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EXTENSION OF LABORATORY-MEASURED SOIL SPECTRA TO FIELD CONDITIONS

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I. ABSTRACT

Spectral responses of two humid mesic region glaciated soils, Chalmers silty clay loam and Fincastle silt loam, formed under prairie grass and forest vegetation, respectively, were measured both in the laboratory under controlled moisture equilibria, and in the field under various moisture and crop residue conditions. The Exotech Model 20C spectroradiometer obtained spectral data in the 0.52 to 2.32 μm wavelength range in 0.1 μm increments while used in an indoor configuration with a bidirectional reflectance factor reflectometer providing an artificial illumination source consisting of a 1000 watt tungsten iodine coiled filament lamp with transfer optics. Asbestos tension tables were used to maintain a pF 2 (approximately one-tenth bar) moisture equilibrium following saturation of crushed, sieved soil samples held in 10-cm diam x 2 cm rings with 50 mesh wire bases. The same spectroradiometer was used outdoors under solar illumination to obtain spectral response from dry and moistened field plots with and without corn residue cover, representing the two different soils. Pressed $BaSO_4$ served as the reflectance standard indoors while a 1.2 m square painted $BaSO_4$ panel (which in turn was compared to pressed $BaSO_4$) served as the calibration standard in the field. Detector height above the indoor samples was 2.44 m using the 3/4° field of view mode, while measurements in the field were made at a 6.1 m height using the 15° field of view mode. Results indicate that laboratory-measured spectra of moist soil are directly proportional to the spectral response of that same moist bare soil in the field over the 0.52 to 1.75 μm wavelength range. The magnitude of differences in spectral response between identically treated Chalmers and Fincastle soils is greatest in the 0.6 to 0.8 μm transition region between the visible and near infrared, regardless of field condition or laboratory preparation studied.

II. INTRODUCTION

A variety of soil parameters and conditions individually and in association with one another contribute to the spectral reflectance of soils. These parameters are known to include the physicochemical properties of organic matter, moisture, silt, clay, and iron oxide contents as well as other variables less well defined as contributors to reflectance.[1,2,4,16,17] Conditions affecting the radiation characteristics of soils in their natural state are green vegetation, shadows, surface roughness, and non-soil residue, all of which vary according to tillage operations, cropping systems, or naturally occurring plant communities.[3,7,8,9,11,18] Although spectroradiometric studies of soils under laboratory and field conditions have contributed to an understanding of soil reflectance, the validity of comparing laboratory-measured soil spectra to field conditions has not been documented.

Recent advances in remote sensing technology applied to soil survey have shown promise of enhanced speed and accuracy in the preparation of these surveys[22,23] Soil erosion monitoring requires an understanding of how crop residues affect reflectance from different soils.[7,8,9] Corn crop residue at the rate of 0.5 metric tons/ha has been found to reduce erosion, while 4 metric tons/ha controlled erosion on plowed ground.[10,15] The adaptability of various corn tillage-planting systems has been found to differ for 23 groups of Indiana soil series.[6] The ability to identify tillage-planting systems on different soils from remote sensing data would be valuable to the soil conservationist. In turn, the ability to differentiate between soil series in spite of tillage-planting systems is desired by the soil surveyor.

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The objectives of this study were to differentiate between two widely occurring humid mesic region glaciated soils on the basis of spectroradiometric response under varied field and laboratory conditions and to verify the validity of laboratory-measured soil spectra for characterizing soil reflectance in the field.

III. MATERIALS AND METHODS

A. FIELD SPECTRORADIOMETRIC DATA

A field experiment was conducted on 12 May 1977 to measure the effects of corn crop residue and soil moisture content on the reflectance of humid mesic region glaciated soils differing greatly in soil color, organic matter content, and natural drainage. Factorial treatment combinations consisted of two levels of soil moisture content (dry and moist) along with two surface soil conditions, i.e., with and without 2.2 metric tons/ha corn stover (about a 35% cover). Two plot sites were chosen at the Purdue University Agronomy Farm to represent the two soils under investigation: Chalmers silty clay loam, a fine loamy mixed mesic Typic Argiaquoll, and Fincastle silt loam, a fine loamy mixed mesic Aeric Ochraqualf (Table 1).[20]

At each soil site twelve plots measuring 3 x 3 m were delineated on soil which had been raked smooth to reduce crusting, providing three replications of each treatment combination randomized in three blocks (Figure 1).

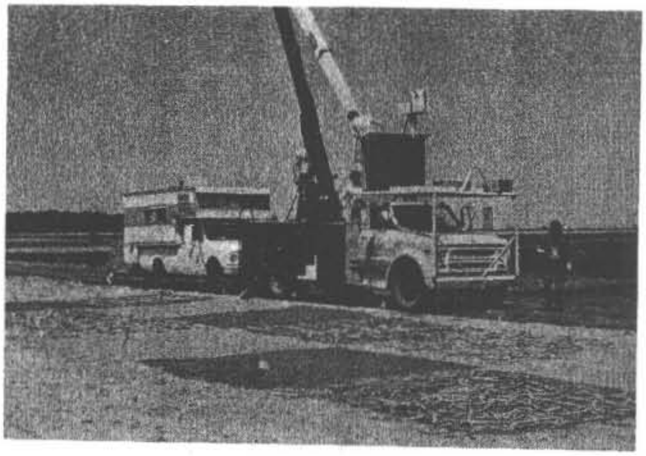


Figure 1. Field Setup for Measurement of Spectral Response from Dry and Moist Fincastle Silt Loam with and without Surface Corn Residue.

An Exotech Model 20C spectroradiometer was used in a 15° field of view mode to obtain spectral data at discrete 0.1 μm intervals over the 0.52-2.32 μm wavelength range from a 1.6 m diam viewing area on the ground.[13] A painted $BaSO_4$ panel was used as a calibration standard.

B. LABORATORY SPECTRORADIOMETRIC DATA

Composite surface soil samples from both of the above soil sites were collected from each of the twelve plots. Sample preparation involved drying,

Table 1. Characteristics of Two Humid Mesic Region Glaciated Soils.

Characteristic	Chalmers SiCL	Fincastle SiL
Taxonomic Subgroup	Typic Argiaquoll	Aeric Ochraqualf
Drainage Class	Very Poorly Drained	Moderately Well Drained
Organic Matter Content	4.7%	1.4%
Munsell Color		
Dry	10YR 4/1	10YR 6/2
Moist	10YR 2/1	10YR 4/3
Soil Moisture Content by Weight		
Field		
Bare Dry Soil	2%	2%
Bare Moist Soil	23%	22%
Residue Covered Dry Soil	4%	5%
Residue Covered Moist Soil	26%	27%
Laboratory		
pF 2 Moisture Tension	37%	29%

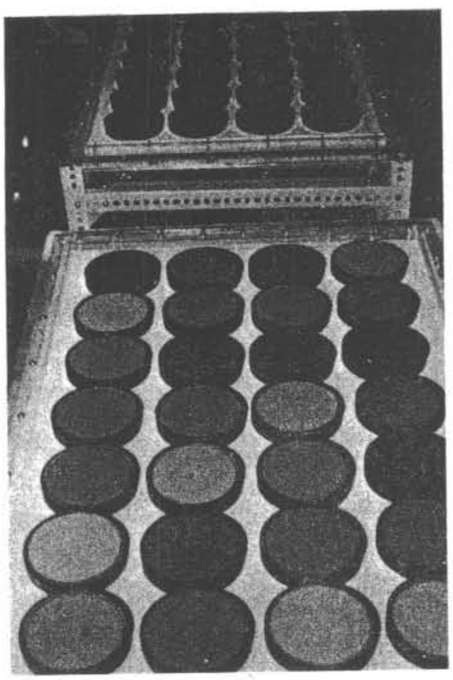
crushing, and sieving all soil samples to remove all particles larger than 2 mm diameter. Special sample holders were designed and constructed of polyvinyl chloride rings 2 cm deep by 10 cm in diameter with 50 mesh brass strainer cloth stretched taut and fastened in a countersunk groove in one end. Non-reflecting black paint was applied to reduce unwanted reflection from the sample holders.

In order to provide an equipotential moisture environment, a procedure was devised to create a pF 2 soil moisture tension on all the soil samples.[12,14] Two plexiglass-framed 61 x 91 cm asbestos tension tables were constructed and set up with a 100 cm column of water in order to maintain a pF 2 soil moisture equilibrium (approximately one-tenth bar). After saturation of the soil-filled, leveled sample holders for about four hours, the samples were placed on the tension tables for 24 hours equilibration (Figure 2).

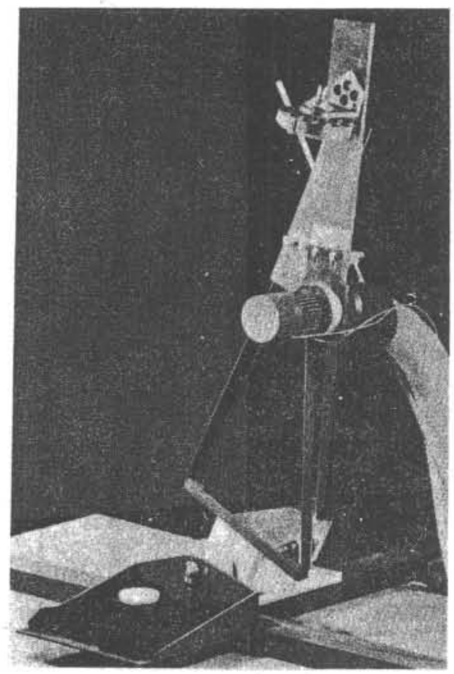
Duplicate subsamples of the composite surface soil samples were measured with an Exotech Model 20C spectroradiometer in an indoor configuration with a bidirectional reflectance factor reflectometer.[5] The illumination source was a 1000 watt tungsten iodine coiled filament lamp which transfers a highly collimated beam by means of a paraboloidal mirror to the sample-viewing plane (Figure 2). A three-fourths degree field of view mode was used with the detector placed 2.44 m above the sample. Spectral measurements of soil samples as well as the pressed $BaSO_4$ reflectance standard were recorded on analog tape for later conversion to annotated digital format for computer processing using the EXOSYS analysis program.[19]

IV. RESULTS

Soil spectral curves from twenty Fincastle silt loam check samples measured on



a. Asbestos tension tables designed to equilibrate soil samples at pF 2 after 24 hrs at 100 cm H_2O tension.



b. BRF reflectometer positioned for soil sample detection.

Figure 2. Laboratory Setup for Measurement of Spectral Response from Soil Samples Equilibrated at pF 2.

ten different days verify the reproducible nature of soil spectra measured under a controlled moisture tension equilibrium (Figure 3). Soil moisture content on a weight percent basis is seen to vary little from an average 31.3 MW% for all check samples. The pF 2 (100 cm of water) moisture tension can be thought to approximate natural field conditions in which the drainage tension of soils tiled at 1 m depth gives the minimum amount of air space found in the drained soil, a factor which has been closely associated to the yield response of many field crops.[14]

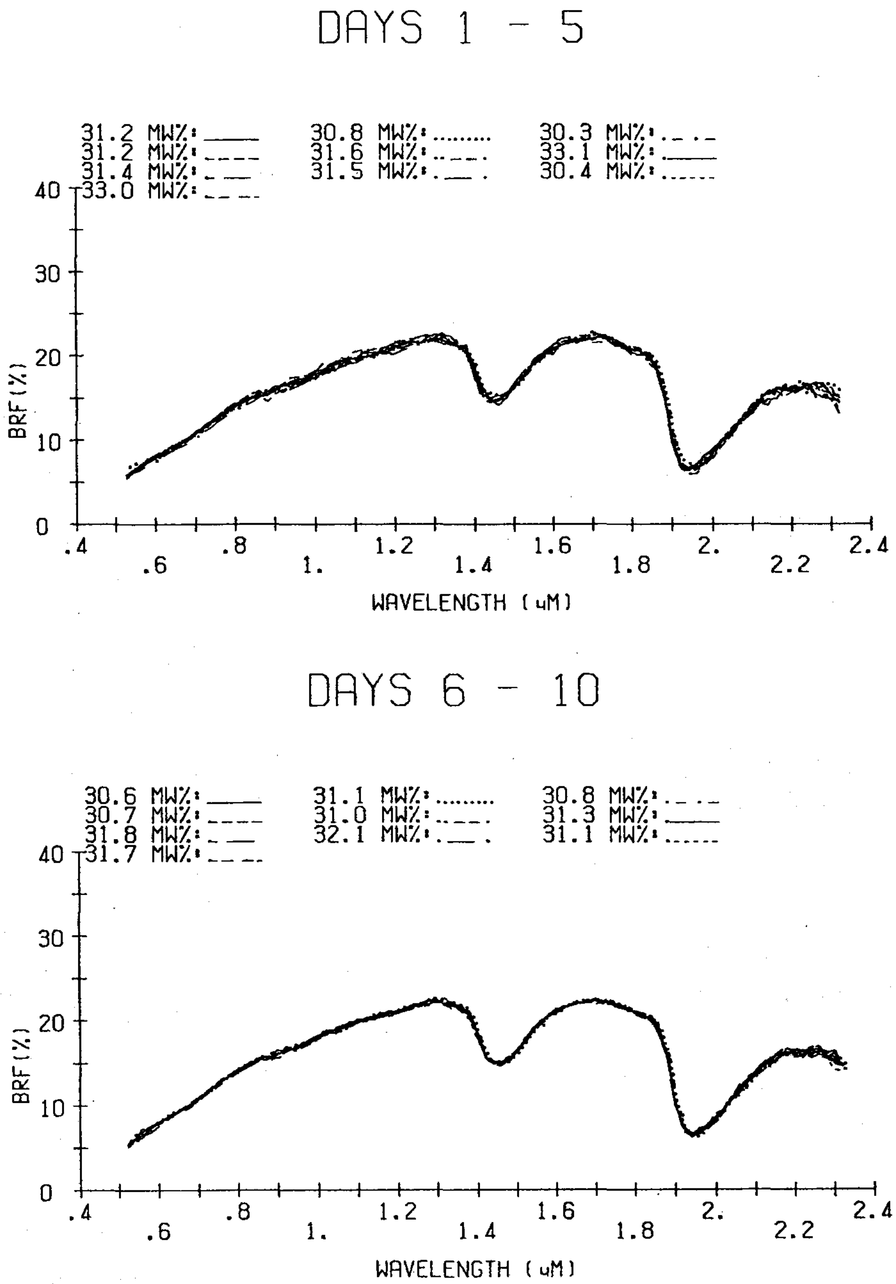


Figure 3. Soil Spectral Curves and Moisture Weight Percentages (MW%) for 20 Fincastle Silt Loam Check Samples from Ten Different Setups of the Tension Table Apparatus.

Laboratory- and field-measured spectra for Chalmers silty clay loam and Fincastle silt loam are shown in Figure 4. The familiar concave trend of the high organic matter Chalmers soil, typical of soils in the Mollisol soil order, is not altered by residue cover or moisture differences.[4,16] Similarly, the convex trend of all spectral curves for the Fincastle soil is typical of observed spectral response for the Alfisol soil order.[16] Field-measured spectral curves do not contain data in the

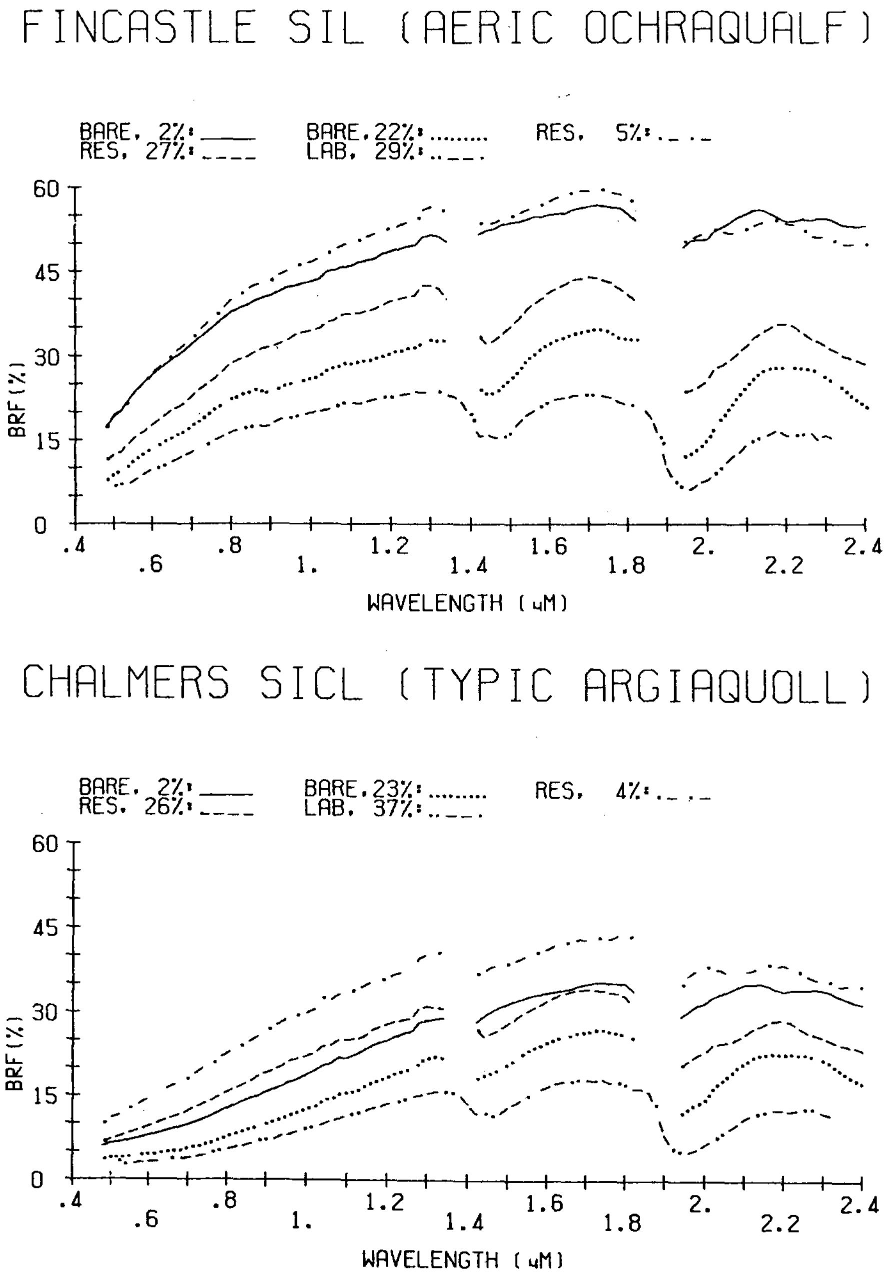


Figure 4. Comparison of Field- and Laboratory-Measured Spectra of Two Soils. Percentage figures are moisture weight percent; RES = corn residue covered soil; BARE = residue-free soil; LAB = laboratory-measured soil.

1.4 and 1.9 μm water absorption bands because of practical difficulties in collecting data in this region where the solar illumination is almost completely absorbed.

Chalmers and Fincastle soils under similar field conditions appear to be spectrally separable throughout the reflective wavelength region regardless of soil moisture level or surface residue cover (Figure 5). This would seem to confirm the observed separability of different soils when areas with similar tillage practices are isolated and classified

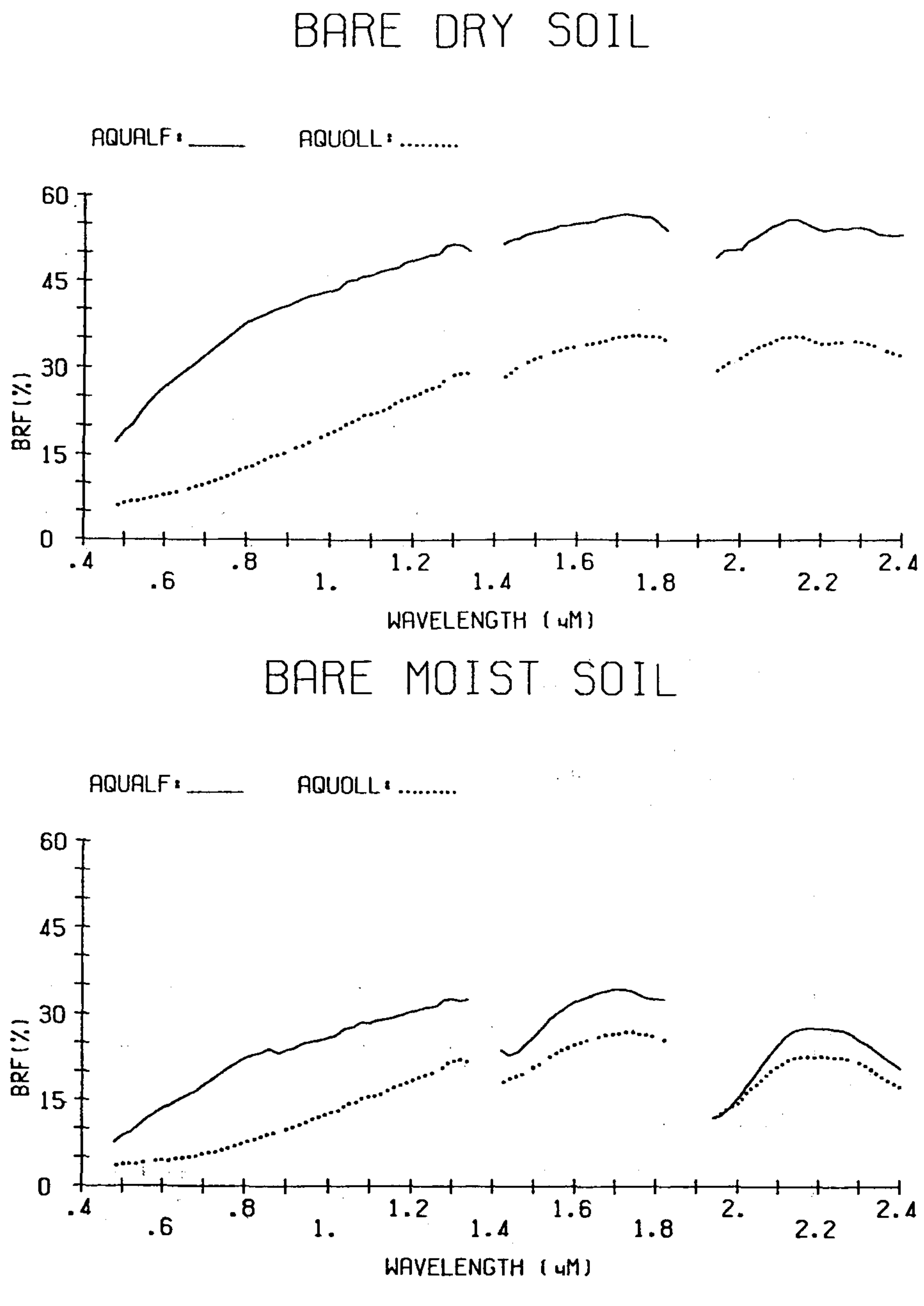
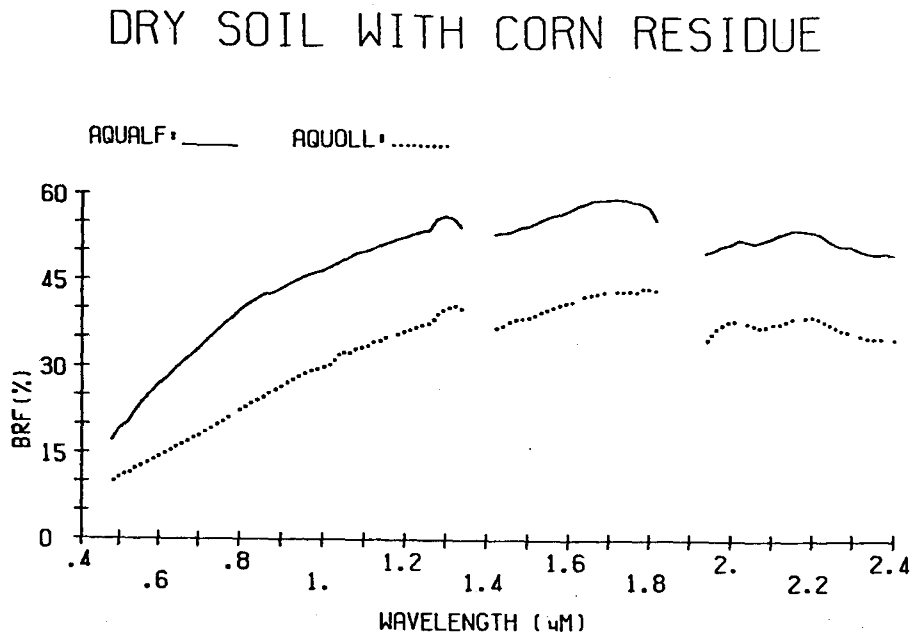


Figure 5. Chalmers Silty Clay Loam (Aquoll) and Fincastle Silt Loam (Aqualf) Soil Spectra Compared under Similar Field Conditions.

separately using airborne MSS data.[21]

Dividing the spectral response of a given soil by the spectral response of another identically treated soil allows for identification of the spectral regions in which the greatest magnitude of differences occur. Response ratios for Fincastle/Chalmers soil comparisons indicate that the greatest magnitude of differences in spectral response between identically treated soils appears in the 0.6 to 0.8 μm transition region between the visible and near infrared, regardless of field condition or laboratory preparation studied (Figure 6). Corn residue cover reduces the magnitude of spectral differences between these two soils, especially in the



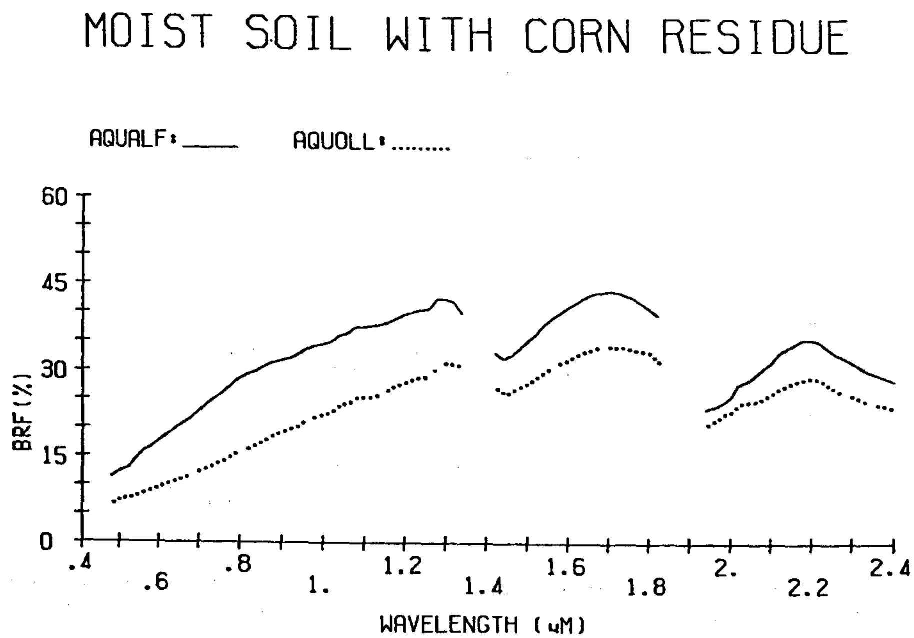


Figure 5. Continued.

0.52 to 1.32 μm region.

Using the same ratio technique, it was demonstrated that laboratory-measured spectra of soils at pF 2 are directly proportional to the spectral response of the same soil when measured in the field under bare moist conditions (Figure 7). This relationship seems to hold for the 0.52 to 1.32 μm region as well as for the 1.55 to 1.75 μm region. Spectral response for either the Fincastle or Chalmers soil as measured under bare moist field conditions can be expected to be about 1.5 times

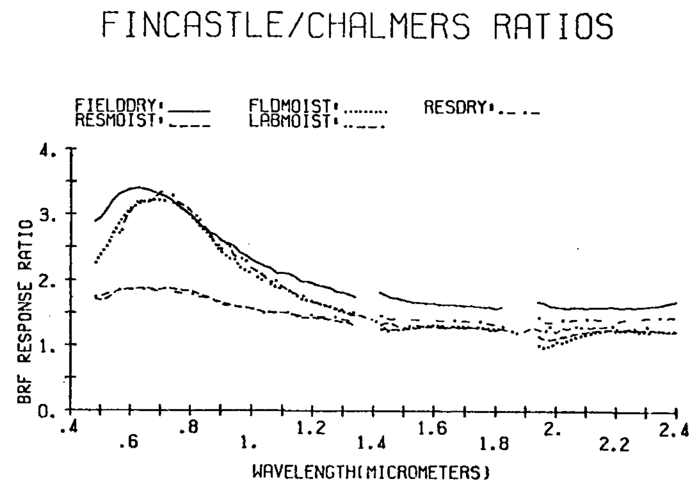


Figure 6. Response Ratios Demonstrating the Magnitude of Difference in Spectral Response Between Spectral Curves for Identically Treated Fincastle/Chalmers Soils. FIELDDRY = bare dry soil; FLDMOIST = bare most soil; RESDRY = dry soil with corn residue; RESMOIST = moist soil with corn residue; LABMOIST = laboratory-measured moist soil.

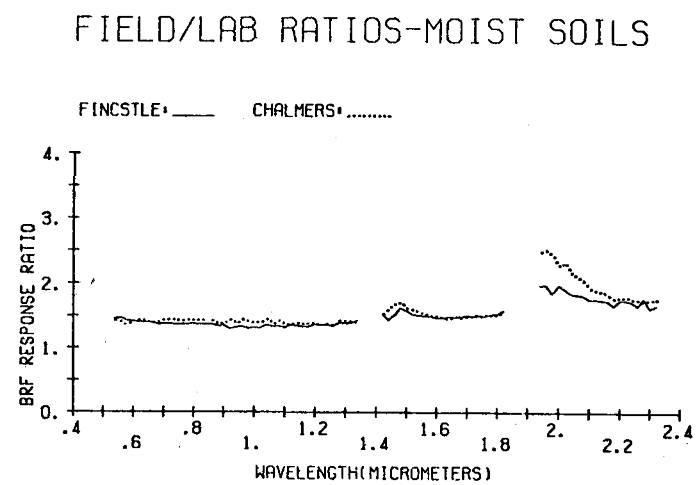


Figure 7. Response Ratios Demonstrating the Magnitude of Difference in Spectral Response Between Spectral Curves for Field-Measured Bare Moist Soil and Laboratory-Measured Soil at pF 2. FINCSTLE = Fincastle silt loam soil; CHALMERS = Chalmers silty clay loam soil.

greater than the spectral response of laboratory-measured moist soils at pF 2 at any given wavelength within these wavelength ranges.

V. CONCLUSIONS

The ability to extend laboratory-measured soil spectra to field conditions has important implications in applying remote sensing techniques to soil survey, land degradation study, and crop inventory. By bringing soil samples into a controlled laboratory environment it is possible to study the spectral properties of large numbers of soils from diverse climatic and geographic regions without having to transport a spectroradiometer to scattered field sites. Experimental results verify the validity of comparing laboratory-measured soil spectra under controlled moisture equilibria to field-measured spectral response from bare moist soil for two humid mesic region glaciated soils.

A technique of ratioing comparably treated soils indicates that the spectral differences between Fincastle silt loam and Chalmers silty clay loam may be most prominent in the transition region between visible and near infrared wavelengths. Current Landsat bands 5 (0.6-0.7 μm) and 6 (0.7-0.8 μm) would seem to be ideal for discrimination of spectral differences between these two unvegetated soils regardless of their field condition.

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