Food and Agriculture
Organization of the
United Nations

GLOBAL SYMPOSIUM ON
SOIL INFORMATION
AND DATA

MEASURE
MONITOR
MANAGE

Past, Present, and Future of Proximal Sensing of Soils: Challenges and Opportunities

A Personal Perspective

Eyal Ben-Dor

THE REMOTE SENSING LABORATORIES
TEL AVIV UNIVERSITY אוניברסיטת תל אביב

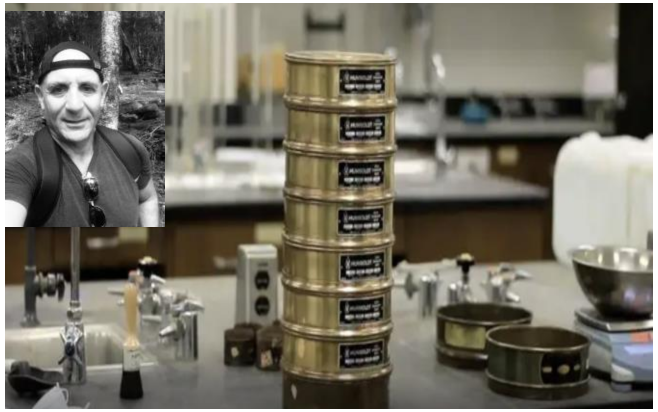
September 25-28, 2024
Nanjing, China

GLOBAL SOIL PARTNERSHIP

1968

1974

1982



2024

How soil is important to me

How soil is important to mankind ?

Soil, like air and water, is **critical to life on earth**. Soils are incredibly resilient, but they are also fragile and can easily be damaged or lost. Improved management of our planet’s limited soil resource is essential to ensure a sustainable future and guarantee healthy and productive soils for **food security**, as well as to support many essential ecosystem services that **enable life on earth**

...comes from crops directly grown in the soil.

theguardian

Third of Earth's soil is acutely degraded due to agriculture

Life for human

Life for mankind

Blood test lab → Chemistry ← Soil Sampling lab

Ultrasound → Morphology ← Penetrating Radar

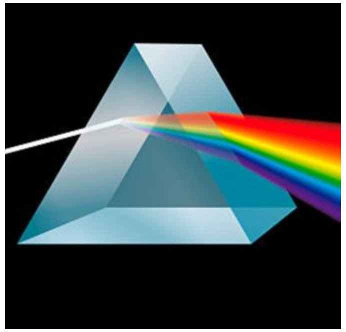
Endoscopy → Inside structure ← Profile Drilling

CT → Morphology/ Structure ← RGB photography

MRI → Morphology/ structure 3D ← Spectral Imaging

Soil Spectroscopy

1666 Isaac Newton



Spectroscopy

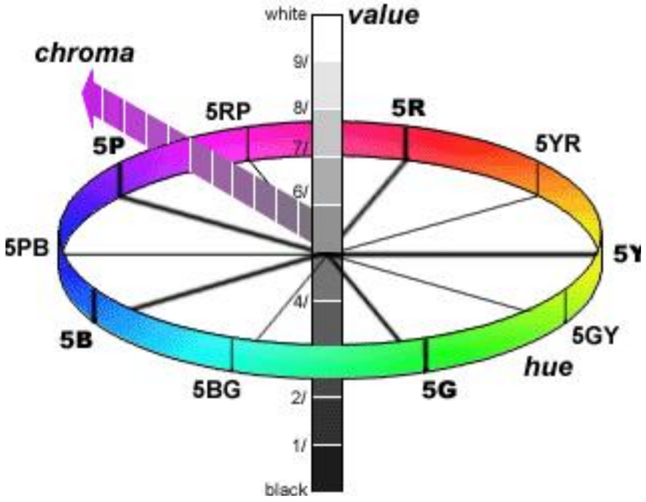
An Introduction to the Theoretical
and Experimental Fundamentals

Issac Newton

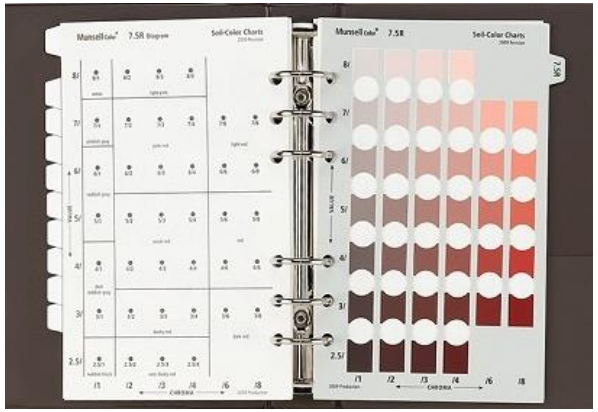
1 Introduction

In the year 1666 at Cambridge, Isaac Newton procured a triangular glass prism and let a ray of sunlight from a small round hole in the window illuminate it. He observed the image created thereby on a paper screen. The white light from the window dissociated into red, yellow, green, blue, and violet. He called the invisible colors in the white sunlight the "spectrum" (lat *spectrum* = image in the soul) [1]. It was at the end of the 19th century that the observation of spectra was first christened "Spectroscopy". This word has both a Latin and Greek root (Greek *skopein* = to look). Arthur Schuster first used the term *spectroscopy* in 1882 during a lecture at the Royal Institution [2].

Soil Color and Spectroscopy



Munsell 1923

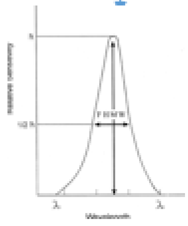


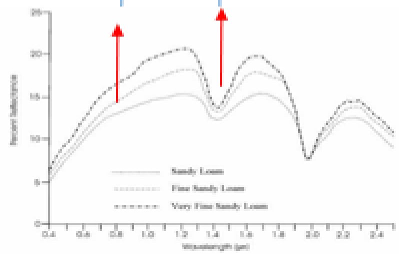
Human visualization and digital detection

Munsell

Spectroscopy

HUE = Wavelength
Value = Albedo
Saturation = FHMW

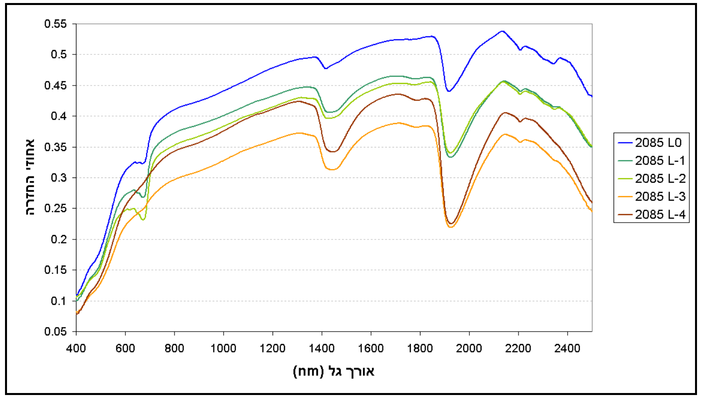




Going beyond human
visualization sense

Definition Soil Spectroscopy

- Soil Spectroscopy refers to the reflectance/emittance part of the electromagnetic radiation that interacts with the soil matter across the VIS-NIR-SWIR-TIR spectral region range (0.35-14μm).



Point – one pixel

Field

Laboratory

Soil is a Complex System composed of 5 major Formation Factors

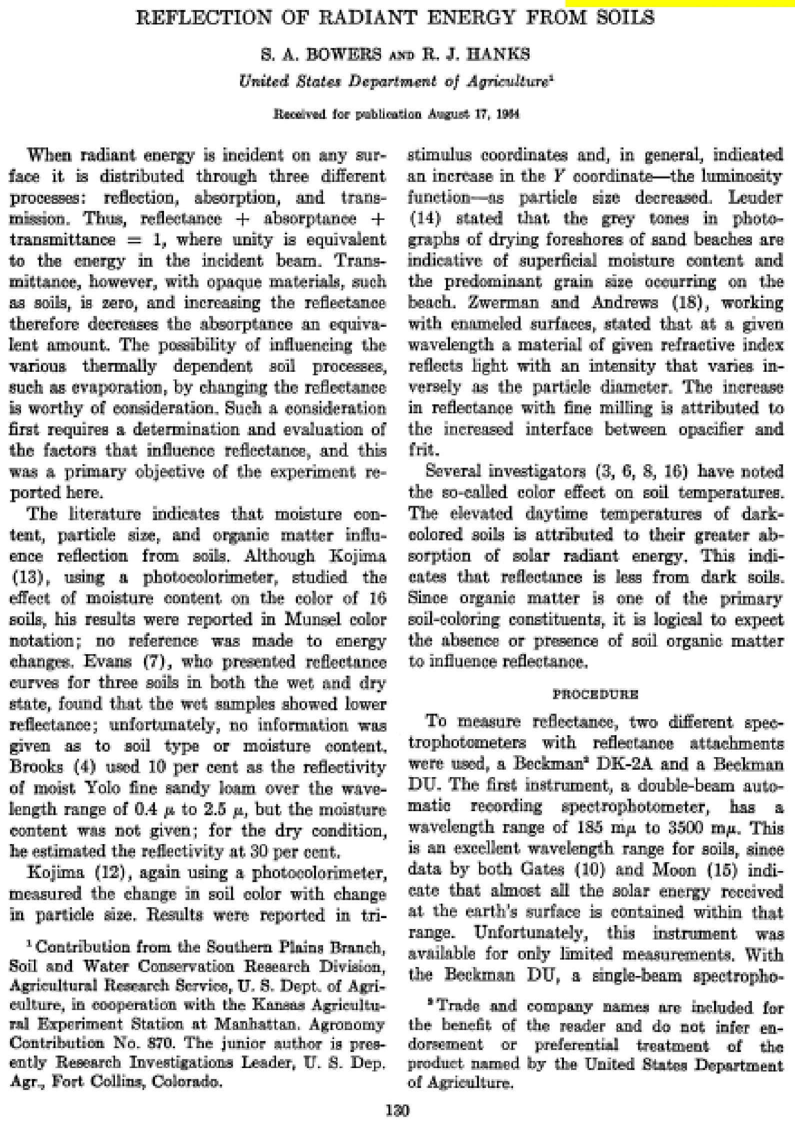
Complex

1) Parent Material (P)
2) Climate (C)
3) Topography (T)
4) Biotic Components (O)
5) Time (t)

$$\boxed{\text{Soil} = f(P, C, T, O, t)}$$

First paper on quantitative information from soil spectrum (1965)

Supervised SPECTRAL analysis



REFLECTION OF RADIANT ENERGY FROM SOILS

S. A. BOWERS AND R. J. HANKS

United States Department of Agriculture[1]

Received for publication August 17, 1964

When radiant energy is incident on any surface it is distributed through three different processes: reflection, absorption, and transmission. Thus, reflectance + absorptance + transmittance = 1, where unity is equivalent to the energy in the incident beam. Transmittance, however, with opaque materials, such as soils, is zero, and increasing the reflectance therefore decreases the absorptance an equivalent amount. The possibility of influencing the various thermally dependent soil processes, such as evaporation, by changing the reflectance is worthy of consideration. Such a consideration first requires a determination and evaluation of the factors that influence reflectance, and this was a primary objective of the experiment reported here.

The literature indicates that moisture content, particle size, and organic matter influence reflection from soils. Although Kojima (13), using a photocolorimeter, studied the effect of moisture content on the color of 16 soils, his results were reported in Munsel color notation; no reference was made to energy changes. Evans (7), who presented reflectance curves for three soils in both the wet and dry state, found that the wet samples showed lower reflectance; unfortunately, no information was given as to soil type or moisture content. Brooks (4) used 10 per cent as the reflectivity of moist Yolo fine sandy loam over the wavelength range of 0.4 μ to 2.5 μ, but the moisture content was not given; for the dry condition, he estimated the reflectivity at 30 per cent.

Kojima (12), again using a photocolorimeter, measured the change in soil color with change in particle size. Results were reported in tristimulus coordinates and, in general, indicated an increase in the *Y* coordinate—the luminosity function—as particle size decreased. Leuder (14) stated that the grey tones in photographs of drying foreshores of sand beaches are indicative of superficial moisture content and the predominant grain size occurring on the beach. Zwerman and Andrews (18), working with enameled surfaces, stated that at a given wavelength a material of given refractive index reflects light with an intensity that varies inversely as the particle diameter. The increase in reflectance with fine milling is attributed to the increased interface between opacifier and frit.

Several investigators (3, 6, 8, 16) have noted the so-called color effect on soil temperatures. The elevated daytime temperatures of dark-colored soils is attributed to their greater absorption of solar radiant energy. This indicates that reflectance is less from dark soils. Since organic matter is one of the primary soil-coloring constituents, it is logical to expect the absence or presence of soil organic matter to influence reflectance.

PROCEDURE

To measure reflectance, two different spectrophotometers with reflectance attachments were used, a Beckman[2] DK-2A and a Beckman DU. The first instrument, a double-beam automatic recording spectrophotometer, has a wavelength range of 185 mμ to 3500 mμ. This is an excellent wavelength range for soils, since data by both Gates (10) and Moon (15) indicate that almost all the solar energy received at the earth's surface is contained within that range. Unfortunately, this instrument was available for only limited measurements. With the Beckman DU, a single-beam spectropho-

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[1] Contribution from the Southern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Dept. of Agriculture, in cooperation with the Kansas Agricultural Experiment Station at Manhattan. Agronomy Contribution No. 870. The junior author is presently Research Investigations Leader, U. S. Dep. Agr., Fort Collins, Colorado.

[2] Trade and company names are included for the benefit of the reader and do not infer endorsement or preferential treatment of the product named by the United States Department of Agriculture.

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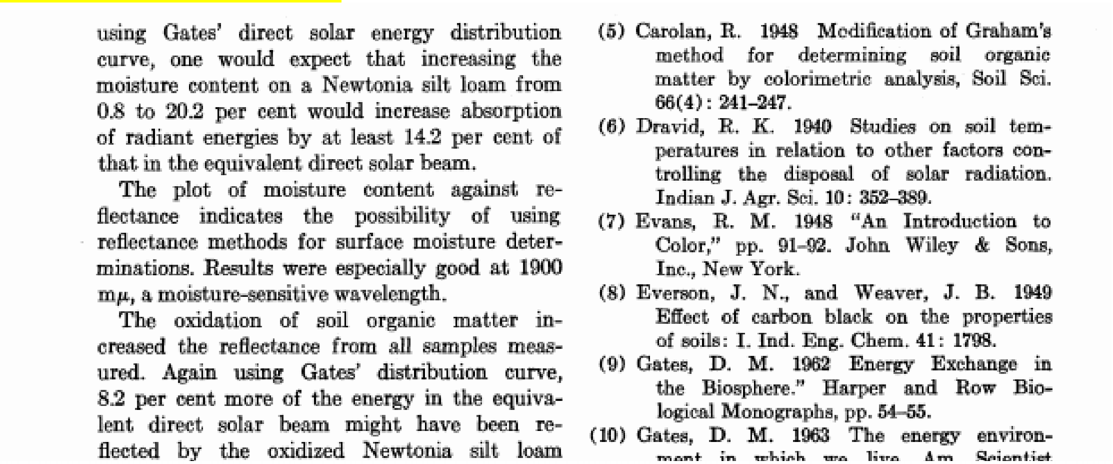


using Gates' direct solar energy distribution curve, one would expect that increasing the moisture content on a Newtonia silt loam from 0.8 to 20.2 per cent would increase absorption of radiant energies by at least 14.2 per cent of that in the equivalent direct solar beam.

The plot of moisture content against reflectance indicates the possibility of using reflectance methods for surface moisture determinations. Results were especially good at 1900 mμ, a moisture-sensitive wavelength.

The oxidation of soil organic matter increased the reflectance from all samples measured. Again using Gates' distribution curve, 8.2 per cent more of the energy in the equivalent direct solar beam might have been reflected by the oxidized Newtonia silt loam

(5) Carolan, R. 1948 Modification of Graham's method for determining soil organic matter by colorimetric analysis. Soil Sci. 66(4): 241–247.
(6) Dravid, R. K. 1940 Studies on soil temperatures in relation to other factors controlling the disposal of solar radiation. Indian J. Agr. Sci. 10: 352–389.
(7) Evans, R. M. 1948 "An Introduction to Color," pp. 91–92. John Wiley & Sons, Inc., New York.
(8) Everson, J. N., and Weaver, J. B. 1949 Effect of carbon black on the properties of soils: I. Ind. Eng. Chem. 41: 1798.
(9) Gates, D. M. 1962 Energy Exchange in the Biosphere." Harper and Row Biological Monographs, pp. 54–55.
(10) Gates, D. M. 1963 The energy environ-

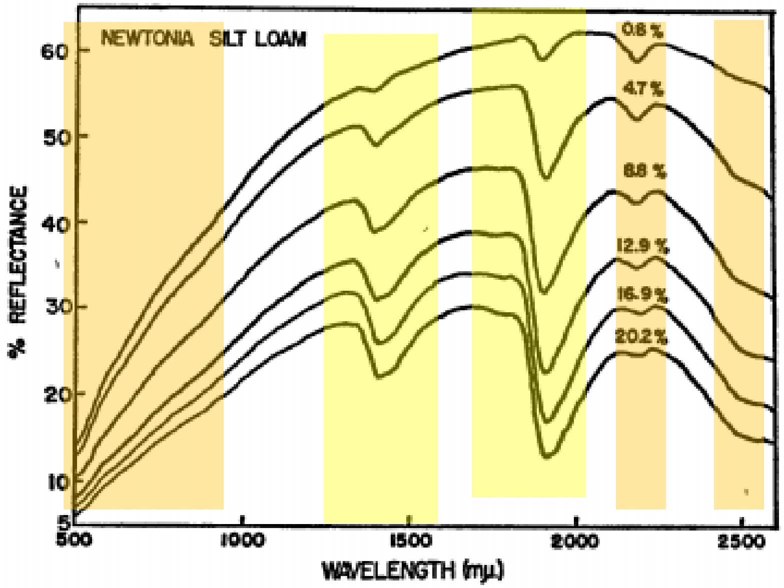
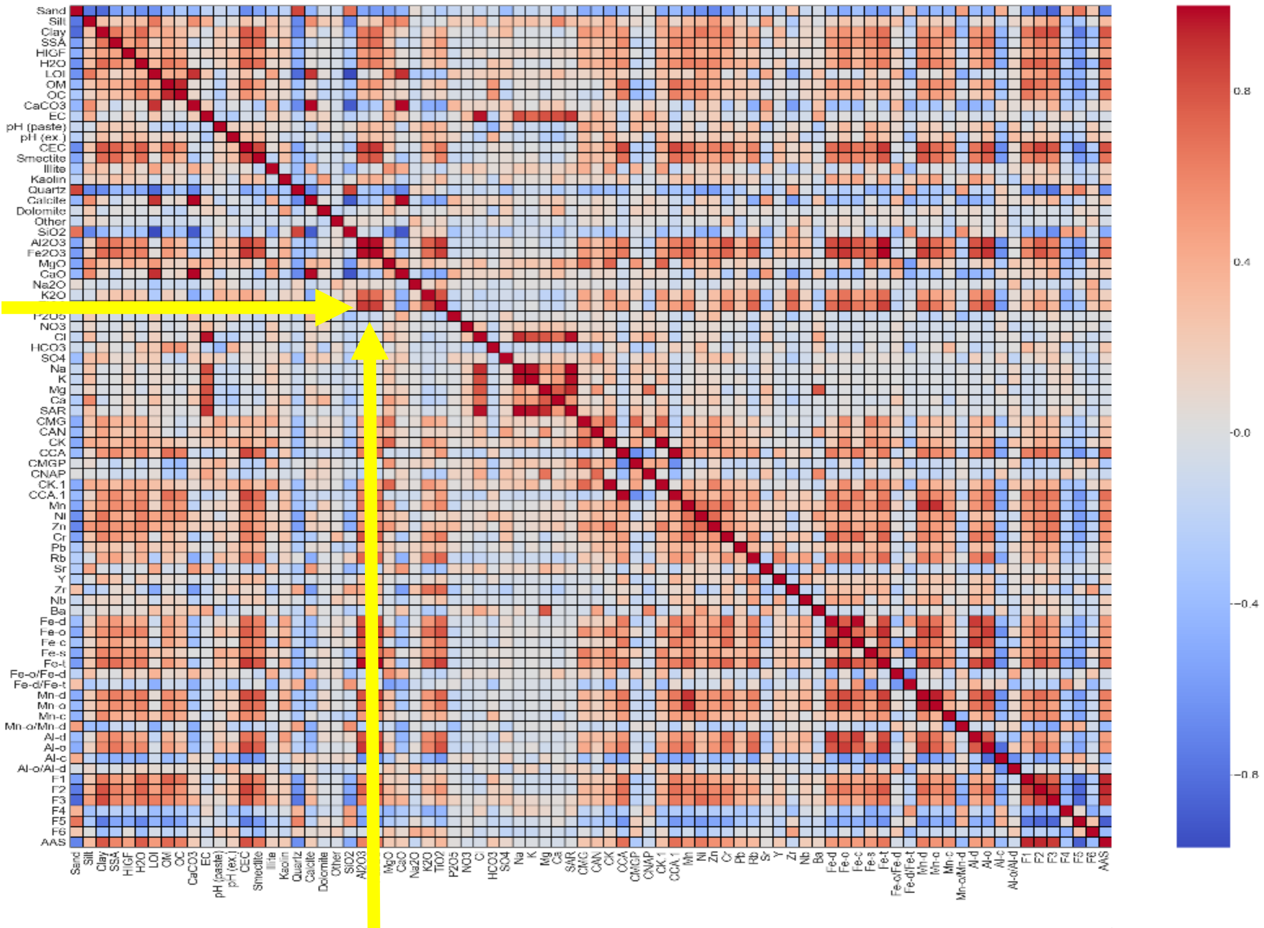


FIG. 1. Per cent reflectance *vs.* wavelength of incident radiation at various moisture contents (moisture contents indicated directly above each curve).

Correlation Matrix between Soil Attributes

Pedotransfer Function (PTS)

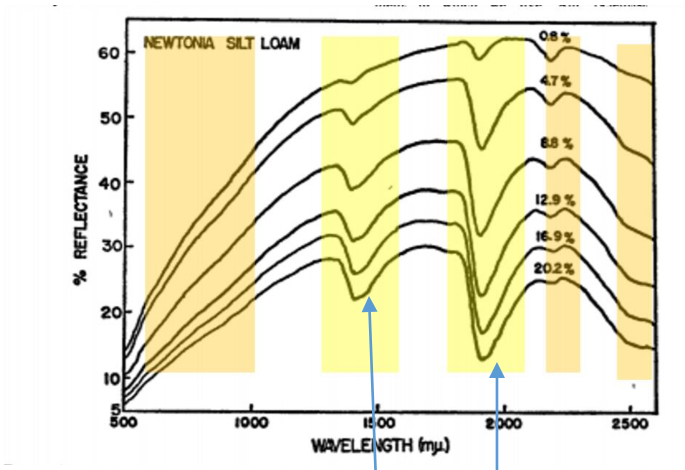
Smectite



Hygroscopic water

A new (spectral) layer

Smectite



Hygroscopic water

Pedo Transfer Spectral Function (PTSF)

Accuracy

$C_{H20} = f(1.4\mu m, 1.9\mu m, \text{Smectite})$

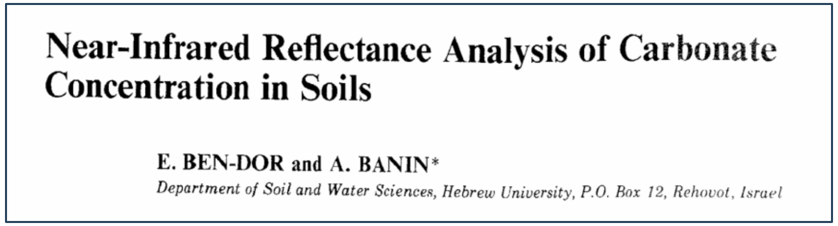
$C_{H20} = f(2.2\mu m, 1.9\mu m, 1.4\mu m, \text{Smectite})$

$C_{H20} = f(2.2\mu m, 0.5\text{-}0.9\mu m, 2.4\text{-}2.5\mu m\ , 1.9\mu m, 1.4\mu m, \text{Smectit}$

Pedo Transfer Spectral Function (PTSF) → Soil Proximal Sensing (SPS)

Supervised SPS

CaCO3



Near-Infrared Reflectance Analysis of Carbonate Concentration in Soils

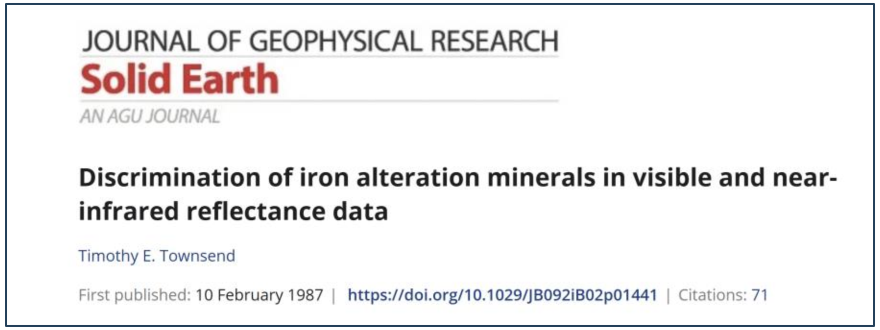
E. BEN-DOR and A. BANIN*

Department of Soil and Water Sciences, Hebrew University, P.O. Box 12, Rehovot, Israel

2.3-2.4μm

1989

Fe



JOURNAL OF GEOPHYSICAL RESEARCH

Solid Earth

AN AGU JOURNAL

Discrimination of iron alteration minerals in visible and near-infrared reflectance data

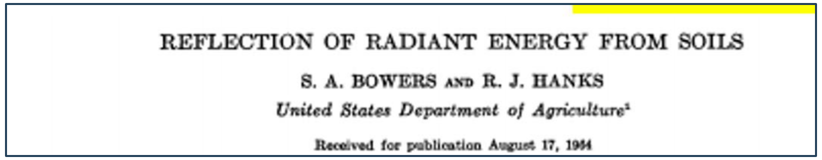
Timothy E. Townsend

First published: 10 February 1987 | https://doi.org/10.1029/JB092iB02p01441 | Citations: 71

0.9 μm

1987

H2O



REFLECTION OF RADIANT ENERGY FROM SOILS

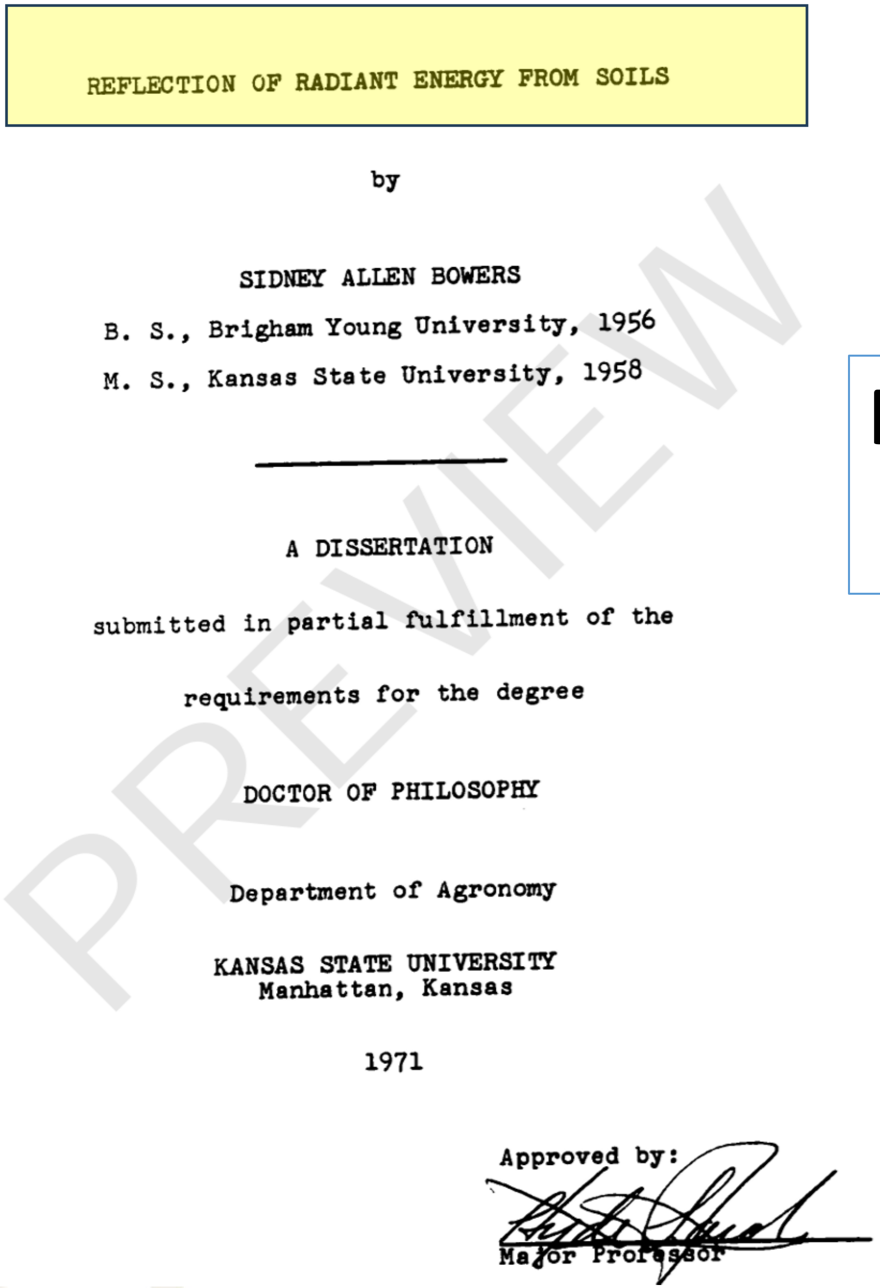
S. A. BOWERS AND R. J. HANKS

United States Department of Agriculture[1]

Received for publication August 17, 1964

1.4, 1.9 μm

1965



REFLECTION OF RADIANT ENERGY FROM SOILS

by

SIDNEY ALLEN BOWERS

B. S., Brigham Young University, 1956

M. S., Kansas State University, 1958

A DISSERTATION

submitted in partial fulfillment of the

requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1971

Approved by:

Major Professor

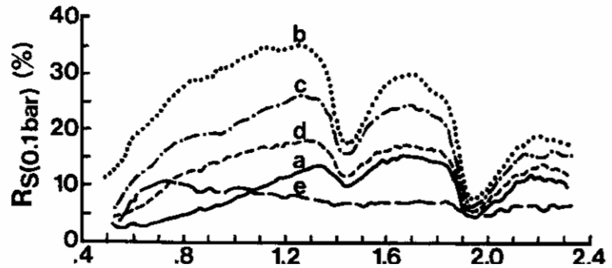
First PhD on soil spectroscopy

1971

Bowers

first soil spectral archive: Spectral Calcification of USA soils

1981



Soil Science Society of America Journal

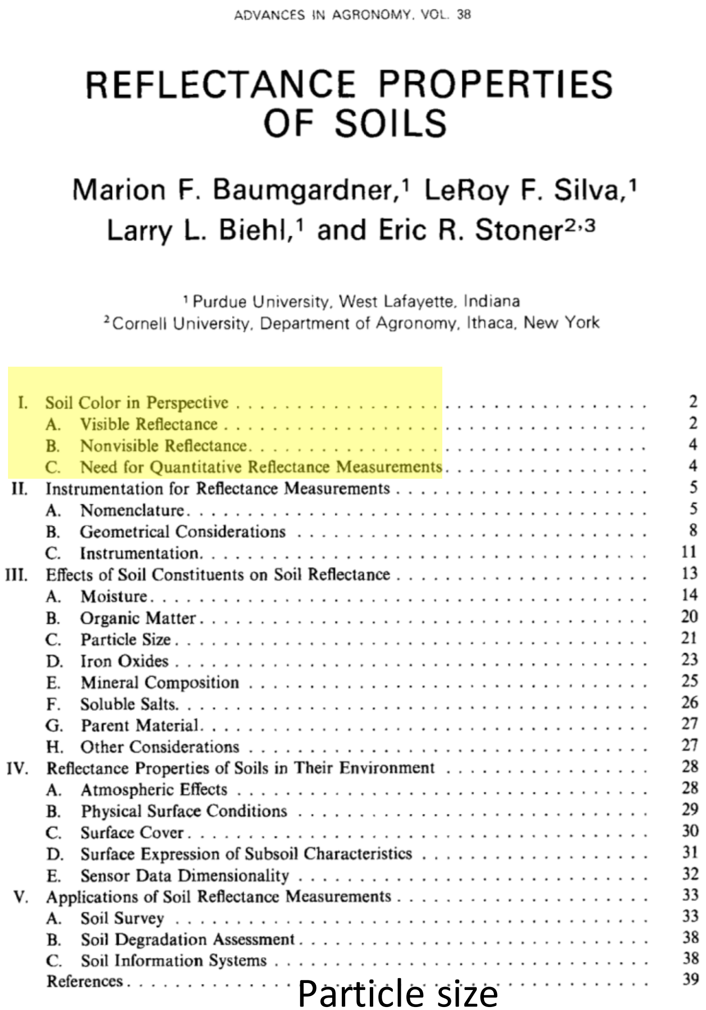
Division S-5—Soil Genesis, Morphology, and Classification

Characteristic Variations in Reflectance of Surface Soils[†]

E. R. Stoner, M. F. Baumgardner

- **Dark Soil Group**: Characterized by low reflectance due to higher organic matter content and often more moisture.
- **Red Soil Group**: Soils that have higher reflectance in the visible red region, often due to iron oxides.
- **Yellow Soil Group**: Similar to red soils but with a yellowish hue, often due to the presence of goethite or other minerals.
- **Bright Soil Group**: Soils with high reflectance across the spectrum, typically sandy or low in organic matter.
- **White Soil Group**: These soils have very high reflectance, often due to high sand content, calcium carbonate, or salt crusts.

Spectral and Color dominants



ADVANCES IN AGRONOMY, VOL. 38

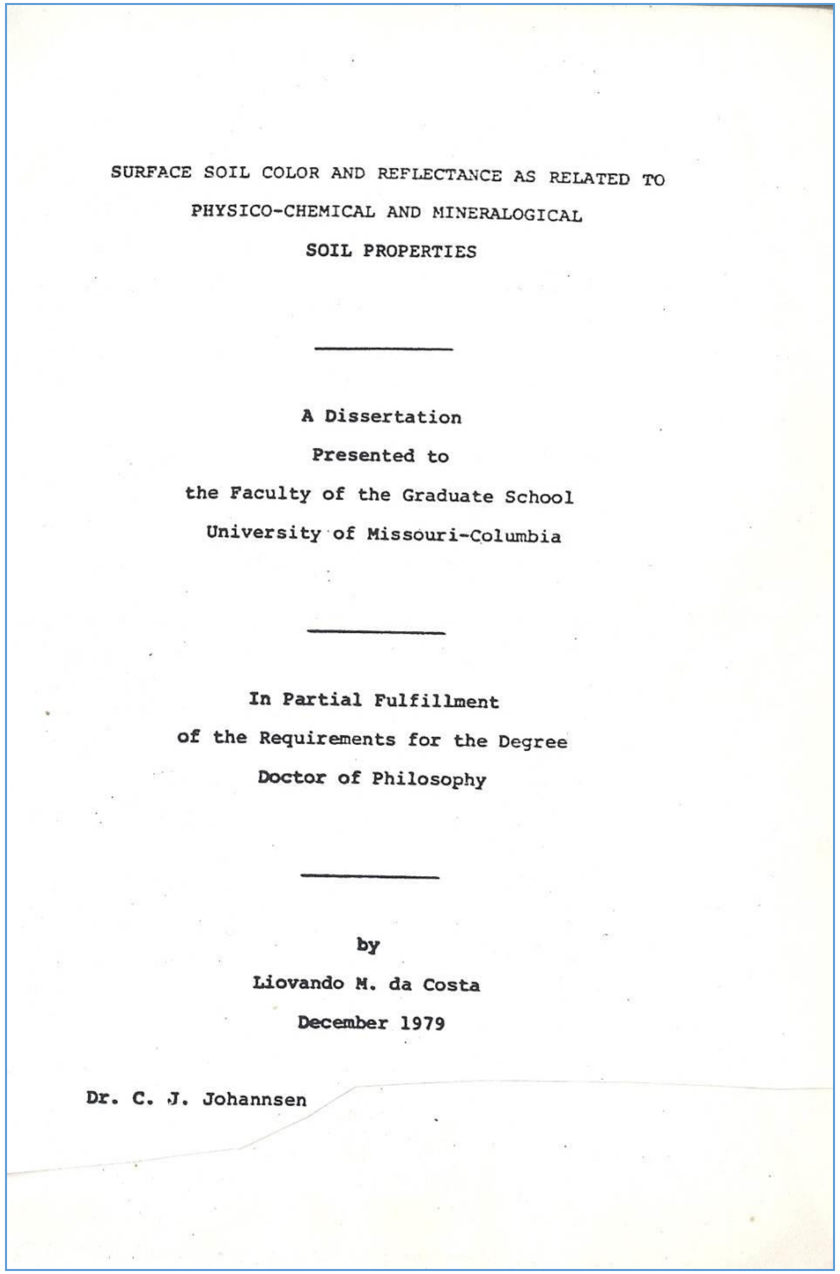
REFLECTANCE PROPERTIES OF SOILS

Marion F. Baumgardner,[1] LeRoy F. Silva,[1]
Larry L. Biehl,[1] and Eric R. Stoner[2,3]

[1] Purdue University, West Lafayette, Indiana
[2] Cornell University, Department of Agronomy, Ithaca, New York

1986

Particle size
Iron oxides
Texture
Water content and ternion
Salinity
CEC



SURFACE SOIL COLOR AND REFLECTANCE AS RELATED TO
PHYSICO-CHEMICAL AND MINERALOGICAL
SOIL PROPERTIES

A Dissertation
Presented to
the Faculty of the Graduate School
University of Missouri-Columbia

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Liovando M. da Costa
December 1979

Dr. C. J. Johannsen

1979

First PhD on Soil Spectroscopy and
quantitative approach
(proximal)

University of Minnesota

De Costa

First comprehensive study on Soil Spectral Analysis (NIRS): De Costa PhD

1979

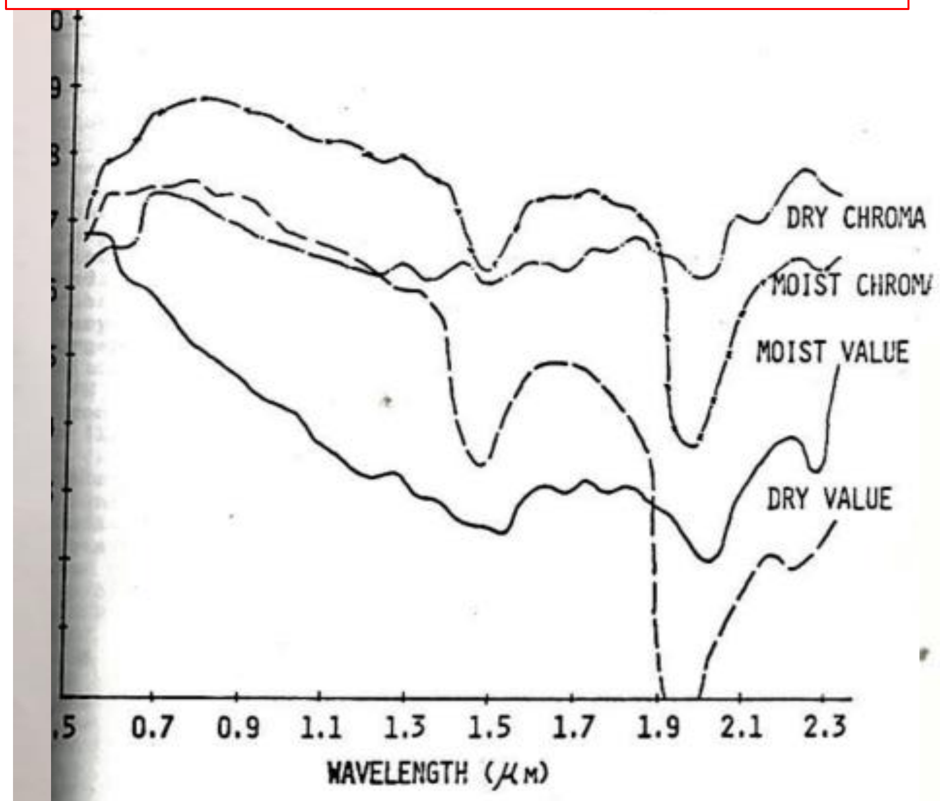
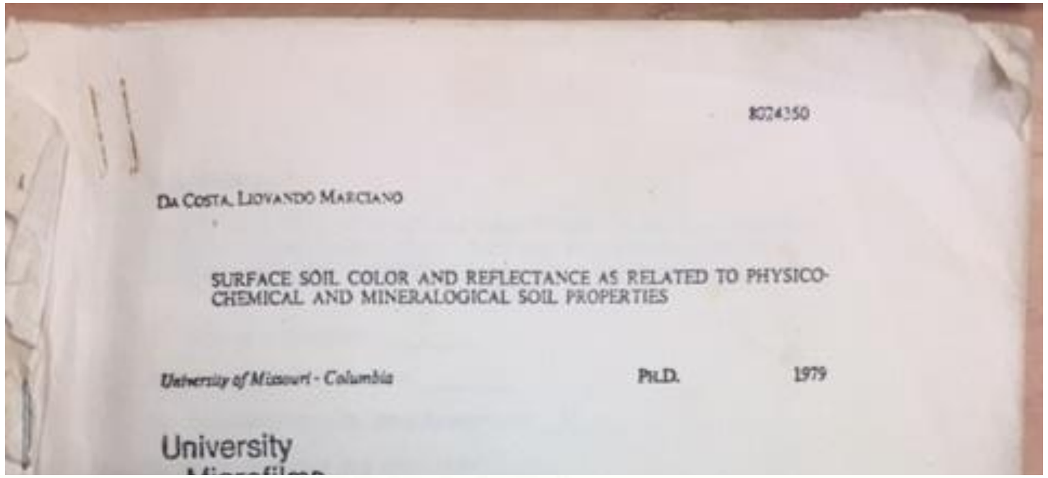


Figure 5-10. Correlation of moist value, moist hroma, dry value and dry chroma with responses in the .50-2.32 μm wavelength interval by a laboratory instrument.



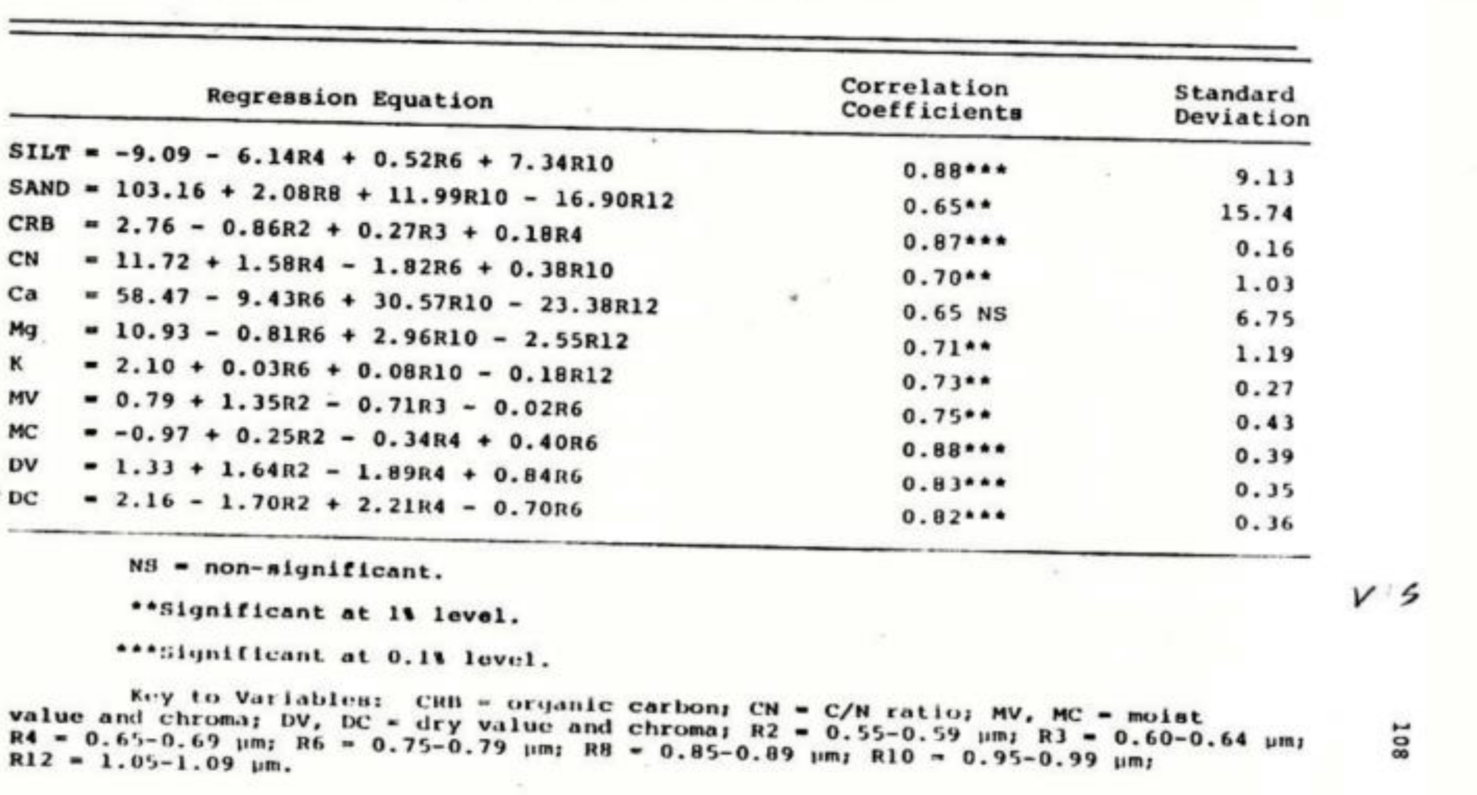
8024350

DA COSTA, LIOVANDO MARCIANO

SURFACE SOIL COLOR AND REFLECTANCE AS RELATED TO PHYSICO-CHEMICAL AND MINERALOGICAL SOIL PROPERTIES

University of Missouri - Columbia Ph.D. 1979

University



Regression Equation	Correlation Coefficients	Standard Deviation
SILT = -9.09 - 6.14R4 + 0.52R6 + 7.34R10	0.88***	9.13
SAND = 103.16 + 2.08R8 + 11.99R10 - 16.90R12	0.65**	15.74
CRB = 2.76 - 0.86R2 + 0.27R3 + 0.18R4	0.87***	0.16
CN = 11.72 + 1.58R4 - 1.82R6 + 0.38R10	0.70**	1.03
Ca = 58.47 - 9.43R6 + 30.57R10 - 23.38R12	0.65 NS	6.75
Mg = 10.93 - 0.81R6 + 2.96R10 - 2.55R12	0.71**	1.19
K = 2.10 + 0.03R6 + 0.08R10 - 0.18R12	0.73**	0.27
MV = 0.79 + 1.35R2 - 0.71R3 - 0.02R6	0.75**	0.43
MC = -0.97 + 0.25R2 - 0.34R4 + 0.40R6	0.88***	0.39
DV = 1.33 + 1.64R2 - 1.89R4 + 0.84R6	0.83***	0.35
DC = 2.16 - 1.70R2 + 2.21R4 - 0.70R6	0.82***	0.36

NS = non-significant.

**Significant at 1% level.

***Significant at 0.1% level.

Key to Variables: CRB = organic carbon; CN = C/N ratio; MV, MC = moist value and chroma; DV, DC = dry value and chroma; R2 = 0.55-0.59 μm; R3 = 0.60-0.64 μm; R4 = 0.65-0.69 μm; R6 = 0.75-0.79 μm; R8 = 0.85-0.89 μm; R10 = 0.95-0.99 μm; R12 = 1.05-1.09 μm.

V 5

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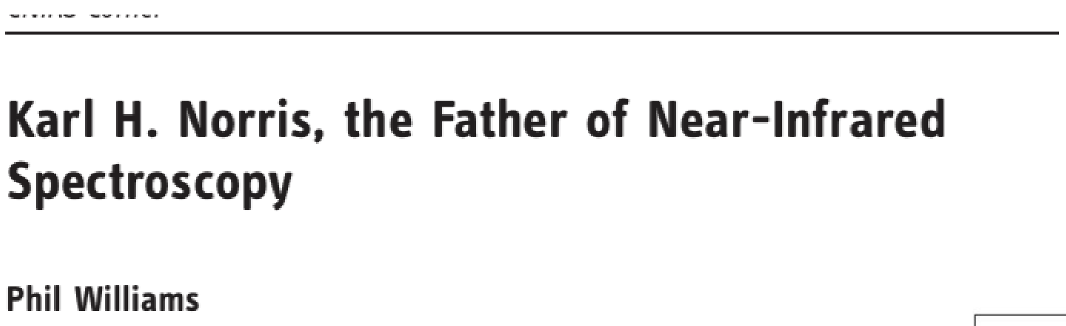
Food Science – The precursor of the modern Proximal Sensing of Soil (1)



Karl H. Norris, the Father of Near-Infrared Spectroscopy

Phil Williams

the Instrument Research Laboratory at the USDA Agricultural Research Centre, Beltsville, M

1950

President Rosevelt visit to USDA 1950

Karl Norris

1921-2019

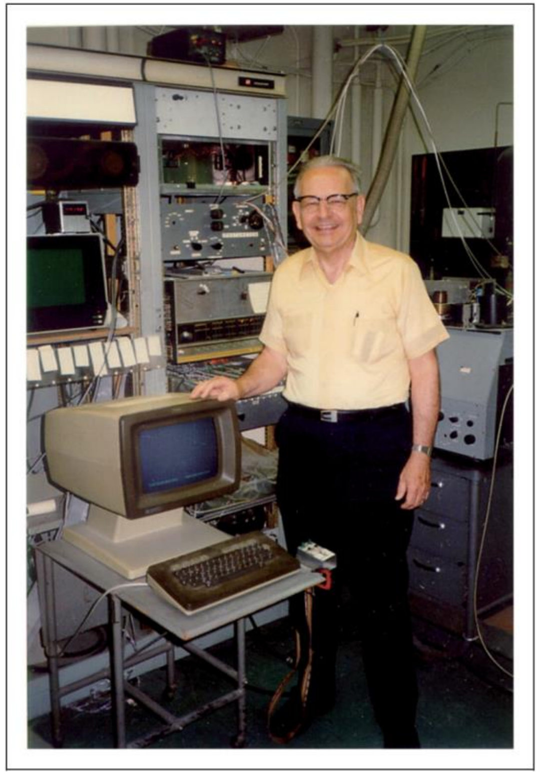


Figure 2. Karl in his element in his instrument laboratory. The image is reproduced by the kind permission of IMPublications.

Check for updates

CNIRS Corner

Karl H. Norris, the Father of Near-Infrared Spectroscopy

Phil Williams

2019

NIR news
2019, Vol. 30(7–8) 25–27
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DOI: 10.1177/0960336019875883
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SAGE

Introduction, materials, and methods

This article is written as a dedication to Karl Norris, the engineer, the near-infrared wizard, and the man. It will be written in the form of a scientific paper, as befits a legendary scientist. There will be an Introduction, followed by Materials and Methods, Results, and Conclusion sections. Karl received a B.Sc. degree in Agricultural Engineering from Pennsylvania State University in 1942, and an honorary Doctorate from Wilson College, Chambersburg, PA in 2006. This is the Introduction.

But what are the materials? The most important materials were a magnificent brain, an astounding memory for detail, and an intuitive capability to identify the things that mattered at the time, or were likely to become important to his work. His years of study with the Armed Services Programme at the University of Chicago (1942–1943), and later with the University of Maryland (1951–1955) afforded him further tools, which enabled him to enter into what turned out to be a momentous career in electronics, and spectroscopy.

These were the Materials. So what about the Methods? In his first job from 1945 to 1946, he worked as a radio engineer with the Airplane and Marine Instrument Co. His first position as an electronic engineer was with the University of Chicago, Institute of Radiobiology and Biophysics. But his impact first became apparent when he began work at the Instrument Research Laboratory at the USDA Agricultural Research Centre, Beltsville, MD. Karl had a highly productive career in spectroscopy before he ventured into near-infrared spectroscopy. Among his earlier works he developed an instrumental method for determination of the quality of fresh eggs spectroscopically. Hitherto the method was 'candling', which involved holding each egg up to the light, one by one. Karl developed an instrument which enabled egg quality to be determined in a batch. The USDA were so impressed with this that Karl's laboratory merited a visit by President Eisenhower (Figure 1: President Ike has the black hat).

His research in the field of plant photobiology focused on non-destructive analysis of pigments, in plants, which resulted in the discovery of the pigment phytochrome, a constituent that is essential to photosynthesis, the process that is mainly responsible for controlling plant metabolism. These are probably Karl's most noteworthy pre-NIRS methods. But Karl's main interest lay in spectroscopy. He considered that every agricultural material should have its own particular spectrum. He considered that these spectral data could be utilized in a rapid method of analysis.

So much for his methods. Now we come to the results. Karl had determined that by rotating a filter through 90°, the effective signal would change by about 10%, so that three filters would provide a range of wavelengths. He built his own spectrometer, using tilting filters, and began to study agricultural materials. The most important wavelengths for many functional groups in the near-infrared area of the electromagnetic spectrum had earlier been documented by Kaye,[1] and Karl figured out that using a computer, with the spectral data as the independent variable it should be possible to predict the composition of an agricultural material by calibrating the instrument, using the laboratory-determined composition as the dependent variable.

His early interest lay with the determination of moisture content in soybeans. He used a discrete filter with optimum wavelength of 1940 nanometers (nm). His results were only moderately successful. It was revealed later that there is a strong protein absorption band at 1978 nm. There is about 10% moisture in ground soybeans, but over 40% protein, so the presence of the higher protein level probably caused the interference in accurate prediction of moisture content (Figure 2).

All of Karl's work had been done on the raw NIR spectral data, and the principles of chemometrics had not been employed. He had been consulted by engineers from Neotec, a small Rockville (MD) company which was considering the development of an instrument that would measure the protein content of wheat. Neotec built, and began to market such an instrument for the rapid on-the-spot determination of protein content in wheat at grain elevators. On the advice of Karl, the

---

PDK Projects, Inc., Nanaimo, Canada

Corresponding author:
Phil Williams, PDK Projects, Inc., Nanaimo, BC, Canada.
Email: philwilliams@pdkgrain.com

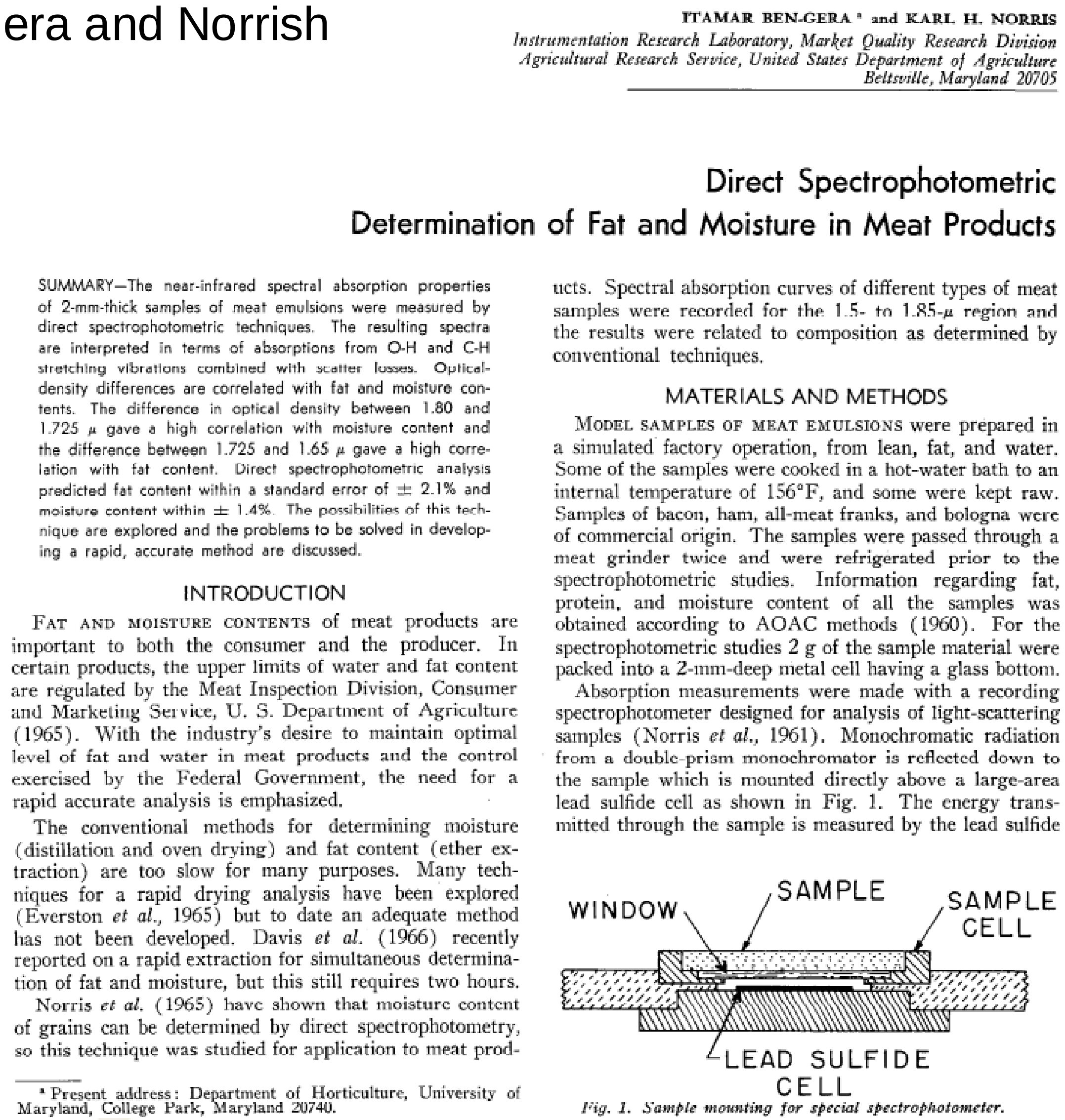
First paper to establish NIRS in Food Sceine

1969

Ben Gera and Norrish

Term: Near Infrared Spectroscopy – NIRS

Using only the 1-2.5 μm region



ITAMAR BEN-GERA [a] and KARL H. NORRIS
Instrumentation Research Laboratory, Market Quality Research Division
Agricultural Research Service, United States Department of Agriculture
Beltsville, Maryland 20705

Direct Spectrophotometric Determination of Fat and Moisture in Meat Products

SUMMARY—The near-infrared spectral absorption properties of 2-mm-thick samples of meat emulsions were measured by direct spectrophotometric techniques. The resulting spectra are interpreted in terms of absorptions from O-H and C-H stretching vibrations combined with scatter losses. Optical-density differences are correlated with fat and moisture contents. The difference in optical density between 1.80 and 1.725 μ gave a high correlation with moisture content and the difference between 1.725 and 1.65 μ gave a high correlation with fat content. Direct spectrophotometric analysis predicted fat content within a standard error of ± 2.1% and moisture content within ± 1.4%. The possibilities of this technique are explored and the problems to be solved in developing a rapid, accurate method are discussed.

INTRODUCTION

FAT AND MOISTURE CONTENTS of meat products are important to both the consumer and the producer. In certain products, the upper limits of water and fat content are regulated by the Meat Inspection Division, Consumer and Marketing Service, U. S. Department of Agriculture (1965). With the industry's desire to maintain optimal level of fat and water in meat products and the control exercised by the Federal Government, the need for a rapid accurate analysis is emphasized.

The conventional methods for determining moisture (distillation and oven drying) and fat content (ether extraction) are too slow for many purposes. Many techniques for a rapid drying analysis have been explored (Everston *et al.*, 1965) but to date an adequate method has not been developed. Davis *et al.* (1966) recently reported on a rapid extraction for simultaneous determination of fat and moisture, but this still requires two hours.

Norris *et al.* (1965) have shown that moisture content of grains can be determined by direct spectrophotometry, so this technique was studied for application to meat products. Spectral absorption curves of different types of meat samples were recorded for the 1.5- to 1.85-μ region and the results were related to composition as determined by conventional techniques.

MATERIALS AND METHODS

MODEL SAMPLES OF MEAT EMULSIONS were prepared in a simulated factory operation, from lean, fat, and water. Some of the samples were cooked in a hot-water bath to an internal temperature of 156°F, and some were kept raw. Samples of bacon, ham, all-meat franks, and bologna were of commercial origin. The samples were passed through a meat grinder twice and were refrigerated prior to the spectrophotometric studies. Information regarding fat, protein, and moisture content of all the samples was obtained according to AOAC methods (1960). For the spectrophotometric studies 2 g of the sample material were packed into a 2-mm-deep metal cell having a glass bottom.

Absorption measurements were made with a recording spectrophotometer designed for analysis of light-scattering samples (Norris *et al.*, 1961). Monochromatic radiation from a double-prism monochromator is reflected down to the sample which is mounted directly above a large-area lead sulfide cell as shown in Fig. 1. The energy transmitted through the sample is measured by the lead sulfide

Fig. 1. Sample mounting for special spectrophotometer.

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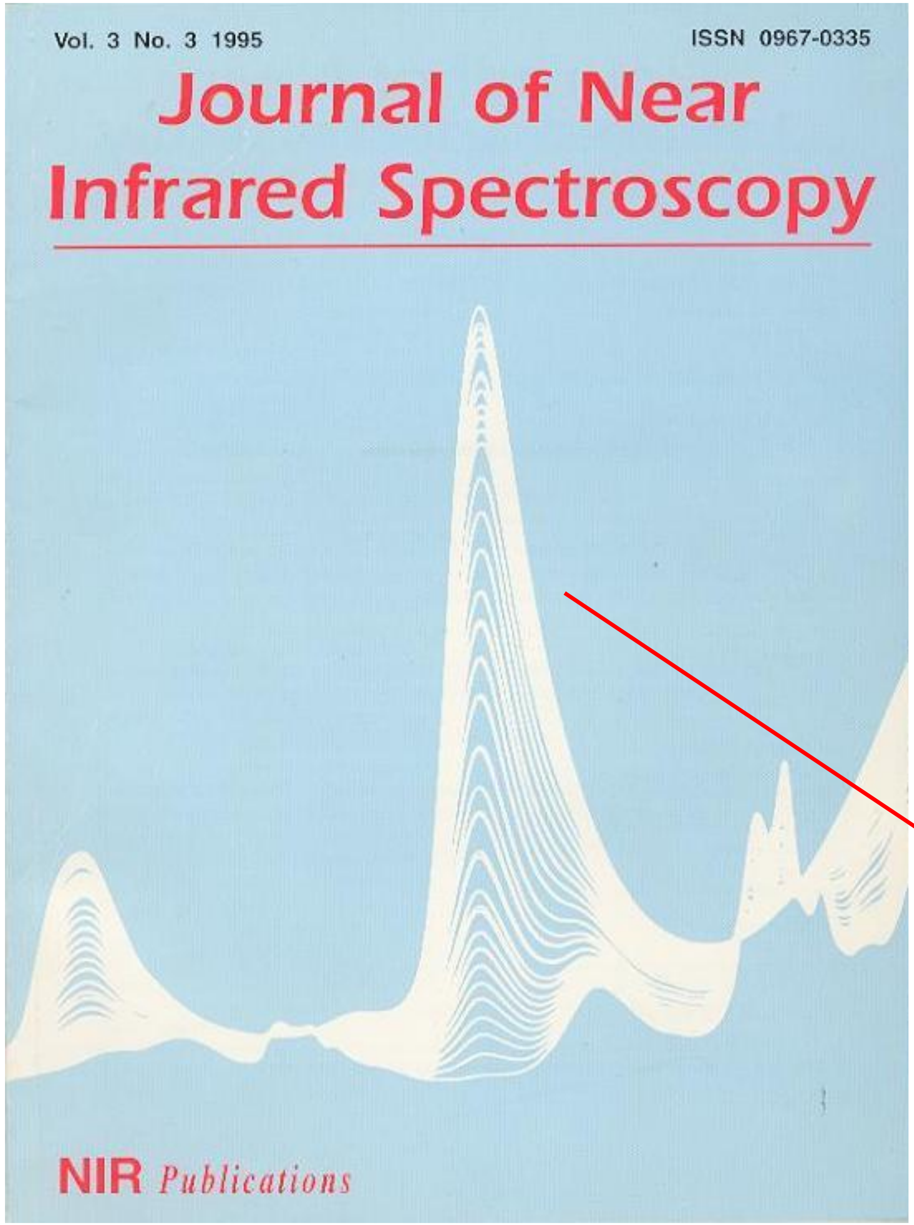
[a] Present address: Department of Horticulture, University of Maryland, College Park, Maryland 20740.



Vol. 3 No. 3 1995

ISSN 0967-0335

Journal of Near Infrared Spectroscopy

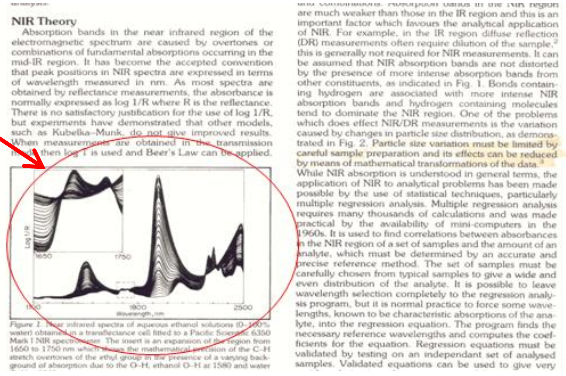
NIR Publications

First Journal in NIR analysis

1986

Impact Factor 1.2

Taken from Davies 1986 paper



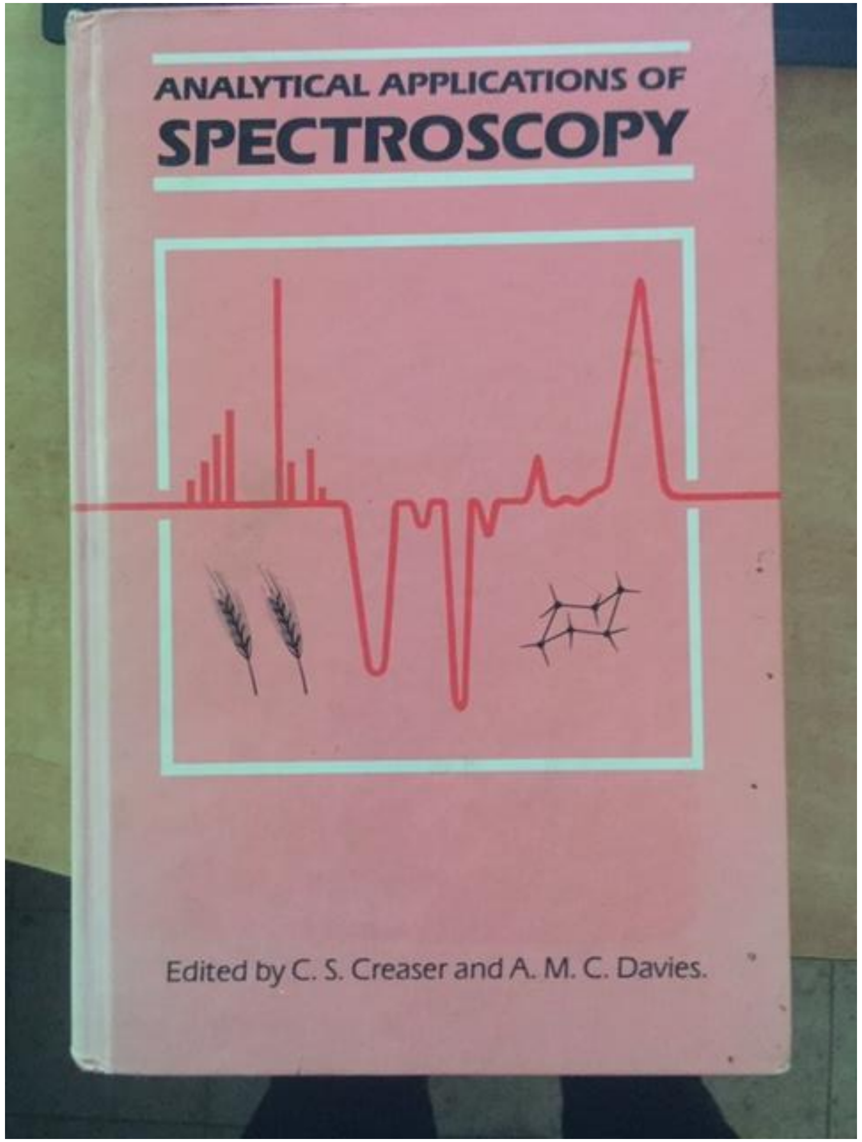
NIR Theory

Absorption bands in the near infrared region of the electromagnetic spectrum are caused by overtones or combinations of fundamental absorptions occurring in the mid-IR region. It has become the accepted convention that peak positions in NIR spectra are expressed in terms of wavelength measured in nm. As most spectra are obtained by reflectance measurements, the absorbance is normally expressed as log 1/R where R is the reflectance. There is no satisfactory justification for the use of log 1/R, but experiments have demonstrated that other models, such as Kubelka–Munk, do not give improved results. When measurements are obtained in the transmission mode then log 1 is used and Beer's Law can be applied.

Figure 1. Near infrared spectra of aqueous ethanol solutions (0–100% water) obtained in a transflectance cell fitted to a Pacific Scientific 6350 Mark I NIR spectrometer. The insert is an expansion of the region from 1650 to 1750 nm which shows the mathematical precision of the C–H stretch overtones of the ethyl group in the presence of a varying background of absorption due to the O–H, ethanol O–H at 1580 and water

are much weaker than those in the IR region and this is an important factor which favours the analytical application of NIR. For example, in the IR region diffuse reflection (DR) measurements often require dilution of the sample,[2] this is generally not required for NIR measurements. It can be assumed that NIR absorption bands are not distorted by the presence of more intense absorption bands from other constituents, as indicated in Fig. 1. Bonds containing hydrogen are associated with more intense NIR absorption bands and hydrogen containing molecules tend to dominate the NIR region. One of the problems which does effect NIR/DR measurements is the variation caused by changes in particle size distribution, as demonstrated in Fig. 2. Particle size variation must be limited by careful sample preparation and its effects can be reduced by means of mathematical transformations of the data.[3] While NIR absorption is understood in general terms, the application of NIR to analytical problems has been made possible by the use of statistical techniques, particularly multiple regression analysis. Multiple regression analysis requires many thousands of calculations and was made practical by the availability of mini-computers in the 1960s. It is used to find correlations between absorbances in the NIR region of a set of samples and the amount of an analyte, which must be determined by an accurate and precise reference method. The set of samples must be carefully chosen from typical samples to give a wide and even distribution of the analyte. It is possible to leave wavelength selection completely to the regression analysis program, but it is normal practice to force some wavelengths, known to be characteristic absorptions of the analyte, into the regression equation. The program finds the necessary reference wavelengths and computes the coefficients for the equation. Regression equations must be validated by testing on an independant set of analysed samples. Validated equations can be used to give very

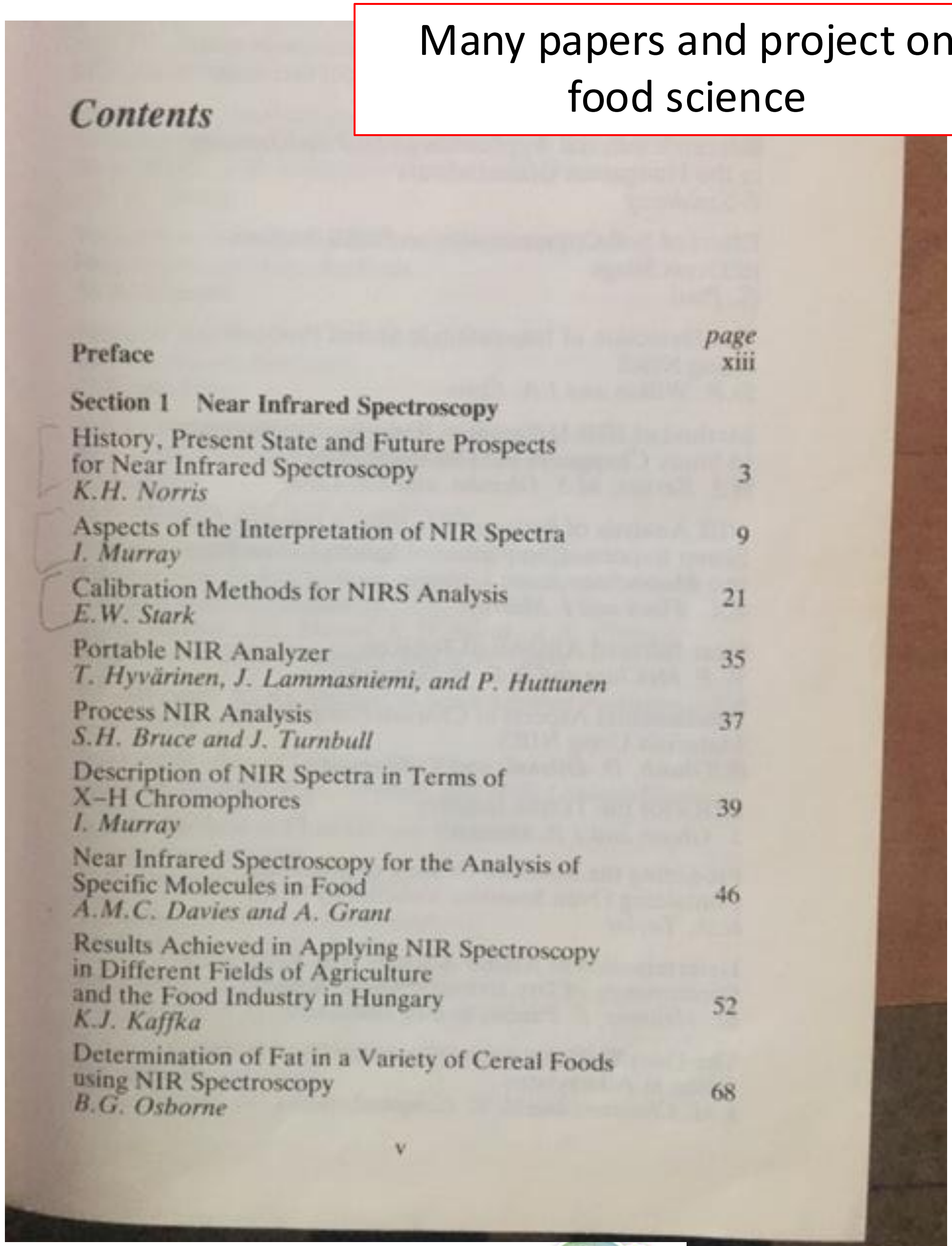
1988 First Conference on NIRS



ANALYTICAL APPLICATIONS OF
SPECTROSCOPY

Edited by C. S. Creaser and A. M. C. Davies.

Many papers and project on food science



Contents

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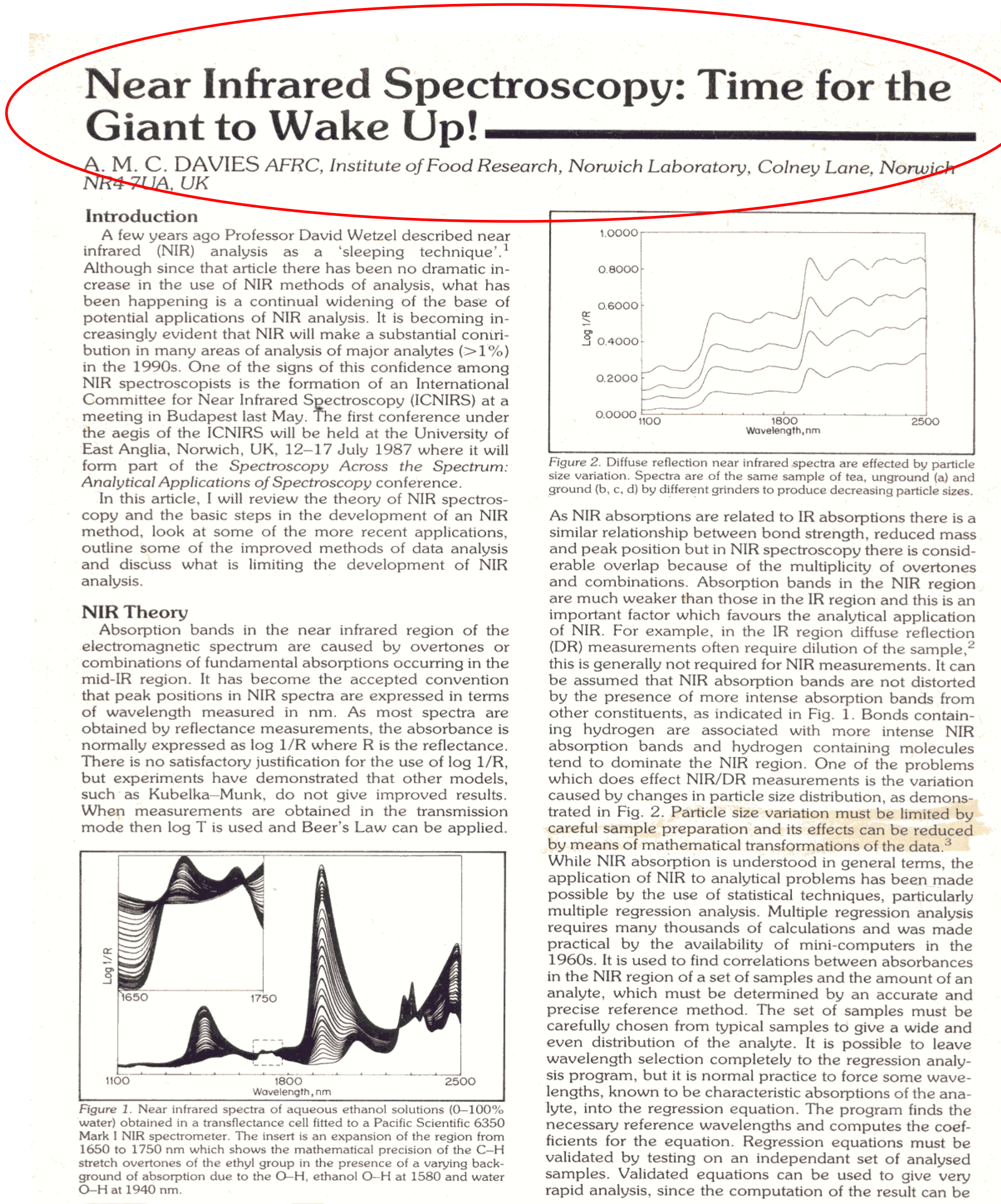
Food Science – The precursor of the modern Proximal Sensing of Soil (2)



Near Infrared Spectroscopy: Time for the Giant to Wake Up!

A. M. C. DAVIES *AFRC, Institute of Food Research, Norwich Laboratory, Colney Lane, Norwich NR4 7UA, UK*

Introduction

A few years ago Professor David Wetzel described near infrared (NIR) analysis as a 'sleeping technique'.[1] Although since that article there has been no dramatic increase in the use of NIR methods of analysis, what has been happening is a continual widening of the base of potential applications of NIR analysis. It is becoming increasingly evident that NIR will make a substantial contribution in many areas of analysis of major analytes (>1%) in the 1990s. One of the signs of this confidence among NIR spectroscopists is the formation of an International Committee for Near Infrared Spectroscopy (ICNIRS) at a meeting in Budapest last May. The first conference under the aegis of the ICNIRS will be held at the University of East Anglia, Norwich, UK, 12–17 July 1987 where it will form part of the *Spectroscopy Across the Spectrum: Analytical Applications of Spectroscopy* conference.

In this article, I will review the theory of NIR spectroscopy and the basic steps in the development of an NIR method, look at some of the more recent applications, outline some of the improved methods of data analysis and discuss what is limiting the development of NIR analysis.

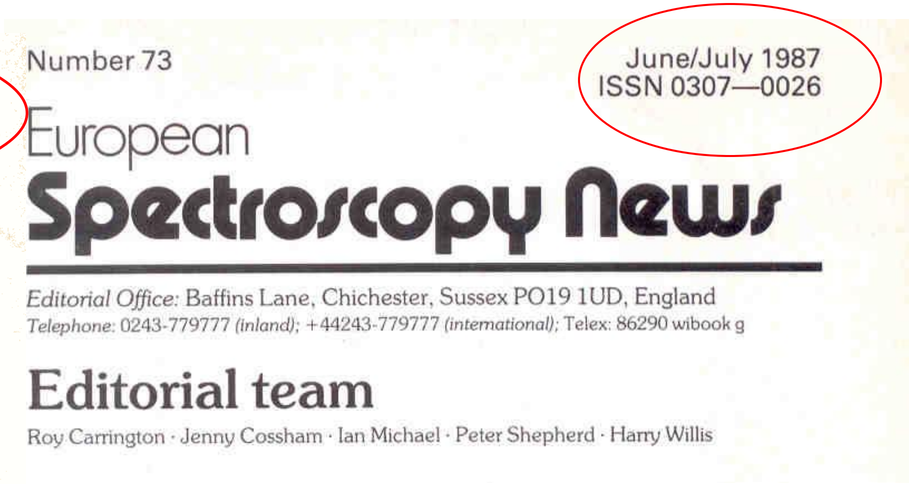
NIR Theory

Absorption bands in the near infrared region of the electromagnetic spectrum are caused by overtones or combinations of fundamental absorptions occurring in the mid-IR region. It has become the accepted convention that peak positions in NIR spectra are expressed in terms of wavelength measured in nm. As most spectra are obtained by reflectance measurements, the absorbance is normally expressed as log 1/R where R is the reflectance. There is no satisfactory justification for the use of log 1/R, but experiments have demonstrated that other models, such as Kubelka–Munk, do not give improved results. When measurements are obtained in the transmission mode then log T is used and Beer's Law can be applied.

Figure 1. Near infrared spectra of aqueous ethanol solutions (0–100% water) obtained in a transflectance cell fitted to a Pacific Scientific 6350 Mark I NIR spectrometer. The insert is an expansion of the region from 1650 to 1750 nm which shows the mathematical precision of the C–H stretch overtones of the ethyl group in the presence of a varying background of absorption due to the O–H, ethanol O–H at 1580 and water O–H at 1940 nm.

Figure 2. Diffuse reflection near infrared spectra are effected by particle size variation. Spectra are of the same sample of tea, unground (a) and ground (b, c, d) by different grinders to produce decreasing particle sizes.

As NIR absorptions are related to IR absorptions there is a similar relationship between bond strength, reduced mass and peak position but in NIR spectroscopy there is considerable overlap because of the multiplicity of overtones and combinations. Absorption bands in the NIR region are much weaker than those in the IR region and this is an important factor which favours the analytical application of NIR. For example, in the IR region diffuse reflection (DR) measurements often require dilution of the sample,[2] this is generally not required for NIR measurements. It can be assumed that NIR absorption bands are not distorted by the presence of more intense absorption bands from other constituents, as indicated in Fig. 1. Bonds containing hydrogen are associated with more intense NIR absorption bands and hydrogen containing molecules tend to dominate the NIR region. One of the problems which does effect NIR/DR measurements is the variation caused by changes in particle size distribution, as demonstrated in Fig. 2. Particle size variation must be limited by careful sample preparation and its effects can be reduced by means of mathematical transformations of the data.[3] While NIR absorption is understood in general terms, the application of NIR to analytical problems has been made possible by the use of statistical techniques, particularly multiple regression analysis. Multiple regression analysis requires many thousands of calculations and was made practical by the availability of mini-computers in the 1960s. It is used to find correlations between absorbances in the NIR region of a set of samples and the amount of an analyte, which must be determined by an accurate and precise reference method. The set of samples must be carefully chosen from typical samples to give a wide and even distribution of the analyte. It is possible to leave wavelength selection completely to the regression analysis program, but it is normal practice to force some wavelengths, known to be characteristic absorptions of the analyte, into the regression equation. The program finds the necessary reference wavelengths and computes the coefficients for the equation. Regression equations must be validated by testing on an independant set of analysed samples. Validated equations can be used to give very rapid analysis, since the computation of the result can be



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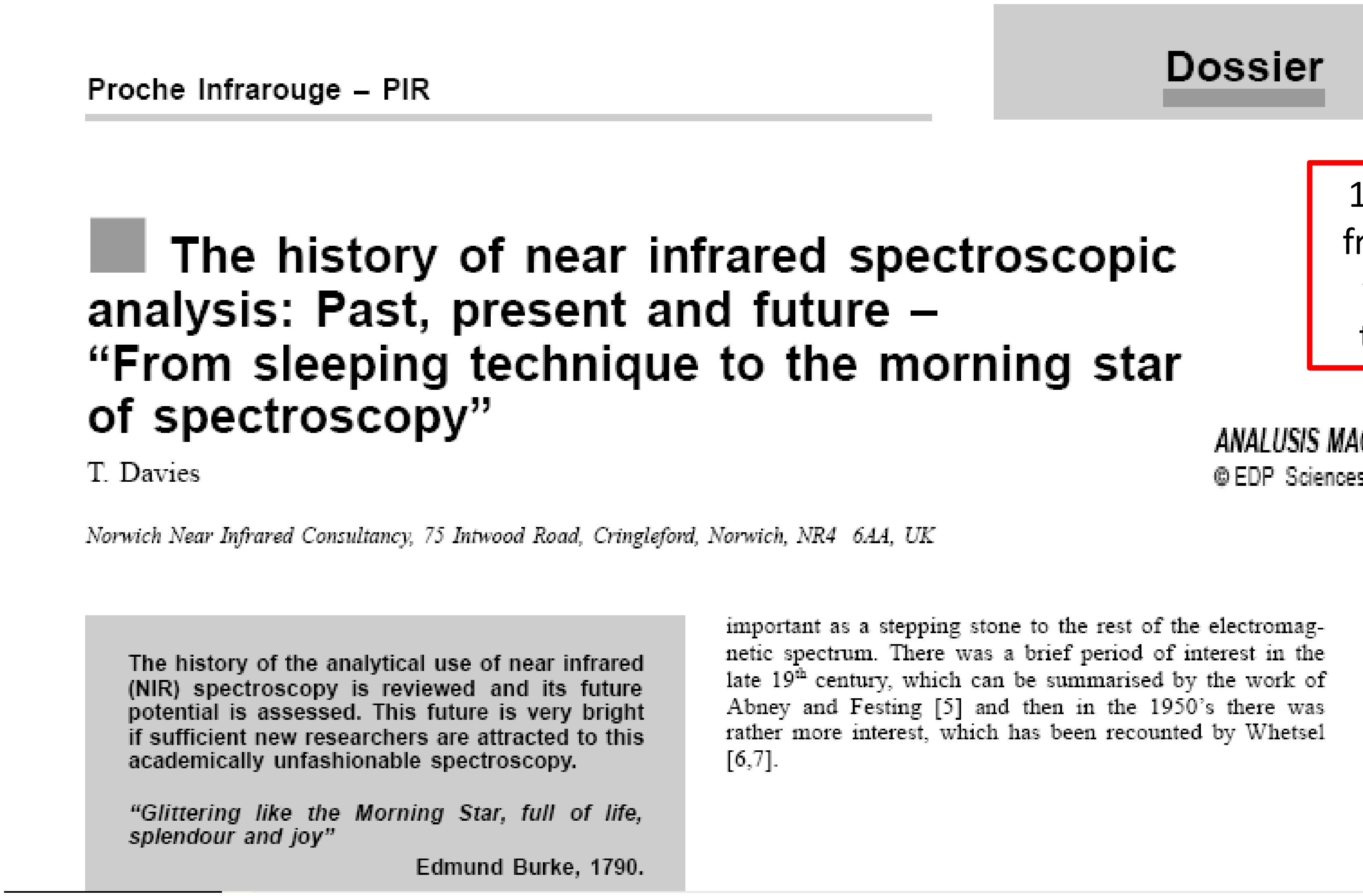
Editorial team

1987

Food Science

Food Science – **The precursor of the modern Proximal Sensing of Soil (3)**

1998



Proche Infrarouge – PIR

Dossier

The history of near infrared spectroscopic analysis: Past, present and future – "From sleeping technique to the morning star of spectroscopy"

T. Davies

Norwich Near Infrared Consultancy, 75 Intwood Road, Cringleford, Norwich, NR4 6AA, UK

The history of the analytical use of near infrared (NIR) spectroscopy is reviewed and its future potential is assessed. This future is very bright if sufficient new researchers are attracted to this academically unfashionable spectroscopy.

"Glittering like the Morning Star, full of life, splendour and joy"

Edmund Burke, 1790.

important as a stepping stone to the rest of the electromagnetic spectrum. There was a brief period of interest in the late 19th century, which can be summarised by the work of Abney and Festing [5] and then in the 1950's there was rather more interest, which has been recounted by Whetsel [6,7].

11 years gap from first call to working technology

ANALUSIS MAGAZINE, 1998, 26, N° 4

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First NIRS soil paper (after the “food science” success)

1986

Soil Science Society of America Journal

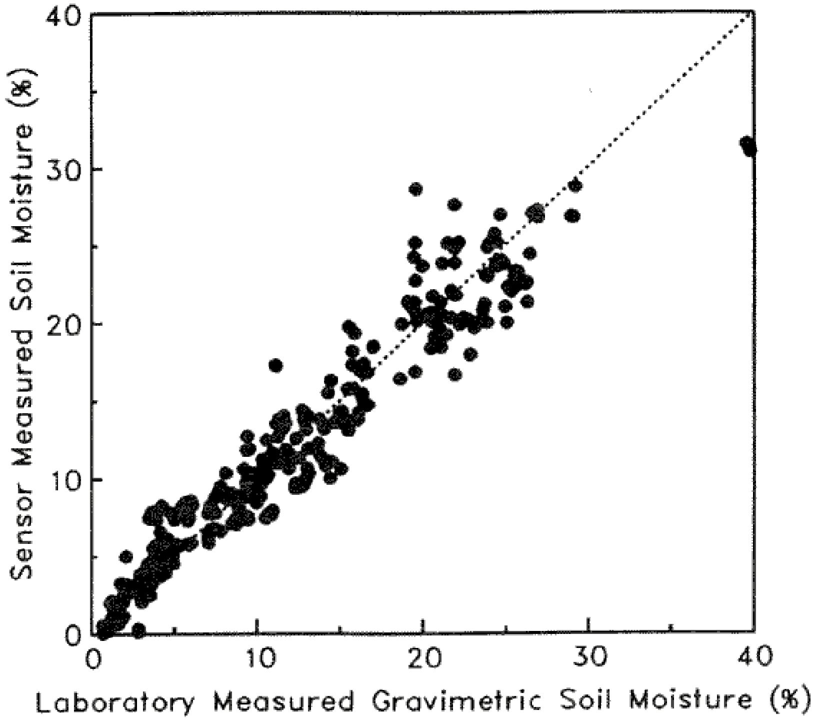
SSSA
Soil Science Society of America

Division S-3—Soil Microbiology and Biochemistry

Simultaneous Determination of Moisture, Organic Carbon, and Total Nitrogen by Near Infrared Reflectance Spectrophotometry†

R. C. Dalal, R. J. Henry

Organic C, Total N, Moisture



First paper to enlarge the Soil Attributes (direct chromophors)

1994

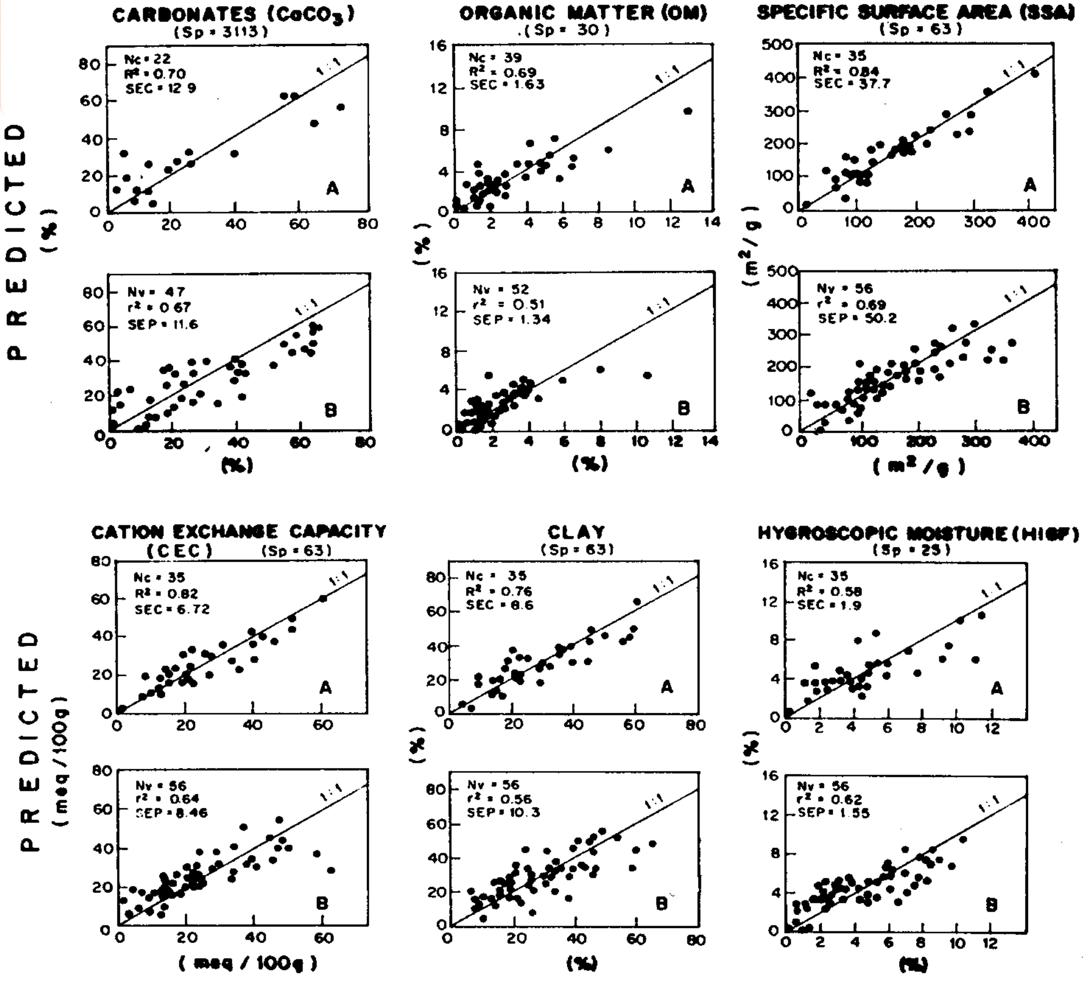
Soil Science Society of America Journal

Division S-2—Soil Chemistry

Near-Infrared Analysis as a Rapid Method to Simultaneously Evaluate Several Soil Properties

E. Ben-Dor, A. Banin

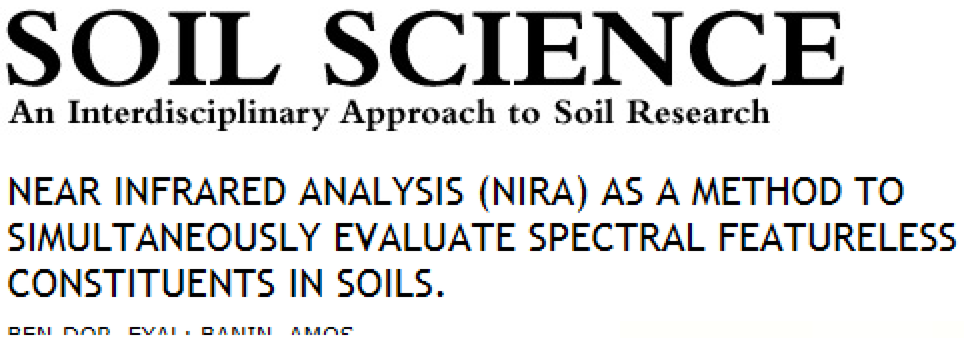
NIRS- SWIR (1-2.5 μm)



First exploitation (or foundation) of the *predotransfer function*

More Soil Attributes (Indirect Chromophors)

1995



SOIL SCIENCE

An Interdisciplinary Approach to Soil Research

NEAR INFRARED ANALYSIS (NIRA) AS A METHOD TO SIMULTANEOUSLY EVALUATE SPECTRAL FEATURELESS CONSTITUENTS IN SOILS.

BEN-DOR, EYAL; BANIN, AMOS

SWIR region (1-2.5 μm)

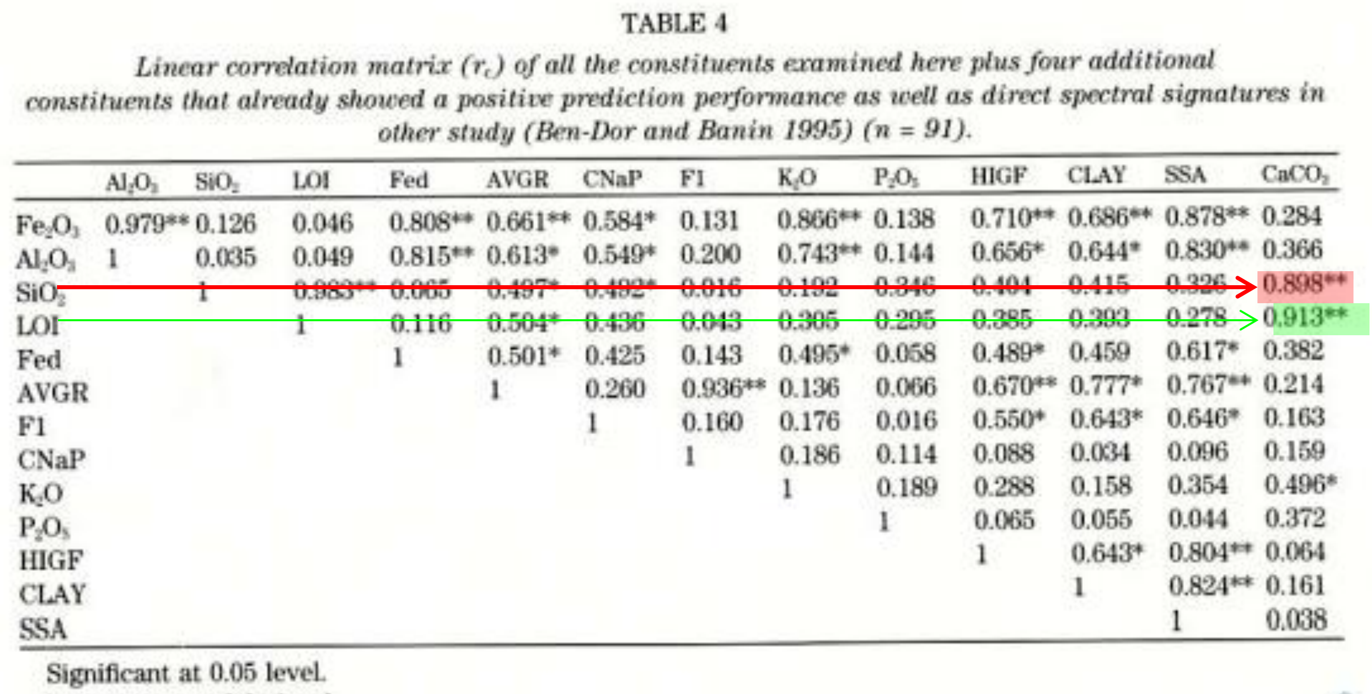


TABLE 4

Linear correlation matrix (r_c) of all the constituents examined here plus four additional constituents that already showed a positive prediction performance as well as direct spectral signatures in other study (Ben-Dor and Banin 1995) (n = 91).

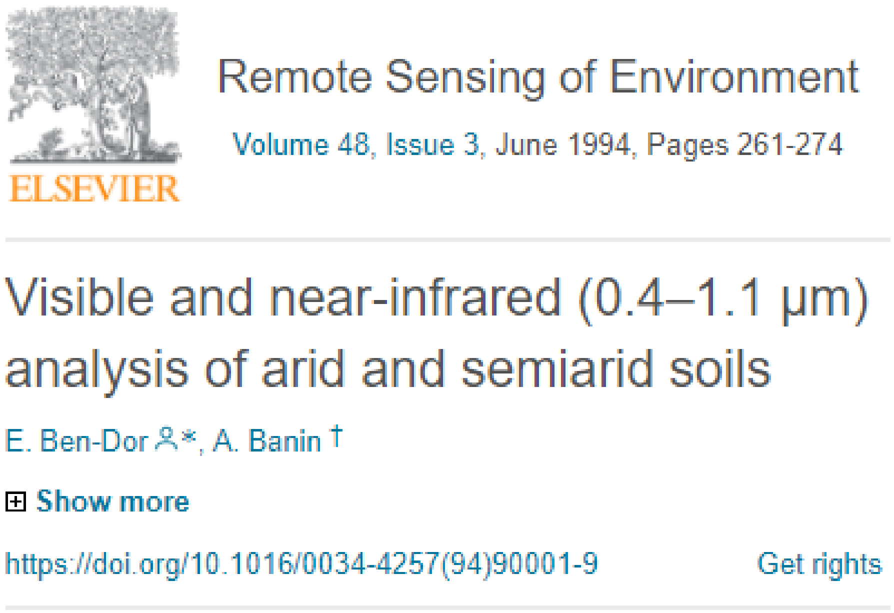
	Al_2O_3	SiO_2	LOI	Fed	AVGR	CNaP	F1	K_2O	P_2O_5	HIGF	CLAY	SSA	$CaCO_3$
Fe_2O_3	0.979**	0.126	0.046	0.808**	0.661**	0.584*	0.131	0.866**	0.138	0.710**	0.686**	0.878**	0.284
Al_2O_3	1	0.035	0.049	0.815**	0.613*	0.549*	0.200	0.743**	0.144	0.656*	0.644*	0.830**	0.366
SiO_2		1	0.983**	0.065	0.497*	0.492*	0.016	0.192	0.346	0.404	0.415	0.326	0.898**
LOI			1	0.116	0.504*	0.436	0.043	0.305	0.295	0.385	0.393	0.278	0.913**
Fed				1	0.501*	0.425	0.143	0.495*	0.058	0.489*	0.459	0.617*	0.382
AVGR					1	0.260	0.936**	0.136	0.066	0.670**	0.777*	0.767**	0.214
F1						1	0.160	0.176	0.016	0.550*	0.643*	0.646*	0.163
CNaP							1	0.186	0.114	0.088	0.034	0.096	0.159
K_2O								1	0.189	0.288	0.158	0.354	0.496*
P_2O_5									1	0.065	0.055	0.044	0.372
HIGF										1	0.643*	0.804**	0.064
CLAY											1	0.824**	0.161
SSA												1	0.038

Significant at 0.05 level.

*Significant at 0.01 level

First paper on soil spectral analysis in the VIS-NIR region 1994

1994



ELSEVIER

Remote Sensing of Environment

Volume 48, Issue 3, June 1994, Pages 261-274

Visible and near-infrared (0.4–1.1 μm) analysis of arid and semiarid soils

E. Ben-Dor, A. Banin †

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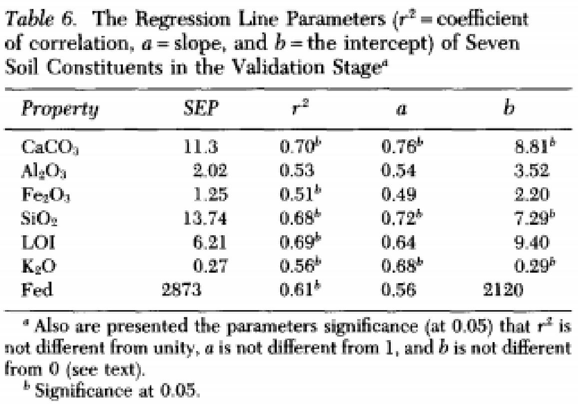
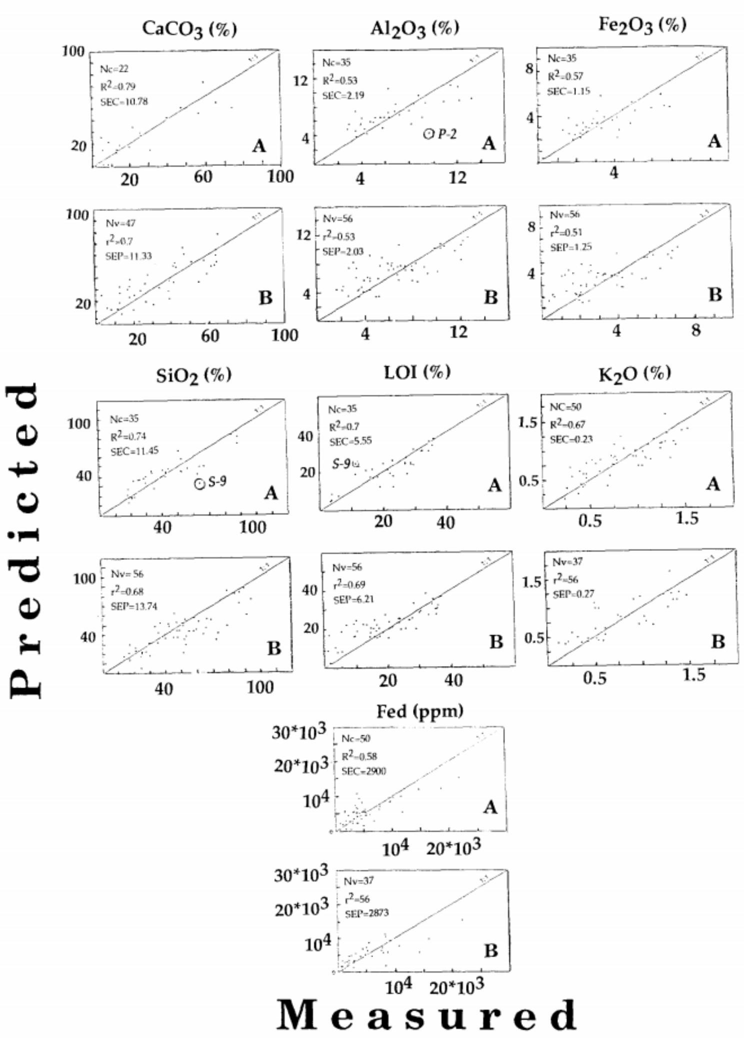


Table 6. The Regression Line Parameters (r^2 = coefficient of correlation, a = slope, and b = the intercept) of Seven Soil Constituents in the Validation Stage[a]

Property	*SEP*	r^2	a	b
$CaCO_3$	11.3	0.70[b]	0.76[b]	8.81[b]
Al_2O_3	2.02	0.53	0.54	3.52
Fe_2O_3	1.25	0.51[b]	0.49	2.20
SiO_2	13.74	0.68[b]	0.72[b]	7.29[b]
LOI	6.21	0.69[b]	0.64	9.40
K_2O	0.27	0.56[b]	0.68[b]	0.29[b]
Fed	2873	0.61[b]	0.56	2120

[a] Also are presented the parameters significance (at 0.05) that r^2 is not different from unity, a is not different from 1, and b is not different from 0 (see text).

[b] Significance at 0.05.



Enlarging the NIRS to VIS-NIR & Lower spectral resolution

First paper demonstrating that not always high spectral resolution yields the best performance

1995

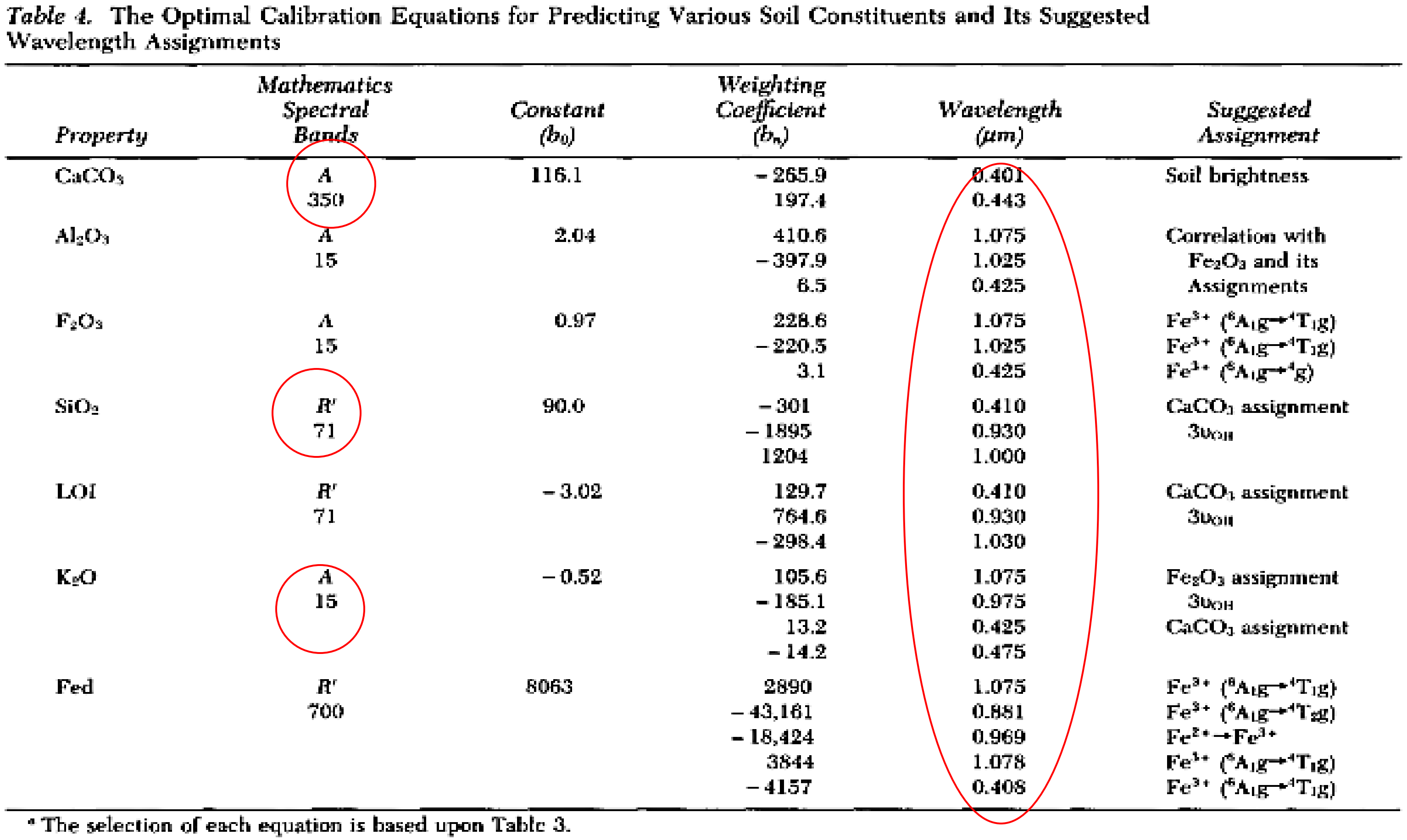


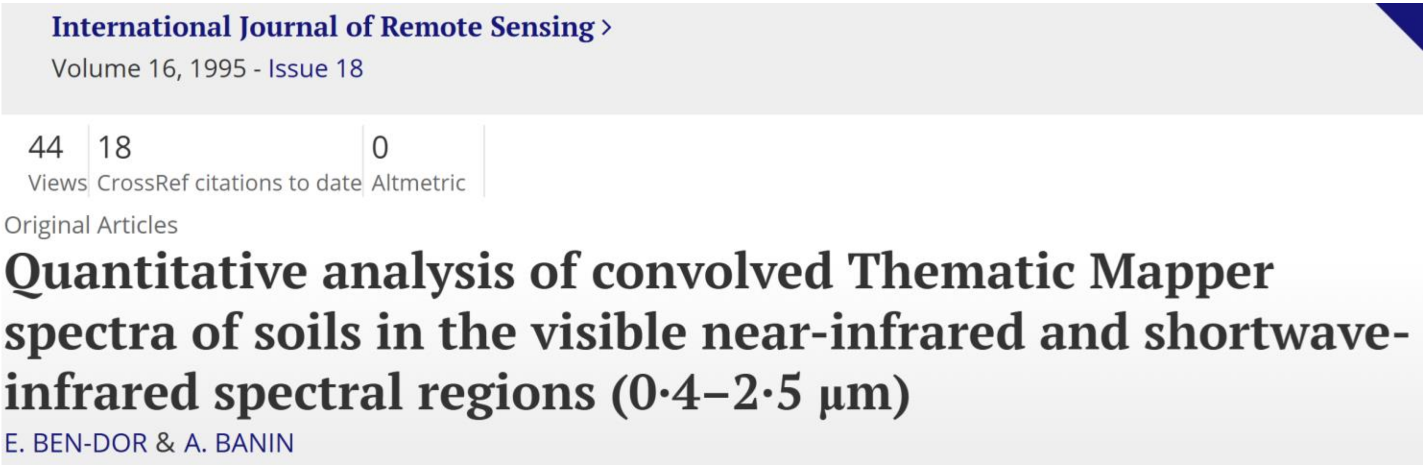
Table 4. The Optimal Calibration Equations for Predicting Various Soil Constituents and Its Suggested Wavelength Assignments

Property	*Mathematics Spectral Bands*	*Constant (b_0)*	*Weighting Coefficient (b_n)*	*Wavelength (μm)*	*Suggested Assignment*
$CaCO_3$	*A* 350	116.1	−265.9 197.4	0.401 0.443	Soil brightness
Al_2O_3	*A* 15	2.04	410.6 −397.9 6.5	1.075 1.025 0.425	Correlation with Fe_2O_3 and its Assignments
F_2O_3	*A* 15	0.97	228.6 −220.5 3.1	1.075 1.025 0.425	Fe^{3+} ($^6A_1g \rightarrow {}^4T_1g$) Fe^{3+} ($^6A_1g \rightarrow {}^4T_1g$) Fe^{3+} ($^6A_1g \rightarrow {}^4g$)
SiO_2	*R'* 71	90.0	−301 −1895 1204	0.410 0.930 1.000	$CaCO_3$ assignment $3\upsilon_{OH}$
LOI	*R'* 71	−3.02	129.7 764.6 −298.4	0.410 0.930 1.030	$CaCO_3$ assignment $3\upsilon_{OH}$
K_2O	*A* 15	−0.52	105.6 −185.1 13.2 −14.2	1.075 0.975 0.425 0.475	Fe_2O_3 assignment $3\upsilon_{OH}$ $CaCO_3$ assignment
Fed	*R'* 700	8063	2890 −43,161 −18,424 3844 −4157	1.075 0.881 0.969 1.078 0.408	Fe^{3+} ($^6A_1g \rightarrow {}^4T_1g$) Fe^{3+} ($^6A_1g \rightarrow {}^4T_2g$) $Fe^{2+} \rightarrow Fe^{3+}$ Fe^{3+} ($^6A_1g \rightarrow {}^4T_1g$) Fe^{3+} ($^6A_1g \rightarrow {}^4T_1g$)

[a] The selection of each equation is based upon Table 3.

First paper demonstrated that low spectral resolution of TM satellite can provide reasonable prediction models

1994



International Journal of Remote Sensing ›

Volume 16, 1995 - Issue 18

44	18	0
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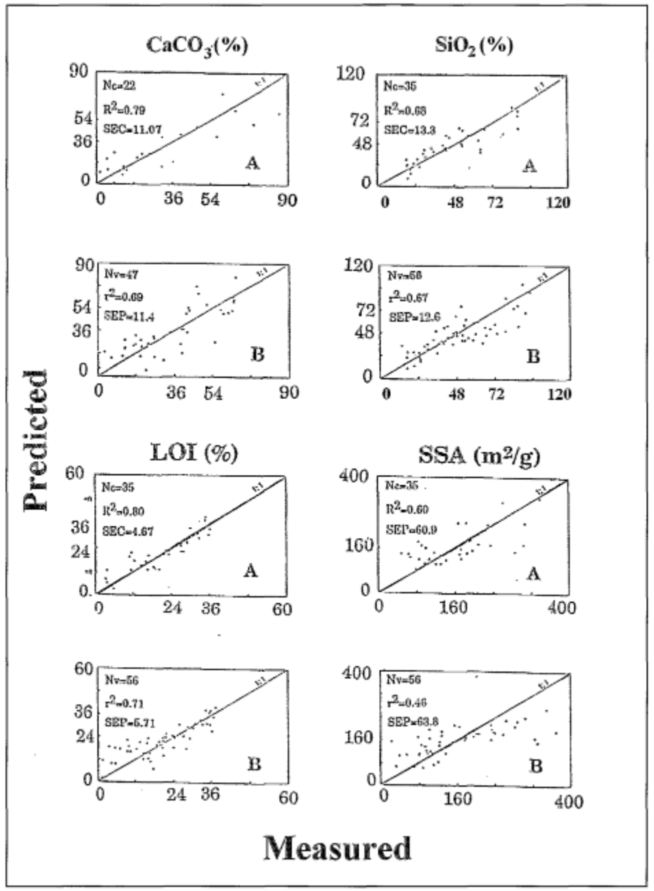
Original Articles

Quantitative analysis of convolved Thematic Mapper spectra of soils in the visible near-infrared and shortwave-infrared spectral regions (0·4–2·5 μm)

E. BEN-DOR & A. BANIN

E. BEN-DOR, A. BANIN



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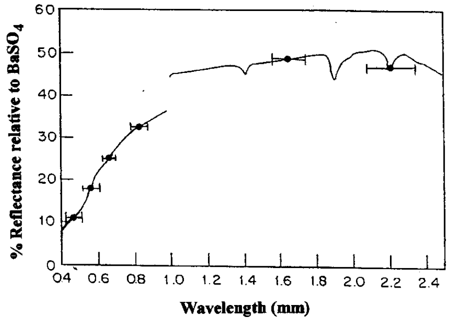

Remote Sensing of Environment

Volume 55, Issue 1, January 1996, Pages 1–10

1996

A modified hapke model for soil bidirectional reflectance *

Shunlin Liang *, John R.G. Townshend *

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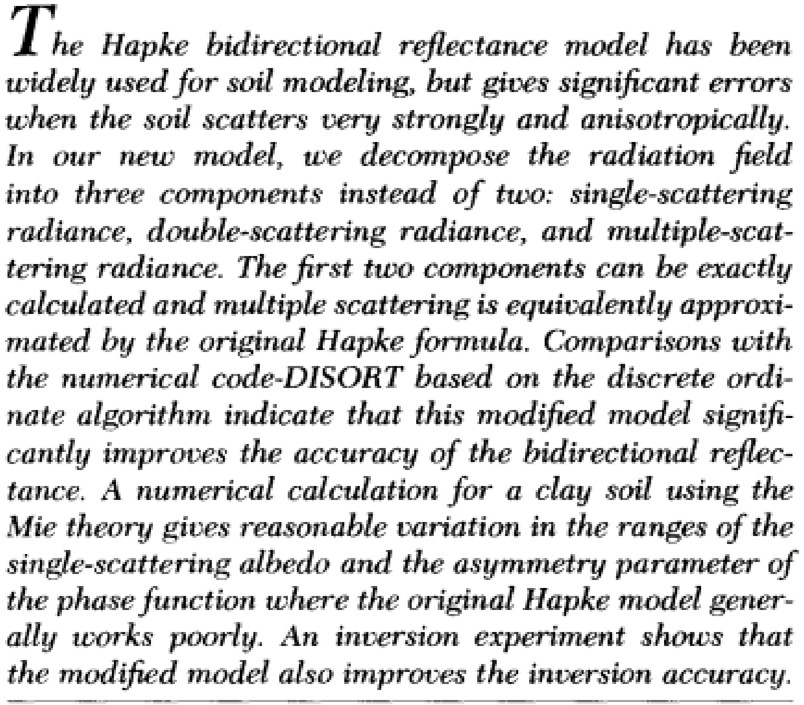
Hapke Radiative Transfer Theory

Bidirectional reflectance spectroscopy: 1. Theory



The Hapke bidirectional reflectance model has been widely used for soil modeling, but gives significant errors when the soil scatters very strongly and anisotropically. In our new model, we decompose the radiation field into three components instead of two: single-scattering radiance, double-scattering radiance, and multiple-scattering radiance. The first two components can be exactly calculated and multiple scattering is equivalently approximated by the original Hapke formula. Comparisons with the numerical code-DISORT based on the discrete ordinate algorithm indicate that this modified model significantly improves the accuracy of the bidirectional reflectance. A numerical calculation for a clay soil using the Mie theory gives reasonable variation in the ranges of the single-scattering albedo and the asymmetry parameter of the phase function where the original Hapke model generally works poorly. An inversion experiment shows that the modified model also improves the inversion accuracy.

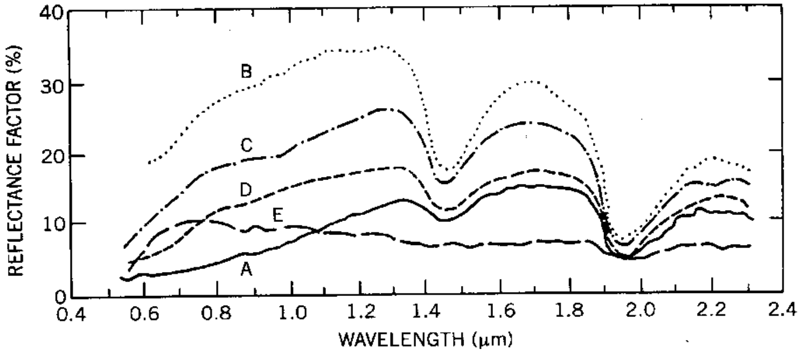
Radiative Transfer Model to Replace the Empirical Models

First Soil Spectral Library

1980

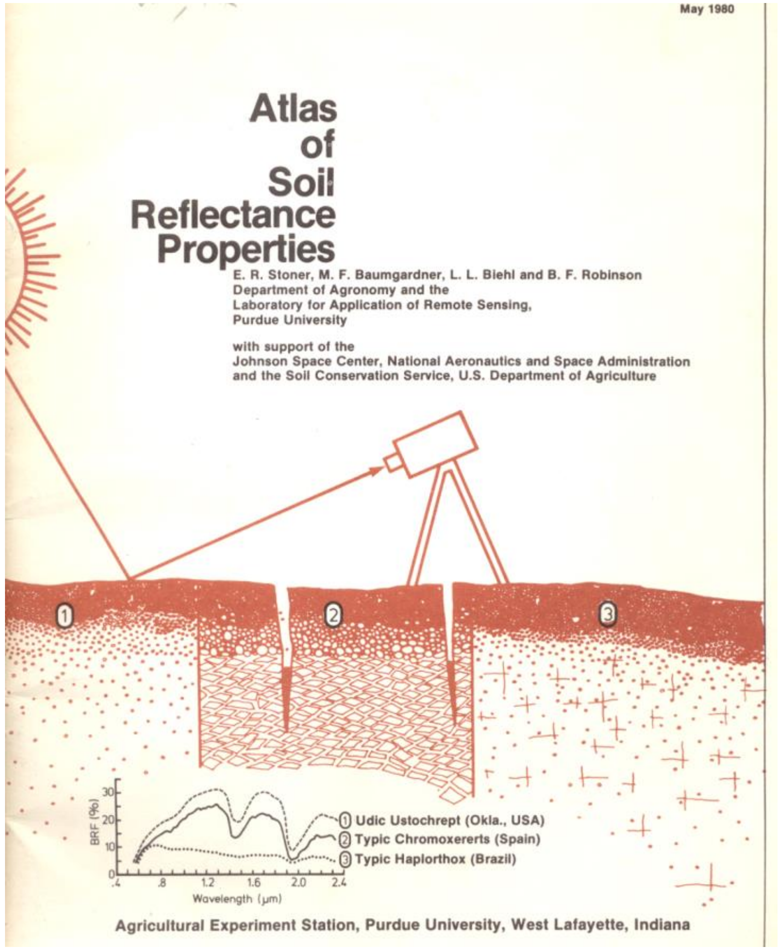
5 spectral types
in USA

Around 4000 spectra



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

Stoner and Baumgardner



May 1980

Atlas
of
Soil
Reflectance
Properties

E. R. Stoner, M. F. Baumgardner, L. L. Biehl and B. F. Robinson
Department of Agronomy and the
Laboratory for Application of Remote Sensing,
Purdue University

with support of the
Johnson Space Center, National Aeronautics and Space Administration
and the Soil Conservation Service, U.S. Department of Agriculture

① Udic Ustochrept (Okla., USA)
② Typic Chromoxererts (Spain)
③ Typic Haplorthox (Brazil)

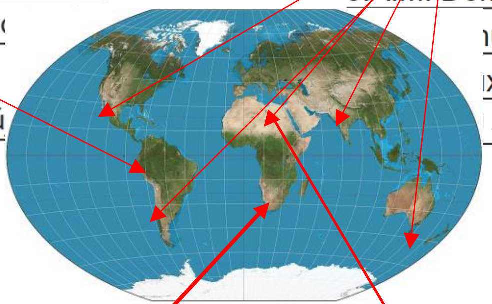
Agricultural Experiment Station, Purdue University, West Lafayette, Indiana

Geoderma

Volume 354, 15 November 2019, 113793

The Brazilian Soil Spectral Library (BSSL): A general view, application and challenges

José A.M. Demattê [a], André Carnieletto Dotto [a], Ariane F.S. Paiva [a], Marcus V. Sato [a], Ricardo S.D. Dalmolin [b], Maria do Socorro B. de Ar Elisângela B. da Silva [d], Marcos R. Nanni [e], Alexandre ten Caten [f], Norberto C. Noronha [g], Marilusa P.C. Lacerda [h], José Coelho de Araú Rodnei Rizzo [j], Henrique Bellinaso [k], Márcio R. Francelino [l], Carlos E.G.R. Schaefer [l], Luiz E. Vicente [m], Uemeson J. dos Santos [n], Everardo V. de Sá Barretto Sampaio [n], Rômulo S.C. Menezes [n]... Hilton T. Zarate do Couto [ao]



Earth-Science Reviews

Volume 155, April 2016, Pages 198-230

A global spectral library to characterize the world's soil

R.A. Viscarra Rossel [a], T. Behrens [b], E. Ben-Dor [c], D.J. Brown [d], J.A.M. Demattê [e], K.D. Shepherd [f], Z. Shi [g], B. Stenberg [h], A. Stevens [i], uk [j], H. Aïchi [k], B.G. Barthès [l], H.M. Bartholomeus [m], A.D. Bayer [n], x [l], K. Böttcher [o p], L. Brodský [q], C.W. Du [r], A. Chappell [a], Y. Fouad [s] [j]

Soil Science Society of America Journal

SSSA

Division S-8—Nutrient Management & Soil & Plant Analysis

Development of Reflectance Spectral Libraries for Characterization of Soil Properties

Keith D. Shepherd, Markus G. Walsh

European Journal of Soil Science

European Journal of Soil Science, January 2018, 69, 140–153 doi: 10.1111/ejss.12499

LUCAS Soil, the largest expandable soil dataset for Europe: a review

A. Orgiazzi, C. Ballabio, P. Panagos, A. Jones & O. Fernández-Ugalde

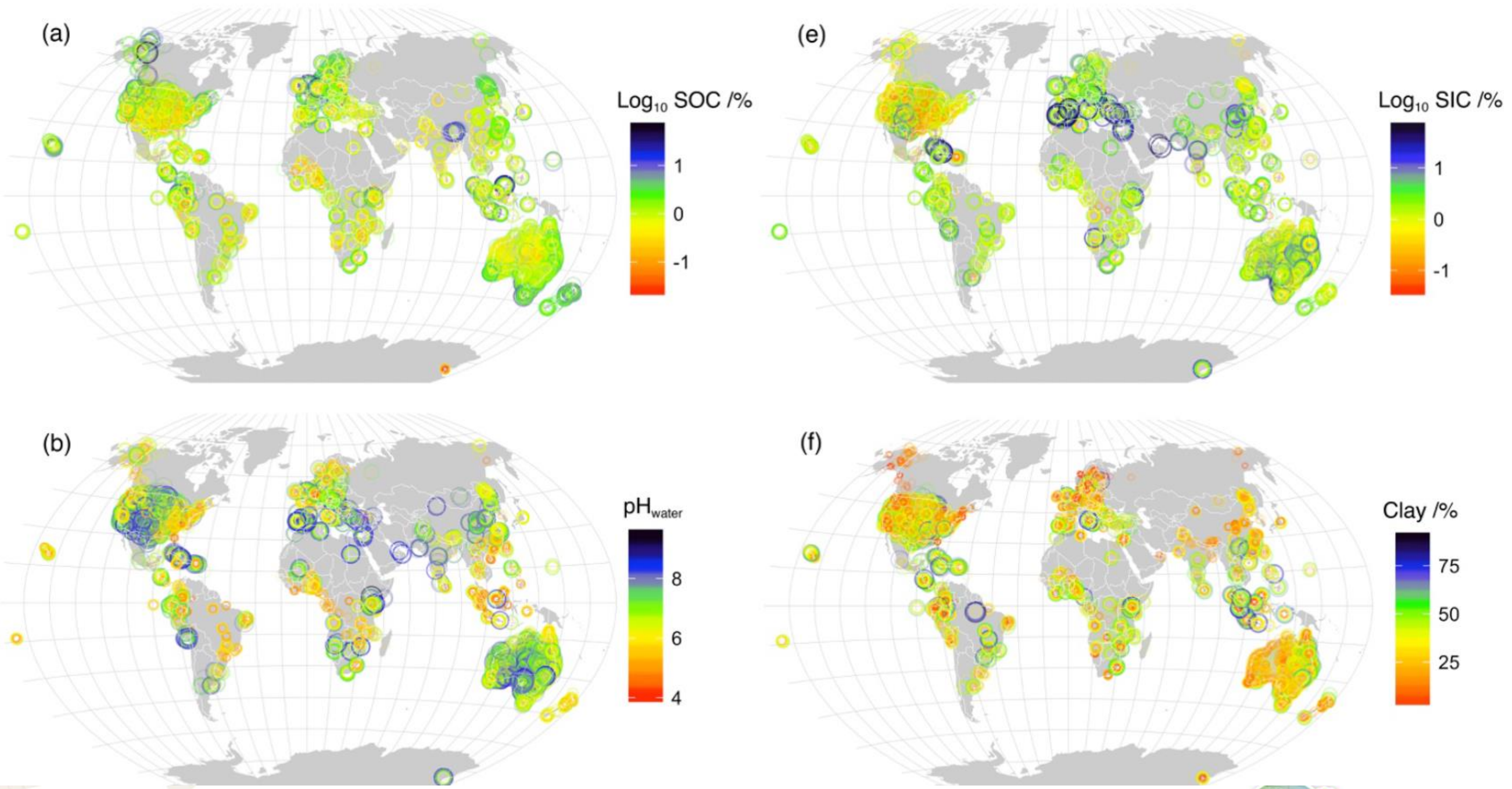
European Commission, Joint Research Centre (JRC), Sustainable Resources Directorate, Land Resources Unit, Via E. Fermi 2749, I-21027 Ispra (VA) Italy

More: Local , regional and Continual

First global map based on proximal sensing of soil

Spatial distribution of predictions

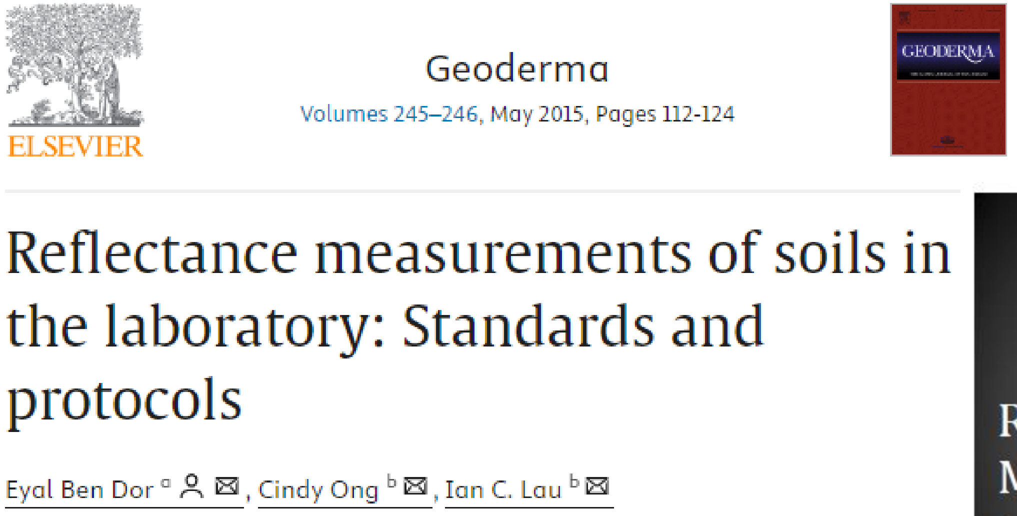
Viscarra Rossel et al 2016



Harmonization   Standard and protocol

First paper of SSL harmonization of Lab measurements

2015



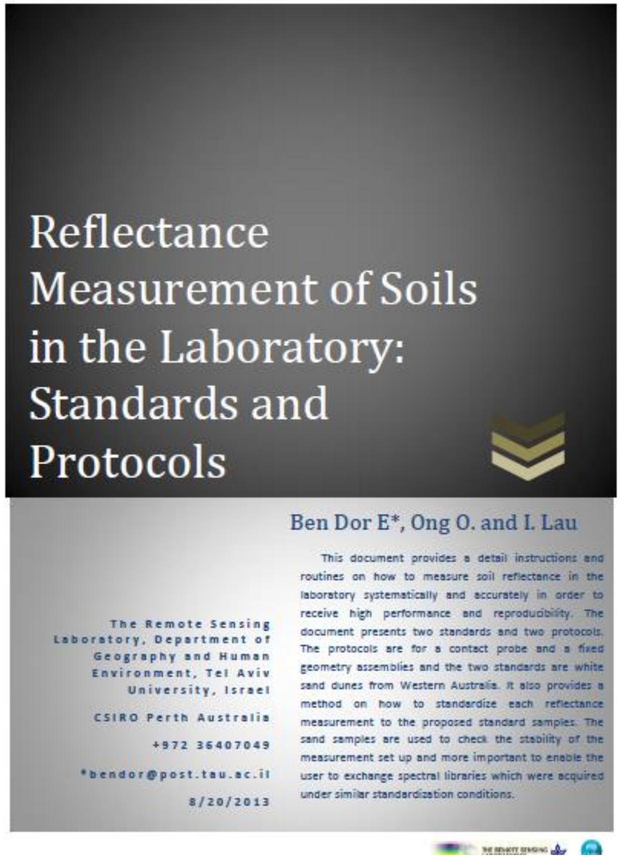
ELSEVIER

Geoderma

Volumes 245–246, May 2015, Pages 112-124

Reflectance measurements of soils in the laboratory: Standards and protocols

Eyal Ben Dor [a], Cindy Ong [b], Ian C. Lau [b]



Reflectance Measurement of Soils in the Laboratory: Standards and Protocols

Ben Dor E*, Ong O. and I. Lau

The Remote Sensing Laboratory, Department of Geography and Human Environment, Tel Aviv University, Israel

CSIRO Perth Australia

+972 36407049

*bendor@post.tau.ac.il

8/20/2013

This document provides a detail instructions and routines on how to measure soil reflectance in the laboratory systematically and accurately in order to receive high performance and reproducibility. The document presents two standards and two protocols. The protocols are for a contact probe and a fixed geometry assemblies and the two standards are white sand dunes from Western Australia. It also provides a method on how to standardize each reflectance measurement to the proposed standard samples. The sand samples are used to check the stability of the measurement set up and more important to enable the user to exchange spectral libraries which were acquired under similar standardization conditions.

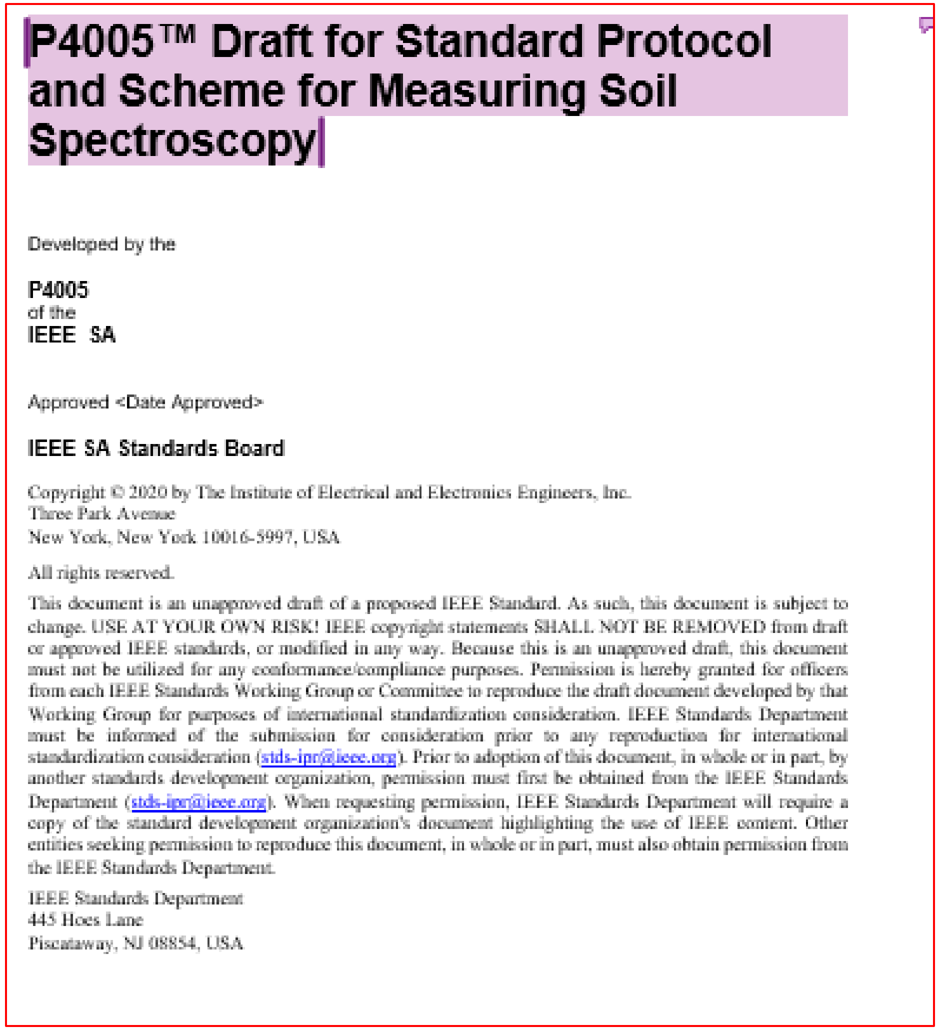
Chemistry

Spectroscopy

Internal Soil Standard

P4005 IEEE protocol

2019-2025 The first attempt to establish ISO spectral measurement of soil (lab, field)



P4005™ Draft for Standard Protocol and Scheme for Measuring Soil Spectroscopy

Developed by the

P4005
of the
IEEE SA

Approved <Date Approved>

IEEE SA Standards Board

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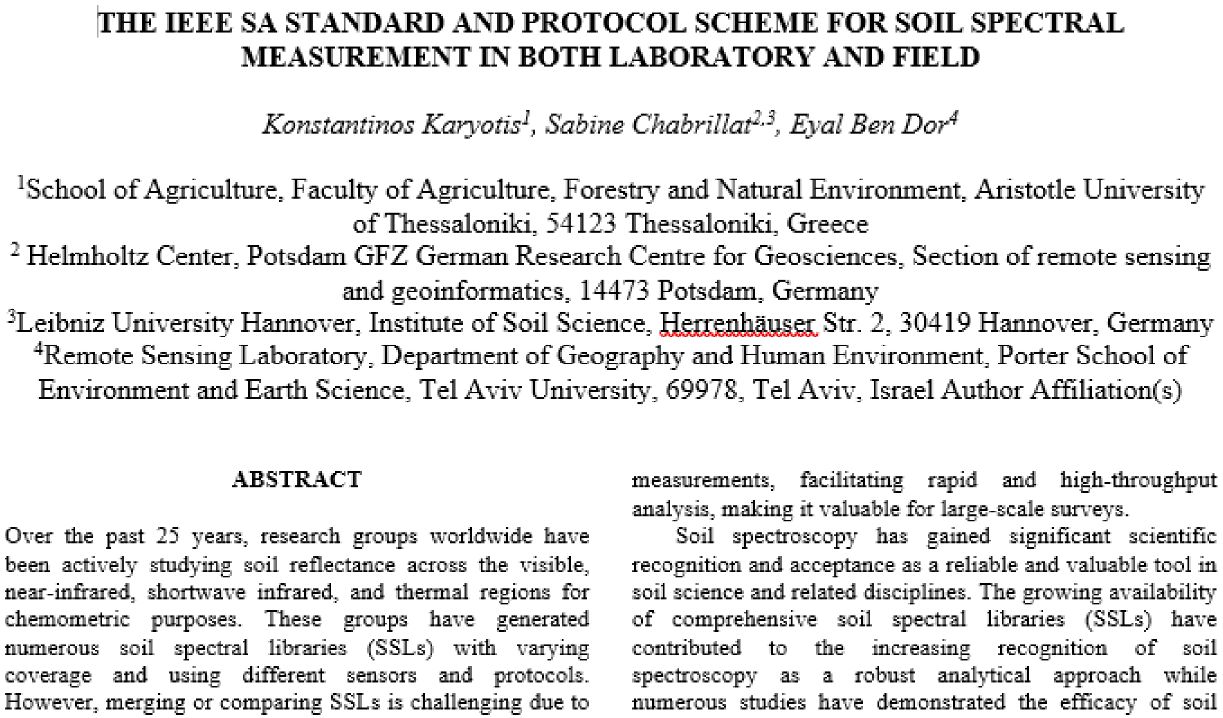


THE IEEE SA STANDARD AND PROTOCOL SCHEME FOR SOIL SPECTRAL MEASUREMENT IN BOTH LABORATORY AND FIELD

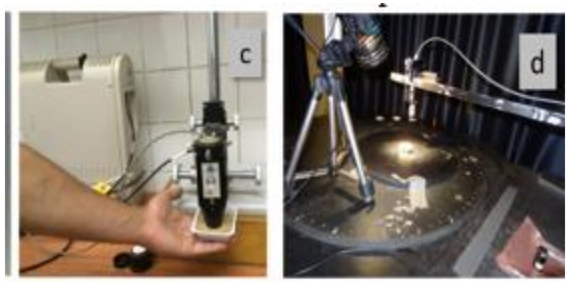
Konstantinos Karyotis[1], Sabine Chabrillat[2,3], Eyal Ben Dor[4]

[1]School of Agriculture, Faculty of Agriculture, Forestry and Natural Environment, Aristotle University of Thessaloniki, 54123 Thessaloniki, Greece
[2] Helmholtz Center, Potsdam GFZ German Research Centre for Geosciences, Section of remote sensing and geoinformatics, 14473 Potsdam, Germany
[3]Leibniz University Hannover, Institute of Soil Science, Herrenhäuser Str. 2, 30419 Hannover, Germany
[4]Remote Sensing Laboratory, Department of Geography and Human Environment, Porter School of Environment and Earth Science, Tel Aviv University, 69978, Tel Aviv, Israel Author Affiliation(s)

ABSTRACT

Over the past 25 years, research groups worldwide have been actively studying soil reflectance across the visible, near-infrared, shortwave infrared, and thermal regions for chemometric purposes. These groups have generated numerous soil spectral libraries (SSLs) with varying coverage and using different sensors and protocols. However, merging or comparing SSLs is challenging due to measurements, facilitating rapid and high-throughput analysis, making it valuable for large-scale surveys.

Soil spectroscopy has gained significant scientific recognition and acceptance as a reliable and valuable tool in soil science and related disciplines. The growing availability of comprehensive soil spectral libraries (SSLs) have contributed to the increasing recognition of soil spectroscopy as a robust analytical approach while numerous studies have demonstrated the efficacy of soil



ELSEVIER

Geoderma

Volume 131, Issues 1–2, March 2006, Pages 59-75

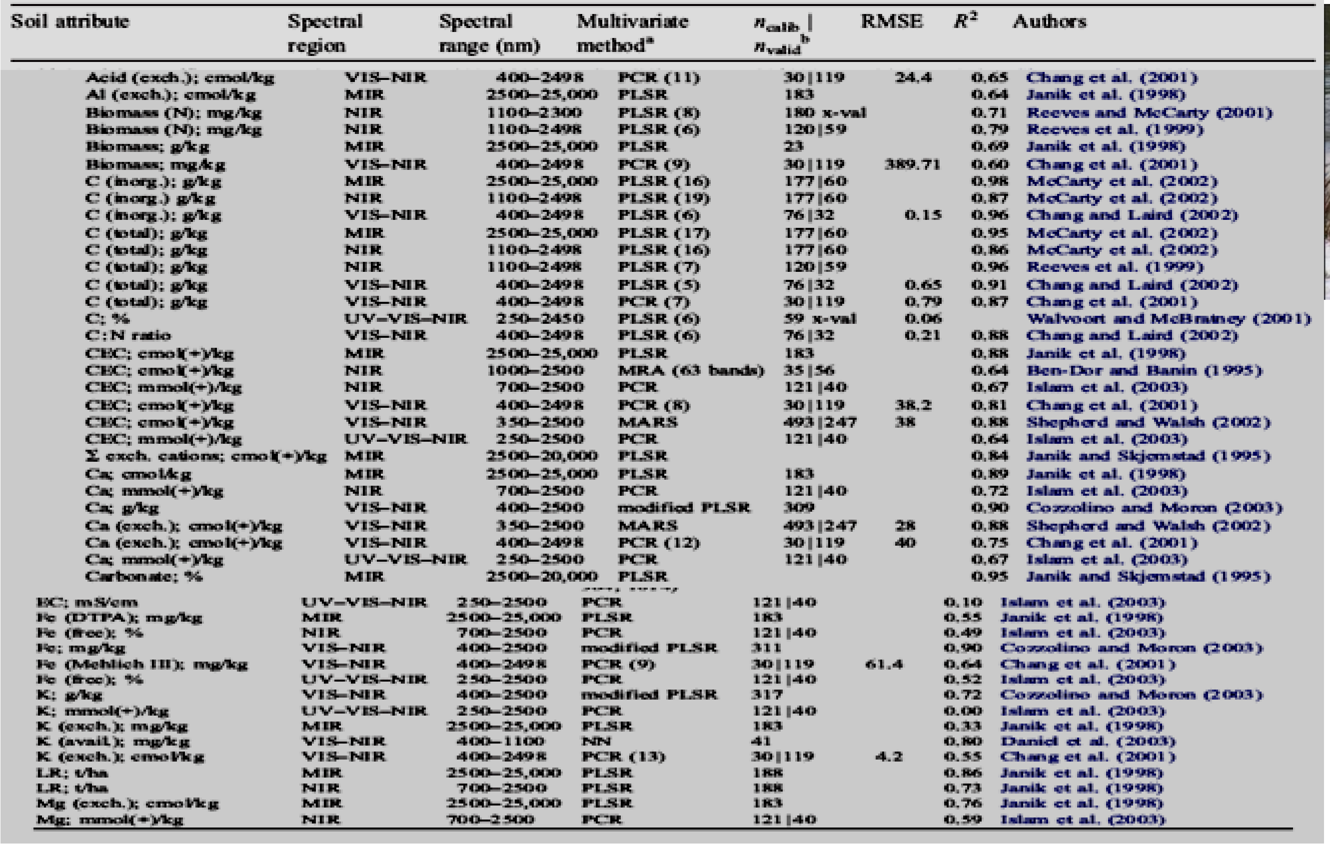
Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties

R.A. Viscarra Rossel [a], D.J.J. Walvoort [b], A.B. McBratney [a], L.J. Janik [c], J.O. Skjemstad [c]

First Paper to describe the chemometric exploitation in soil sceince

2006

Soil Spectral Analysis :
“The flood “ in 2006 !



Soil attribute	Spectral region	Spectral range (nm)	Multivariate method[a]	$n_{\text{calib}} \mid n_{\text{valid}}$[b]	RMSE	R^2	Authors
Acid (exch.); cmol/kg	VIS–NIR	400–2498	PCR (11)	30 | 119	24.4	0.65	Chang et al. (2001)
Al (exch.); cmol/kg	MIR	2500–25,000	PLSR	183		0.64	Janik et al. (1998)
Biomass (N); mg/kg	NIR	1100–2300	PLSR (8)	180 x-val		0.71	Reeves and McCarty (2001)
Biomass (N); mg/kg	NIR	1100–2498	PLSR (6)	120 | 59		0.79	Reeves et al. (1999)
Biomass; g/kg	MIR	2500–25,000	PLSR	23		0.69	Janik et al. (1998)
Biomass; mg/kg	VIS–NIR	400–2498	PCR (9)	30 | 119	389.71	0.60	Chang et al. (2001)
C (inorg.); g/kg	MIR	2500–25,000	PLSR (16)	177 | 60		0.98	McCarty et al. (2002)
C (inorg.) g/kg	NIR	1100–2498	PLSR (19)	177 | 60		0.87	McCarty et al. (2002)
C (inorg.); g/kg	VIS–NIR	400–2498	PLSR (6)	76 | 32	0.15	0.96	Chang and Laird (2002)
C (total); g/kg	MIR	2500–25,000	PLSR (17)	177 | 60		0.95	McCarty et al. (2002)
C (total); g/kg	NIR	1100–2498	PLSR (16)	177 | 60		0.86	McCarty et al. (2002)
C (total); g/kg	NIR	1100–2498	PLSR (7)	120 | 59		0.96	Reeves et al. (1999)
C (total); g/kg	VIS–NIR	400–2498	PLSR (5)	76 | 32	0.65	0.91	Chang and Laird (2002)
C (total); g/kg	VIS–NIR	400–2498	PCR (7)	30 | 119	0.79	0.87	Chang et al. (2001)
C; %	UV–VIS–NIR	250–2450	PLSR (6)	59 x-val	0.06		Walvoort and McBratney (2001)
C:N ratio	VIS–NIR	400–2498	PLSR (6)	76 | 32	0.21	0.88	Chang and Laird (2002)
CEC; cmol(+)/kg	MIR	2500–25,000	PLSR	183		0.88	Janik et al. (1998)
CEC; cmol(+)/kg	NIR	1000–2500	MRA (63 bands)	35 | 56		0.64	Ben-Dor and Banin (1995)
CEC; mmol(+)/kg	NIR	700–2500	PCR	121 | 40		0.67	Islam et al. (2003)
CEC; cmol(+)/kg	VIS–NIR	400–2498	PCR (8)	30 | 119	38.2	0.81	Chang et al. (2001)
CEC; cmol(+)/kg	VIS–NIR	350–2500	MARS	493 | 247	38	0.88	Shepherd and Walsh (2002)
CEC; mmol(+)/kg	UV–VIS–NIR	250–2500	PCR	121 | 40		0.64	Islam et al. (2003)
Σ exch. cations; cmol(+)/kg	MIR	2500–20,000	PLSR			0.84	Janik and Skjemstad (1995)
Ca; cmol/kg	MIR	2500–25,000	PLSR	183		0.89	Janik et al. (1998)
Ca; mmol(+)/kg	NIR	700–2500	PCR	121 | 40		0.72	Islam et al. (2003)
Ca; g/kg	VIS–NIR	400–2500	modified PLSR	309		0.90	Cozzolino and Moron (2003)
Ca (exch.); cmol(+)/kg	VIS–NIR	350–2500	MARS	493 | 247	28	0.88	Shepherd and Walsh (2002)
Ca (exch.); cmol(+)/kg	VIS–NIR	400–2498	PCR (12)	30 | 119	40	0.75	Chang et al. (2001)
Ca; mmol(+)/kg	UV–VIS–NIR	250–2500	PCR	121 | 40		0.67	Islam et al. (2003)
Carbonate; %	MIR	2500–20,000	PLSR			0.95	Janik and Skjemstad (1995)
EC; mS/cm	UV–VIS–NIR	250–2500	PCR	121 | 40		0.10	Islam et al. (2003)
Fe (DTPA); mg/kg	MIR	2500–25,000	PLSR	183		0.55	Janik et al. (1998)
Fe (free); %	NIR	700–2500	PCR	121 | 40		0.49	Islam et al. (2003)
Fe; mg/kg	VIS–NIR	400–2500	modified PLSR	311		0.90	Cozzolino and Moron (2003)
Fe (Mehlich III); mg/kg	VIS–NIR	400–2498	PCR (9)	30 | 119	61.4	0.64	Chang et al. (2001)
Fe (free); %	UV–VIS–NIR	250–2500	PCR	121 | 40		0.52	Islam et al. (2003)
K; g/kg	VIS–NIR	400–2500	modified PLSR	317		0.72	Cozzolino and Moron (2003)
K; mmol(+)/kg	UV–VIS–NIR	250–2500	PCR	121 | 40		0.00	Islam et al. (2003)
K (exch.); mg/kg	MIR	2500–25,000	PLSR	183		0.33	Janik et al. (1998)
K (avail.); mg/kg	VIS–NIR	400–1100	NN	41		0.80	Daniel et al. (2003)
K (exch.); cmol/kg	VIS–NIR	400–2498	PCR (13)	30 | 119	4.2	0.55	Chang et al. (2001)
LR; t/ha	MIR	2500–25,000	PLSR	188		0.86	Janik et al. (1998)
LR; t/ha	NIR	700–2500	PLSR	188		0.73	Janik et al. (1998)
Mg (exch.); cmol/kg	MIR	2500–25,000	PLSR	183		0.76	Janik et al. (1998)
Mg; mmol(+)/kg	NIR	700–2500	PCR	121 | 40		0.59	Islam et al. (2003)

R.A. Viscarra Rossel et al. / Geoderma 131 (2006) 59–75

Food Sceince : 1968 -1998 30Y

Soil Sceince – 1986 – 2006 20 y

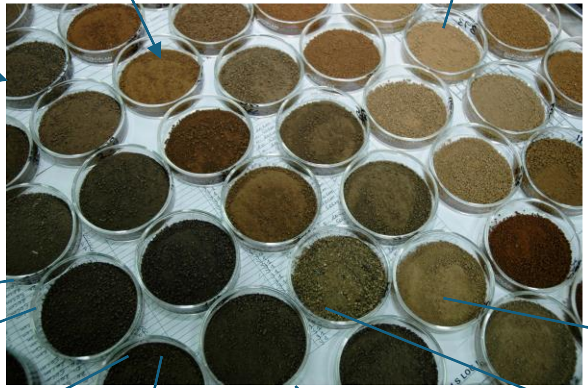
Most studied Soil Properties

Aggregate Stability

Adsorbed Isotherm

More to come!

Infiltration



Water Hydrophobicity

Salinity

SSA
Specific Surface Area

Carbonates
$CaCO_3$

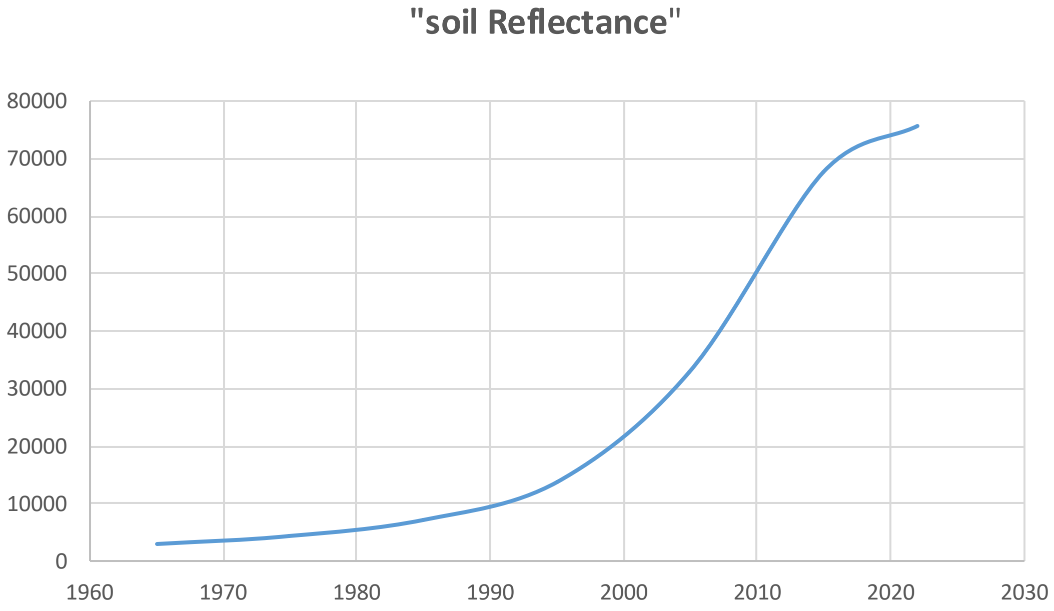
Clay Silt Sand
Size Fraction

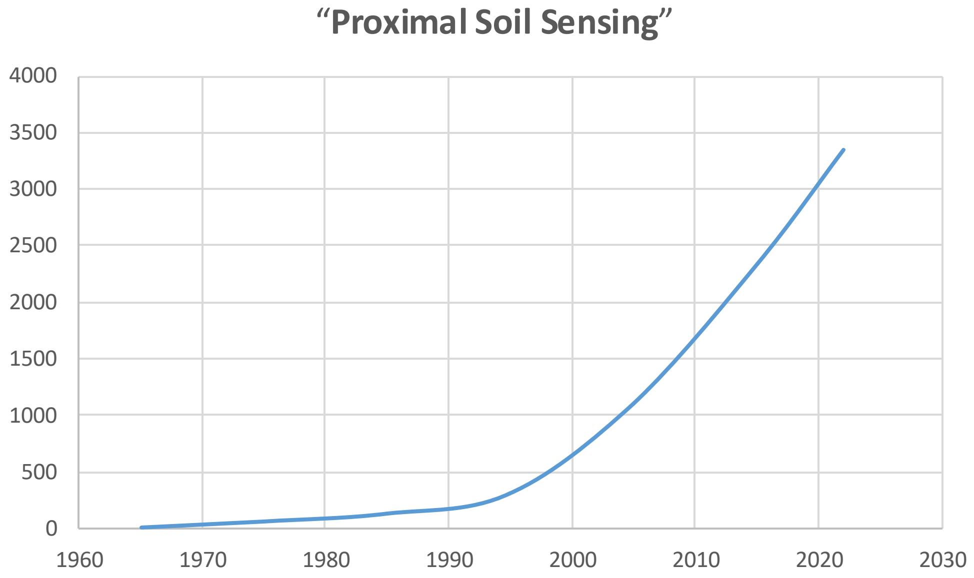
HIGF
Hygroscopic Water

CEC
Cation Exchange Capacity

OM, OC
Organic Matter, Carbon

Number of papers with the above mentioned " keywords"



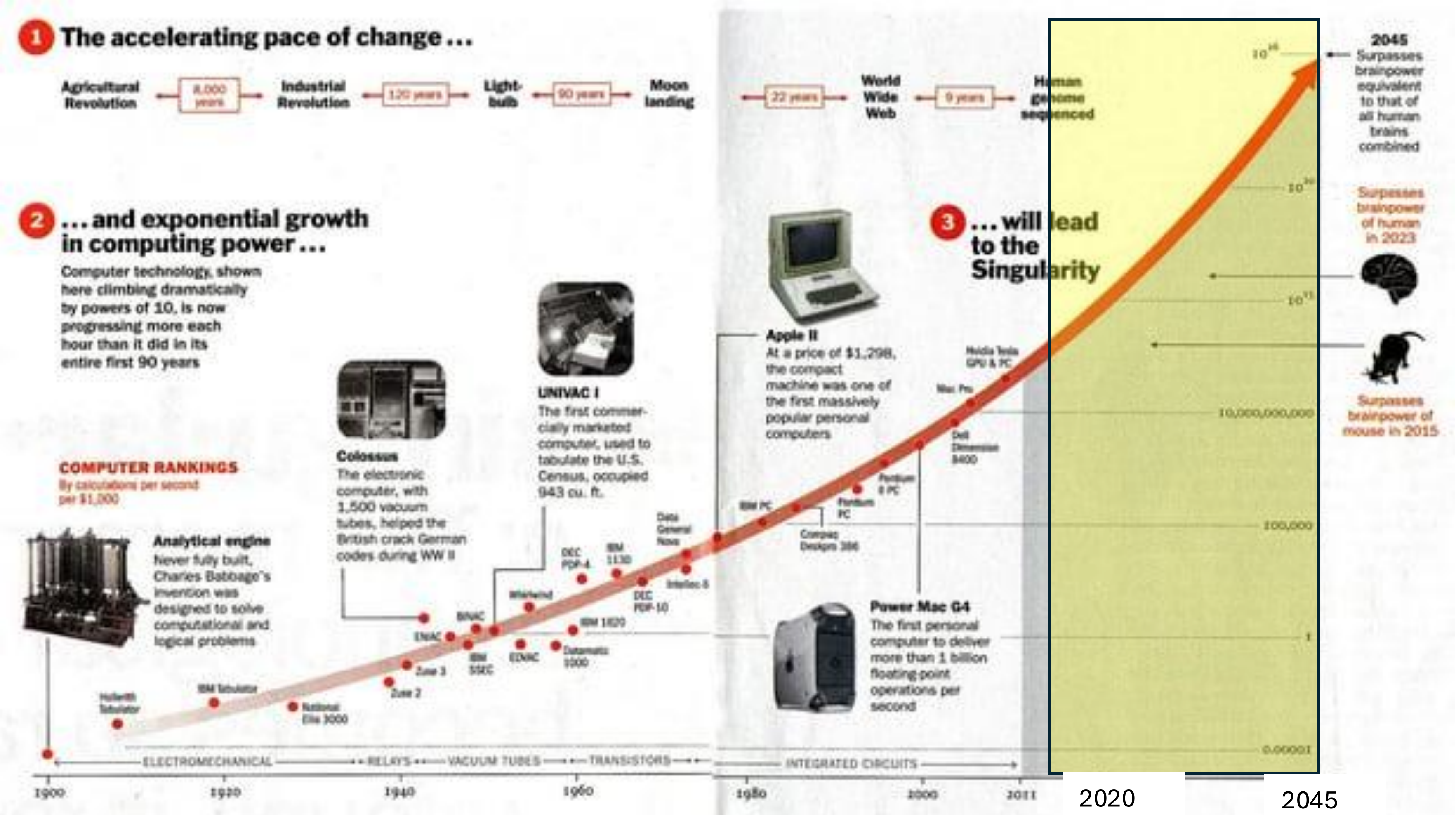


Extra Flood in 2024

SEMANTIC **SCHOLAR**

Moving from Machine learning to Deep learning and big data

The Computing Power



① The accelerating pace of change …

② … and exponential growth in computing power …

Computer technology, shown here climbing dramatically by powers of 10, is now progressing more each hour than it did in its entire first 90 years

③ … will lead to the Singularity

COMPUTER RANKINGS
By calculations per second per $1,000

Analytical engine Never fully built, Charles Babbage's invention was designed to solve computational and logical problems

Colossus The electronic computer, with 1,500 vacuum tubes, helped the British crack German codes during WW II

UNIVAC I The first commercially marketed computer, used to tabulate the U.S. Census, occupied 943 cu. ft.

Apple II At a price of $1,298, the compact machine was one of the first massively popular personal computers

Power Mac G4 The first personal computer to deliver more than 1 billion floating-point operations per second

2045 Surpasses brainpower equivalent to that of all human brains combined

Surpasses brainpower of human in 2023

Surpasses brainpower of mouse in 2015

Portable Spectrometers

“Chemical Analysis through Spectral Observations”

G. Kirchhoff und R. Bunsen, Poggendorff's Ann. der Physik und Chemie 60 (1860)
161 und 63 (1861) 337.

1861 Kirchhoff first spectrometer

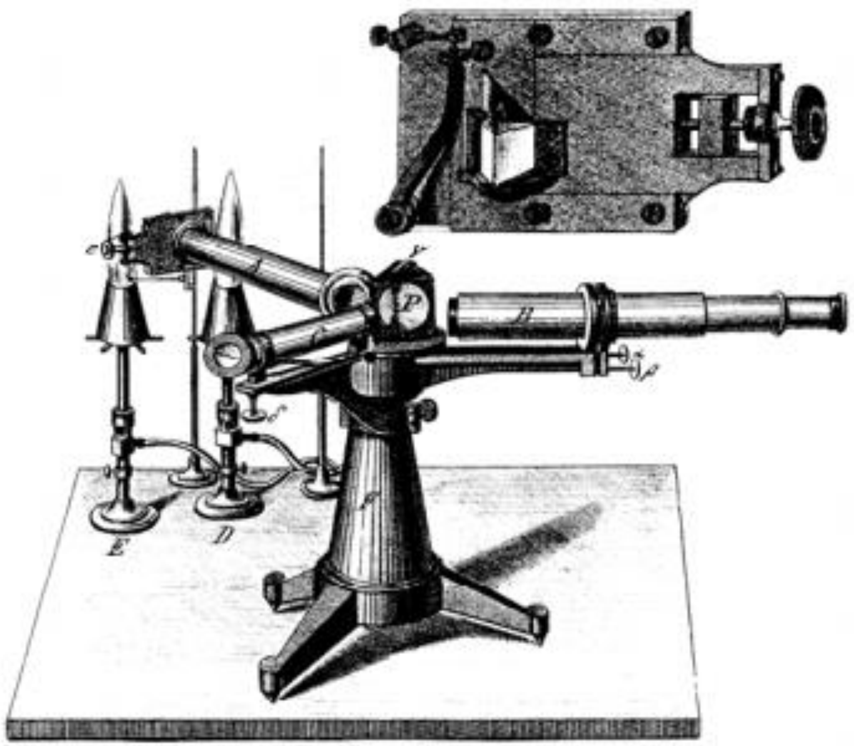


Fig. 1.1 The spectroscope of Kirchhoff, Bunsen and Steinheil from the year 1861 [12]. The collimator tube *A* is solidly connected to the frame and contains a plate with a vertical entrance slit and converging lens at the opposite end. The flint glass prism *P* is solidly mounted, but the observation tube *B* can be rotated. The scale tube *C* has an externally illuminated scale *S* on a black background. It is added to the spectrum with the aid of a lens in *C* and a mirrored surface of *P*. The lower portion of the entrance slit is covered by a prism which adds the light of the control light source *D* into the ray trajectory. The substance in question is heated by the flame *E* and its light, together with the light of the flame, enters the upper portion of the entrance slit. The upper part of the observed spectrum is therefore a combination of substance and flame, the lower part only the spectrum of the flame.

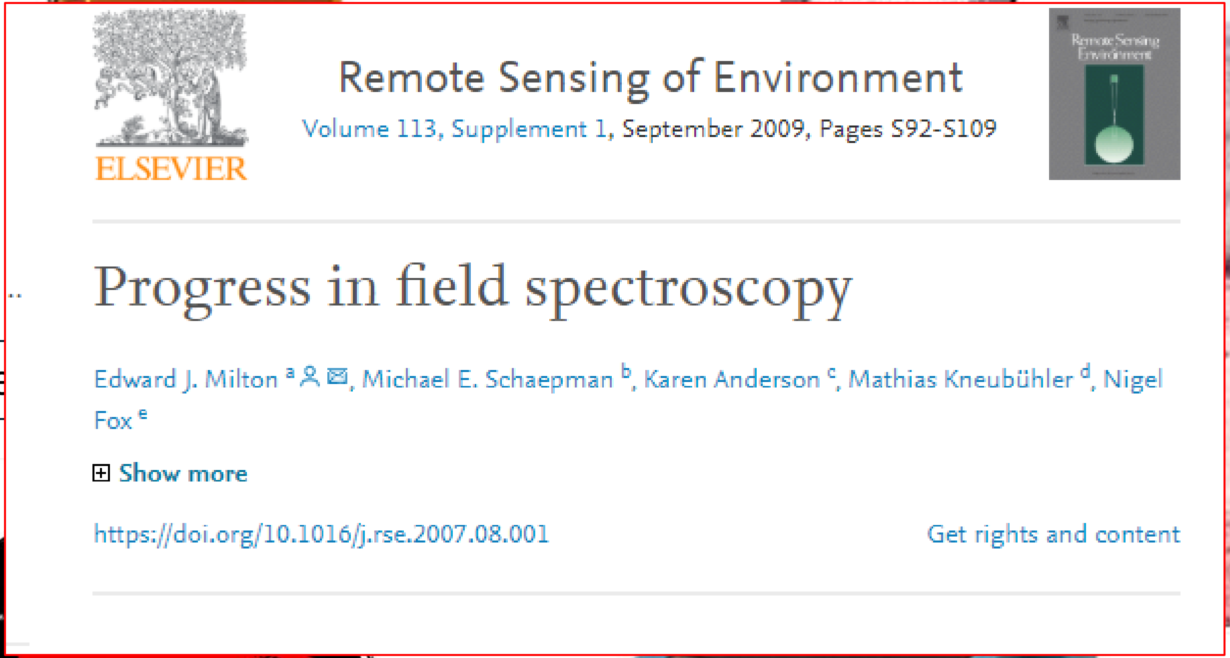
Portable sensors for Soil Spectroscopy

2004

1991

1975

PERS



ELSEVIER

Remote Sensing of Environment

Volume 113, Supplement 1, September 2009, Pages S92-S109

Progress in field spectroscopy

Edward J. Milton [a], Michael E. Schaepman [b], Karen Anderson [c], Mathias Kneubühler [d], Nigel Fox [e]

⊞ Show more

https://doi.org/10.1016/j.rse.2007.08.001

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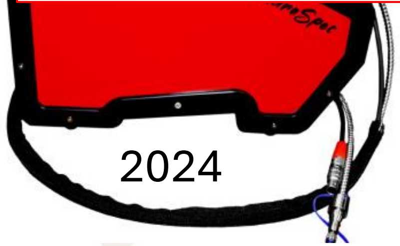
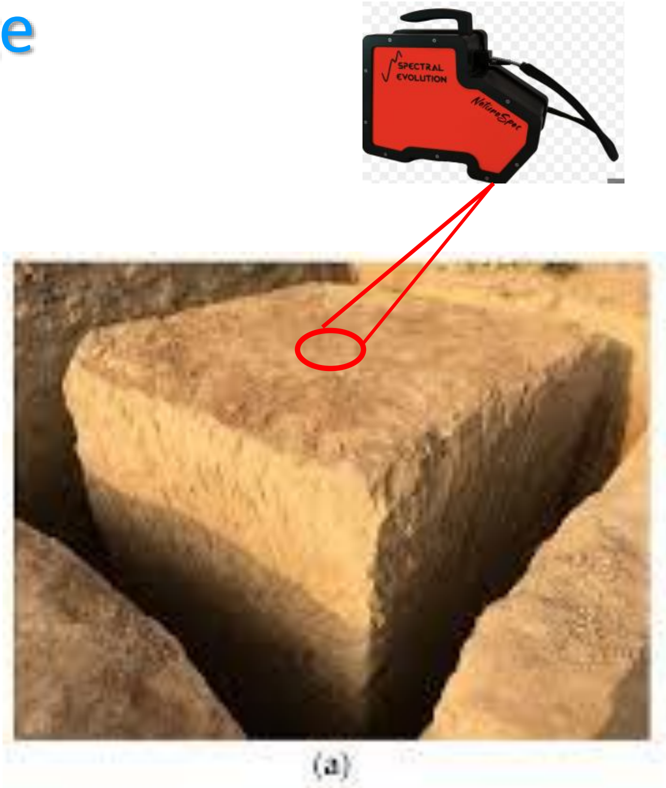
Spe



2024

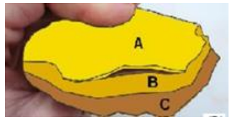
2024

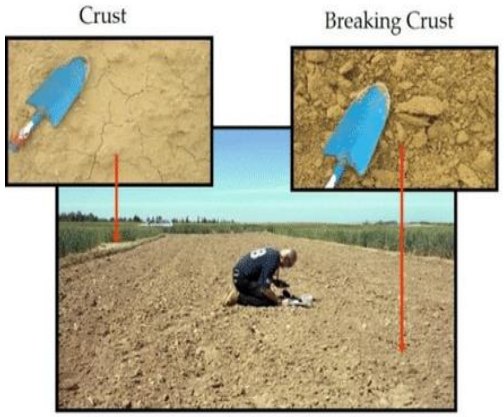
Portable Spectrometer Challenge

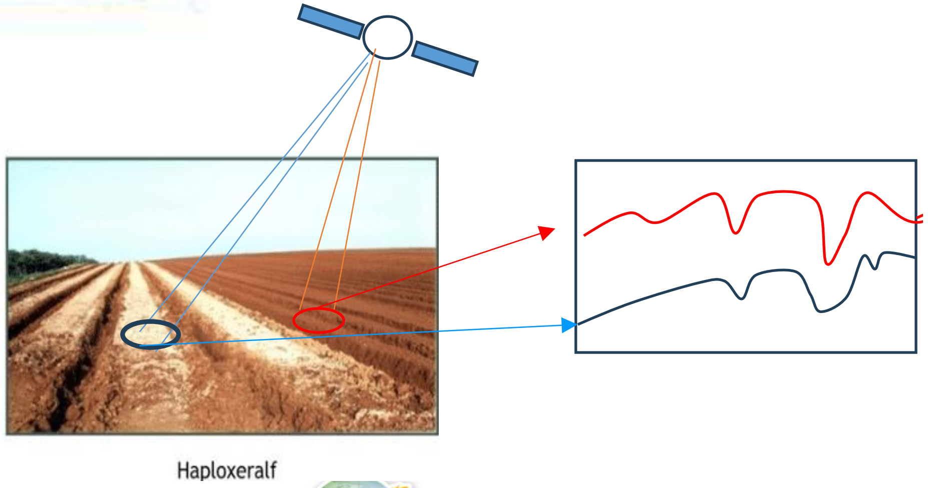


Only surface – Profile is important

Soil Disturbed in Lab – Soil undisturbed
Remote Sensing View is important

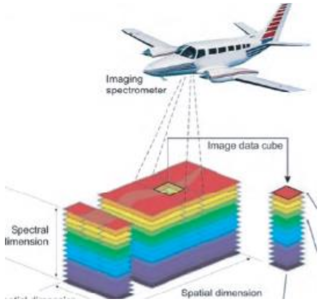






De Jong S.M., E.A. Addink, D. Duijsing & L.P.H. van Beek, 2011, Physical Characterization and Spectral Response of Mediterranean Soil Surface Crusts. CATENA 86(1), 24-35

First paper on Soil Endoscopy : Soil Profile information 3D view



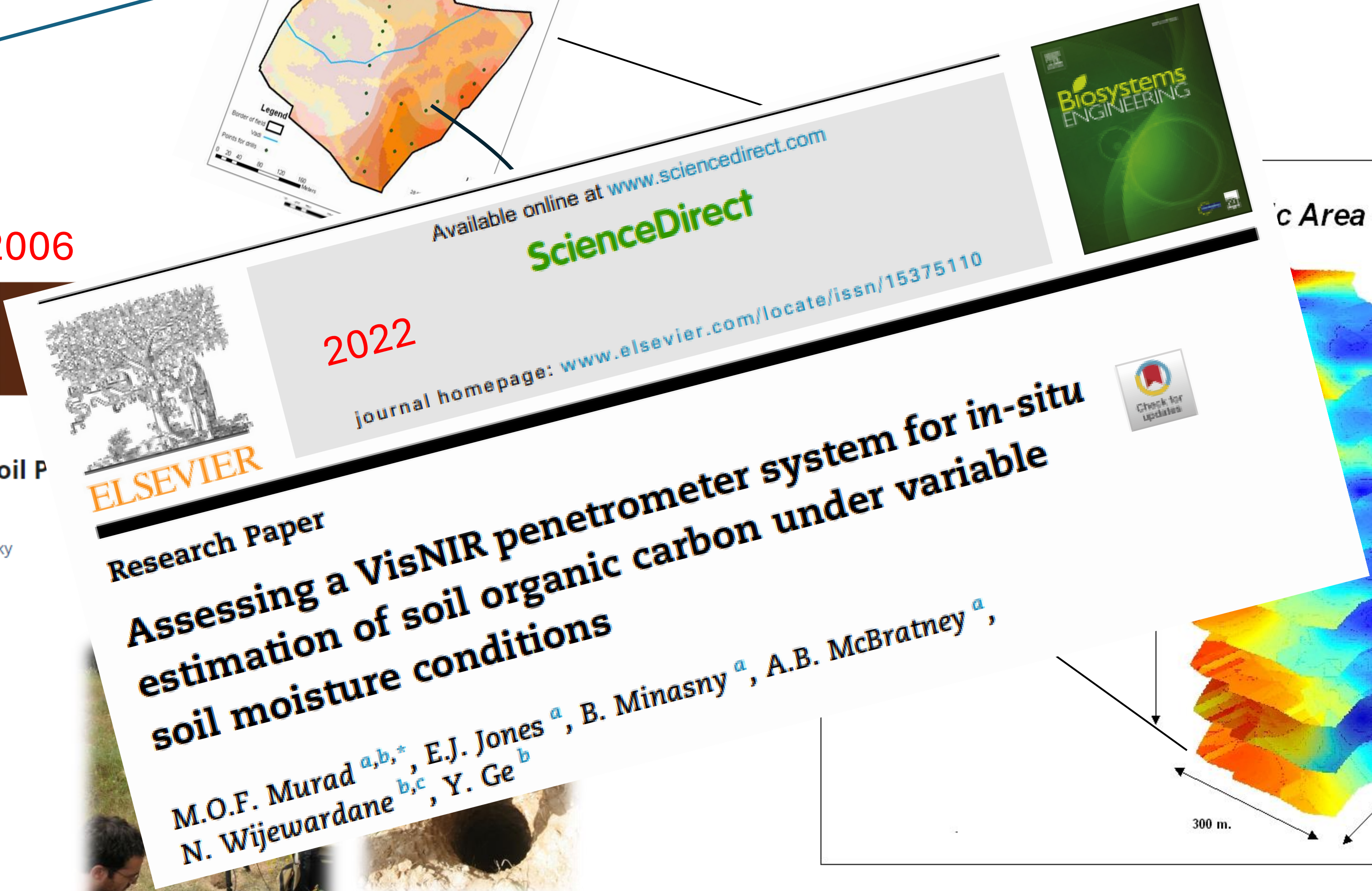
2006


Soil Science Society of America Journal

Pedology | Full Access

**A Novel Method of Classifying Soil P
Optical Means**

Eyal Ben-Dor, Daniela Heller, Alexandra Chudnovsky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journal homepage: www.elsevier.com/locate/issn/15375110

ELSEVIER

Biosystems Engineering

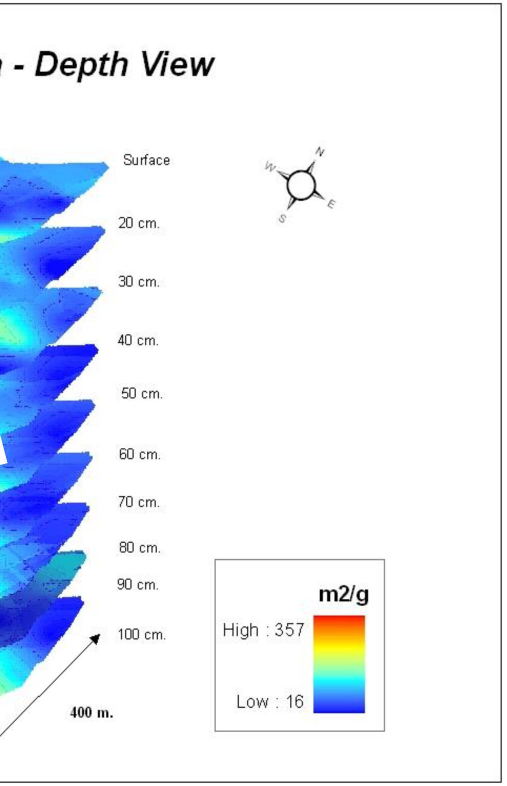
Check for updates

2022

Research Paper

Assessing a VisNIR penetrometer system for in-situ estimation of soil organic carbon under variable soil moisture conditions

M.O.F. Murad [a,b,*], E.J. Jones [a], B. Minasny [a], A.B. McBratney [a], N. Wijewardane [b,c], Y. Ge [b]



2020

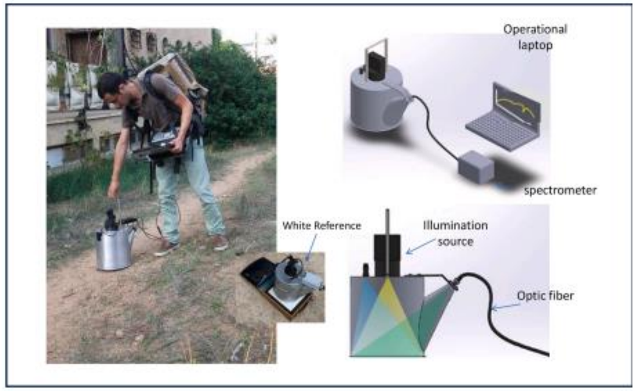
Time

2017

Geoderma
Volume 306, 15 November 2017, Pages 73-80

A simple apparatus to measure soil
spectral infor
stable conditi

Eyal Ben-Dor, Amihai Granot

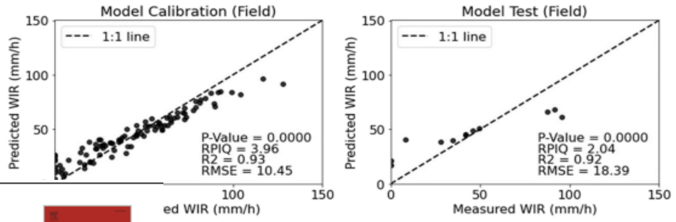


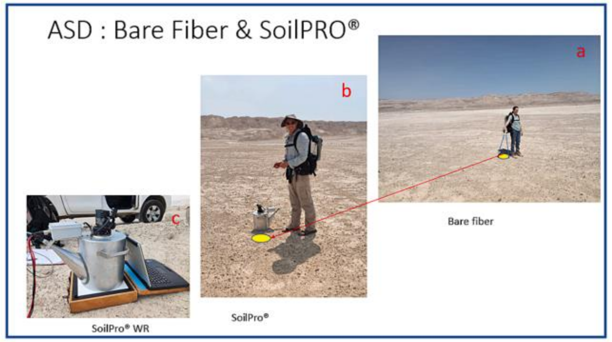
2022

Geoderma
Volume 405, 1 January 2022, 115432

A transfer function to predict soil surface reflectance from laboratory soil spectral libraries

Nicolas Francos, Eyal Ben-Dor



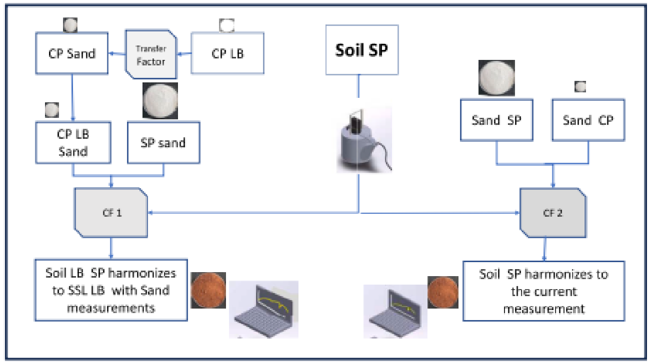


2024

Geoderma
Volume 438, October 2023, 116636

Exploitation of the SoilPRO® (SP)
apparatus to
reflectance in

Eyal Ben Dor [a], Amihai
Daniela Heller Pearlstein [a], B
:hmid [d]



2024

Geoderma
Volume 447, July 2024, 116920

A standard and protocol for in-situ measurement of surface soil reflectance

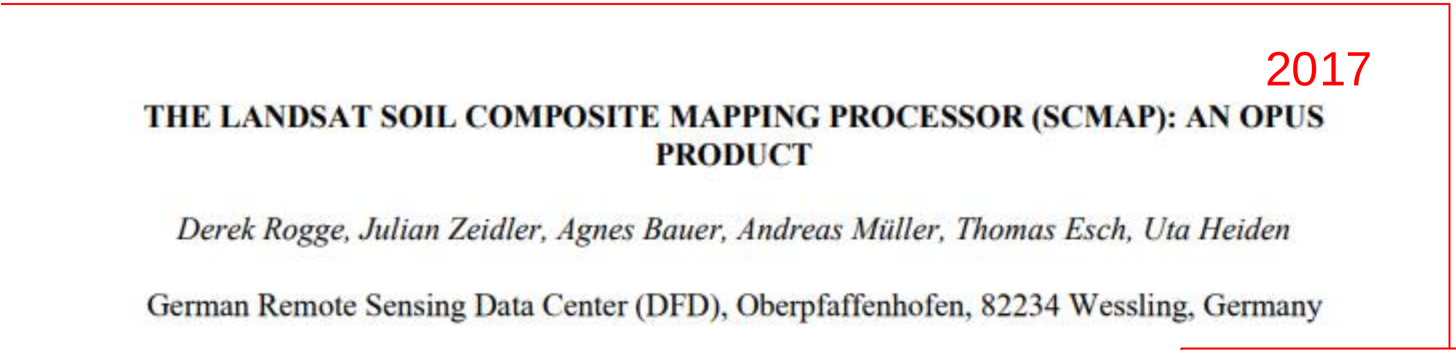
Eyal Ben Dor [a] [b], Bar Efrati [a], Or Amir [a], Nicolas Francos [c], Jonti Shepherd [a], Vahid Khosravi [b], Asa Gholizadeh [b], Aleš Klement [b], Luboš Borůvka [b]

The Space Era

Soil spectroscopy and proximal sensing from air and orbit

First papers on real Proximal Sensing with multispectral satellite (based on *1996 paper of Ben Dor et al*., “Simulation of TM bands to predict soil properties):

2017

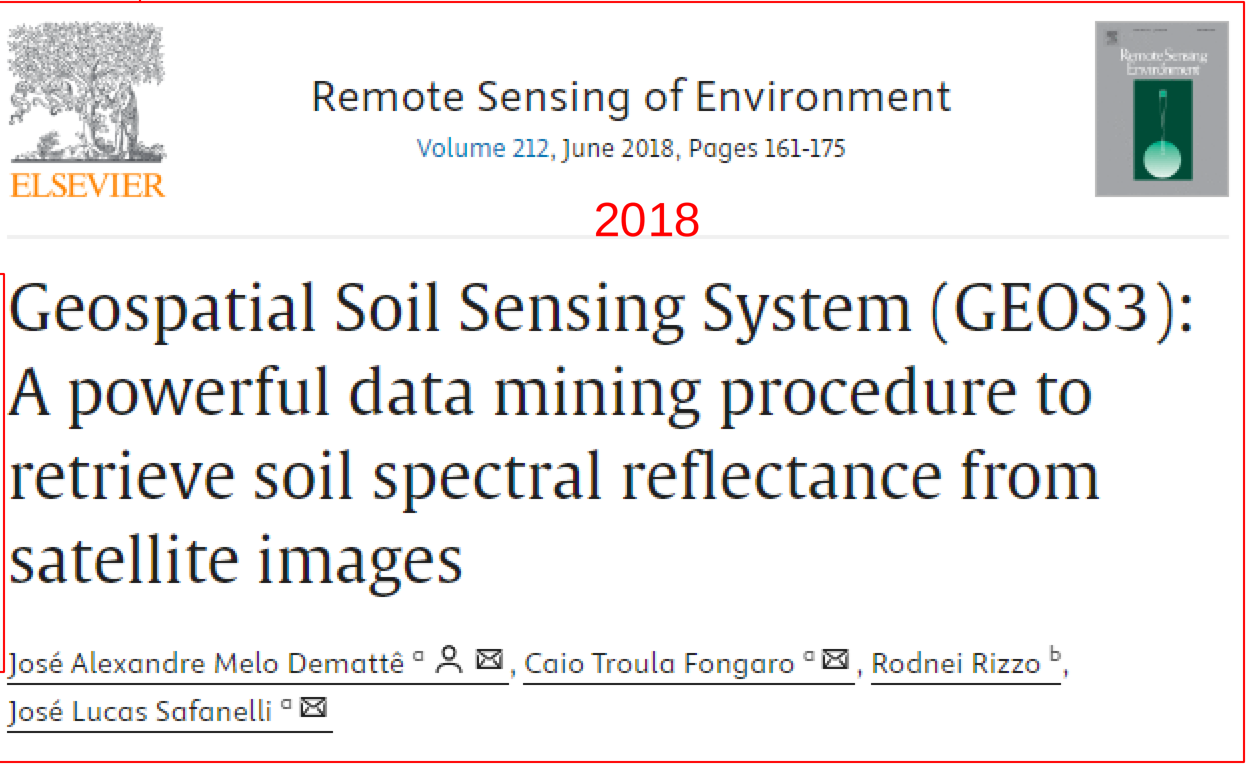


THE LANDSAT SOIL COMPOSITE MAPPING PROCESSOR (SCMAP): AN OPUS PRODUCT

Derek Rogge, Julian Zeidler, Agnes Bauer, Andreas Müller, Thomas Esch, Uta Heiden

German Remote Sensing Data Center (DFD), Oberpfaffenhofen, 82234 Wessling, Germany

2018



Remote Sensing of Environment

Volume 212, June 2018, Pages 161-175

ELSEVIER

Geospatial Soil Sensing System (GEOS3): A powerful data mining procedure to retrieve soil spectral reflectance from satellite images

José Alexandre Melo Demattê [a], Caio Troula Fongaro [a], Rodnei Rizzo [b], José Lucas Safanelli [a]

2021

Open Access Article

Sentinel-2 Exposed Soil Composite for Soil Organic Carbon Prediction

by Klara Dvorakova [1,*], Uta Heiden [2] and Bas van Wesemael [1]

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Proximal Sensing with State of the Art Hperspectral Remote Sensing Sensors

Image Spectroscopy

Conferences > 2020 IEEE Aerospace Conference

The Earth Surface Mine

An Earth Science Imag

Cite This

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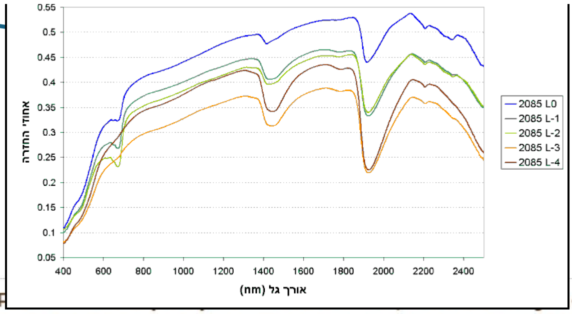
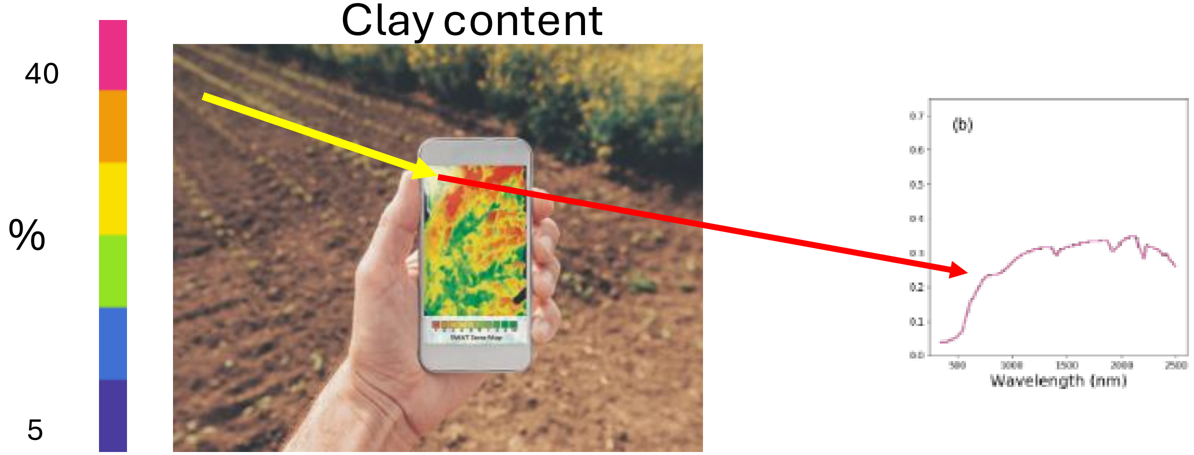


What is next ?

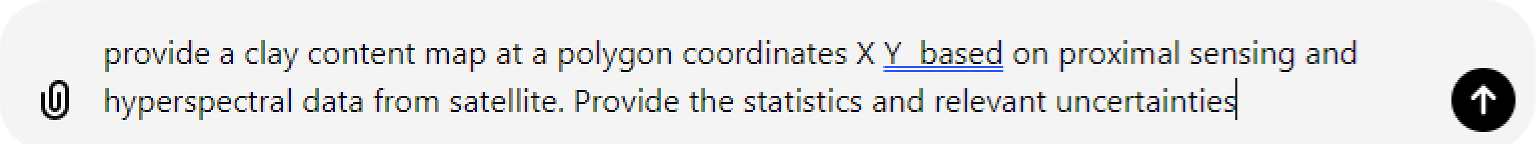
Smartphone

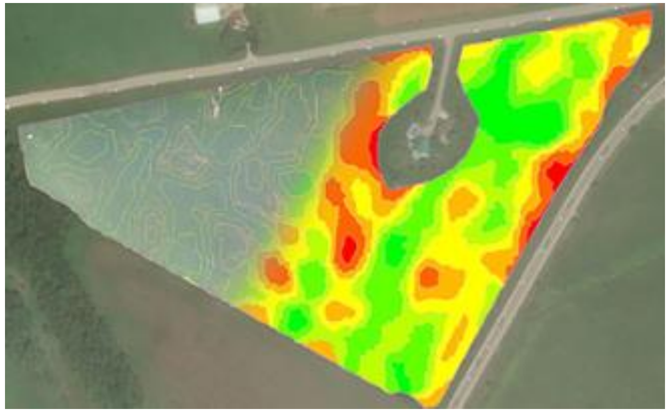
Image spectrometer
with appropriate model for real time mapping

Clay content

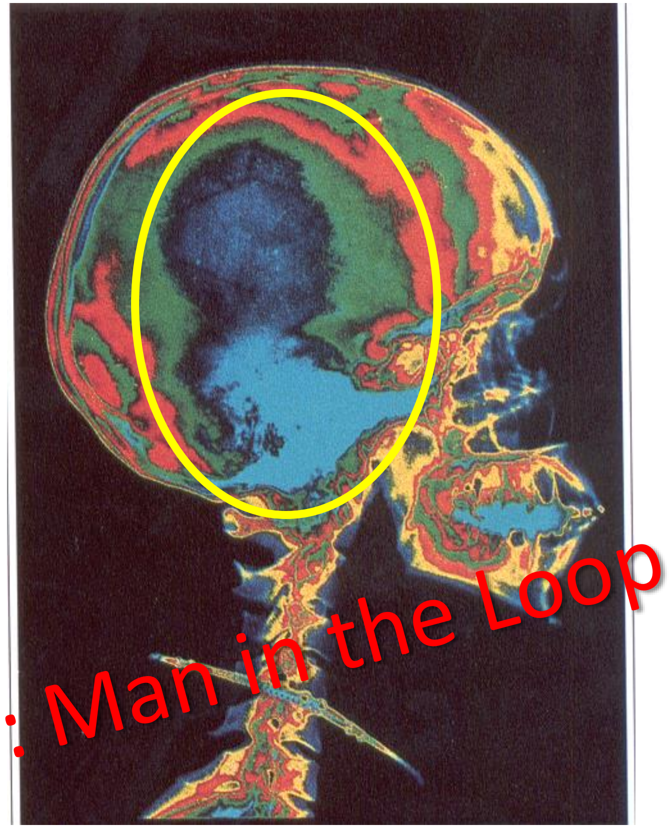


ChatGPT 6


provide a clay content map at a polygon coordinates X Y based on proximal sensing and hyperspectral data from satellite. Provide the statistics and relevant uncertainties



In each of us, a little man is hidden. This man is our imagination: use it!



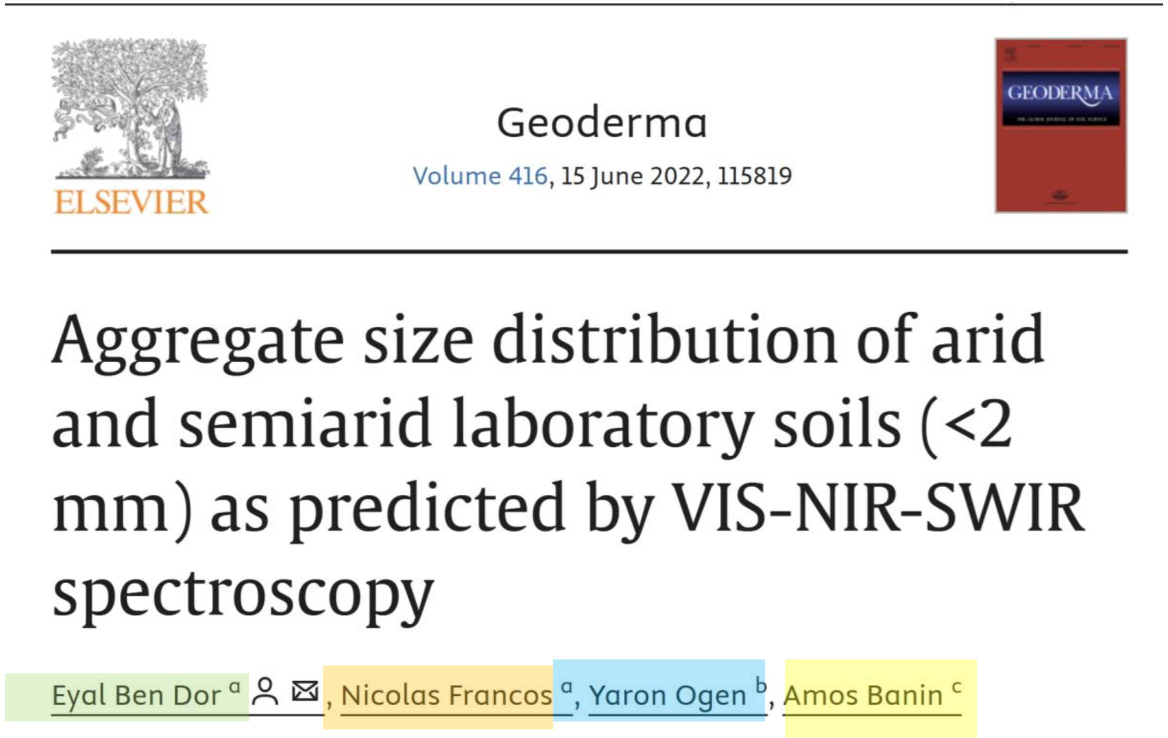
Always remember: Man in the Loop is Important

Summary

Three Generation in Soil Proximal sensing in one paper

Working period of soil proximal sensing 1986 -2022

37 years



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Aggregate size distribution of arid and semiarid laboratory soils (<2 mm) as predicted by VIS-NIR-SWIR spectroscopy

Eyal Ben Dor [a], Nicolas Francos [a], Yaron Ogen [b], Amos Banin [c]

Prof. Amos Banin

1940-2022

The father of soil proximal approach

1987-1992	Prof Eyal Ben Dor – Phd Student of Banin in soil proximal sensing
2010-2015	Dr, Yaron Ogen – A Phd Student of Ben Dor on soil proximal sensing
2018 -2023	Dr, Nicolas Francos – A PhD student of Ben Dor on soil proximal sensing

Epilogue

This paper is a three-generation effort: Prof. Banin was Prof. Ben-Dor’s Ph.D. supervisor and paved the way for the soil spectroscopy discipline 32years ago with his extensive vision. Prof. Ben-Dor was Dr. Ogen's Ph.D. supervisor and is currently supervising Mr. Francos’ doctoral studies. Prof. Banin passed away during the submission of this paper, and it is therefore dedicated to his memory. Prof. Amos Banin will always be remembered as the pioneering scientist who brought the field of soil…

Thank You !!

TAU-RSL

THE REMOTE SENSING LABORATORIES

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