SECTION 6

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# SPECTRAL REFLECTANCE MEASUREMENTS OF PLANT-SOIL COMBINATIONS

by

N. H. MacLeod

Laboratory for Meteorology
and Earth Sciences

Goddard Space Flight Center
Greenbelt, Maryland 20771

As part of the Goddard Space Flight Center, Earth Observations Program, we have made field and laboratory observations of plant and soil reflectance spectra to develop an understanding of the reflectance of solar energy by plants and soils. A related objective is the isolation of factors we feel contribute to the image formed by multi-spectral scanners and return beam vidicons carried by ERTS or film-filter combinations used in the field or on aircraft.

In this work we want to develop a set of objective criteria for identifying plant and soil types and their changing condition through the seasons for application of space imagery to resource management. This is because the global scale of Earth Observations Satellites requires objective rather than subjective techniques, a particularly where ground truth is either not available or too costly to acquire.

Before we started we knew that people can visually discriminate between plant species, between sick and healthy plants and, with training, between soil types. People correlate in their minds clues from a scene such as the shape and arrangement of leaves on a plant, the color of leaves and soils - the motion and even the sound of crops and forests. But these clues are not available for use with space imagery because of spatial and spectral limitations.

As the acquiring of ground truth for training sets may be impractical in many cases, we have attempted to identify objectively standard responses which could be used for image interpretation. These are the responses or factors we are especially interested in to form a base for detecting changes in a scene or series of images.

In the laboratory we started with the question of whether or not plant leaves have specific reflectance spectra or whether the reflectance of leaves is the same for all species. Using single, normal, mature leaves, we measured the reflectance spectra of many species in a Cary 14 Reflectance Spectrometer.

Figure 1 shows the spectra for four of these species. The now familiar leaf reflectance curve is very similar for all of the species used. This observation was supported by a statistical analysis in which no significant differences between the species were found at any wavelength. The 1.6 micrometer wavelength values were most nearly significant and with more replication may show significance in future tests. Replication is not easy to achieve with space imagery, however.

We investigated the source of the leaf spectra similarities by taking the leaves apart. Figure 2 shows the reflectance spectra of chlorophyll extracted with methanol from fescue leaves. Chlorophyll extracts from other species appear to be the same. In the top curve we see the reflectance spectrum of chlorophyll over a bright background. It is essentially a chlorophyll absorption spectrum. The fiberglass background is very bright across these wavelengths. Therefore where chlorophyll does not absorb, the percent reflectance is high. The regions where chlorophyll does absorb are those of the typical features of leaf reflectance at 0.45 and 0.68 micrometers.

The lower curve is the percent reflectance obtained when chlorophyll was placed over a black matte background. Any reflectance is due to chlorophyll with perhaps some influence from the glass disc upon which the chlorophyll was placed. We find virtually no reflectance occurring in this case. Thus the reflectance features noted at 0.45 and 0.68 micrometers cannot be due to light back scattered from chlorophyll. Instead, the features are produced by chlorophyll absorption of light scattered by some other substance or structure in the leaf.

Figure 3 demonstrates that this is indeed the case. Here normal fescue leaves are compared to fescue leaf matter from which chlorophyll has been extracted, and to intact leaves where water was removed by simple drying at low heat. Removal of the chlorophyll results in increased reflectance in the visible, chlorophyll absorption regions. Removal of water results in increased reflectance in the IR regions where water absorbs at 0.9, 1.1, 1.45 and 1.9 micrometers. The reflectance of leaf material with minimal amounts of either chlorophyll or water is typically very high in the IR and decreases smoothly in the visible.

Normal mature leaves have much the same constituents and arrangements of cellular material - pigments, such as chlorophyll; cellulose cell walls, water; thus it is not surprising that, most plants have similar reflectance spectra, if these constituents are the absorbers and reflectors of light energy in these regions. The data indicate that we do have an adequate baseline from which to detect changes from normal leaf conditions.

In **Figure** 4 we see the reflectance spectra from two soils in the wet and dry condition. The Goddard soil is a sandy loam typical of the mid atlantic states coastal plain. The Houston soil is a highly organic, well aggregated soil from the Houston area. The Houston soil is black in color, while the Goddard soil is light tan. The spectra are smooth, except in the water absorption bands. It is expected that a large difference would be found in their spectra. The effect of wetting the soils is, of course, to deepen the water absorption features, less in the case of the light textured Goddard soil than in the Houston soil. In most soils the percent reflectance is reduced by about 50% across the spectrum shown here. Using a collection from around the world we find this to be quite constant. In the Houston soil the reflection of the dry soil is already quite low. It may even be increased slightly in the visible by wetting, though the water absorption features deepened as expected.

Unlike plant leaves, soils do differ in brightness, and red soils, white sands and black loams can be differentiated. Knowledge of the reflectance of a soil when dry can be used as a baseline to develop information on soil moisture content.

Figure 5 shows that these differences in soils appear in the reflectance spectra of leaves and soils combined. The differences appear in the wavelengths where neither water nor chlorophyll are strong absorbers. The two leaf cases presented are one and, then, nine leaves of normal mature soybean. The soils are a bright Salt Lake City soil, the Goddard soil and a red laterite of Kenya. The effect of a difference in soil brightness (these are air dry soils) is seen in both leaf cases. The difference between soils is, of course, much obscured by the presence of leaves. The major effect in this experiment is the increase in reflectance due to increase in leaf numbers. The location and intensity of the absorption features is not shifted, but the difference of intensity of reflectance in the non-absorbing regions is statistically significant. This latter effect is being well studies at Weslaco by USDA. In essence, increasing the number of leaves results in a smooth increase in reflectance except at the chlorophyll and water absorption peaks. The effect in a series of images can be interpreted in terms of plant growth, where the number of leaves over a particular unit area of soil increases with growth.

So far we have dealt with normal leaves. Diseased leaves differ from normal leaves in a rather limited number of ways. They lose chlorophyll and become yellow; they die and become brown as a result of oxidation of cell contents. Leaves may develop transparent spots due to virus attack, they may wilt. Nutritional diffeciencies produce specific patterns of color change. Southern corn leaf blight produces dead leaves and yellow leaves in additon to the typical lesions. In Figure 4 we compare normal corn leaves to blighted leaves and to leaves infected with ring virus. In all the leaf cases, three backgrounds are used. Black, in which only the reflectance of the leaf itself is observed; white background where the full effect of leaf transmission is added to leaf reflectance and a background of Miami silt loam, the soil in which the corn was grown. The measurements were made at Goddard but the materials came from Lewis Research Center through their cooperative program in SCLB study with the Ohio State Agricultural Experiment Station.

In the normal leaf the background effect is pronounced only in the infrared. In the dead SCLB leaf (100% necrotic), the chlorophyll has been lost and its absorption features are not seen. But the oxidation products are apparently absorbing energy reflected from the background as the soil and white backgrounds are not really different in effect. Before corn leaf tissue not directly infested with the fungus dies, it becomes yellow or chlorotic. We see that some absorption still occurs in the blue by some of the accessory leaf pigments, but the chlorophyll features in the red band have disappeared. In this leaf condition the background effect is very pronounced both in the IR and the visible. This leaf is not a very bright reflector by itself as seen in the black background curve. It has become more transparent in wavelengths longer than 0.5 micrometers. Thus, over a bright soil, the chlorotic condition should be distinquishable from the dead condition both in terms of spectral differences and in terms of brightness. Over a darker soil, the two conditions would be perhaps more difficult to separate.

The virus disease has produced a third spectral response. Over a bright soil it would appear as a brighter green and orange than a normal leaf. However, over a black background it is not distinquishable from a normal leaf. Thus we have found that reflectance of single normal leaves provides us with information upon which to base separation of normal and abnormal conditions, to follow leaf area with growth and to distinquish some disease or pathological conditions. In dealing with such conditions we can explain much of the change in reflectance in terms of loss of pigment, oxidation products and changes in water content. As these are very common changes, and the spectral effects of all diseases in all plants have not yet been studies, we should use great caution in interpretation of remote sensing imagery in regard to disease.

The effect of soil background is two fold. First, the specific brightness of various soils will have a direct effect on the observed brightening of diseased leaves. Second, the effect of soil moisture will be to darken the radiance of a scene across the spectrum studied here.

This discussion has led us to recognize some predictable changes in observed reflectance from leaf-soil combinations in the laboratory. Most of these are explainable in terms of pigment and water absorption in leaves and as variations in soil spectral brightness and variations in soil moisture.

The laboratory observations of factors affecting tone and spectral content of the scene are useful as a start. But it is quite obvious that, if normal leaves have virtually indistinquishable reflectance features, there must be other factors in the scene which permit us to tell one plant from another or one plant community from another. Thus leaf spectra do not yield complete information on differences seen in the MSS and Nimbus imagery of seasonal change or geographic differences in complex plant communities discussed by Drs. Short and Salomonson at this session.

Therefore, to predict quantitatively the content of an image requires isolation of additional objective factors associated with the plant-soil combinations and the reflected energy. Some such factors might be leaf arrangement, effective leaf area normal to the sensor viewing angle, extent and depth of canopy cover, proportion of open soil in the scene and so on. Crop and soil management practices also may be effective in changing radiance of a scene, but our understanding of these factors is still incomplete.

In going from the laboratory to the field to study plants and soils as they exist in nature, we will be able to use some of the baseline response information presented here, but even more emphasis must be placed on identification of new additional objective factors which relate the physical objects in a scene to a remotely sensed image.

Again, for Global Applications of Space acquired imagery to problems or resource management, understanding of the factors which change the plant and soil reflection of solar energy - the principal source of remote sensing information is essential. We have just scratched the surface.

Figure 1

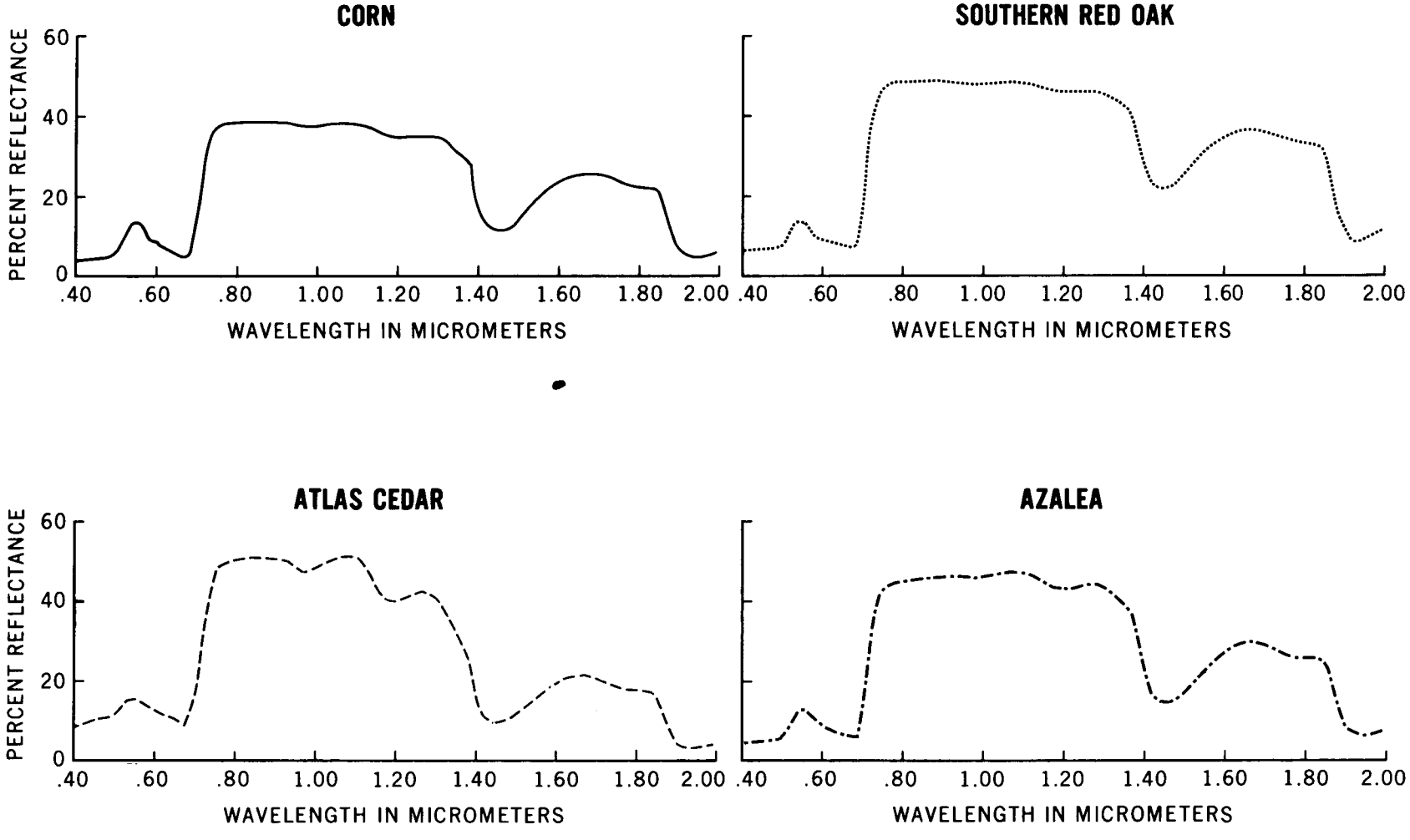

CORN
SOUTHERN RED OAK
ATLAS CEDAR
AZALEA
PERCENT REFLECTANCE
0
20
40
60
.40
.60
.80
1.00
1.20
1.40
1.60
1.80
2.00
WAVELENGTH IN MICROMETERS

Figure 2

# CHLOROPHYLL EXTRACT

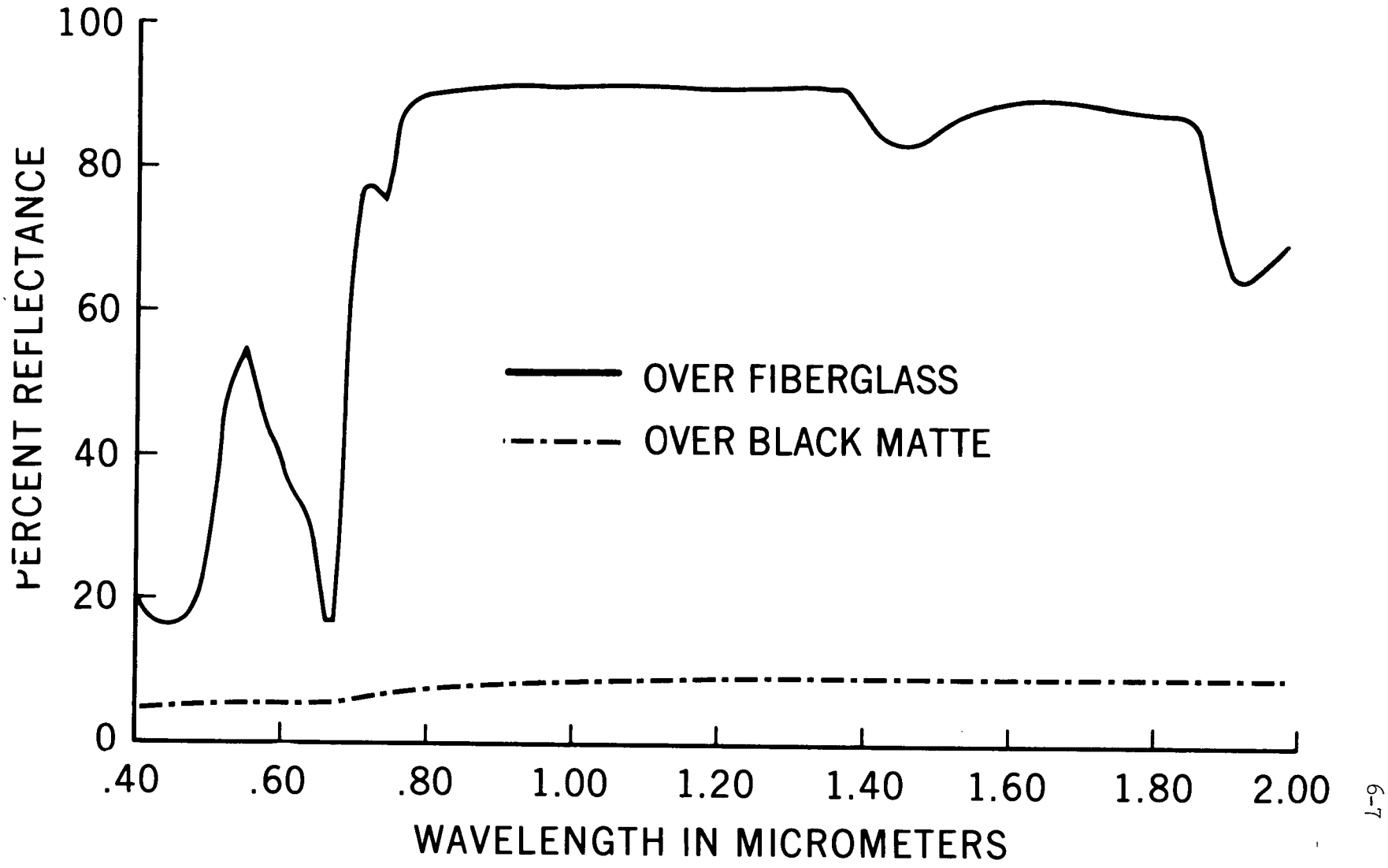


Figure 3

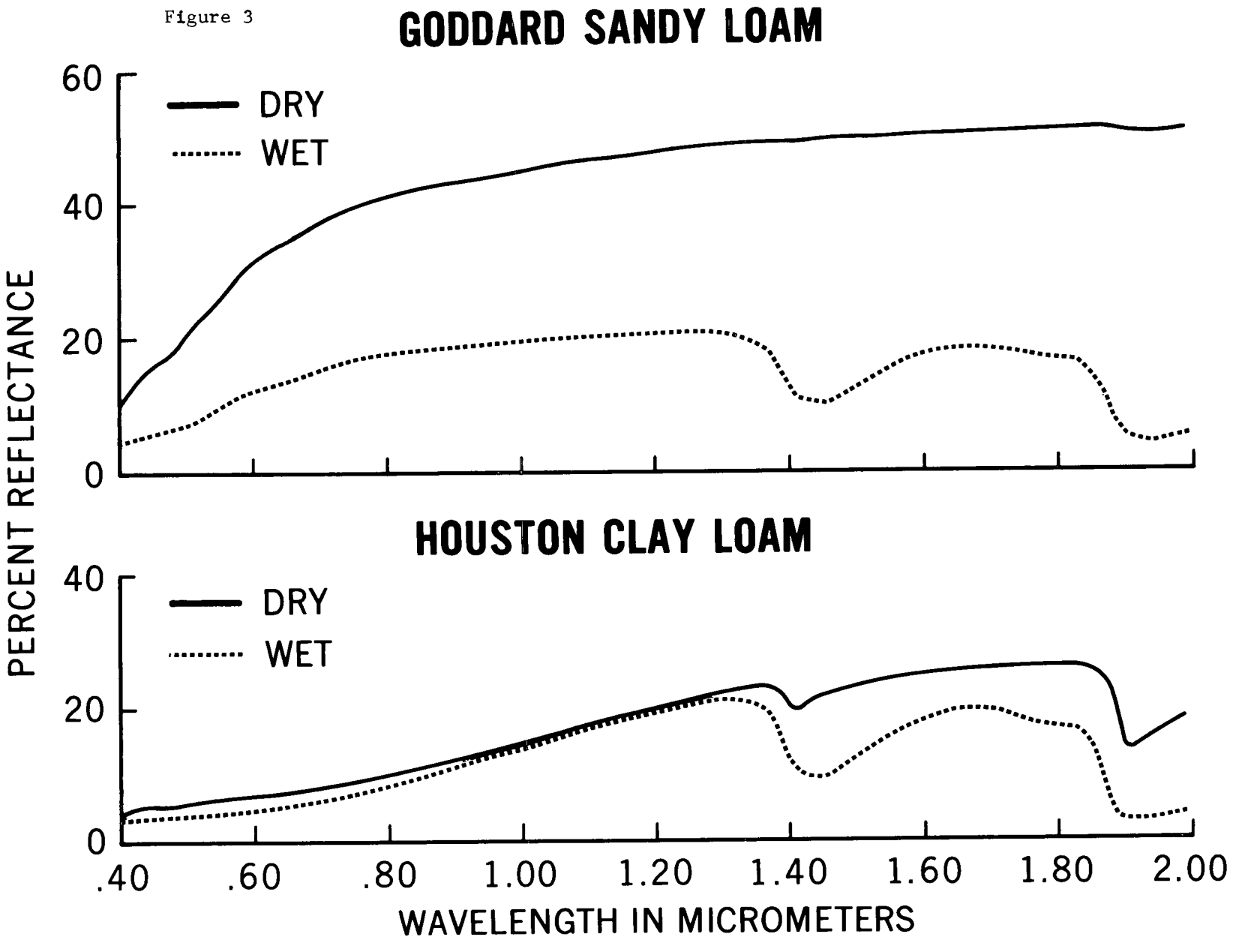

GODDARD SANDY LOAM
DRY
WET
60
40
20
0
HOUSTON CLAY LOAM
DRY
WET
40
20
0
PERCENT REFLECTANCE
.40
.60
.80
1.00
1.20
1.40
1.60
1.80
2.00
WAVELENGTH IN MICROMETERS

Figure 4

**PERCENT REFLECTION OF SINGLE SOYBEAN LEAF**

**PERCENT REFLECTION OF NINE SOYBEAN LEAVES**

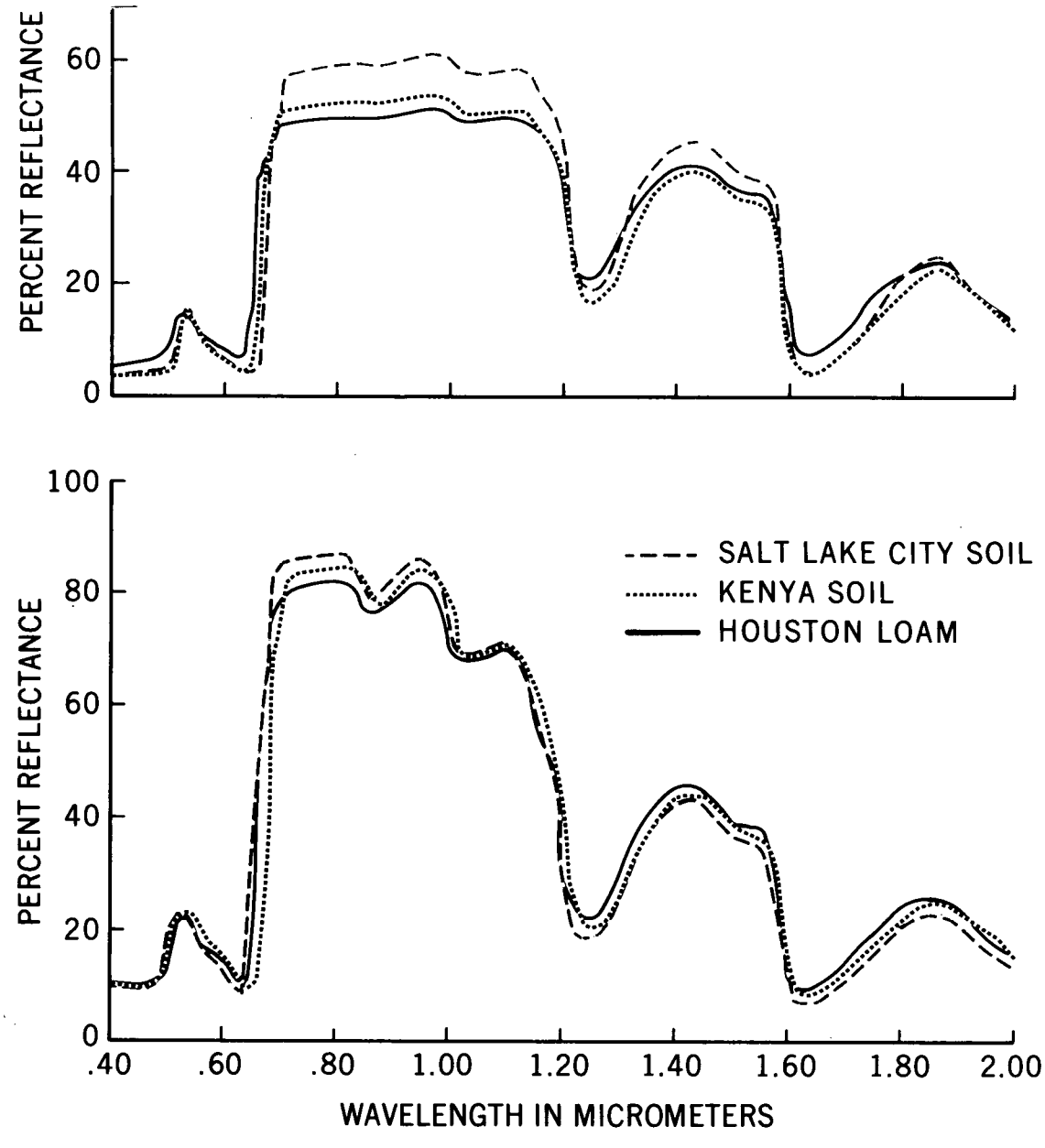


Figure 5

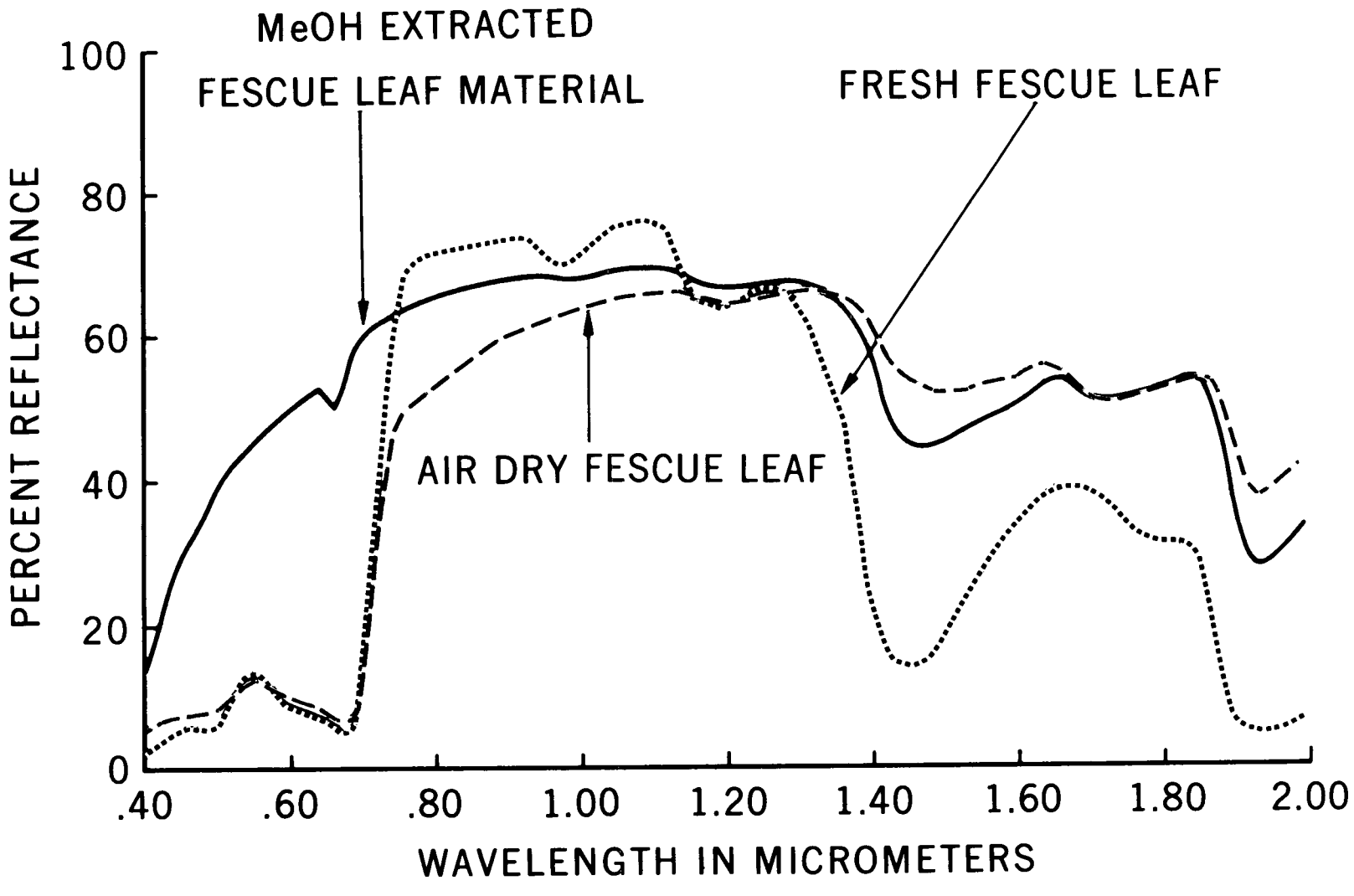
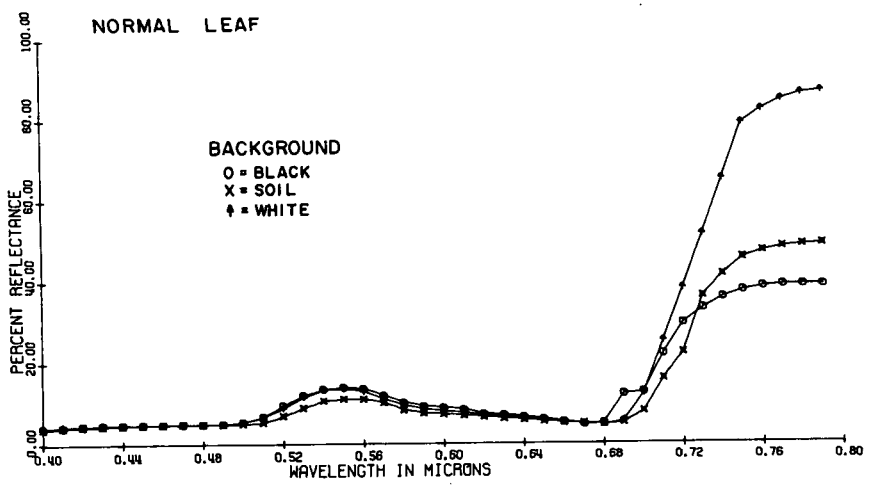
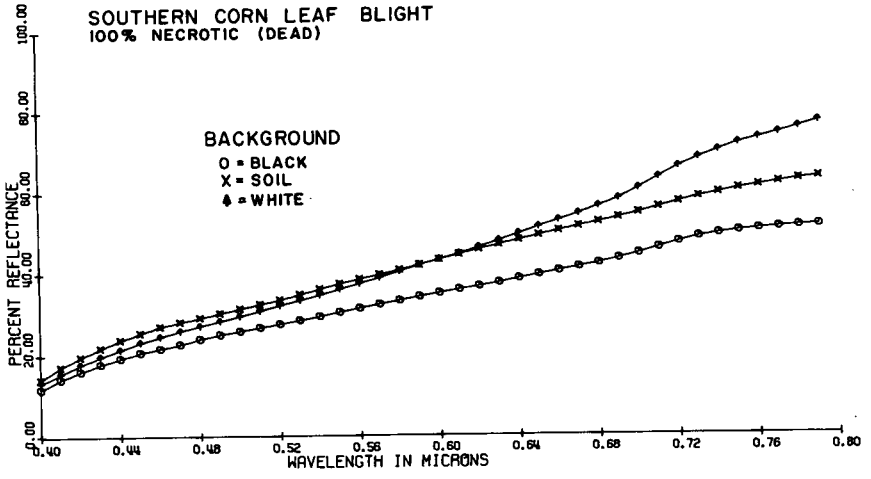
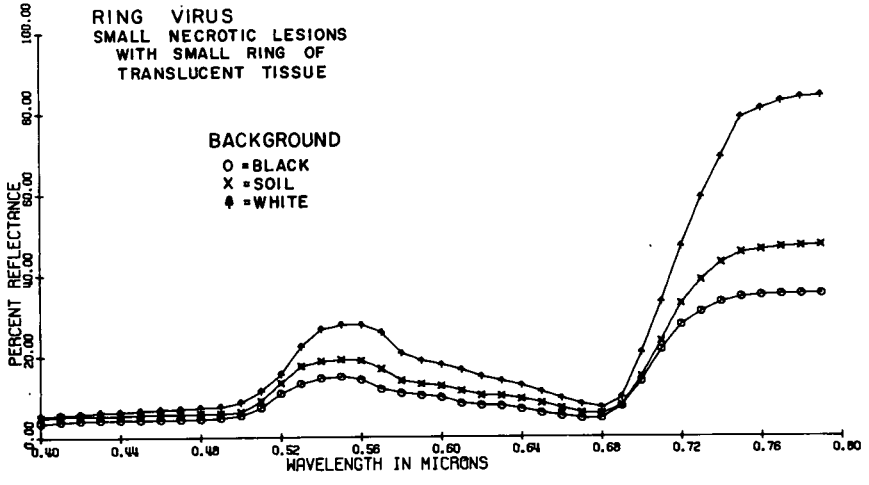
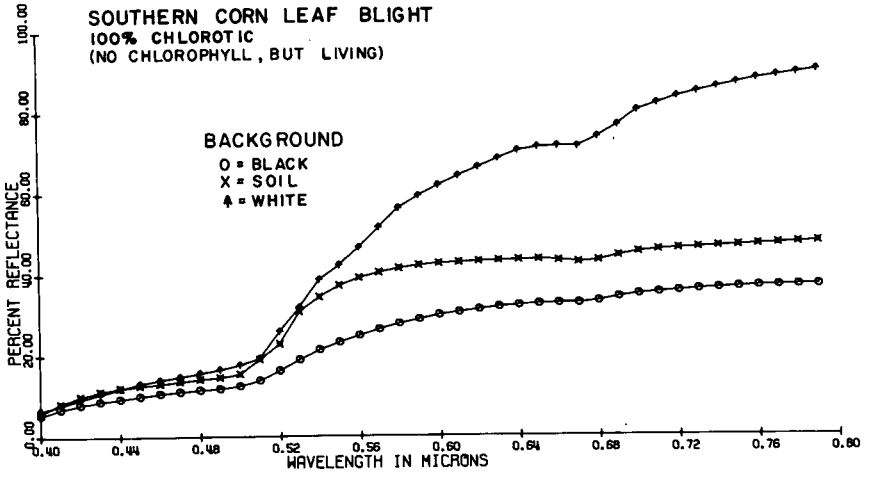

MeOH EXTRACTED
FESCUE LEAF MATERIAL
FRESH FESCUE LEAF
AIR DRY FESCUE LEAF
PERCENT REFLECTANCE
100
80
60
40
20
0
.40
.60
.80
1.00
1.20
1.40
1.60
1.80
2.00
WAVELENGTH IN MICROMETERS

Figure 6


NORMAL LEAF
BACKGROUND
O = BLACK
X = SOIL
♦ = WHITE
PERCENT REFLECTANCE
WAVELENGTH IN MICRONS


SOUTHERN CORN LEAF BLIGHT
100% NECROTIC (DEAD)
BACKGROUND
O = BLACK
X = SOIL
♦ = WHITE
PERCENT REFLECTANCE
WAVELENGTH IN MICRONS


RING VIRUS
SMALL NECROTIC LESIONS
WITH SMALL RING OF
TRANSLUCENT TISSUE
BACKGROUND
O = BLACK
X = SOIL
♦ = WHITE
PERCENT REFLECTANCE
WAVELENGTH IN MICRONS


SOUTHERN CORN LEAF BLIGHT
100% CHLOROTIC
(NO CHLOROPHYLL, BUT LIVING)
BACKGROUND
O = BLACK
X = SOIL
♦ = WHITE
PERCENT REFLECTANCE
WAVELENGTH IN MICRONS