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REFLECTION OF RADIANT ENERGY FROM SOILS

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When radiant energy is incident on any surface it is distributed through three different processes: reflection, absorption, and transmission. Thus, reflectance + absorptance + transmittance = 1, where unity is equivalent to the energy in the incident beam. Transmittance, however, with opaque materials, such as soils, is zero, and increasing the reflectance therefore decreases the absorptance an equivalent amount. The possibility of influencing the various thermally dependent soil processes, such as evaporation, by changing the reflectance is worthy of consideration. Such a consideration first requires a determination and evaluation of the factors that influence reflectance, and this was a primary objective of the experiment reported here.

The literature indicates that moisture content, particle size, and organic matter influence reflection from soils. Although Kojima (13), using a photocolorimeter, studied the effect of moisture content on the color of 16 soils, his results were reported in Munsel color notation; no reference was made to energy changes. Evans (7), who presented reflectance curves for three soils in both the wet and dry state, found that the wet samples showed lower reflectance; unfortunately, no information was given as to soil type or moisture content. Brooks (4) used 10 per cent as the reflectivity of moist Yolo fine sandy loam over the wavelength range of 0.4 μ to 2.5 μ, but the moisture content was not given; for the dry condition, he estimated the reflectivity at 30 per cent.

Kojima (12), again using a photocolorimeter, measured the change in soil color with change in particle size. Results were reported in tristimulus coordinates and, in general, indicated an increase in the Y coordinate—the luminosity function—as particle size decreased. Leuder (14) stated that the grey tones in photographs of drying foreshores of sand beaches are indicative of superficial moisture content and the predominant grain size occurring on the beach. Zwerman and Andrews (18), working with enameled surfaces, stated that at a given wavelength a material of given refractive index reflects light with an intensity that varies inversely as the particle diameter. The increase in reflectance with fine milling is attributed to the increased interface between opacifier and frit.

Several investigators (3, 6, 8, 16) have noted the so-called color effect on soil temperatures. The elevated daytime temperatures of dark-colored soils is attributed to their greater absorption of solar radiant energy. This indicates that reflectance is less from dark soils. Since organic matter is one of the primary soil-coloring constituents, it is logical to expect the absence or presence of soil organic matter to influence reflectance.

PROCEDURE

To measure reflectance, two different spectrophotometers with reflectance attachments were used, a Beckman[2] DK-2A and a Beckman DU. The first instrument, a double-beam automatic recording spectrophotometer, has a wavelength range of 185 mμ to 3500 mμ. This is an excellent wavelength range for soils, since data by both Gates (10) and Moon (15) indicate that almost all the solar energy received at the earth's surface is contained within that range. Unfortunately, this instrument was available for only limited measurements. With the Beckman DU, a single-beam spectropho-

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[2] Trade and company names are included for the benefit of the reader and do not infer endorsement or preferential treatment of the product named by the United States Department of Agriculture.

tometer, the wavelength range is between 210 mμ and 1000 mμ. Although this range is not as extensive as that of the DK-2A, the data of both Gates (10) and Moon (15) indicate that approximately 70 per cent of the solar energy reaching the earth's surface falls within this range.

Because of physical differences in the two spectrophotometers, the procedures for sample preparation and measurement varied slightly. With the DK-2A, the sample had to be placed on one of the vertical sides of the reflectance attachment. To prevent the sample from spilling, it was necessary to make reflectance measurements through a microscope slide placed over one end of the sample container. To equalize the optical path length, a microscope slide was placed over the MgO reference. With the DU, reflectance measurements were made direct from the soil sample surface, since the sample container was placed at the base of the reflectance attachments. MgO was used as a reference for both instruments.

To measure the influence of moisture content with the DU, soils were packed in small, plastic cylinders with removable tops and bottoms. The cylinders were 3 cm. in diameter and 1.5 cm. deep. A piece of fine mesh screen was placed against the top of the cylinder before the soil was inserted in it. This screen helped to establish more uniform surface conditions and prevented the wet soil from sticking to the plastic top. After the soils were packed, a predetermined amount of water was added. The tubes were then sealed and allowed to equilibrate for approximately 2 weeks. At the end of this period the top was removed, the screen peeled from the surface, and reflectance measurements quickly made. Approximately ⅛ inch of soil was removed from the surface and the moisture content was determined gravimetrically.

With the DK-2A, the samples were packed wet into their containers, and measurements were made through the glass-covered side. Measurements for each soil were made at several different moisture contents. Initially, all soils had been passed through a 20-mesh sieve and oven-dried at 70°C.

To determine the influence of organic matter on reflectance, samples were oxidized with 30 per cent H_2O_2 while on a hotplate set at 90°C. The end point of oxidation was determined visually. The preparation of the check and oxidized samples was identical, except where H_2O_2 was added to one and H_2O was added to the other. Organic matter content was determined by Carolan's method (5). In addition, the carbonate equivalents for the check soils were calculated from volumetric displacement due to CO_2 released by HCl (1). Samples were oven-dried at 70°C., and reflectance measurements were made as indicated above.

The effect of particle size was determined by sieving oven-dry bentonite and kaolinite clay minerals into various-size fractions and measuring the reflectance from each fraction with the DU spectrophotometer. Before measurement, the surface of each fraction was smoothed to the level of the container top.

RESULTS AND DISCUSSION

Our experiment was intended to evaluate only the influences of moisture content, organic matter, and particle size, and, therefore, no inference concerning the existence or relative importance of other influencing factors can be made from our results. The factors that were examined were selected because of their importance in agriculture, their ease of isolation, and the remote possibility that they are subject to some field control.

Although the results differed with each soil, the trends shown in figures 1 through 11 are typical. For each graph, the spectrophotometer used is indicated by the wavelength range. Where the range exceeded 1000 mμ, the DK-2A was used; the DU was used where the range was 1000 mμ or less. Figures 1 through 5 indicate the relation between surface moisture content and reflectance. Figure 1 shows the plot of reflectance *vs.* wavelength at several different moisture contents on a Newtonia silt loam. Reflectance is the ratio of the energy reflected from the sample to the energy reflected from the MgO reference. Reflectance from the MgO is near 100 per cent for the range of wavelengths used. Since, at all wavelengths measured, the reflectance decreased as the surface moisture content increased, increasing the surface moisture content can be said to increase the absorption of radiant energy.

Of the three absorption bands found at approximately 1440 mμ, 1900 mμ, and 2,200 mμ, the last has not been identified. These first two bands are centered on wavelengths strongly absorbed by water and specifically represent overtones of the fundamental frequencies at which water molecules vibrate (2). The amplitude of the third band, contrary to the other two, appears to diminish with increasing moisture content. This is probably an illusion

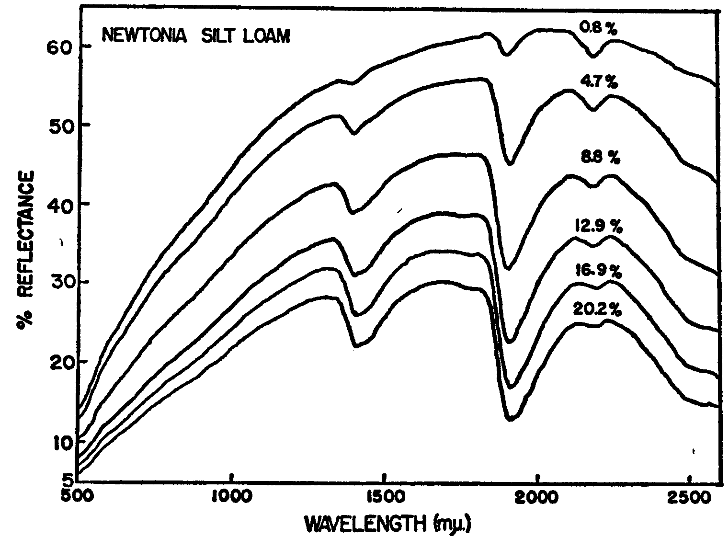

FIG. 1. Per cent reflectance *vs.* wavelength of incident radiation at various moisture contents (moisture contents indicated directly above each curve).

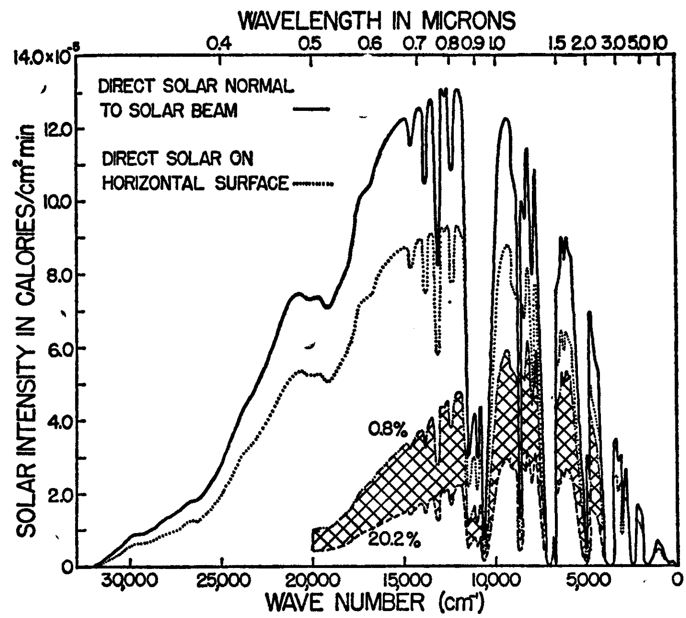

FIG. 2. Transformation of two Newtonia silt loam reflectance curves, 0.8 and 20.2 per cent moisture to reflected energy curves. Transformation is based on Gates' direct solar spectral distribution curve which was measured at sea level on a horizontal surface (*dotted curve*). *Shaded area* represents the additional solar energy absorbed due to increasing moisture content.

caused by the overlapping of the absorption band centered at 1900 mμ and, as such, masks the true trend of the band at 2200 mμ.

Because measurements were made under laboratory conditions, the influence of these moist samples on distribution of solar radiant energy cannot be determined precisely. However, by using previously measured direct solar spectral distribution curves, one can acquire a reasonable indication of their potential effect in a field situation. By plotting the product of the reflectances (figure 1) times the energy values from a distribution curve, wavelength by wavelength, the graph indicates the amount of solar energy that could be reflected for conditions under which the distribution curve was measured.

An example of the above procedure is shown in figure 2, where the direct solar spectral distribution curve measured by Gates (10) was used. This curve, indicated by the dotted line (fig. 2), was measured on a horizontal surface, at sea level, on a clear day, through an optical air mass of approximately 1.4 (zenith angle 44° 20′). Because the incident beams in the spectrophotometers were normal to the sample surfaces, one should determine the energy on the surface perpendicular to the direct solar beam. Using Gates' data this calculation is easily made as follows:

$$Q_p = Q_o/\cos. Z \qquad (9)$$

where Q_p = direct radiant solar energy on a surface perpendicular to sun rays in cal./cm.^{2} min.; Q_o = direct radiant solar energy measured on a horizontal surface; and Z = zenith angle. For $Z = 44° 20'$, $Q_p = 1.4Q_o$.

Q_p is the solid curve in figure 2. The curves marked 0.8 and 20.2 per cent moisture show how much of the direct solar energy would be reflected by the driest and wettest Newtonia silt loam samples had they been turned perpendicular to the solar beam at the site of Gates' measurements. The shaded area between the 0.8 and 20.2 per cent moisture curves represents the additional energy absorbed due to the indicated increase in moisture content. Integration with a planimeter shows that this area represents approximately 18.3 per cent of the direct solar energy received in the 0.5-μ to 2.6-μ wavelength range. This same shaded area accounts for approximately 14.2 per cent of the entire energy of the incident beam. Under the conditions in which Gates' measurements were made, one would expect the Newtonia silt loam sample at 20.2 per cent moisture to absorb an additional 14.2 to 18.3 per cent of the direct solar energy owing to its increased moisture content. Such substantial increases in energy absorption may, in part, explain the rapid initial evaporation rates from soils after a rain or irrigation.

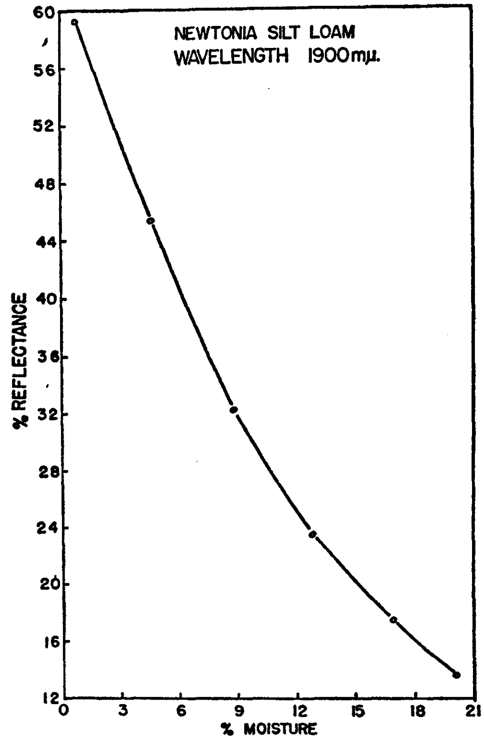

FIG. 3. Per cent reflectance *vs.* surface moisture content for incident radiant energy of 1900 mμ.

Figure 3 shows the influence of moisture content on reflection at approximately 1900 mμ. The excellent fit of the points to the curve indicates the potential of reflectance measurements for determining surface soil moisture content. The use of such a procedure would be hampered by the fact that each soil appears to have a unique moisture-reflectance curve. Although wavelengths other than 1900 mμ could be used, this wavelength is preferable because of its greater sensitivity to moisture (fig. 1).

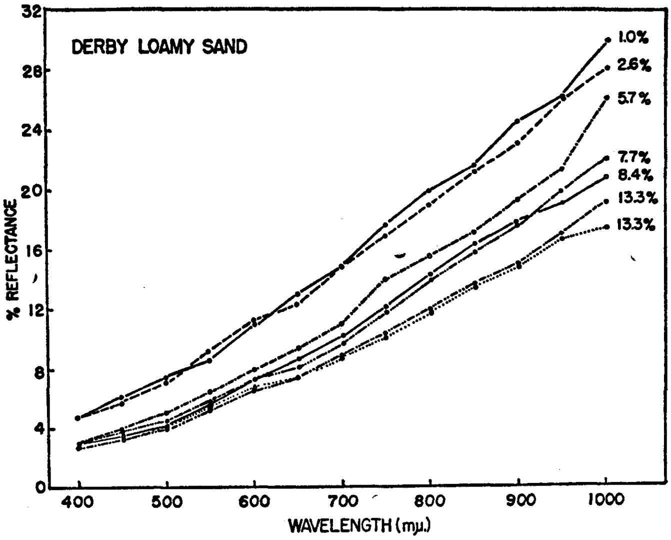

FIG. 4. Per cent reflectance *vs.* wavelength of incident radiant energy at various moisture contents (per cent moisture indicated to the right of each curve).

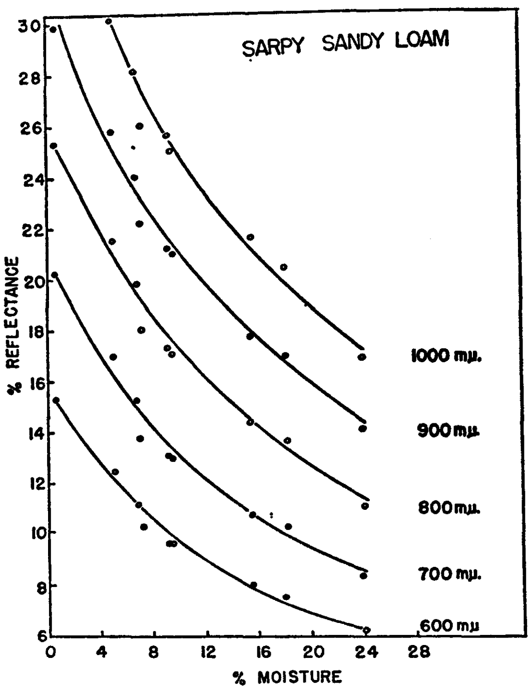

FIG. 5. Per cent reflectance *vs.* moisture content for various wavelengths (wavelength of incident radiation indicated to the right of each curve).

Figures 4 and 5 reaffirm that reflectance decreases as moisture content increases. This is substantiated by numerous other measurements not shown. The two curves marked 13.3 per cent in figure 4 indicate that it is possible to obtain repeatable results. Repeatable results also were obtained with the DK-2A spectrophotometer. No doubt such repeatability depends on establishing similar surface conditions. Figure 5 again demonstrates a potential for measuring surface moisture content by the reflectance method; moreover, it indicates the possibility of using wavelengths other than highly moisture-sensitive ones. If reflectance *vs.* moisture content were plotted from figure 4, the resulting curves would be very similar to figure 5.

By drawing smooth curves in figure 5, possibly the significance of some data was lost. Sudden changes of slope in point to point drawings could be indicative of water film thickness on the soil particle surface. However, it was observed that small reflection differences could be induced by minor changes in surface configuration or often by varying the sample orientation. Since it was not apparent whether sudden slope changes were due to minor surface irregularities or to other factors, such as film thickness, smooth curves were utilized.

The influence of organic matter on reflectance is seen in figures 6 through 8. It is evident at all wavelengths measured that the oxidized sample had a greater reflectance than did the check sample. Although in figure 6 the difference in reflectance beyond 1800 mμ becomes very small, it is not important from a practical standpoint, since the amount of solar energy received at these wavelengths is very small. Assuming the samples of figure 6 were at the site of Gates' measurement and perpendicular to the solar beam, an indication of their influence on the reflection and absorption of direct solar radiant energy can be calculated as was done for figure 2. Such calculations show that, under the then-existing atmospheric conditions, at least 8.2 per cent of the total direct solar energy received at the earth's surface would be absorbed owing to organic matter. This substantiates reports of dark soils heating faster during daylight hours because of greater absorption of radiant energy. Similar results are shown in figures 7 and 8.

Oxidation may have changed factors other

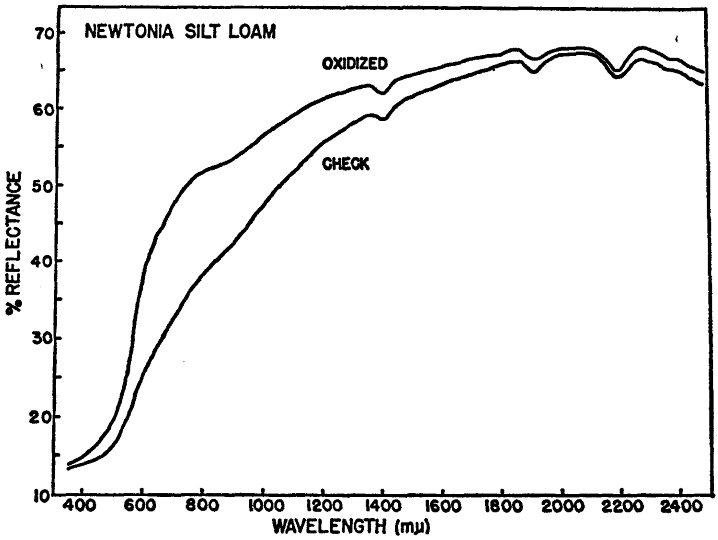

FIG. 6. Per cent reflectance *vs.* wavelength of incident radiation for H_2O_2 oxidized and check samples.

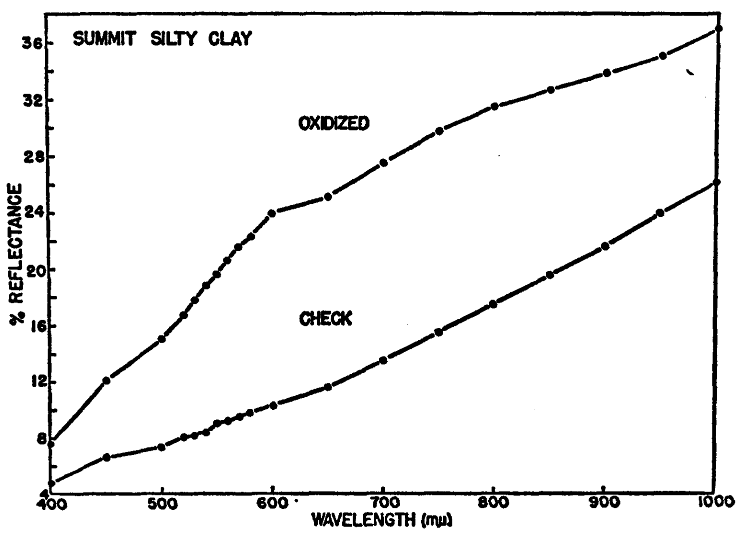

FIG. 7. Per cent reflectance *vs.* wavelength of incident radiation for H_2O_2 oxidized and check samples.

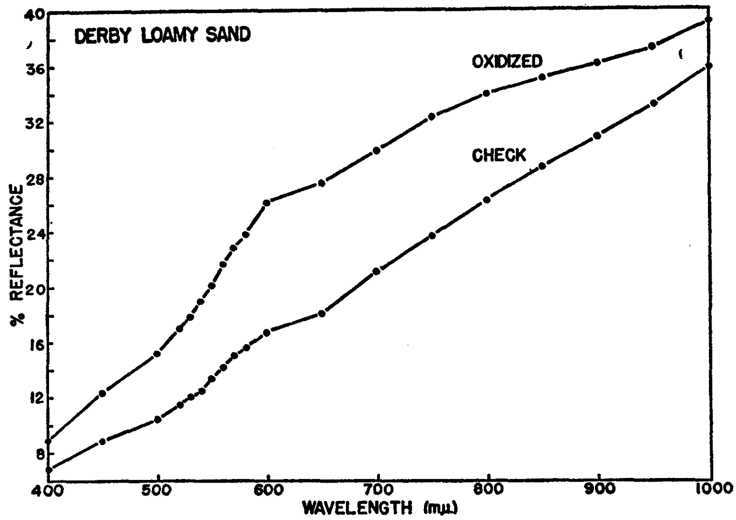

FIG. 8. Per cent reflectance *vs.* wavelength of incident radiation for H_2O_2 oxidized and check samples.

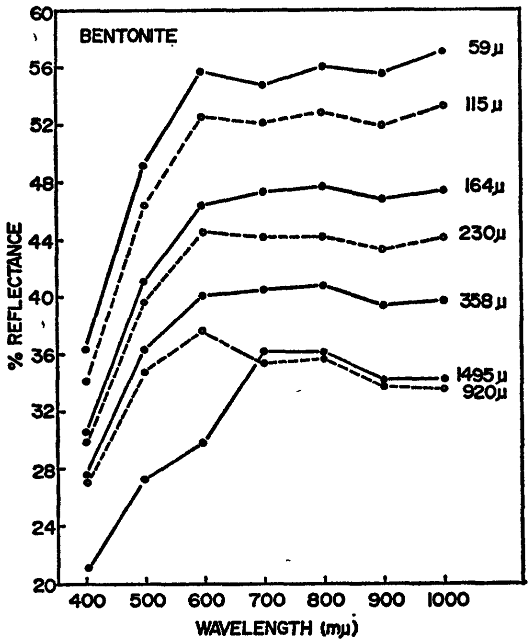

FIG. 9. Per cent reflectance *vs.* wavelength of incident radiation for various particle sizes (particle diameter indicated to the right of each curve).

than organic matter. The carbonates probably were destroyed by H_2O_2. However, with the Newtonia silt loam, no carbonates were detected; the organic matter content was 1.4 per cent. Derby loamy sand contained 0.8 per cent organic matter and 0.49 per cent carbonates. Summit clay contained 2.2 per cent organic matter and 0.02 per cent carbonates.

Figures 9 through 11 show the effects of particle size on reflectance. The particle size indicated is the midpoint of the range of particles retained between two successive sieves. Clay minerals were used because sieving soils might lead to mineralogical differences among the various fractions. Thus, reflectance differences, for one particular clay mineral, could only be due to differences in particle size. Reflectance from kaolinite (fig. 10) was much greater than from bentonite (fig. 9). However, reflectance differences between particles of similar size were of the same magnitude for both clay minerals. With both clays, differences in reflectance as large as 24 per cent were evident. The authors are indebted to the unknown reviewer of their manuscript for pointing out that the lower reflectance of bentonite results, as contrasted with kaolinite, from its micro-structural characteristics and lower mass density, and that similar differences are encountered in a comparison of reflectance from platinum wire versus porous platinum black where the pores act as light "traps" (17). Grim (11) reports the density of montmorillonite and kaolinite as 2.348

g./cm.^{3} and 2.667 g./cm.^{3}, respectively, at 0 per cent moisture content.

The rapid exponential increase in reflectance with decreasing particle size is very evident in figure 11, which is a replot of a portion of figure 10. The most noticeable increases occur at sizes less than 400 μ. The decreasing slope of the curve indicates that particles larger than those shown apparently would have little influence on additional absorption of solar energy. The good fit of the points to the curve for particles smaller than 400 μ substantiates the validity of using the midpoint of each range for the average particle size when the range is relatively narrow. For larger intervals the points deviate considerably. Similar results were obtained with nearly all other wavelengths for both clays.

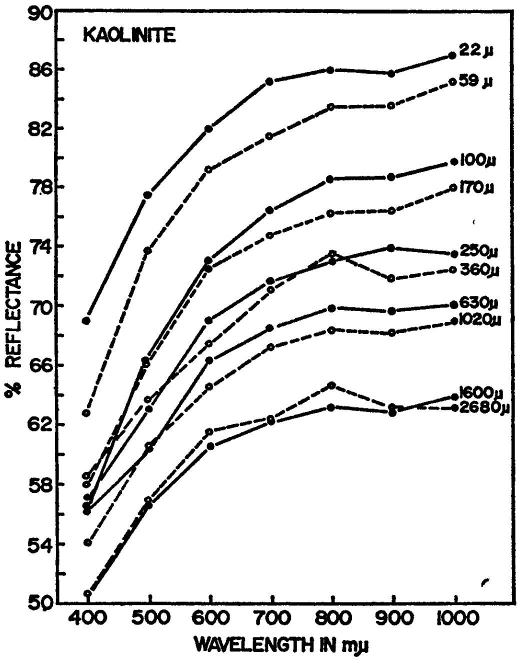

FIG. 10. Per cent reflectance *vs.* wavelength of incident radiation for various particle sizes (particle diameter indicated to the right of each curve).

Using Gates' data in conjunction with the kaolinite reflectance curves, it was calculated that by increasing the particle size from 22 μ to 2650 μ, at least an additional 14.6 per cent of the direct solar radiant energy would be absorbed. With both kaolinite and bentonite clays, it appears that changes in reflectance are functions of the surface roughness. Although no measure of surface roughness was made, it was apparent visually that, as particle size decreased, the surfaces became smoother. Thus, the roughness of the surface is, in turn, a function of the particle size.

SUMMARY

Data secured with spectrophotometers show that surface moisture content, organic matter, and particle size strongly influence the reflectance and absorptance of solar radiant energy by soils.

At all wavelengths measured, on all samples, reflectance decreased and absorptance increased as moisture content increased. By

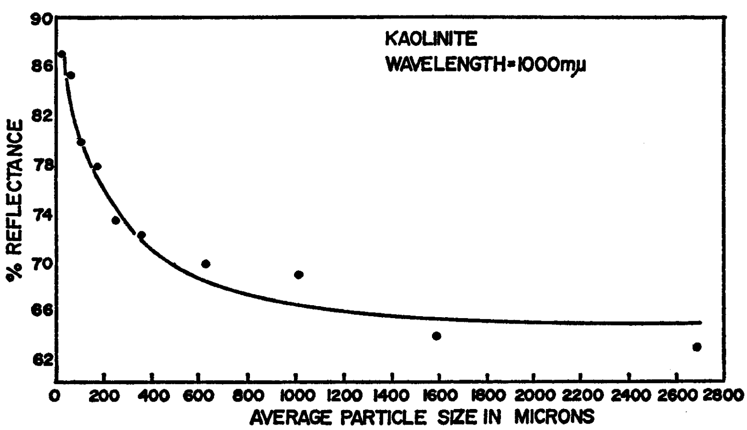

FIG. 11. Per cent reflectance *vs.* particle size for incident radiation of 1000 mμ wavelength

using Gates' direct solar energy distribution curve, one would expect that increasing the moisture content on a Newtonia silt loam from 0.8 to 20.2 per cent would increase absorption of radiant energies by at least 14.2 per cent of that in the equivalent direct solar beam.

The plot of moisture content against reflectance indicates the possibility of using reflectance methods for surface moisture determinations. Results were especially good at 1900 mμ, a moisture-sensitive wavelength.

The oxidation of soil organic matter increased the reflectance from all samples measured. Again using Gates' distribution curve, 8.2 per cent more of the energy in the equivalent direct solar beam might have been reflected by the oxidized Newtonia silt loam sample.

With both kaolinite and bentonite clays, reflectance increased exponentially as particle size decreased. The magnitude of reflectance change was very similar with both clays. By applying the kaolinite reflectance data to Gates' direct solar energy distribution curve, one would expect energy absorption to increase by at least an additional 14.6 per cent of that in the incident beam when the particle size is increased from 22 μ to 2650 μ.

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