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FINAL REPORT
Project No. A-061-IND
September 30, 1982

Use of Spectral Data to Estimate the Relationships Between Soil Moisture Tensions and Their Corresponding Reflectances

Principal Investigator: M.F. Baumgardner

Use of Spectral Data to Estimate the Relationships Between Soil Moisture Tensions and Their Corresponding Reflectances

I. STUDENT ASSISTANTS

A. Shaheen F. Madaani
Ph.D. candidate, Soil Science, now completing thesis research. Continuing as self-supporting student in Agronomy. (Native of Iran.)

B. Lu Ann Brown
Undergraduate, Humanities. Received extra labor support from OWRT. Worked 40 hours preparing samples.

II. NARRATIVE STATEMENTS

A. Research Project Accomplishments

Introductory Statement.

The major objective of this project was to perfect a method for evaluating the moisture tensions of soils from their corresponding reflectances and for predicting the changes in soil reflectance with changes in moisture tension.

Previous Accomplishments.

Preliminary research by the project leader revealed an orderly relationship between the loss in reflectance on wetting and the corresponding reflectances at oven dry of 15 Indiana surface soils. An array of ratios of reflectances for oven-dry over those for one-third bar water tension levels of 15 Indiana soils showed 11 dark-colored Mollisols to be in a significantly different population by the T test than were four light-colored Alfisols. However, the loss in percentage bidrectional reflectance (%BRF) values at one-third bar versus the % BRF at oven-dry for all 15 soils had an R^2 of .935 compared with one of .974 for only the 11 Mollisols. This showed that even though two populations existed, the darkening effect of wetting was closely porportional to the reflectance of the soils when oven dry over the whole range although the agreement was closer within subsets of soils of similar soil color. Similar results were obtained at spectral band widths of .52-.58 μm, .76-.90μm, .90-1.22 μm, and 1.51-1.73μm.

These encouraging results indicated a good probability of developing a capability to predict soil moisture tensions from spectral measurements and led to the research being done under this grant.

To accomplish the objectives of this project, the uniqueness of the techniques available had to be taken into consideration. At LARS a specially modified Exotech Model C spectroradiometer is available, developed by two electrical engineers on the LARS staff, Larry L. Biehl and Barrett F. Robinson, who are available to use this equipment to measure and analyze the reflectance of soil samples. This equipment is set up in a specially designed dark room and needs to be operated by the two engineers, the only ones conversant with the technique. Since it takes half a day to set up and four or five hours to make a run, it is not convenient to run only a few samples at a time. Consequently, by purchasing two 15 Bar extraction pressure plates and borrowing five others from Agronomy, it was possible to prepare and analyze enough samples at one time to justify calibrating the equipment and making a run.

Research Performed, Results and Conclusions

Fifty-seven samples were selected from surface samples representing 240 representative soil series widely distributed over the United States and supplied to LARS by the Soil Conservation Service (SCS). The 240 samples were selected to cover as large a range of visible spectral properties (colors) as possible. From these 240 samples, 57 were selected to represent the range in soil characteristics known to affect reflectance, such as iron oxide, organic matter content, texture, etc. Oven-dried samples of this subset were compared to matching (split) samples wetted to 1/10 bar moisture tension. Spectral analysis was made in all cases with an Exotech Model C spectroradiometer capable of providing readings in 0.01 μm increments in the 0.52-2.32 μm wavelength range. Data were recorded for subsequent digitization and computer processing.

Losses in reflectance on wetting (% BRF oven - %BRF at 1/10 bar) versus % BRF oven dry were subjected to regression analysis. The regression curves at seven different wavelength bands with their corresponding R^2 values and equations are shown in Figures 1-4, Appendix I. (Originals were submitted in FY80 report.)

The curves indicate that the brighter the soil, higher % BRF when dry, the greater the darkening effect on wetting. The following R^2 values for 7 wavelength bands show the loss in reflectance values best fitting the regression curves at the 2 wavelength bands most closely associated with water absorption, bands 1.42 to 1.75μm and 1.92 to 2.02μm:

Wavelength Band	R^2
0.45-0.52 μm	.786
0.52-0.58 μm	.845
0.76-0.90 μm	.652
1.20-1.30 μm	.554
1.42-1.52 μm	.916
1.55-1.75 μm	.754
1.92-2.02 μm	.963

These data may be taken as evidence of the uniformity of the moisture films at oven dry and 1/10 bar. The closeness with which the values approach the regression curves at these wavelengths possibly results from the low reflectance of incoming radiation at these "absorption" bands and hence less confounding influence on reflectance values. It is also encouraging that a fairly high R^2 value, R^2 .845 at 0.52-.845 μm, is found in the visible range of the spectrum. The prospect of developing formulas based on the regression curves at these wavelengths as prediction equations for soil tension levels is promising.

Present opinions of soil physicists generally credit soil moisture films on particle surfaces to be of uniform depths for specific soil moisture tensions. The orderly shift in reflectance over a series of soils representing a wide range in properties on wetting to a constant tension found in this study seems to bear out this theory.

The research on this project up to this point naturally led to speculation as to the type of curves which would result from data on the loss of reflectance for a given soil versus the reflectance when dry over a range of soil moisture tensions.

In order to study the effect of different soil moisture tension levels on soil spectral properties, subsamples from 12 of the master samples used in the previous study were brought to 1/3 bar moisture tension and analyzed with the Model 20C. The resulting curves over the range of wavelengths used are shown together with those for oven dry and 1/10 bar moisture levels for the same soils.

Four of the soils, Amarillo, Paola, McCarran and Cushing, exhibited stepwise increases in reflectance at higher moisture tensions, whereas little differences in reflectance at the 1/10 and 1/3 bar moisture levels were noted from the other 8 soils. Comparisons of the measured properties of these soils, namely, texture, CEC, organic matter and iron content, were made. The only soil property showing uniqueness for one of the sets was CEC. The soils for which the 1/10 bar and the 1/3 bar curves were very similar were those with higher CEC values. This indicated that for the large-size samples needed for the Exotech analysis, equilibrium in moisture tension apparently was not reached in the heavier-textured soils.

To further explore the relationship of different moisture tensions to soil spectral properties, 6 of the 12 samples were analyzed for % BRF after being brought to equilibrium at 15 bar. As with the spectral responses at oven dry, 1/3 bar and 1/10 bar moisture treatments, when the % BRF for the 15 bar treatment was plotted against wavelength, the resulting reflectance curves were not noticeably different from those at 1/3 and 1/10 bar for the heavy-textured soils.

The reflectance curves for Amarillo, 10.5 meq./100 g. CEC, shown in Figure I, Appendix II, is typical of those for low CEC soils. The curves for Peever, 38.7 meq/100 g. CEC, Figure 2, Appendix II, are representative of those for soils with high exchange capacities.

Because of the doubts that the 15 bar samples in the above-mentioned study were at true equilibrium values, at least for samples of high CEC, a second set of 25 samples was run at 15 bar, 11 of them also at 10 bar, for a period of 120 hours, hopefully to secure equilibrium values for all the samples regardless of their cation exchange capacities (CEC) (Appendix III).

Because of a malfunction in the Exotech 20C spectroradiometer which would delay data analysis, a request for an extension to September 30, 1982 was made and received.

Plots of curves of reflectances versus wavelengths (μm) from .4-2.4 μm for the 25 soils at moisture tensions of oven dry, 15 bar and 1/10 bar and when available at 10 bar and 1/3 bar, revealed marked increased reflectance on drying to higher moisture tensions, except for 6 of 17 soils of the set with CEC values greater than 14 meq./100 g. Although the data in general appeared more dependable, a proposal has been submitted to the Purdue Research Foundation which outlines a procedure for definitely checking the true equilibrium values for various soils at tensions of 10 bar and higher where large samples (110 mm circumference and 5 mm depth) are required.

B. Publications

Peterson, John B., Barrett F. Robinson and Robert H. Beck. 1979. Predictability of change in soil reflectance on wetting. In Proceedings of Machine Processing of Remotely Sensed Data Symposium, 1979, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, IN 47906-1399.

C. Project Status

Results are promising. Definite evidence was found of orderly and predictable relationships among soil moisture tensions of soils and their respective reflectances for an array of various soils from over the continental United States. A proposal has been prepared for funding to perfect a technique for bringing the size of soil samples needed for Exotech analysis to true equilibria at moisture tensions of 10 to 15 bar and to analyze soil moisture data with the resulting improved technique.

III. ACTUAL APPLICATION OF RESULTS

The results of these experiments indicate the possibility of estimating soil moisture tensions of a soil from its reflectance values. If further studies with more dependable readings at the higher moisture tensions bear out the earlier assumptions, people in the LARS Soil Measurements Research area will attempt to develop sensing equipment which can be used on small soil samples either in the laboratory or in the field.

IV. PHOTOGRAPHS

Photographs were submitted with the FY1980 and 1981 annual reports.

FINAL REPORT SUMMARY

Research prior to this project revealed an orderly relationship between the loss in reflectance on wetting and the corresponding reflectances at oven-dry of 15 Indiana surface soils.

Encouraged by these results the research as continued under OWRT support found a similar orderly relationship for 57 surface soil samples selected from 240 SCS bench mark samples covering the continental United States. Oven-dried samples of this subset were compared to matching (split) samples wetted to 1/10 bar moisture tension. Spectral analysis was made with an Exotech Model C spectroradiometer capable of providing readings in 0.01 μm increments in the 0.52-2.32 μm wavelength range. Data were recorded and computer processed. Regression analysis of seven different wavelength bands of losses in reflectance on wetting (% BRF oven dry - % BRF at 1/10 bar) versus % BRF oven dry gave the following R values.

Wavelength Band	R
0.45-0.52 μm	.786
0.52-0.58 μm	.845
0.76-0.90 μm	.652
1.20-1.30 μm	.554
1.42-1.52 μm	.916
1.55-1.75 μm	.754
1.92-2.02 μm	.963

These data may be taken as evidence of the uniformity of soil moisture films at oven dry and 1/10 bar. Present opinions of soil physicists generally credit soil moisture films on particle surfaces to be of uniform depths for specific soil moisture tensions. The orderly shift in reflectance for a series of soils representing a wide range in properties on wetting to a constant tension found in this study seems to bear out this theory.

In order to study the effects of different soil moisture tensions on soil spectral properties subsamples from 12 of the 57 master samples used in the previous study were brought to 1/3 bar moisture tension and analyzed with the Model 20C. Because for the lighter-textured soils (lower cation exchange capacity, CEC), a much wider difference in reflectance was found than for the heavier-textured soils (high CEC), it was expected that the heavier soils had not come to equilibrium at the 1/3 bar moisture tension.

When the 12 soils were evaluated for reflectance at 15 bar tension, the same problem occurred.

Consequently, a set of 25 samples were exposed to 15 bar pressure, and 11 samples at 10 bar pressure for 70 hours to attempt to insure equilibria before analyzing for reflectance. The data still showed less differentiation in some of the heavier soils. Consequently, funds are being sought to develop a technique for insuring equilibria at 10 and 15 bar before measuring reflectance in order to determine whether the observed effect is due to the finer particle size and/or greater surface of the heavier soils or to failure to bring the heavier soils to moisture equilibria.

APPENDIX I

Regression of Loss in Reflectance (Oven Dry % BRF - % 0.1 Bar) Versus % BRF Oven Dry of 57 Soils from the Contiguous United States Selected to Represent as Wide a Range as Possible of Characteristics Known to Influence Reflectance.

Figures 1 through 4.

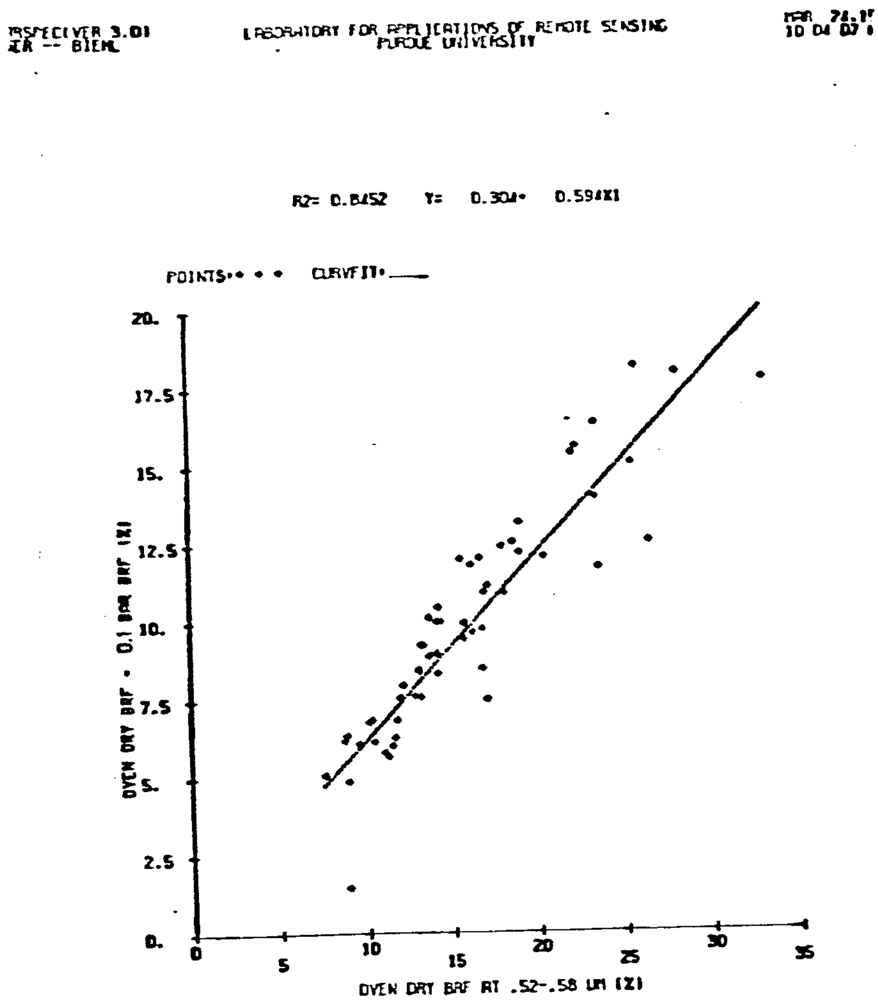

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY
R2= 0.8452 Y= 0.304+ 0.594X1
POINTS
CURVFIT
OVEN DRY BRF AT .52-.58 UM (%)
0 5 10 15 20 25 30 35
0. 2.5 5. 7.5 10. 12.5 15. 17.5 20.

Figure 1.

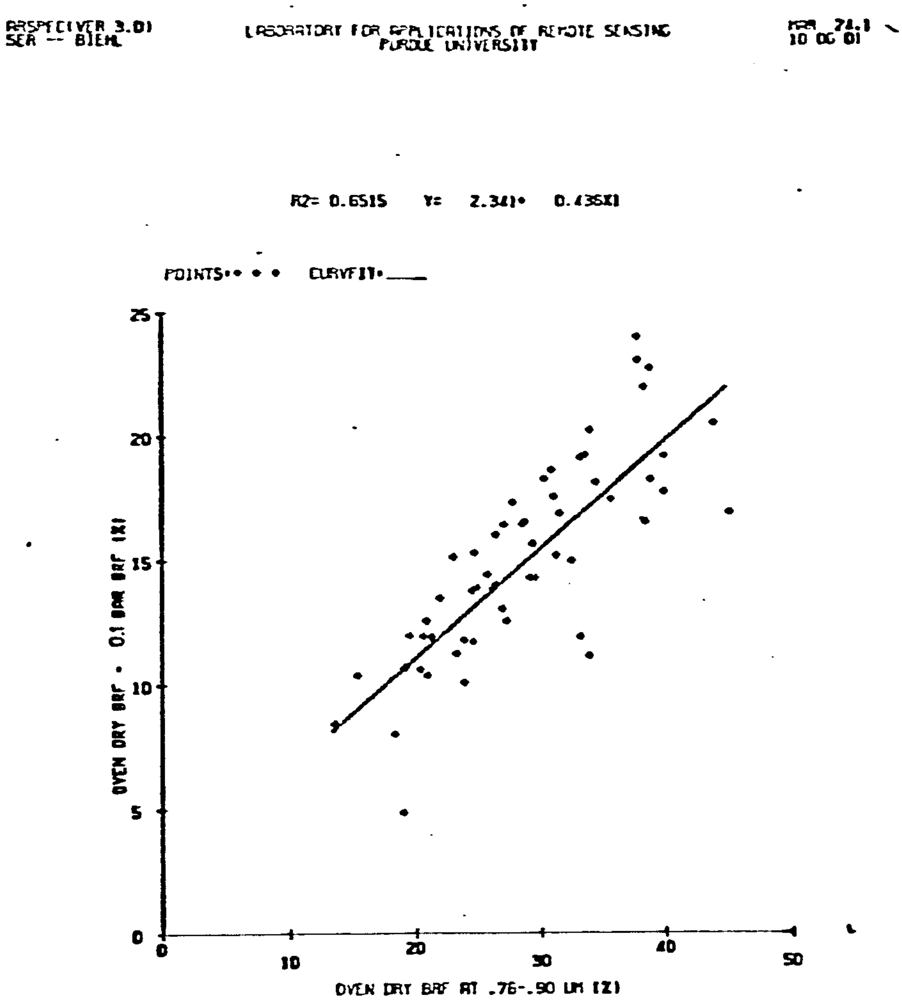
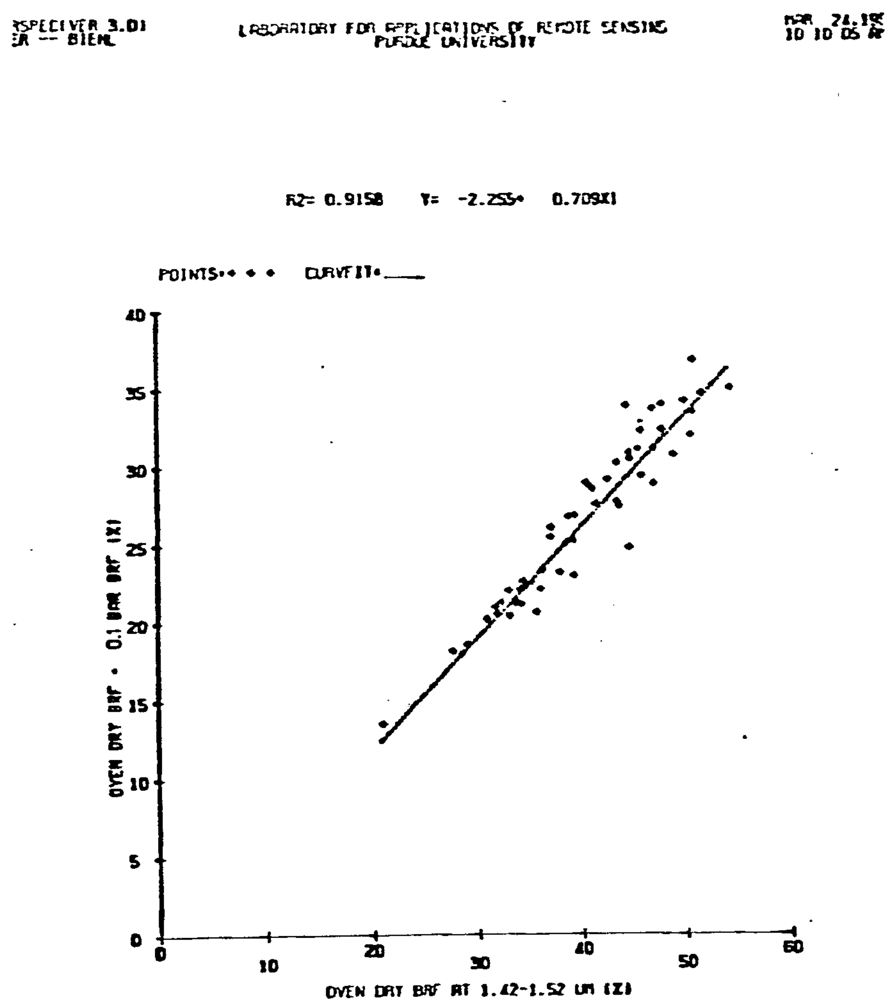

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY
POINTS
CURVFIT
OVEN DRY BRF + 0.1 BAR BRF (%)
OVEN DRY BRF AT .76-.90 UM (%)
0
5
10
15
20
25
0
10
20
30
40
50

Figure 2.



LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY
R2= 0.9158 Y= -2.255+ 0.709X1
POINTS
CURVFIT
OVEN DRY BRF - 0.1 BAR BRF (%)
OVEN DRY BRF AT 1.42-1.52 UM (%)
0
5
10
15
20
25
30
35
40
10
20
30
40
50
60

Figure 3.

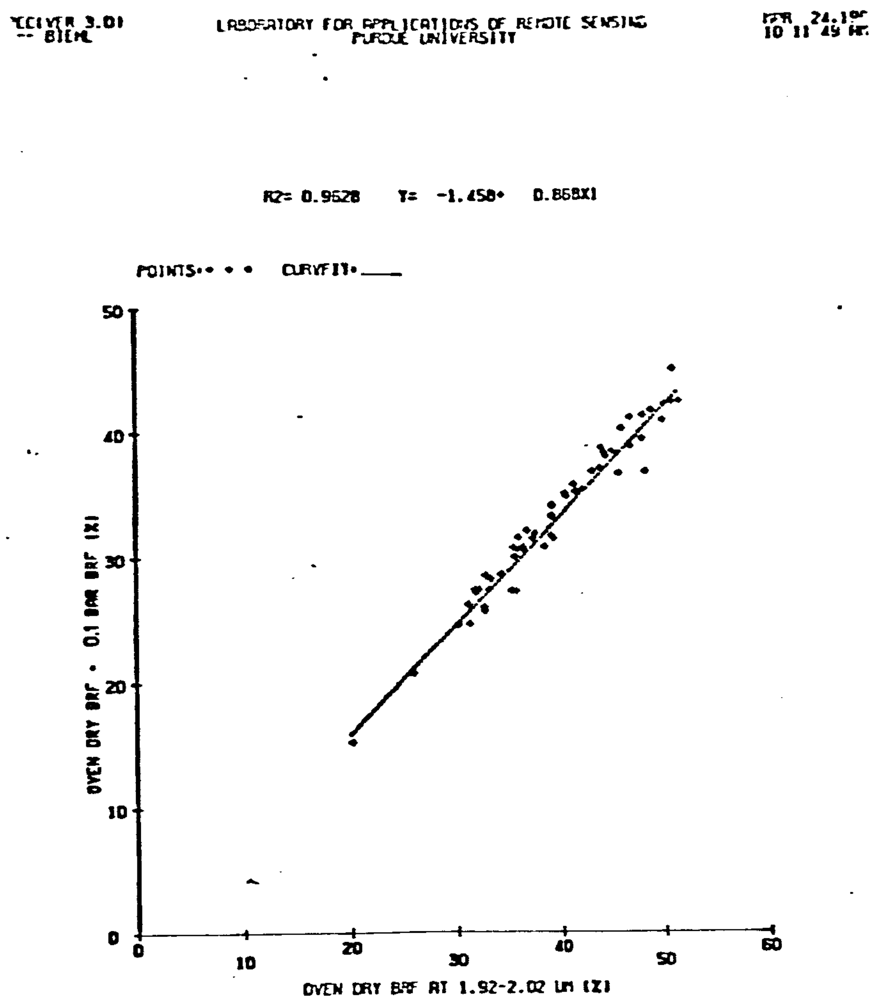

LABORATORY FOR APPLICATIONS OF REMOTE SENSING
PURDUE UNIVERSITY
R2= 0.9528 Y= -1.458+ 0.868X1
POINTS
CURVFIT
0
10
20
30
40
50
60
OVEN DRY BRF + 0.1 BAR BRF (%)
OVEN DRY BRF AT 1.92-2.02 UM (%)

Figure 4.

APPENDIX II

Examples of High Spectral Discriminatability of Moisture Levels in Soils of Low CEC Compared to Those of High CEC.

Figures 1 and 2.

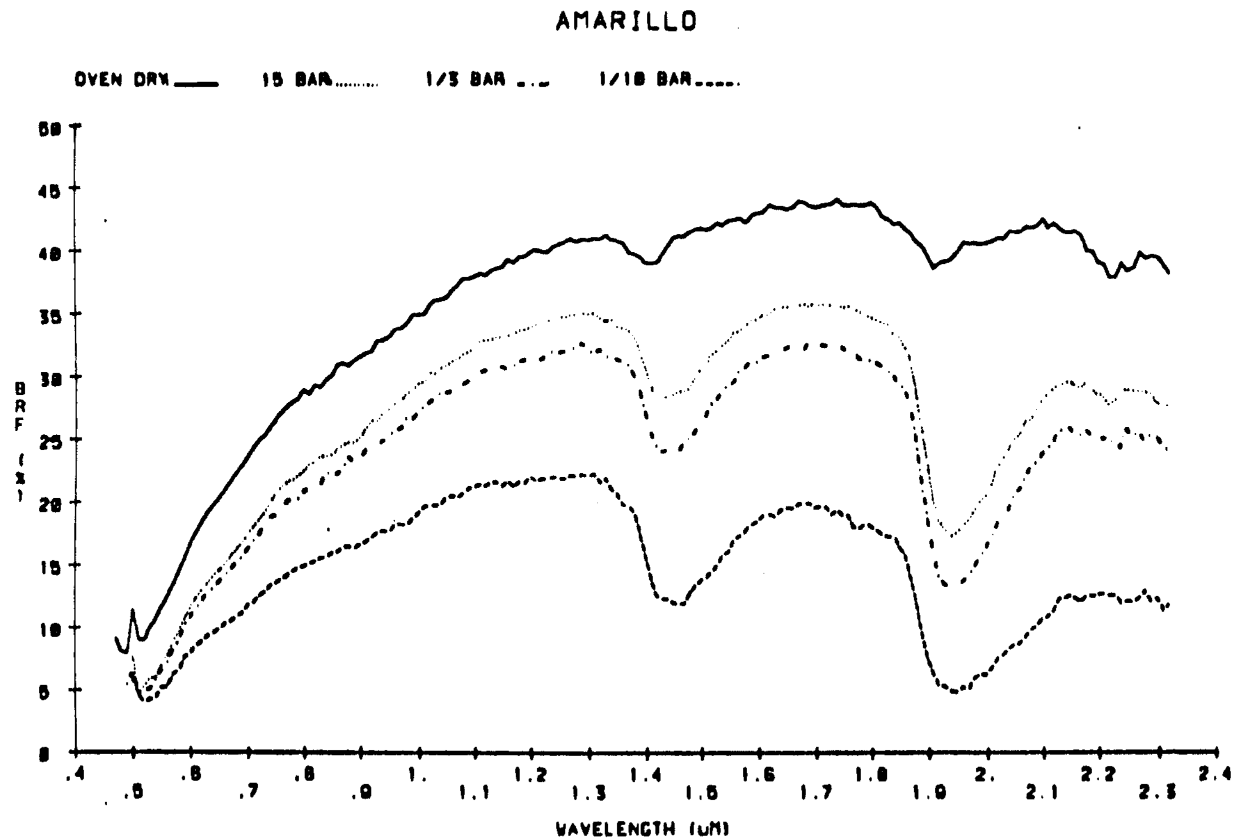


Figure 1. Soil of Low CEC
Meg/g = 10.5

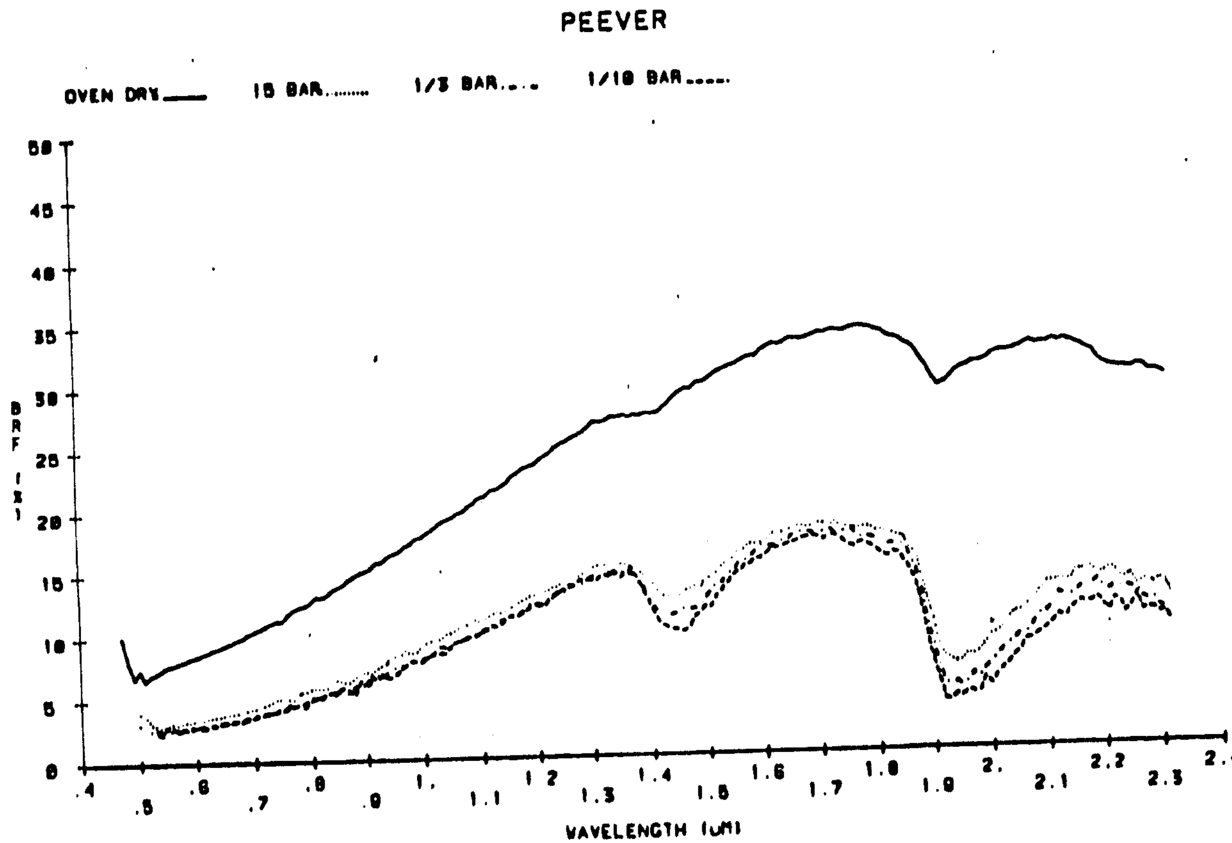


Figure 2. Soil of High CEC
Meg/100 g = 38.7

APPENDIX III

Examples of High Discriminatability of Moisture Levels in Soils of Low CEC Compared to Those of High CEC after Subjection to 120 Hours at 15 Bar Pressure.

Figures 1 and 2.

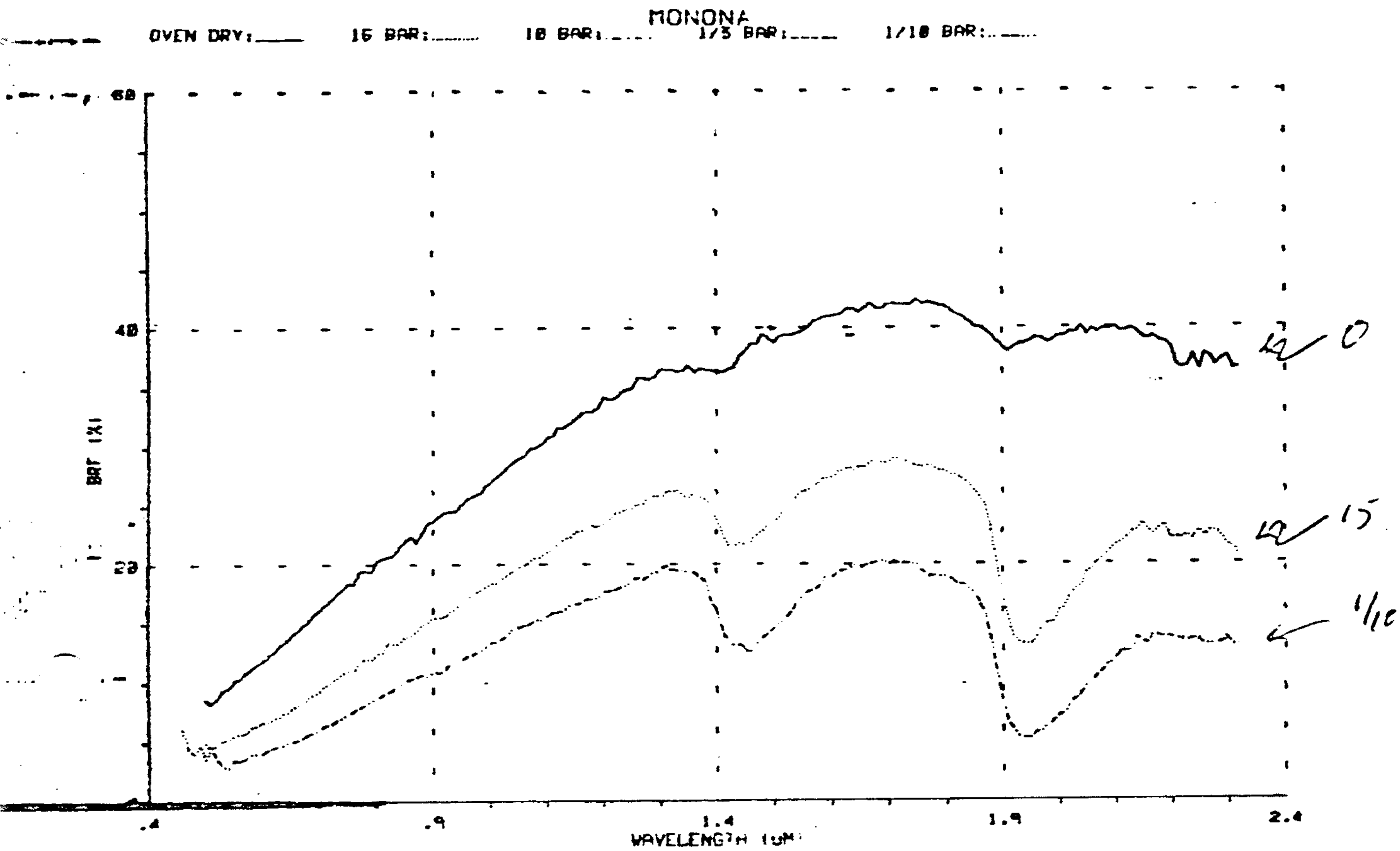


Figure 1. Refleftance curves for a soil sample of high CEC exposed to 120 hours of 15 bar pressure.

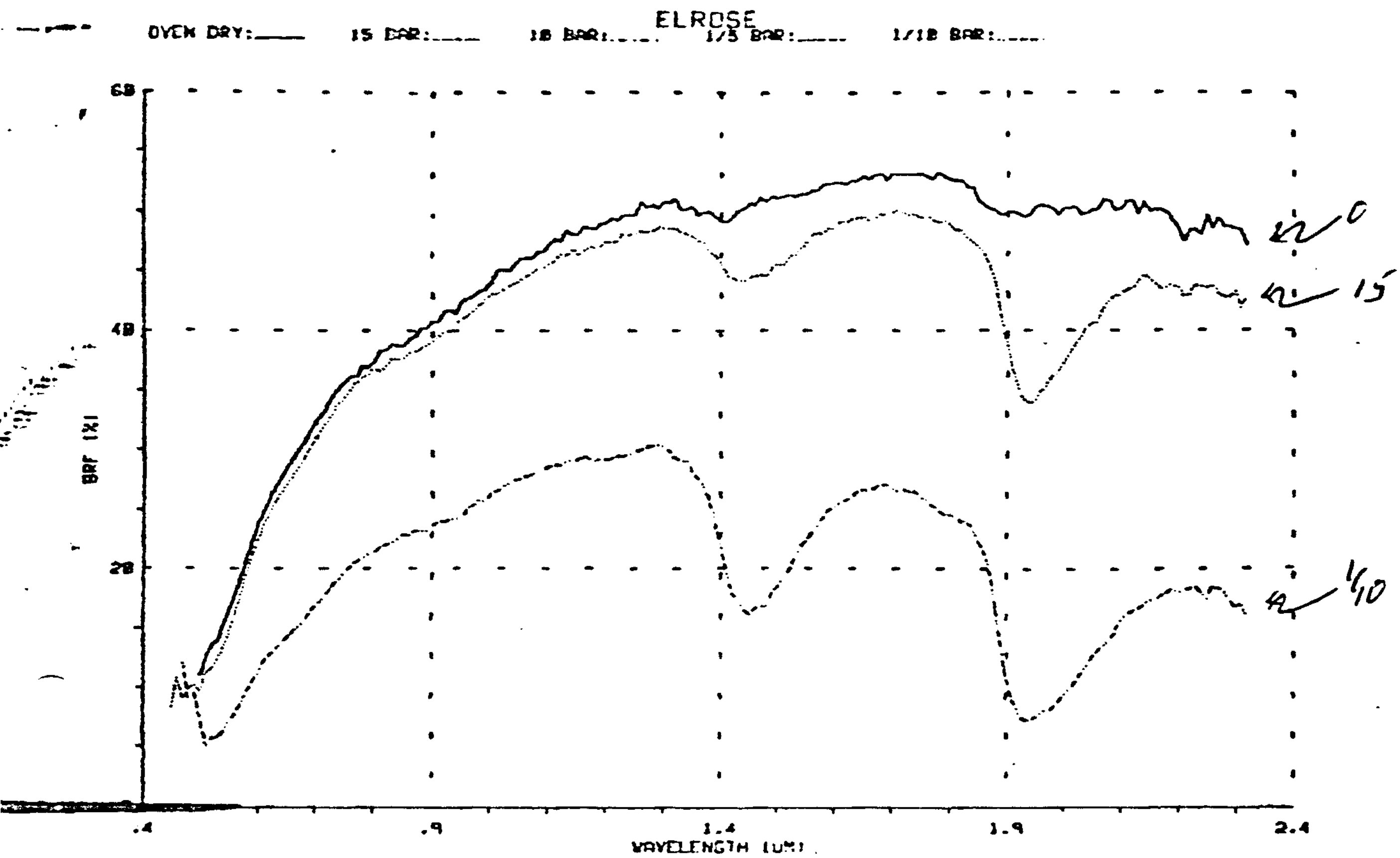


Figure 2. Reflectance curves for a soil sample of high CEC exposed to 120 hours of 15 bar pressure.