VIEWING NOTES

Spectral Properties of Soils

by Marion F. Baumgardner

VIDEOTAPE SERIES

Introduction to Quantitative Analysis of Remote Sensing Data

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PREFACE

Remote sensing helps provide up-to-date information critical to the management of earth resources on a regional, national, and international level. As data collection and communication techniques are refined, as computational and analysis technologies evolve, and as sophisticated output devices become more economical, remote sensing will play an ever larger role as a source of information. The videotape you are about to see is one in a group of educational programs developed at Purdue University to keep scientists and administrators abreast of this rapidly evolving technology.

Purdue University has long been a leader in the development of remote sensing technology through the Laboratory for Applications of Remote Sensing (LARS). For over fifteen-years, the interdisciplinary staff, from the schools of agriculture, engineering, and science, has been responsible for much of the development in remote sensing and has gained world-wide recognition through these accomplishments. Today, activities at the Laboratory include both fundamental research and applications research, with additional major emphasis on training people in the use of quantitative remote sensing systems and developing educational materials to foster understanding of the technology.

Several key aspects of remote sensing technology are addressed in these videotapes, which make up the series Introduction to Quantitative Analysis of Remote Sensing Data. The tapes focus on such topics as scene radiation, data collection and preprocessing, and data analysis -- from both theoretical and applications perspectives -- and each from the perspective of a single scientist who is recognized as an expert in the field. In this way, when you view each tape, you are able to share personally in the insights and judgements offered on this increasingly important technology.

Videotape presentations in the series include the following titles:

The Role of Numerical Analysis in Forest Management by Roger M. Hoffer, professor of forestry.
The Role of Pattern Recognition in Remote Sensing by Philip H. Swain, associate professor of electrical engineering.
The Remote Sensing Information System by David A. Landgrebe, professor of electrical engineering and associate dean of engineering.
Correction and Enhancement of Digital Image Data by Paul E. Anuta, research engineer.
Spectral Properties of Soils by Marion F. Baumgardner, professor of Agronomy.

Level and Prerequisites

The videotape series was prepared for graduate and advanced undergraduate students and professionals new to the field of remote sensing. Before viewing this tape, you should already have a basic understanding of remote sensing and its related terminology, such as can be gained through any of a number of introductory texts or through studying selected minicourses in the series Fundamentals of Remote Sensing (Purdue University, 1976, 1980).

Despite the mathematical and statistical nature of some aspects of the technology, the videotapes have been prepared with non-mathematical audiences in mind. Whenever possible mathematical relationships are illustrated graphically and described verbally. You may wish to consult the textbook Remote Sensing, the Quantitative Approach, edited by Philip H. Swain and Shirley M. Davis (McGraw-Hill Book Company, New York, 1978), for in-depth explanations of many of the concepts presented.

About the Author

Marion F. Baumgardner is professor of agronomy at Purdue University and associate director of the Laboratory for Applications of Remote Sensing. Having traveled and lectured in more than 50 countries, Professor Baumgardner is frequently invited to serve as consultant to international development agencies and national planning panels.

His research interests include the study of the relationships between the radiative and other physical/chemical properties of soils and the assessment of remote sensing techniques for surveying and monitoring land resources.

He has been honored for his accomplishments in research and education by the awarding of an honorary Doctor of Science degree by DePauw University and through election as a Danforth Associate, a Fellow of the American Society of Agronomy and a Fellow of the Soil Science Society of America.

Acknowledgements

Others at Purdue University who contributed to this videotaped program were Eric Stoner, graduate student in agronomy; Shirley M. Davis, senior education and training specialist; James D. Russell, associate professor of education; Neil Sydor, producer-director; Susan L. Ferringer, visual designer; and Sara Jane Coffman, instructional developer. Music composed by Richard K. Thomas. Viewing notes were prepared by James Tilton. Research support for recent work shown was supplied by the National Aeronautics and Space Administration and U.S. Department of Agriculture

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Time: 29 1/2 minutes

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Synopsis

The increasing pressures of the expanding human population, exerted on the food-producing lands of the world, signal the critical need for better information about global land resources. Recent developments in data acquisition and analysis techniques provide new opportunities to inventory soil, vegetation and water resources. Today laboratory, field, air-borne and space-borne spectroradiometers can be used to measure soil reflectance quantitatively over the 0.5 to 2.4 μm range of the electromagnetic spectrum. These measurements may assist scientists in identifying and characterizing differences among soils. The degree to which reflectance data may be of assistance in determining soil productivity, internal drainage characteristics, and rates of soil degradation is greatly dependent upon our understanding of the relationships between reflectance and other properties of soils. To contribute to this understanding numerous spectral, chemical and physical determinations were obtained for 500 different soils, sampled in seventeen different climatic zones in the United States. Each of the 500 spectral curves could be related to one of five general types of curve forms. The specific shape of the spectral curve for an individual soil is to a large extent related to the soil organic matter, the moisture and iron oxide contents, texture, internal drainage, soil erosion and climatic variables of the region where the soil was formed. Continuing research in this area is extremely important if we are to realize maximum benefit from current and future Earth observations systems. Remote sensing promises to play an increasingly important role as a tool for inventorying, monitoring and managing our soil resources.

Objectives

Upon completion of this videotape, you should be able to:

1. State why a knowledge of worldwide soil quality and degradation is important.

2. Define hue, value and chroma and describe how these characteristics are used in the Munsell Soil Color Notation.

3. State general soil characteristics related to soil color (dark, gray, red, yellow, white).

4. Compare the relative merits of using Munsell color charts and quantitative measurements of soil reflectance for studying soils.

5. List seven factors that influence the spectral properties of soils and briefly describe the effects these factors have on soil spectral properties.

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I. Introduction and Motivation

The current race between population and food supply underscores the need for optimal agricultural planning and management. Knowledge of worldwide soil quality and degradation is a key input into such planning and management.

> "Our purpose during the next half hour is to present a new approach for characterizing the quality of our soil resources and for assessing their productivity and rate of degradation."

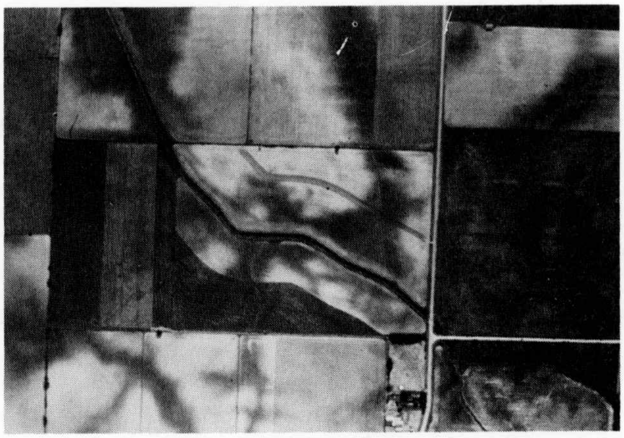
Physical and chemical properties of soils influence the quality and quantity of the sun's rays reflected from surface soil. An improved understanding of this phenomenon will aid interpretation of soil measurements obtained by aircraft and satellite sensors, making possible the use of these sensors for more rapid and accurate mapping and monitoring of soil resources.

II. Early Perceptions of Soils

The Chinese recorded differences in soils over 4,000 years ago. They undoubtedly noticed that soils with different color characteristics had different productivities.

In the 12th century, a Moorish scholar, YAHYA IBN MUHAMMAD, wrote the Book of Agriculture in which he related soil color to soil quality.

In the 1880's, the Dokuchaiev school in Russia devised a system for mapping soils. They advanced the revolutionary concept that soil characteristics can be determined looking at vertical cuts through the soil.



The next major soil survey breakthrough was aerial photography, first used in Jennings County, Indiana, in 1929.

> "But because soil surveys were tedious and expensive, scientists continually looked for new ways to identify and classify soils."

III. Soil Color

"...the most obvious way to distinguish among soils is by color.

For years, soil colors were given common names such as "rust," "chocolate brown," and "mouse gray." But soil color was deemed so important that by the 1930's a system of soil color standards was developed called the Munsell Soil Color Notation.

A. Munsell Soil Color Notation

The Munsell Soil Color Notation was developed to describe the broadest possible range of soil color. The Munsell Notation designates soil colors by hue, value and chroma -- the three variables that form all colors.

- Hue is the dominant spectral color and is related to the dominant wavelength of light.
- Value refers to the relative lightness or darkness of color and is a function of the total amount of light.
- Chroma is the relative purity or strength of the spectral color.

All colors on a given Munsell color chart card are of a constant hue. From the top to the bottom of each card, the colors become successively darker by equal steps. The colors increase in chroma to the right and become grayer to the left. Each hue, value and chroma is assigned a number/letter designation, which forms the Munsell Notation for a particular color.

> "The development of this system of standard color notations was a significant contribution to soil taxonomy and survey. Soil color is one characteristic that is easy to determine and is readily comprehended by both professionals and non-professionals."

B. Soil Color Related to Other Soil Characterists

"Color is an important soil parameter because it provides information about other charactristics of soil that are not as easily or accurately observed."

Color	Related Characteristics
Dark	high organic matter content, a fertile condition, and a high moisture holding capacity.
Gray	low content of organic matter and iron oxides. Often indicates poor drainage.
Red	unhydrated iron oxides indicating good drainage and aeration. Sometimes directly related to parent material. More prevalent in tropical climates. Lower inherent productivity.
Yellow	more prevalent in tropical climates, especially where there is high humidity and heavy cloud cover. Lower inherent productivity.
White	usually formed in arid and semi-arid areas, high in soluble salts. Usually unproductive.

"Although the Munsell color notation system has greatly helped to classify and map soils, the system is highly subjective, and its accuracy is dependent upon the user."

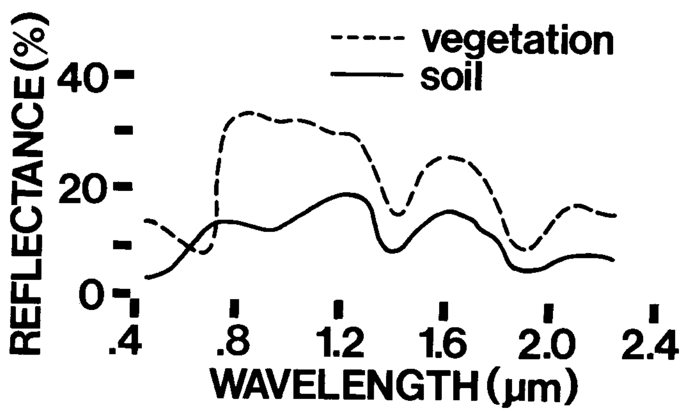
"For this reason, laboratory, field, air, and space borne instruments are now being used to measure quantitatively the reflectance from soils over the visible and the near and middle infrared spectral regions of the electromagnetic spectrum."

IV. Quantitative Measurement of Soil Reflectance

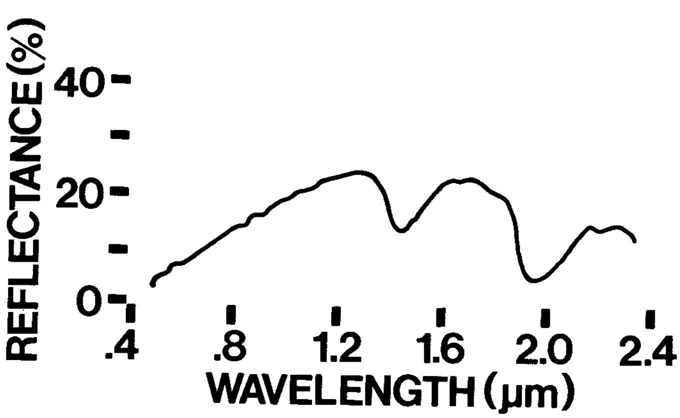
Photographic sensors can be used to produce images representing soil reflectance directly on film. However, the greatest contribution to understanding the properties of soils comes from "non-imaging" systems such as multispectral sensors which can be calibrated precisely.

> "The basis for multispectral sensing is that materials, in this case soils, with different chemical and physical characteristics are often spectrally unique. That is, reflectance at different wavelengths may be uniquely characteristic of a specific soil condition."

"Typical" spectral curves are often used for comparison purposes:

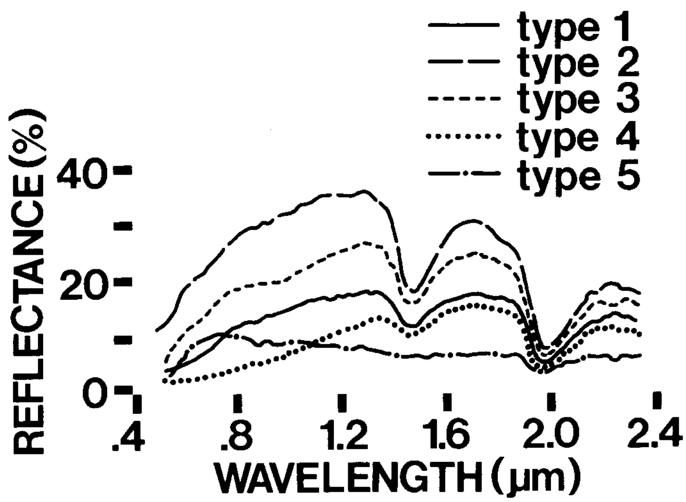


> "Here the typical responses for green vegetation and soil are compared continuously over the spectral range from 0.4 to 2.3 micrometers shown along the horizontal axis.... The vertical axis represents spectral bidirectional reflectance factor measurements or intensity of reflected energy. This measure is labeled here and on succeeding curves simply as reflectance."



A "typical" spectral curve for soil. Note the water absorption bands at 1.45 and 1.95 µm.

A recent research project described five types of spectral curves for soils derived from examining 500 soils representing a wide range of climates and parent materials.



In the above graph, type 1 soil is represented by a dark-colored silty clay loam soil in a landscape depression of the eastern Corn Belt of the United States.

Type 2 soil is represented by a brown soil from New Mexico. Note the higher spectral response of this soil as compared to Type 1 soil.

Type 3 soil is represented in the graph by a soil with a strong brown color from Rutherford County, Tennessee. The reflectance for this soil lies between that for Type 1 and Type 2 soils.

Type 4 soil is represented by a dark brown, moderately coarse-textured soil from Delta County, Michigan. The reflectance for this soil is similar to that of the Type 3 soil in the visible range, but rises more slowly in the near IR.

Type 5 soil is represented here by a dark red, excessively drained clay soil from the state of Parana, Brazil. Note the extremely low infrared reflectance.

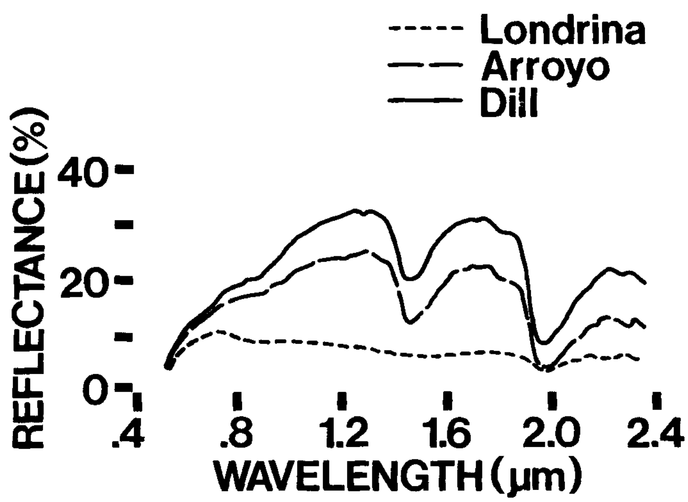
> "But the central issue is still unanswered. Although we can obtain precise quantitative multispectral measurements, we still have much to learn about the causes of these spectral variations among soils."

V. Causes of Spectral Variations Among Soils

An extensive study of causes of spectral variations among soils was made in the late 1970's by the Laboratory for Applications of Remote Sensing at Purdue University in cooperation with the Soil Conservation Service of the U.S. Department of Agriculture. Some 500 soil samples were analyzed for:

- Spectral Reflectance (.52 to 2.38μm)
- Cation Exchange Capacity
- Organic Carbon
- Extractable Iron
- Particle Size

Field surveyors gave identical descriptions for three dark red soils: Londrina, Arroyo and Dill soils. Londrina soil is derived from basalt and was formed under a humid hyperthermic climate. Arroyo soil is derived from limestone and was formed under a semiarid mesic climate. Dill soil is derived from sandstone and was formed under a subhumid, thermic climate.



"When we compare the spectral curves, we see that while the three soils do have similarities in the visible region, they're dramatically different in the near and middle infrared."

"Under the three different soil-forming environments [of these soils], we would expect to find significant differences in the physical and chemical properties of soils and in their potential productivity.

We now look at how seven different soil characteristics affect reflectance. These seven characteristics are divided into three categories for convenience:

Inherent characteristics:

- organic matter content,
- texture, and
- internal drainage.

Climatic characteristics:

- temperature region and
- rainfall.

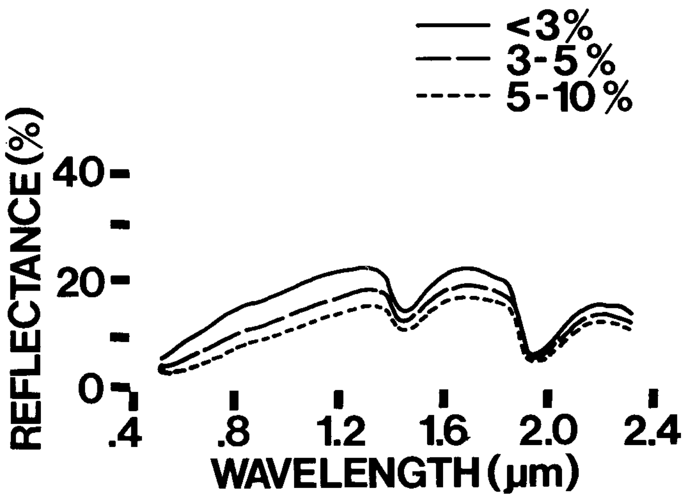
Dynamic characteristics:

- erosion and
- moisture content.

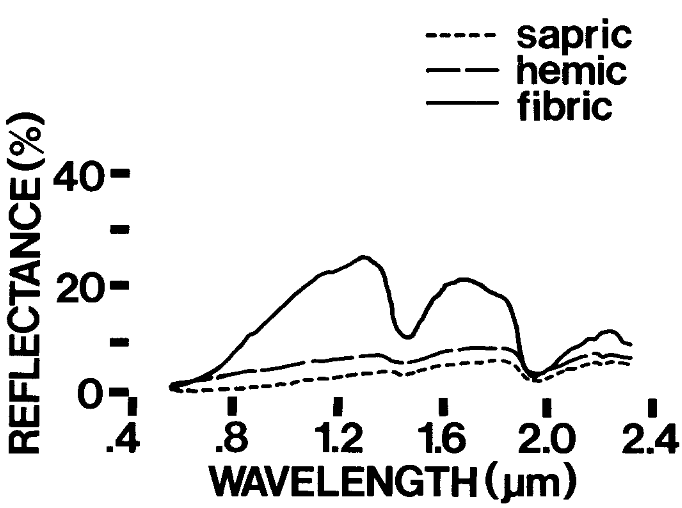
A. Inherent Characteristics

1. Organic Matter Content

"In general an increase in soil organic matter content will cause a decreased reflectance in both the visible and infrared."

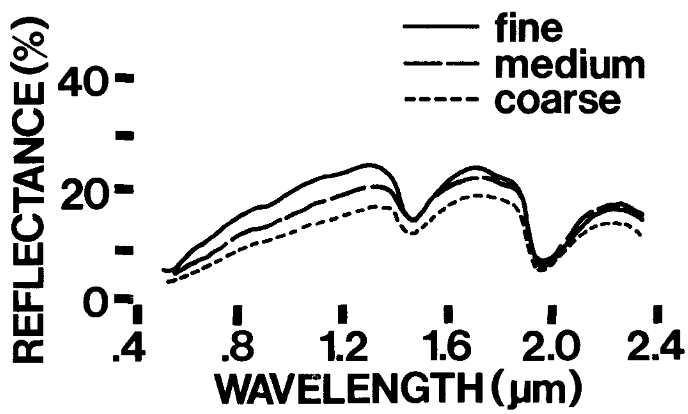


Average reflectance curves for soils of varying organic matter content.



The organic matter in the sapric soil has undergone the greatest decomposition, while that in the fibric soil has undergone the least. Hemic soil is moderately decomposed.

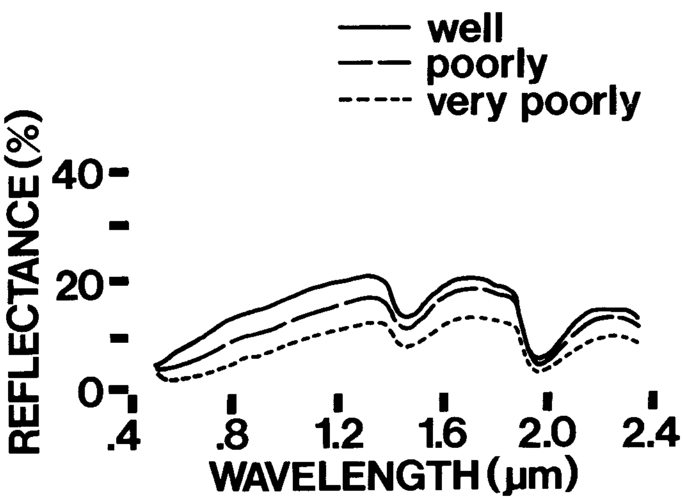
2. Texture



Texture affects soil reflectance.

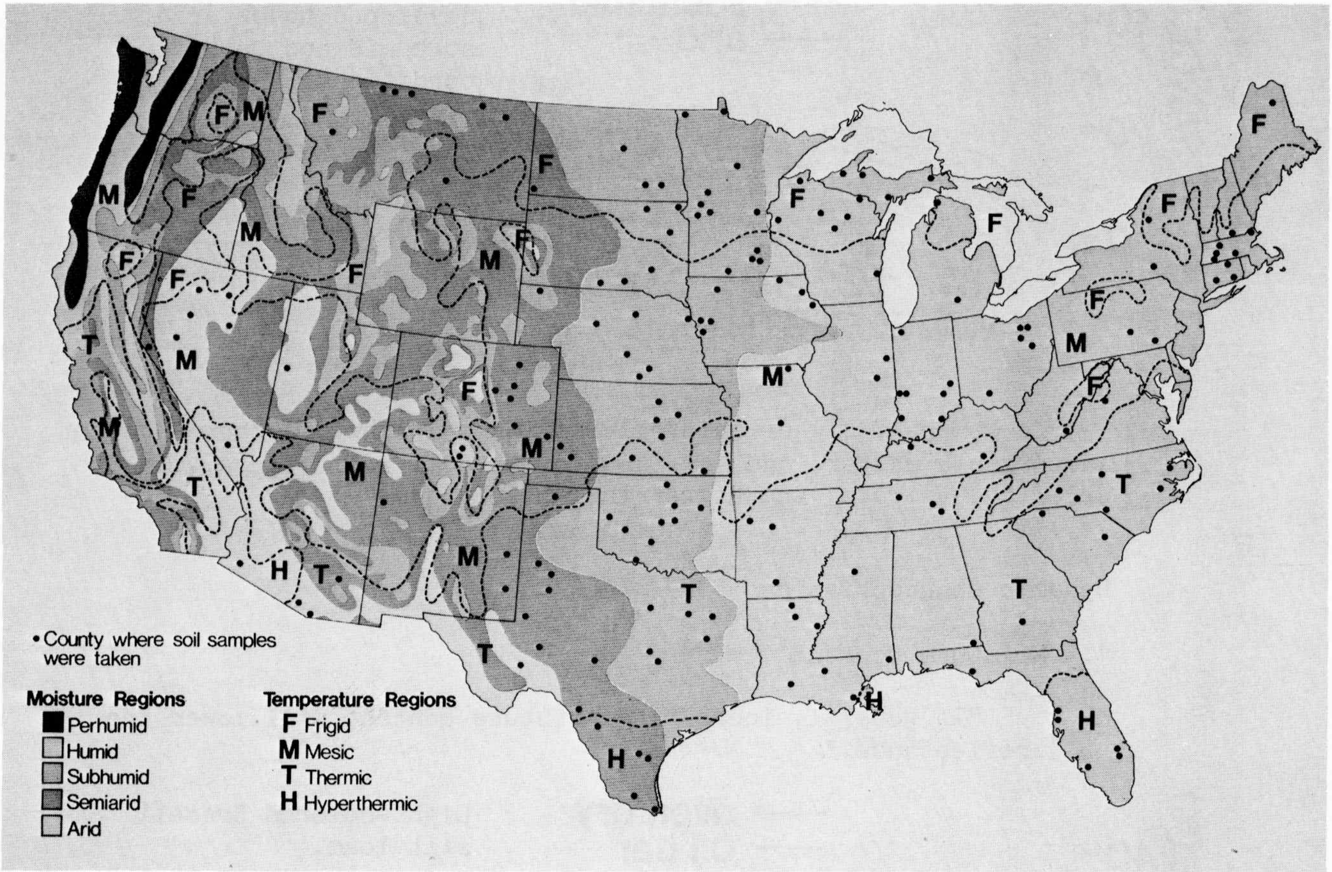
"In general, the finer the texture, the higher the reflectance. For extremely fine-textured soils in which clay predominates, this relationship between texture and reflectance is more complex and may, in fact, be reversed."

3. Internal Drainage

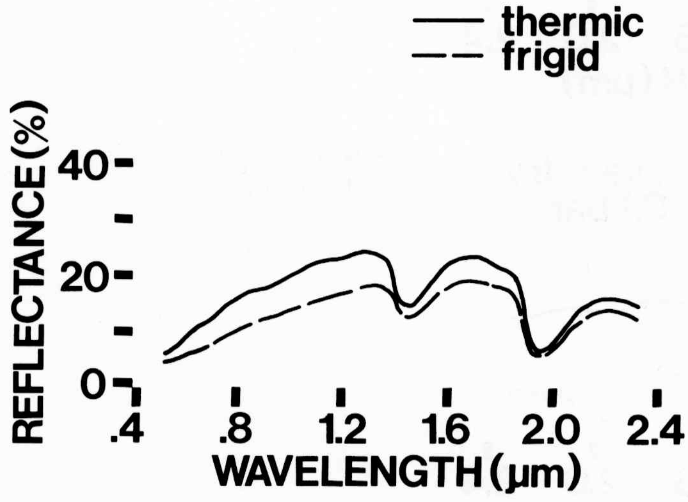


The poorer the internal drainage, the lower the reflectance. Well drained soils give the highest reflectance.

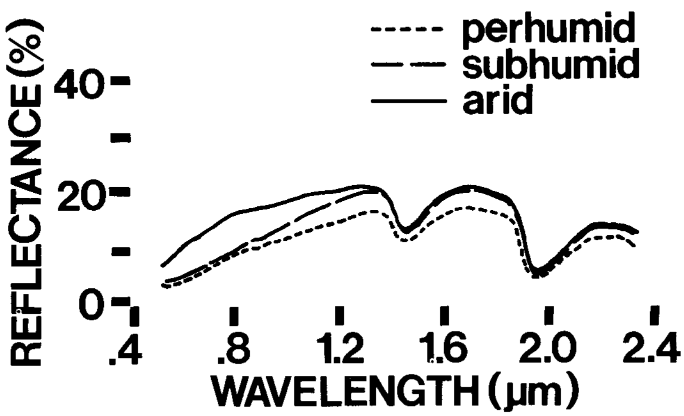
B. Climatic Characteristics



United States soil samples were stratified into four soil temperature regions (F, M, T, H) and five moisture zones (gray shadings).



Soils from the high temperature region (thermic) have the highest reflectance; while those from the cold or frigid regions have the lowest reflectance.



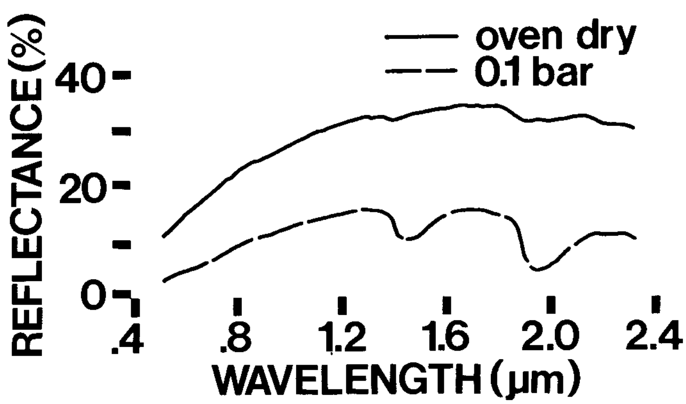
Comparison of soil reflectance from soils developed under arid, subhumid and perhumid conditions.

> "In general, higher rainfall results in higher moisture content and organic matter, and this lowers the soil reflectance.... The drier the climate, the higher the reflectance."

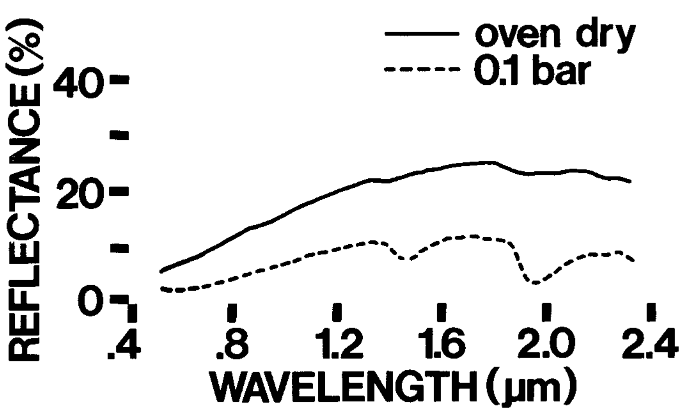
C. Dynamic Charactristics

1. Moisture Content

> "In general, increasing moisture content will lower the reflectance."



Light-colored Russell silt loam.



Dark-colored Corwin silt loam.

Comparison of oven dried (OD) and moistened (0.1 bar moisture tension) light and dark colored soils.

2. Erosion

" Erosion , along with desertification and salinization is responsible for much soil degradation and loss of productivity. Research results show that in humid regions and with cultivated soils, the loss of topsoil by erosion can be detected by spectral measurements. Spectral responses from severe erosional sequences from subhumid and humid regions show that in general severe erosion increases soil reflectance."

VI. Summary

"For the past few minutes we have tried to provide you with an idea about where we are in our understanding of soil reflectance. Continuing research in this area is extremely important if we are to realize maximum benefit from current and future earth observation systems."

"An exciting, new arena for mapping, characterizing and monitoring our soil resources is emerging. Soil scientists must be aware of these new tools and must play a key role in designing and implementing state, national and global soil information systems of the future."

SELF-CHECK QUESTIONS

1. Why is a knowledge of worldwide soil quality and degradation important?

2. Define hue, value and chroma. How are these characteristics used in the Munsell Soil Color Notation?

3. What are soil characteristics that are generally related to a dark soil color? gray? red? yellow? white?

CHALLENGE QUESTIONS

1. For many years the Munsell Soil Color Notation has been used to categorize and study soils. In recent years quantitative measurements of soil reflectance over the visible and the near and middle infrared spectral regions have been used for these purposes. What are the relative merits of these two approaches?

2. What are three inherent characteristics of soils that affect soil reflectance? two climatic characteristics? two dynamic characteristics? In what way is soil reflectance affected by these characteristics?

FURTHER READING

Montgomery, O.L., M.F. Baumgardner and R.A. Weismiller, 1976. "An Investigation of the Relationship Between Spectral Reflectance and the Chemical, Physical and Genetic Characteristics of Soils." LARS Information Note 082776, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907.

Stoner, E.R., M.F. Baumgardner, L.L. Biehl and B.F. Robinson, 1979. "Atlas of Soil Reflectance Properties." LARS Information Note 111579, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907

Stoner, E.R., and M.F. Baumgardner. 1979. "Physicochemical, Site, and Bidirectional Reflectance Factor Characteristics of Uniformly-Moist Soils." LARS Information Note 111679, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana 47907.

ANSWERS TO SELF-CHECK QUESTIONS

1. Optimal agricultural planning and management is needed if we are to win the current race between population and food supply. Knowledge of worldwide soil quality and degradation is a key input into such planning and management.

2. Hue is the dominant spectral color and is related to the dominant wavelength of light. Value refers to the relative lightness or darkness of color and is a function of the total amount of light. Chroma is the relative purity or strength of the spectral color.

   All colors on a given Munsell color chart are of a constant hue. From the top to the bottom of each card, the colors become successively darker by equal steps. The colors increase in chroma to the right and become grayer to the left. Each hue, value and chroma is assigned a number/letter designation, which forms the Munsell Soil Color Notation for a particular color.

3. Dark soil color is generally related to high organic matter content, a fertile condition, and a high moisture holding capacity. A gray soil color generally indicates low organic matter and iron oxides content. Gray color often indicates poor drainage. Red soil color is related to the presence of unhydrated iron oxides indicating good drainage and aeration. A red color is sometimes related to the parent material from which the soil is formed. Red and yellow soils tend to be more prevalent in tropical climates; the yellow occur especially where there is generally high humidity and heavy cloud cover. Red and yellow soils have lower inherent productivity. A white soil is usually unproductive. It is usually formed in arid and semi-arid areas and is high in soluble salts.