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PREDICTABILITY OF CHANGE IN SOIL REFLECTANCE
ON WETTING

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ABSTRACT

The loss of reflectance from the oven dry state to field capacity for 15 surface soils from Central Indiana, representative of the Mollisol and Alfisol great soil groups, is definitely related to the oven dry reflectances of the soils. A regression analysis of the relationship of the darkening effect of wetting on the reflectance of the soils when dry results in regression curves with R^2 values ranging from .9914 to .9291 over the five wavelength bands used, .52-.58 μm , .71 μm , .76 - .90 μm , .90-1.22 μm and 1.50-1.73 μm .

Furthermore, striking evidence of the predictability of soil moisture tensions from reflectance data was noted when the regression curves at .71 μm were run for the reflectance values of the 15 soils at 15 bar and 1/3 bar against their reflectances when oven dry. When the reflectances at 15 bar were plotted against those of the same samples when oven dry an R^2 of 0.95 was found. The equation for predicting the reflectances at 15 bar from the reflectance values when oven dry was found to be:

$$15 \text{ bar} = 1.685 + 1.067 \text{ oven dry}$$

Similarly, when data for reflectances of the 15 soils at 1/3 bar were plotted against the oven dry reflectances, an R^2 of .96 was computed and the formula for estimating reflectances of the samples at 1/3 bar on the basis of their oven dry reflectance was:

$$1/3 \text{ bar} = 0.709 + 0.487 \text{ oven dry}$$

This evidence strongly supports the thesis that moisture tensions of soils can be predicted from reflectance measurements.

I. INTRODUCTION

An analysis of the influence of wetting on the loss of reflectance for 15 representative Indiana soils was made to determine if the commonly observed loss in brightness on wetting was orderly enough to permit predicting the anticipated change in reflectance. A definite relationship was found among the reflectances between two moisture contents at each of four wavelength bands tested. The R^2 values for loss of reflectance for the 15 soils at 1/3 bar (reflectance oven dry minus reflectance at 1/3 bar) versus reflectances at oven dry ranged from 0.919 to 0.991 R^2 . This evidence of predictability of the loss of reflectance for a dry soil on wetting to 1/3 bar or field capacity or conversely of the gain in reflectance on drying is of importance to all who may use spectral sensors, particularly in remote sensing, to help delineate different soils and/or rocks. Such information has been lacking to date. The range in change of soil color upon wetting is stated in "Soil Taxonomy," the standard for soil survey over much of the world, as varying between $\frac{1}{4}$ to 3 Munsell color steps.¹¹ No formulae are proposed for predicting change in color between the wet and the dry state.

Soil surveyors correct for differences in moisture by comparing soil color with Munsell standards at both air dry and field capacity. The directions for a wet reading specify color at field capacity as the estimated color observed after moistening a sample and reading the result as soon as visible moisture films have disappeared.¹¹

Since remote sensing techniques have been found to be greatly expeditious aids to soil surveying, the actual status of soil moisture in the different surface soils for which multispectral scanner data from high altitude platforms are being collected, becomes important. In relating the reflectance data from the surface soils of

different soil types to mapping units on the ground, striking moisture differences need to be considered such as those which can occur when an isolated rain shower has recently covered only part of an area for which remotely sensed data are being obtained for correlation with ground-survey data. Comparisons of reflectance data can be made within stratified zones of wet versus dry areas, but it would be helpful if corrections in reflectance between the two conditions could be calculated from reflectance data.

II. LITERATURE REVIEW

Recent promising results from research on the utility of remote sensing techniques as aids to on-ground soil surveying have further stimulated interest in the influence of different soil properties on reflectance.^{5, 8, 13, 14} Of these, soil moisture and organic matter generally have been found to be most important.

The darkening of soil on wetting is readily observed. An outstanding example is the obvious track of a rain storm across Texas noted in a photograph taken from Gemini 4.⁷

Using a spectrophotometer Bowers and Hanks in 1965 were able to measure a lowering in reflectance for Newtonia silt loam at 6 moisture levels over a range in wavelength from 0.5 to 2.5 μm . Hoffer reported the same type of phenomena for both clay and sandy soils.⁶ The importance of soil moisture and/or soil organic matter content as factors affecting soil color has been established by Bowers and Hanks and Beck.^{3, 2} Beck, using an Exotech 20C spectroradiometer, found that of the several factors studied, soil moisture had the greatest influence on soil reflectance at the 1/3 bar moisture level with organic matter second. However, at a drier state, 15 bar, the same soils showed organic matter to have the greatest effect at certain wavelength bands.

The reduction of reflectance or absorption of light by water occurs differently at different wavelengths, the absorption of water at approximately 1.45 and 1.95 μm being quite pronounced. The darkening effect on reflectance of water when present on a surface has been attributed by Angstrom to internal total reflections within the thin water layer covering the surface.¹ Angstrom believed a portion of the energy would not be reflected to space but would be internally reflected between the surface of the particle and the surface of the water film. Reflectance tends to decrease with in-

crease in index of refraction of the transmitting medium. As a result Planet found objects to be darker in media of greater refractive indices.⁹ The index of refraction for a substance will vary at different wavelengths.¹⁰ For example, the index of refraction for the red end of the spectrum is less than for that of the violet end and on refraction red is deviated less than violet.

Interferences may be suspected of affecting the reflectance of a substance covered by a film of a translucent liquid. According to Standberg, interference occurs when white light passes through a thin film, such as oil suspended on water.¹² White light is split into the colors of the spectrum where the film of oil is thick in relation to the wavelength of light. Under these conditions Standberg suggests that some of the energy is reflected from the top of the surface of the soil film, while additional energy passes through the film and is reflected back from the bottom surface. These waveforms can interfere with or reinforce each other, depending on their phase. If they are out of phase and of the same wavelength, they will cancel one another, and the surface will appear black. If they are in phase, they can selectively reinforce one another, wavelength by wavelength, thus through polarization creating a rainbow effect. Thus, if this explanation is accepted, the amount and nature of solute and/or suspended material in soil water will influence the absorption of light impinging on a wet soil.

III. METHODS

A. SOIL SELECTION AND SAMPLES

Fifteen surface soils were selected to represent a wide range of organic carbon content and were predominantly silt loams and silty clay loams. All of the samples were collected in western Tippecanoe County, Indiana, where they developed in upland, Wisconsin age loess (<40 inches) over Wisconsin age, calcareous, loam till. Each sampling site, approximately 4 square meters (2 x 2), was sampled to a depth of 3 cm by skimming the soil with a flat shovel. All the samples were from soils that had been cultivated for at least 20 years. The soil samples were air dried and crushed by hand to pass all the soil through a 2.38 mm sieve. Each sieved sample was then subsampled using a Cenco soil sample splitter.

B. MOISTURE EQUILIBRATION OF THE SOIL SAMPLES

To determine how much of the variation in spectral reflectance of soils could be explained by their water content, subsamples from each soil (approximately 130 grams) were equilibrated at two moisture tensions: 1/3 bar (4.9 psi) and 15 bars (220 psi). After being allowed to equilibrate 48 hours, the samples were spectrally measured in the laboratory using a field spectroradiometer (Exotech 20C), weighted, oven dried and reweighed to determine percent water at each tension and the oven dried 1/3 bar samples were measured. This resulted in spectral measurements at three moisture tensions providing data for comparing the relationship of the various soils over a range of wetness. The spectral reflectance curves for each soil sample at 1/3 bar and oven dry were from the same sample because it was desirable to have the same surface roughness on all samples spectrally measured.

Air-dried samples were placed in rubber rings 2 cm deep and 10 cm in diameter and then saturated with water for 16 hours and equilibrated at 1/3 bar in a pressure plate apparatus for 48 hours. All samples were later oven dried at 105°C for 48 hours in a forced air drying oven and exposed to the atmosphere only during spectral measurement (2 minutes).

C. SPECTRAL MEASUREMENTS OF THE SOILS

After the soils had equilibrated at the desired moisture tension, they were spectrally measured indoors over the range from .53 microns to 2.32 microns using a field spectroradiometer (Exotech 20C) with collimated illumination provided by a specially housed General Electric DXW lamp and a spherical mirror. The spectroradiometer has a short wavelength head (.37-2.5 μm) and a long wavelength head (2.8-14 μm). The short wavelength head was used and has two detectors. The silicon detector covers the wavelength 0.35 to 0.70 μm and the lead sulfide detector uses a circular variable filter to cover two wavelength ranges, 0.65 to 1.30 μm and 1.25 to 2.5 μm .⁴

To calibrate the instrument, pressed barium sulfate, a perfect diffuser, is measured spectrally. After every fifth sample, the standard, barium sulfate, is measured and the ratio of the sample response to the standard is multiplied by a correction factor, to correct for changes in sensitivity of the detector. The ratio can be converted to percent reflectance by multiplication by π (π) if two assump-

tions are true, i.e., (1) the standard is a perfect diffuser and (2) the sample is a perfect diffuser. If both assumptions are not true, then multiplication by π is still the best estimate and the result is called the reflectance factor. If the ratio is not converted to percent reflectance, the ratio is referred to as Rho-Prime (P') and is the unit accepted by the National Bureau of Standards for energy being measured. The relationship between percent reflectance and P' is as follows: 100% reflectance is equal to π times P' , 31.8 for barium sulfate. The values recorded consist of six complete scans covering the entire wavelength range measured and when these values are digitized and processed, the average of these six scans are reported as P' .

The high intensity lamp used for in-lab experiments has different properties than solar radiation. There are several bands in the infrared region that reflect little solar energy due to absorption by water in the atmosphere, but the lamp has energy in these bands so extrapolation of laboratory results to the field must be made carefully.

IV. RESULTS AND DISCUSSION

When the reflectance of soil samples representing 15 Indiana soils from the soil orders of Mollisol and Alfisol representative of much of the corn belt, were determined at two controlled moisture contents of oven dry and 1/3 bar (field capacity), the wet soils displayed a marked reduction in reflectance. Several factors prompted a study to determine the predictability of the differences in reflectance between the dry soils versus the wet soils. In the first place no consistent change in reflectance on wetting is recognized by professional soil surveyors in the field. They handle the problem by comparing soil colors with Munsell color standards at both the air dry and the moist state as previously described. Secondly, now that the spectral properties of surface soils can be quantitatively identified and evaluated through remote sensing techniques with enough specificity and detail to be extremely helpful to soil survey programs, knowledge of the influence of differences in soil moisture on reflectance becomes critical to using spectral properties of soils in comparing and delineating soils and relating these delineations to soil survey units in various categories.

Regression curves for the 15 soils were determined for the loss of reflectance upon wetting oven dry soils to field capacity (1/3 bar) versus the reflectances

of the oven dry soils [(reflectance oven dry - reflectance at 1/3 bar) versus reflectance when dry]. At each of the five wavelengths analyzed the regression values were R^2 , 0.9914 for .52-.58 μm (Figure 1); R^2 , 0.9784 for .71 μm (Figure 2); R^2 , 0.9331 for .76-.90 μm (Figure 3); R^2 , 0.9291 for .90-1.22 μm (Figure 4); and R^2 , 0.9185 for 1.5-1.73 μm (Figure 5). Thus, the possibility of predicting the loss in reflectance between the spectral reading of a soil when wet compared with that of the same soil when dry is evident.

The slopes of the curves indicate that the lighter the soil the greater the loss in reflectance on wetting (Table 1). This is more pronounced for the wavelengths of .52-.58 μm , .71 μm and 1.50-1.73 μm than for .76-.90 μm and .90-1.22 μm .

Table 1. Slope of Curves for Loss in Reflectance of Oven Dry Soils on Wetting.

Wavelength (μm)	Slope of Curve
.52-.58	0.619
.71	0.534
.76-.90	0.465
.90-1.22	0.411
1.50-1.73	0.529

Furthermore, striking evidence of the predictability of soil moisture tensions from reflectance data was noted when the regression curves at .71 μm were run for the reflectance values of the 15 soils at 15 bar and 1/3 bar against their reflectances when oven dry. When the reflectances at 15 bar were plotted against those of the same samples when oven dry, an R^2 of 0.95 was found. The equation for predicting the reflectances at 15 bar from the reflectance values when oven dry was found to be:

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This evidence strongly supports the thesis that moisture tensions of soils can be predicted from reflectance measurements.

V. CONCLUSIONS

The loss of reflectance from the oven dry state to field capacity for 15 surface soils from central Indiana, representative of the Mollisol and Alfisol great soil groups, is definitely related to the oven dry reflectances of the soils. A regression analysis of the relationship of the darkening effect of wetting on the reflectance of the soils when dry results in regression curves with R^2 values ranging from .9914 to .9291 over the five wavelength bands used, i.e., .52-.58 μm , .71 μm , .76-.90 μm , .90-1.22 μm and 1.50-1.73 μm . Also at .71 μm the regression value for the reflectances of the soils at 15 bar moisture tensions versus their tensions at oven dry is R^2 of .95.

The evidence indicates the existence of orderly relationships among moisture tensions of soils and their reflectance values.

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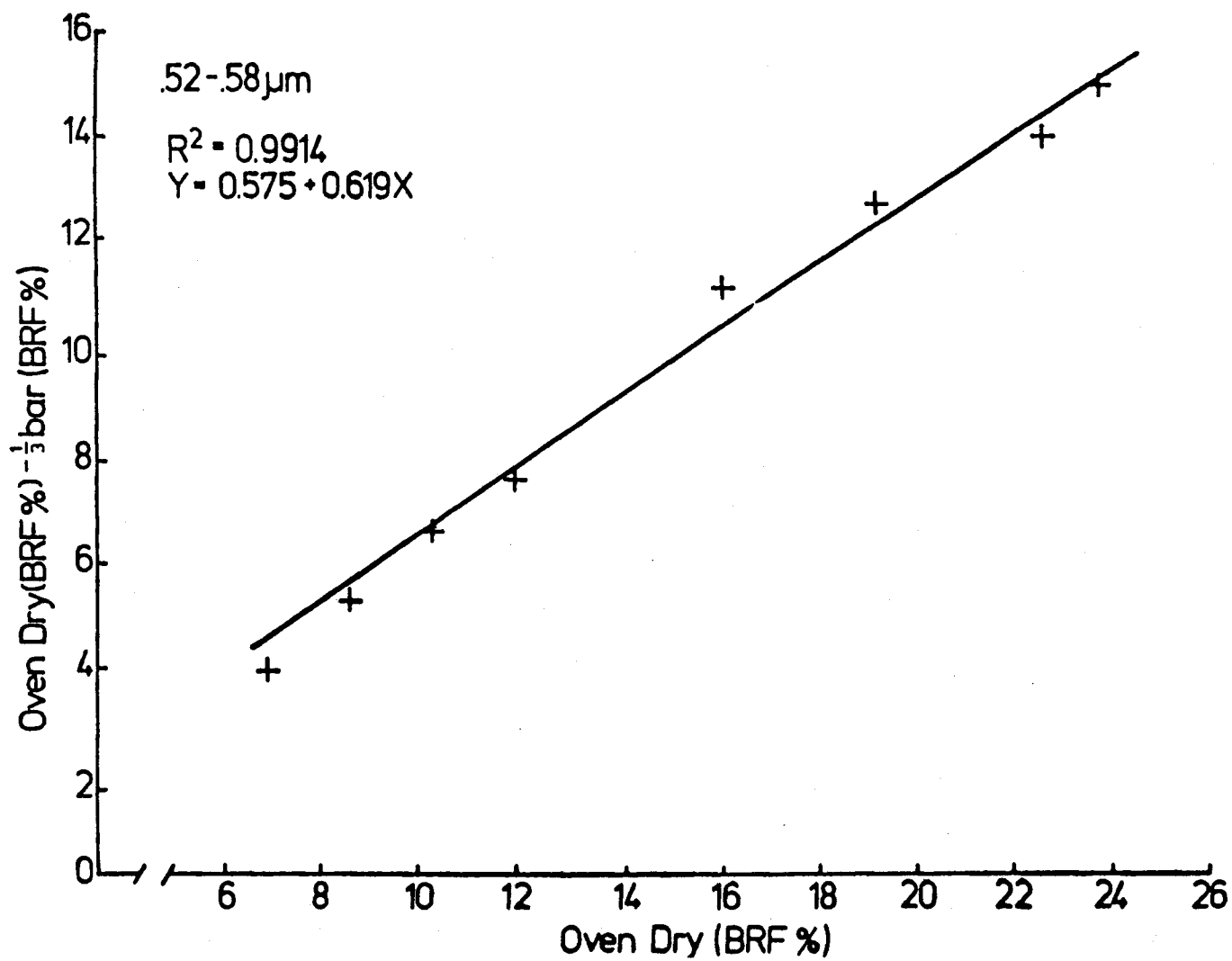


Figure 1.

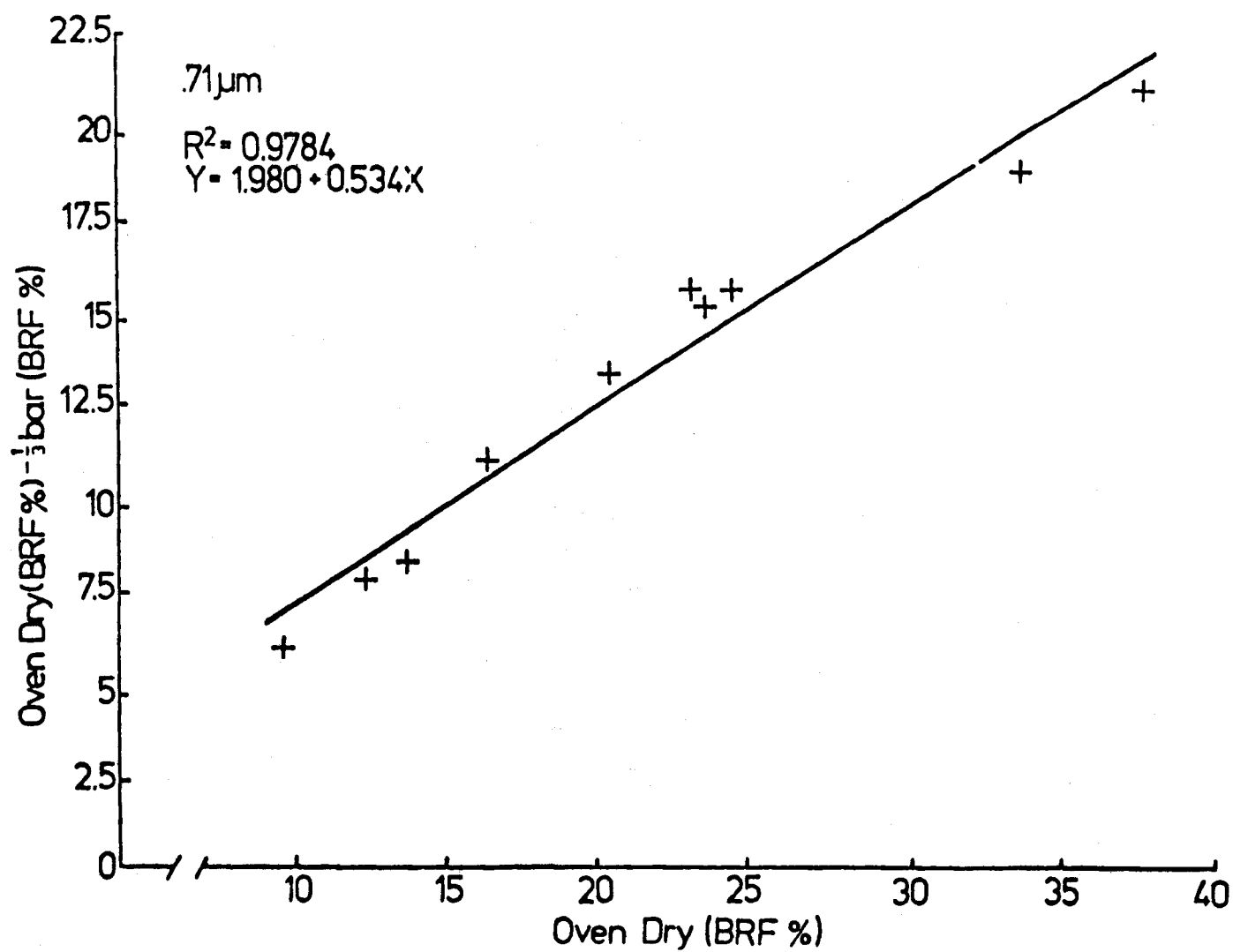


Figure 2.

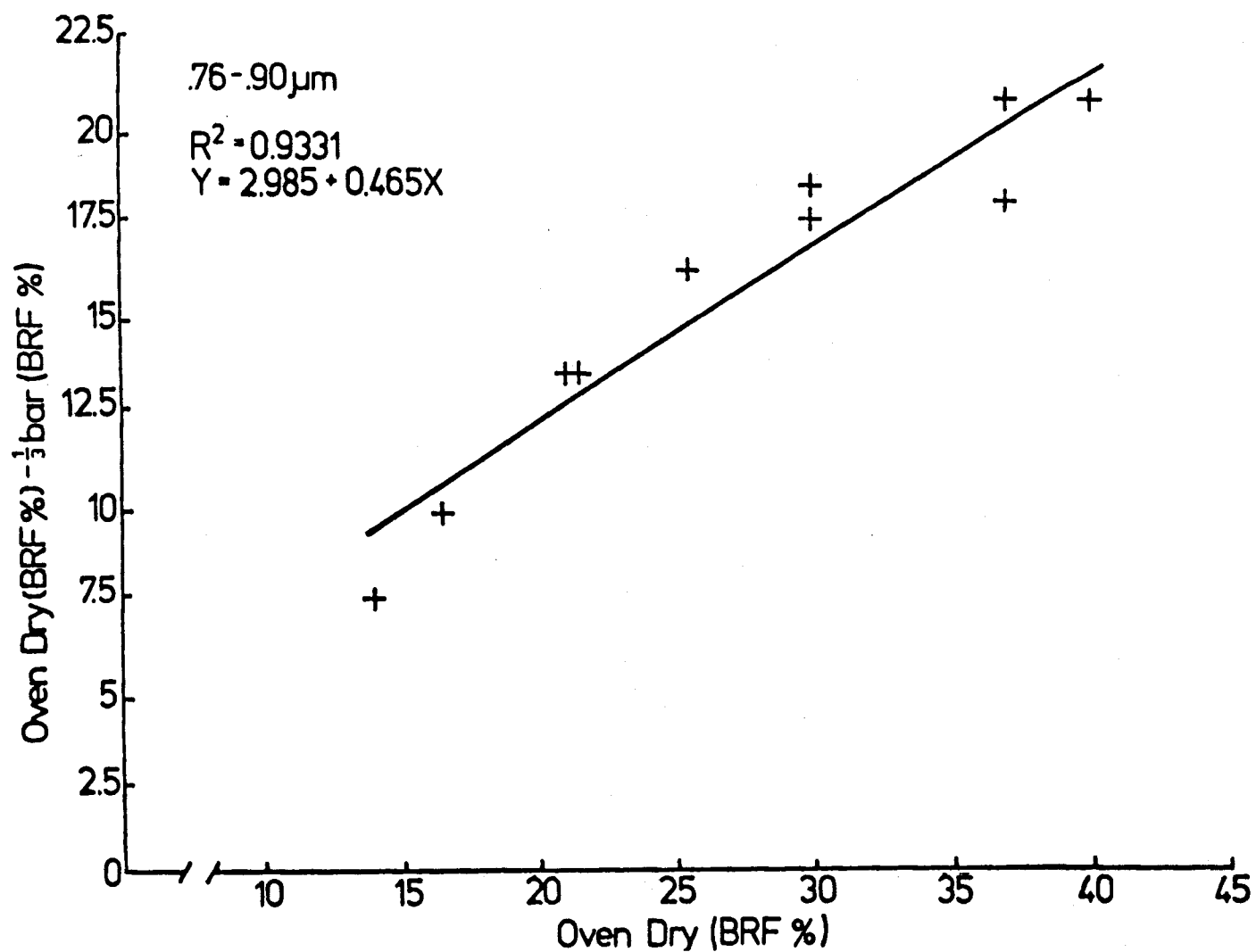


Figure 3.

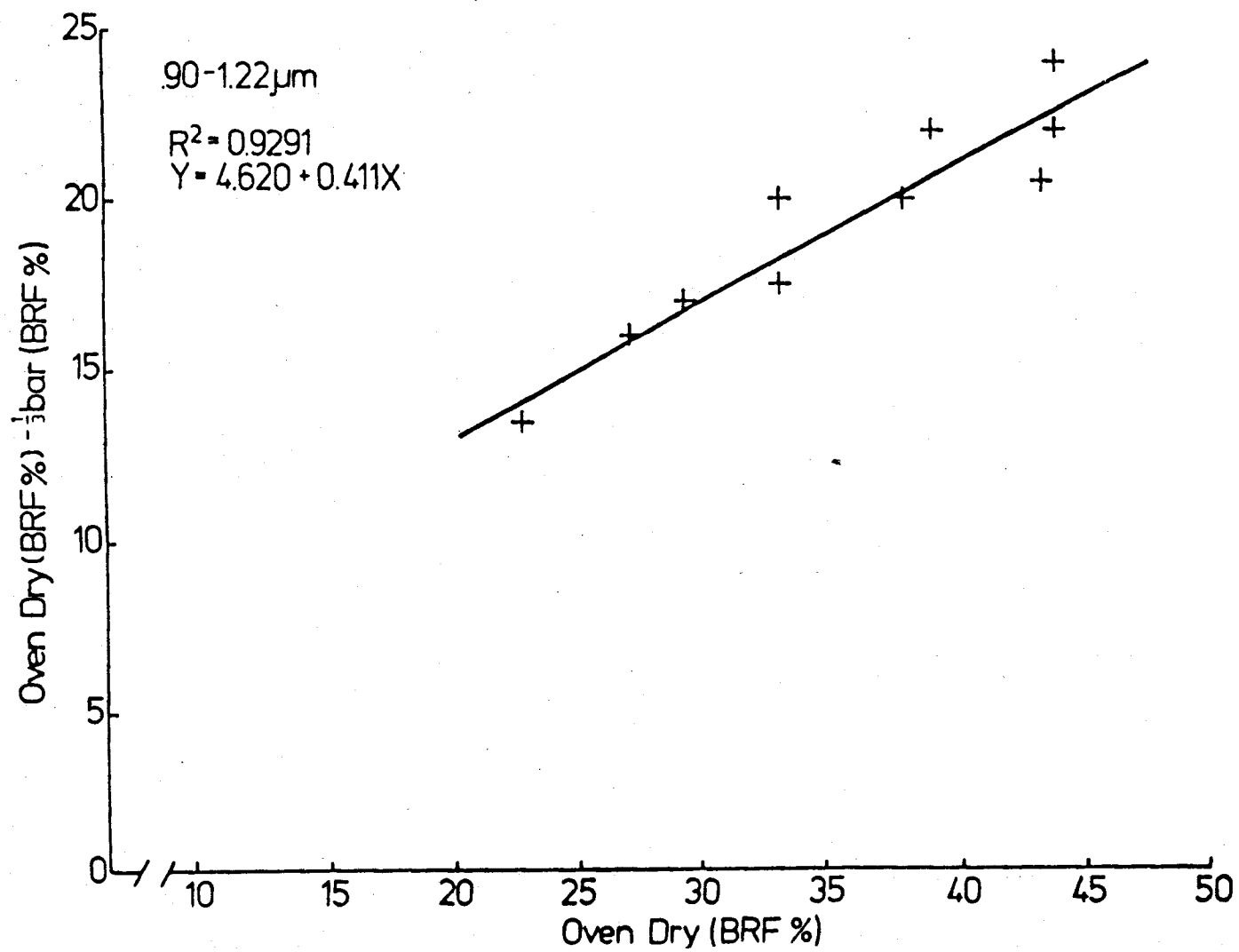


Figure 4.

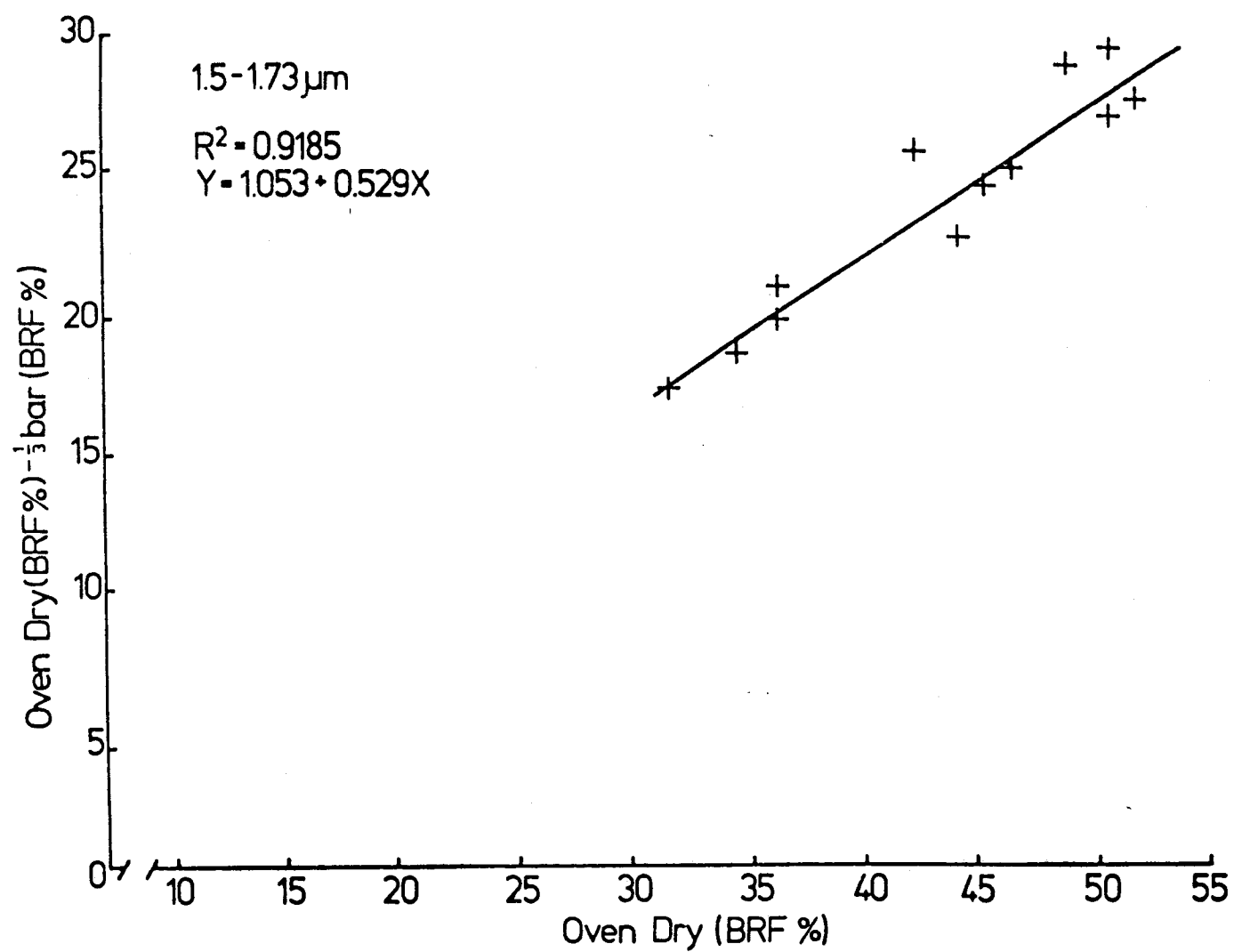


Figure 5.

John B. Peterson, B.S., Oregon State University; M.S., Ph.D., Iowa State University; National Research Foundation post-doctoral fellowship, University of California, Berkeley, has received the American Society of Agronomy Soil Science Research and Agronomic Service Awards and served as president of the society. As Head of Purdue University's Agronomy Department (1948-71) he directed plant and soil science, meteorology and land use. He has served as consultant for government programs in Greece and Saudi Arabia and for FAO, USAID, the InterAmerican Bank and the Ford and the Rockefeller Foundations in Latin America. At LARS he assists in Administration and does research in the earth sciences program.

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Robert H. Beck, B.S., Montana State University, 1972; M.S., Ph.D., Purdue University, 1975, 1979; conducted his M.S. thesis research on a study of the spectral characteristics of soils. In his doctorate study he investigated the kinetics of potassium and ammonium uptake by plants.