenclature for reflectance. National Bureau of Standards Monograph No. 160. U.S. Government Printing Office, Washington, D.C.

Ray, Alice A. 1982. SAS Users Guide: Statistics. SAS Institute Inc., SAS Circle, Box 8000, Cary, N.C.

Robinson, B. F. and L. L. Biehl. 1979. Calibration procedures for measurement of reflectance factor in remote sensing research. J. Soc. Photo-Optical Instr. Eng. 196:16-26.

Seevers, P. M., D. T. Lewis, and J. V. Drew. 1974. Application of ERTS-1 Imagery in Mapping and Managing Soil and Range Resources in the Sand Hills Region of Nebraska. p. 225-232. In S. C. Freden et al. (ed.) 3rd. Earth Resources Technology Satellite Symp., Vol. 1, NASA SP-351, Goddard Space Flight Center, Greenbelt., Md. 10-14 Dec. 1973. Scientific and Technical Information Office, NASA, Washington, D.C.

Seubert, C. E., M. F. Baumgardner, and R. A. Weismiller. 1979. Mapping and estimating aerial extent of severely eroded soils of selected sites in Northern Indiana. Institute of Electrical and Electronic Engineers 1979. pp. 234-239.

Soil Survey Staff. 1972. List of benchmark soils in the United States and Caribbean area. National Soils Handb. no. 19, SCS-USDA. U.S. Government Printing Office, Washington, DC.

Soil Survey Staff. 1975. Soil Taxonomy-A basic system of soil classification for making and interpreting soil survey. Handb. no. 436, SCS-USDA. U.S. Government Printing Office, Washington, DC.

Stoner, E. R. and M. F. Baumgardner, R. A. Weismilles, L. L. Biehl, and B. F. Robinson. 1980. Extension of laboratory measured soil spectra to field condition. Soil Sci. Soc. Am. J. 44:572-574.

Stoner, E. R. and M. F. Baumgardner. 1981. Characteristic variations in reflectance to surface soils. Soil Sci. Soc. Am. J. 45:1161-1165.

Weismiller, R. A., I. D. Persinger, and O. L. Montgomery. 1977. Soil inventory for digital analysis of satellite scanner and topographic data. Soil Sci. Soc. Am. J. 41:1166-1170.

Westin, F. C. and C. J. Frazee. 1976. Landsat data, its use in a soil survey program. Soil Sci. Soc. Am. J. 40:81-89.