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EXTENDED WAVELENGTH FIELD SPECTRORADIOMETRY

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ABSTRACT

The proper interpretation of multispectral scanner data is enhanced by the use of spectral data taken under field conditions. The application of such field data to the analysis of multispectral information may allow the interpretation of second order differences in the airborne observations. A field spectral instrument, therefore, should cover the wavelength range of multispectral scanners currently in use. This paper describes an instrument capable of covering the wavelength range from 0.37 micrometers to 14 micrometers with a spectral resolution sufficient for proper interpretation of multispectral data. The instrument is rugged and capable of operation in relatively adverse field conditions.

INTRODUCTION

20B

Use of multispectral scanner data, as well as color and color infrared films, has indicated tremendous potentials for remotely sensed spectral measurements on a variety of vegetative, soil, and hydrological situations. The use of color infrared film for disease detection, for example, has gained widespread attention. The capability to predict the stage in development of a disease at which remote sensors could be effectively utilized depends on accurate knowledge of the temporal changes in the spectral characteristics of the materials of concern. Such knowledge of the relationships between the spectral characteristics and the plant or soil materials of interest can best be obtained by detailed, ground-based studies over small field plots where complete data concerning the condition of the material is attainable, and where frequent spectral measurements can be obtained economically. The results of measurements made in such situations can frequently be applied in the development of multispectral data analysis procedures.

Experience with several makes of field spectroradiometers during the past five years has indicated that many different requirements must be met before such instruments can be properly utilized to optimum advantage.(1,2,3,4) For example, Figure 1 shows data obtained at a single wavelength, where the spectroradiometer was recording data over a single, small area (about 4" x 12") in a corn field. The variation in signal is caused by either (1) the relatively violent action of the corn leaves over this small area or (2) the effect of clouds on the incident solar radiation. The leaf action effects point to the need for an instrument capable of collecting spectral data over an area large enough that the variability such as observed in Figure 1 is integrated over the entire area and smoothed out. On the other hand, it is desirable to have an instrument capable of collecting data from a relatively small area, such as a single plant or row of plants, or the soil between plant rows, etc. This results in the need for an instrument capable of both a large and small field of view (F.O.V.) or better yet, a variable F.O.V. The effects of cloud cover are indicated in Figure 1 as a function of time at a single wavelength, and are also shown in Figure 2 as a function of wavelength.

These two figures illustrate convincingly the effect of atmospheric conditions on spectral response and how rapidly such conditions can change. Thus, a field spectroradiometer should be capable of very rapid spectral scan times (0.5-5 seconds), and should also be capable of monitoring incident solar radiation at the same time the reflected or emitted radiation is being recorded. Such rapid scan rates would require a tape recording capability for the data, but it would also be highly desirable to monitor the data recording process with an X-Y or strip chart recorder.

For the reasons outlined above, field studies have been severely hampered by a lack of suitable instrumentation for obtaining reliable spectral masurements. Consequently, much work has relied on laboratory instrumentation and spectral measurements of individual leaves or soil samples. Such techniques have been used effectively, but the resulting spectra lack the interrelationships between green leaves, dry brown leaves, the soil, shadows, etc. for the entire scene, as measured by an airborne remote sensing system. During the summer of 1970, a newly developed extended wavelength field spectroradiometer was tested and evaluatec by Purdue as a part of a cooperative program with the USDA facility at Weslaco, Texas. The instrument is capable of covering the wavelength range from 0.37 μm to 14 μm. The spectrum scan time is adjustable so that scan times appropriate to the scene lighting conditions may be chosen. The instrument was constructed by Exotech, Inc., of Gaithersburg, Md., under the direction of D. Fain to specifications developed by R. Leamer of USDA, Weslaco, Tex., and R. Holmes of Purdue.

INSTRUMENT DESCRIPTION

A schematic eiagram of the basic mechanical-optical configuration of the instrument is shown in Figure 3. The instrument is basically divided into two heads, namely, a short wavelength head and a long wavelength head. An external view of the spectroradiometer is shown in Figure 4. Each head may be used independently of the other or they may be used in tandem in a bore-sighted mode of operation. The short wavelength head covers the wavelength range from 0.37 μm to 2.5 μm while the long wavelength head covers the wavelength range from 2.8 μm to 14 μm. Each head contains two detectors, and except for differences in detectors and circular variable filter materials, the heads are essentially identical.

The chopper wheel in the instrument is made of polished aluminum and then coated with silicon monoxide. The radiation from the scene passes through the foreoptics of the spectroradiometer and is chopped by the filter wheel. The arrangement of the detectors is such that each detector looks alternately at the scene radiation and at an internal blackbody reference. A circular variable filter (C.V.F.) in conjunction with a slit and relay optics performs the dispersion and focusing functions in the instrument. The detectors and the associated C.V.F. are arranged as follows:

Short Wavelength Head

Section (1) C.V.F. #1
One segment 0.35 μm to 0.7 μm
Photovoltaic Silicon Detector 295°K

Section (2) C.V.F. #2
One segment 0.65 μm to 1.3 μm
One segment 1.25 μm to 2.5 μm

Long Wavelength Head

Section (3) C.V.F. #3
One segment 2.8 μm to 5.6 μm
One segment 2.8 μm to 5.6 μm

Section (4) C.V.F. #4
One segment 7 μm to 14 μm
Mercury Cadmium Teluride 77°K

Joule-Thompson cooling devices are used to cool three of the detectors to 77°K. This permits the instrument to be operated at a variety of angles and enhances its use as a laboratory instrument as well as a field instrument. Although it is not necessary to operate the lead sulfide detector at 77°K, such operation does tend to remove the effects of environmental temperature variations upon the detectivity of the lead sulfide detector. A chopping frequency of approiimately 1000 Hertz is used as a compromise value to satisfy the time response requirements of each detector.

The short wavelength head uses a V-groove blackbody as a reference. The blackbody operates at ambient temperature and no attempt is made to regulate its temperature. The ambient temperature of approximately 300°K is sufficiently below solar effective temperatures so as to be considered a zero reference. The reference in the long wavelength head is a temperature controlled V-groove blackbody of the same mechanical configuration as that in the short wavelength head. The temperature of the blackbody may be chosen by the operator, using a control on the instrument operating panel. The short wavelength head is equipped with a mirror that can be inserted into the optical path so as to permit the detector to view a diffuser plate located in the top of the instrument. The diffuser plate is so oriented and constructed so as to approximate a Lambertian receiver in the short wavelength range. This arrangement allows incident solar information to be included as a part of the observed data.

The F.O.V. of the instrument is adjustable from 1 degree to 15 degrees by the insertion of a lens into the optical path. The short wavelength head uses a lens made out of quartz whereas the long wavelength head uses a lens made of KRS-5. To change the field of view it is necessary to unscrew the lens and remove it from the instrument. Because of the reflectivtty of the back side of the KRS-5 lens, it is impossible to obtain absolute radiometric calibration in the long wavelength head with the 1° F.O.V. lens in place. Absolute calibration can only be obtained with the lens removed. Refracting optics were chosen because the instrument is sealed when they are in place and field dust becomes less of a problem. However, field experience indicated that the 15° F.O.V. mode was frequently used, in which case the instrument was unsealed.

The amplifiers for the various detectors are located in the instrument head in close proximity to each detector. The pre-amplifier output signals are fed through shielded armored cable to the control panel where ultimately they are amplified to a maximum voltage output of approximately 5 volts. The positions of the circular variable filters are detected by an optical encoder and converted to a series of 1000 pulses per revolution. The pulse train is integrated so as to develop a ramp whose instantaneous amplitude is proportional to the C.V.F. position. The four radiometric signals and the two C.V.F. position (i.e., wavelength) signals constitute the data output of the instrument. In addition, several other d-c voltage levels which constitute instrument status such as control position, mirror position, etc., are available as ancillary data for recording on a suitable data track. In order to minimize electrical interference, d-c brushless Hall-effect motors are used to drive the C.V.F. units and the chopper blades.

During field use, the instrument is normally mounted on a special platform that is affixed to the bucket of an aerial lift. Armored cables are used to feed the electrical signals to an instrument van that is located in front of the aerial lift truck. Figure 5 illustrates a typical field setup of the system. The control electronics, recording equipment, and other data recording instruments are located in the instrument van. A power unit towed behind the instrument van provides power for both the instrument van and the spectroradiometer. Normally, a technician operates the equipment while the natural scientist directs the experiment.

The short wavelength unit is periodically calibrated in an optics laboratory using an NBS traceable lamp as a source. Neutral density screen filters were used to attenuate the standard lamps radiation so that the instrument could be calibrated on all of its gain ranges. The long wavelength unit was calibrated with a blackbody consisting of a water can so prepared as to present a high emissivity surface to the spectroradiometer. The spectrum scan of the instrument is adjustable from one scan per second to one scan every thirty seconds. When the slow scan speed is used, the amplifier bandpass may be restricted so as to eliminate high frequency noise components from the radiometric signal. Under slow scan conditions in bright sunlight, signal to noise ratios in the short wavelength unit in excess of 10,000 to 1 were obtained. The scan speed chosen depends upon the lighting conditions prevalent during the experiment. When scattered clouds are present it is necessary to use fast scan speeds in order to be insured of a uniform lighting condition during the time of the spectrum scan. However, the use of the fast scan results in a deterioration of the signal to noise ratio to approximately 1000:1 under high ambient lighting conditions.

The radiometric data will ultimately be recorded in two forms. For on-the-spot observation by the experimenter, the spectra are presented on a multichannel strip chart recorder in the field. At the same time, the same data will be recorded on magnetic tape for subsequent digitization and computer processing. The strip chart recording aids in selecting data on the magnetic tape during subsequent data handling and analysis procedures and aids the experimenter in adjusting field setups.

EXPECTED BENEFITS

This field spectroradiometer should prove extremely useful in many areas of research, including the following:

(1) Percentage ground cover and vegetative modeling.

The question frequently is raised concerning the effect on scanner data spectral response of different row spacing of corn, or variations in percentage ground cover (due to many possible causes), or the impact of different soil backgrounds on spectral response. This instrument should offer an opportunity to study such problem areas in situ under well controlled situations.

(2) Spectral response of various species and cover types, as a function of time of day and portion of growing seasons.

Aircraft flights are extremely costly affairs, both from the standpoint of the aircraft operations and data collection, and also because of ground crew actions and efforts. Yet, it is very difficult to predict time of day to fly in order to observe various thermal phenomena or sun angle effects. With this field spectroradiometer, preliminary studies could be made, for example, at hourly intervals throughout a growing season as a relatively inexpensive technique to allow much better and more accurate aircraft scheduling than might otherwise be possible.

(3) Disease or insect stressed vegetation studies.

Past studies of spectral characteristics of stressed vegetation have primarily relied on laboratory spectral measurements of the vegetation alone, or on aerial photography, particularly color infrared photos. Little is known concerning detection capabilities at different stages of disease development, or the various vegetation-soil interrelationships for different stress conditions, or the best wavelength bands to use for detecting different types and stages of stress. A field spectroradiometer offers obvious advantages for these types of study. A similar instrument now under construction will be heavily utilized during the summer of 1971 for these types of studies involving corn leaf blight.

(4) Soil texture, moisture, organic matter content, or chemical composition studies.

Laboratory instruments such as a DK-2 spectrophotometer do not allow soil conditions to be studied without disturbing the soil sample. There is a great need for a field instrument capable of studying soils in situ. The next section describes a field study on soil, crust, and moisture conditions conducted with the spectroradiometer during the summer of 1970.

TYPICAL EXPERIMENT

The spectroradiometer was used to measure reflectance and the radiative properties of soils throughout the 0.37 μm to 14.2 μm wavelength region. Since software has not yet been completed to reduce the data from the longer wavelengths, only the results from the 0.37 μm to 0.74 μm wavelength region are presented here. Surface samples were collected from three Indiana soil series -- Crider, Dana, and Fincastle silt loams. These series are representations of the Ultisol, Mollisol, and Alfisol soil orders, respectively. Crider and Fincastle soils were developed under hardwood forest and Dana was developed under tall prairie vegetation.

Radiation measurements were taken on soils with a crusted surface and on dry and wetted soils with the crust broken. All measurements of radiation from the soil surfaces were taken vertically at a height of five meters above the sample. Using a 1° F.O.V., energy was integrated over an area of approximately 100 cm^2. Data were collected under natural lighting conditions on August 12, 1970, between 12:30 pm and 1:30 pm E.D.T. The sky was clear when data were collected.

Output from the spectroradiometer was recorded on a strip-chart recorder. Readings were taken for incident and target radiation, and percent reflectance was computed manually as the ratio of target radiation to incident radiation. For these computations, readings were taken from the ordinate of the strip-chart record at 30 nm intervals.

Figure 6 shows the spectral curve obtained from the sample of the Crider soil. This sample had a pale brown color (Munsell designation 10 YR 6/3). It had a high reflectance in the red portion of the spectrum both in the crusted and non-crusted condition. The crusted surface had a uniformly higher reflectance at all wavelengths than the non-crusted soil. This sample contained 2.5% moisture.

Figure 7 shows the spectra obtained from samples of Dana and Fincastle silt loams, respectively, in dry and wet conditions. As would be expected, the dry samples reflected more of the incident energy than did the corresponding wet samples. The spectra for the wet sample of Fincastle was very similar to that of the dry sample for Dana. Extended wavelength spectra would have been very useful in this situation for differentiating these two soils. Fincastle reflected more energy at all wavelengths than Dana when both were dry (3.5% and 3.4% moisture, respectively). This difference is related to soil color (Munsell designations 10 YR 6/2, light brownish gray, and 10 YR 5/2, grayish brown, respectively). Likewise, when wet, the Fincastle soil reflected more energy than the Dana (25% and 24% moisture, respectively). Spectra taken with this instrument for samples of several Indiana soil series have been reported previously.[5] This capability to collect field spectra should provide information in the future which will aid in interpretation of spectral data collected by airborne scanning spectrometers.

PROPOSED INSTRUMENT MODIFICATIONS

A second instrument, similar to the one described in this paper, is now under construction by Exotech, Inc. It was found during field use that the advantage of having a sealed instrument through the use of refracting optics was not fully realized. In fact, in 1970 the instrument was used in over half of the cases in the unsealed mode, that is, the 15° F.O.V. mode. Another field difficulty that arose concerned the rapid changing of the F.O.V. from 1° to 15°. For example, a frequent experiment involved the effect of soil background upon the spectral response of vegetation. A convenient way to do this is to first point the instrument at a vegetative species and an area of bare soil in the 1° F.O.V. mode, and then open F.O.V to 15° to examine the combination of vegetation and the soil background. With the refractive optics it was quite difficult to remove the lenses in the foreoptic system without disturbing the setup of the instrument. Therefore, in the revised instrument, reflective foreoptics will be used and a rotary solenoid operated mirror will allow switching the F.O.V. of the instrument from 1° to 15° without upsetting the setup of the instrument. To minimize the entrance of dust into the instrument, protective dust caps will be placed over the foreoptics of the spectroradiometer while it is being moved from site to site in the field test area.

In order to expedite the calibration of the instrument in the field, a field calibrator has been designed. This device will essentially permit a laboratory quality instrument calibration check to be made frequently on the spectroradiometer while it is in the field. This calibrator is only useable on the short wavelength head. The long wavelength head will be calibrated with an improved field type blackbody that is currently under construction.

Finally, the use of a reflective foreoptical system in the long wavelength head will permit absolute radiometric calibration in both the 1° and 15° F.O.V. modes.

SUMMARY

The spectroradiometer described here is a rugged instrument capable of being applied in a wide variety of field situations. This instrument is similar to an infrared C.V.F. instrument described previously by Hovis.[6] The data obtained are of sufficient resolution to adequately describe field spectral situations observed throughout the 0.37 μm to 14.2 μm region by airborne multispectral scanners. In addition, data can be obtained in the 2 μm to 4 μm region which is not normally used in airborne multispectral scanning since the atmosphere is opaque in this region. In the 2 μm to 4 μm region both reflective and emissive properties can be studied and additional information as to vegetation behavior may be obtained with field and laboratory experiments in this spectral region.

Ultimately, an automatic data logging system will be developed for the revised instrument. This will enable production of computer compatible digital tapes in the field and will minimize the amount of computer preprocessing. The instrument described in this paper should fulfill a long-standing need for a field spectroradiometer which can be utilized as a very effective adjunct to airborne remote sensing instruments. Such a ground-based instrument should, in fact, be considered an integral part of a remote sensing system.

ACKNOWLEDGMENTS

The valuable suggestions of Mr. D. Fain of Exotech, Inc., and Dr. R. Leamer of USDA, Weslaco, Texas, during the course of this study are hereby acknowledged. The contributions of Dr. R. Holmes, now of the University of South Carolina, were invaluable in the realization of the instrument described here.

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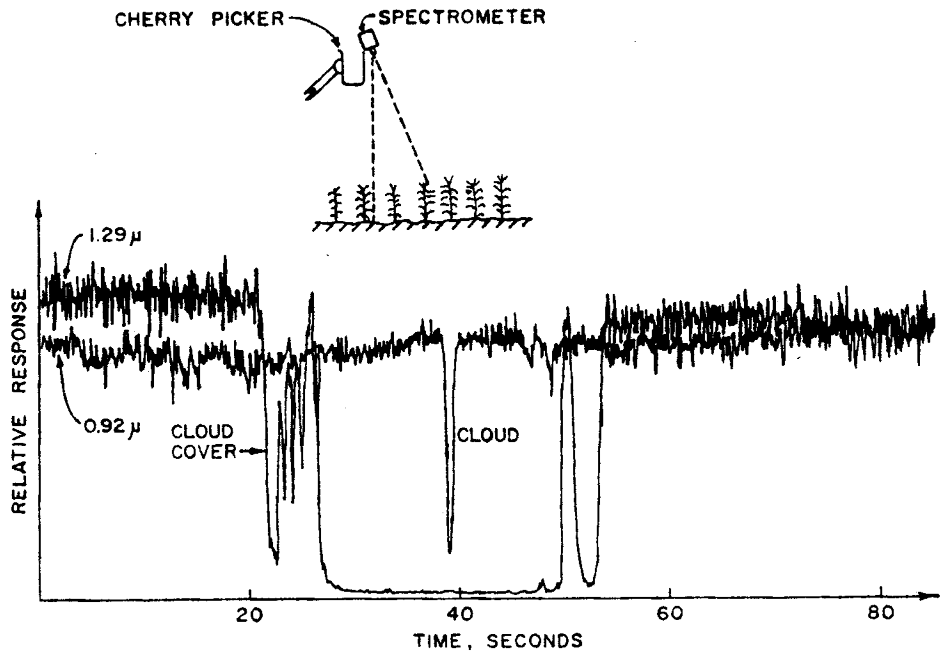

FIGURE 1. A consistency plot of a corn field on a cloudy, windy day viewed for 80 seconds at each of two wavelength bands.

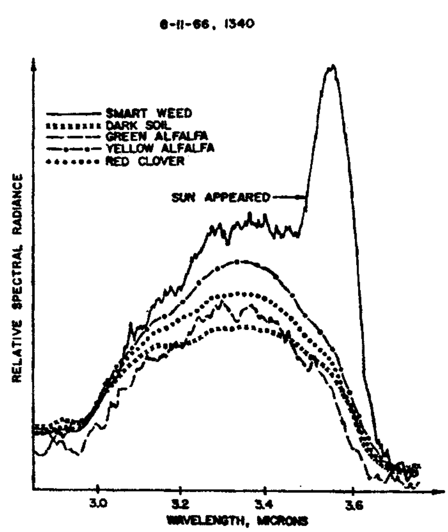

FIGURE 2. Spectra of soil, red clover, alfalfa and smart weed illustrating the solar input variation problem (2.8 μm to 4.0 μm).

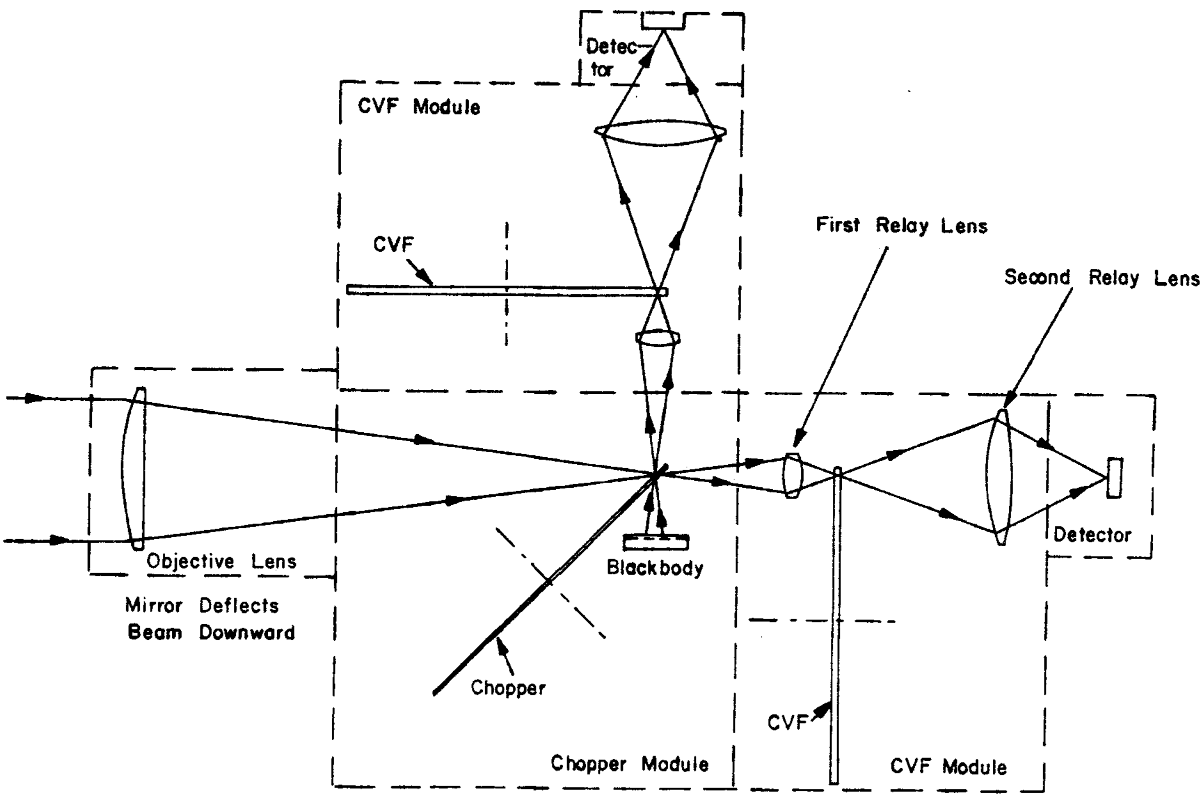

FIGURE 3. Schematic diagram of the optical layout of the field spectroradiometer.

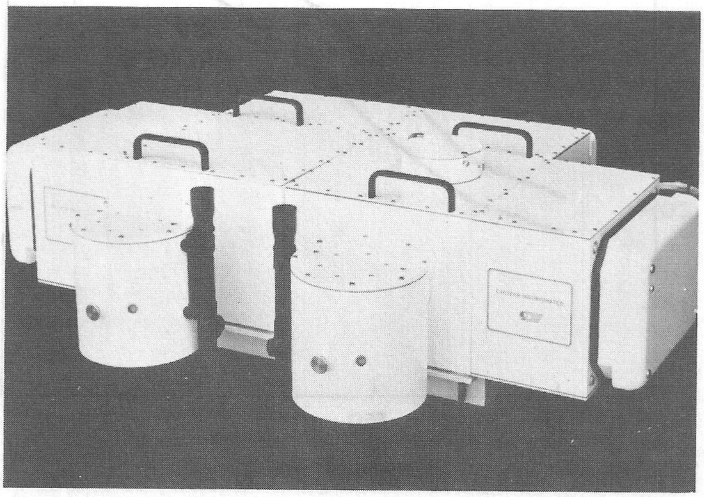

FIGURE 4. Long wavelength and short wavelength heads arranged in the foresighted mode for extended wavelength spectroradiometry.

FIGURE 5. Typical setup of the field spectroradiometer system.

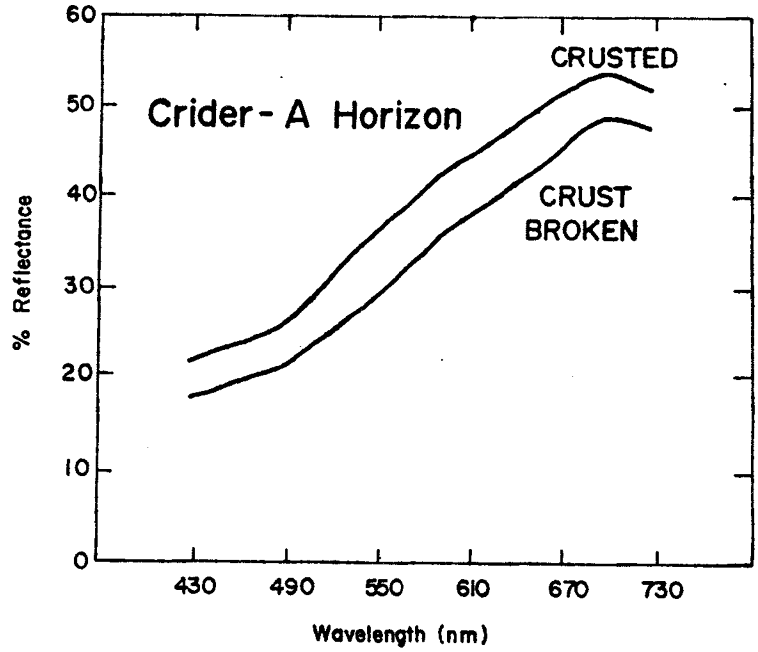

FIGURE 6. Percentage of incident radiation reflected from a surface sample of an Ultisol, Crider silt loam, in the visible portion of the electromagnetic spectrum.

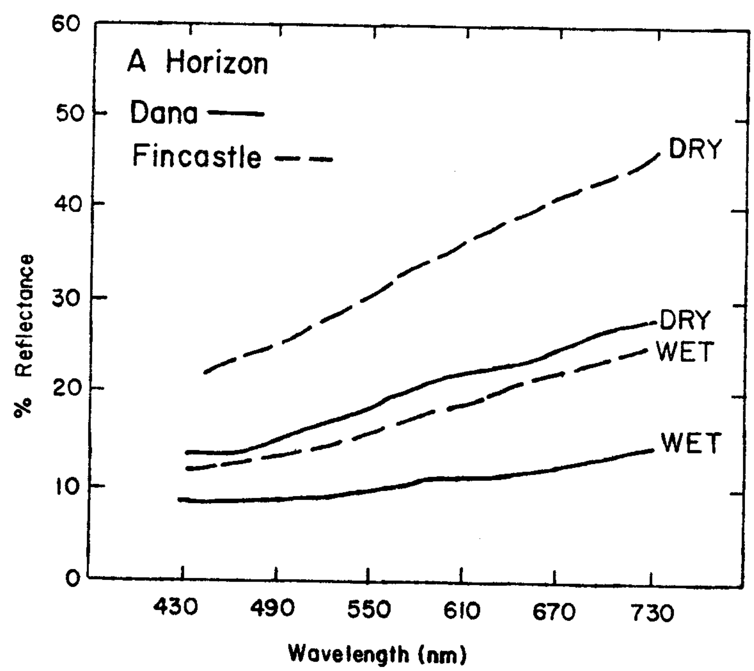

FIGURE 7. Percentage of incident radiation reflected from surface samples of a Mollisol, Dana silt loam, and an Alfisol, Fincastle silt loam, in wetted and air-dry conditions.