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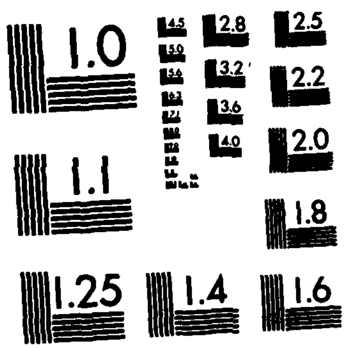

ETL-0284



# Vegetative cover effects on soil spectral reflectance

Melvin B. Satterwhite
Ponder Henley
Miklos Treiber

MARCH 1982



U.S. ARMY CORPS OF ENGINEERS
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The reflectance characteristics in the 400 to 1100 nm region of two different soil types and the effect of varying vegetative cover on each are described. The spectral reflectance of the test sites was proportional to the cover and highly dependent on soil color. A cover of 24–35 percent was required to affect significantly the spectral reflection (400 to 1100 nm) of the background soil types. Equations for these relations are given.

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## SUMMARY


Two field test plots, each 1.9m square were constructed to serve as background targets. One was filled with a dark-toned organic loam soil, and the other, with a light-toned sand soil. The amount of vegetative cover in each plot was varied by removing potted plants, which were either a dark green marigold (*Targetes* sp.), or a silver gray dusty miller (*Cineraria* sp.). Spectral reflectance in the 400 to 1100 nm (nanometer) region was measured for each plant type, soil type, and plant/soil combination using an EG&G spectroradiometer modified for field work. Reflectance measurements were made at 10 nm intervals in the 400 to 1100 nm region for selected vegetation covers. Other auxiliary data recorded were solar azimuth and total incoming radiation.

Polynomial regression analysis of the relations between percent reflectance and percent vegetative cover for each soil type and vegetation type showed that on the light-toned soil background, there was an inverse relation with the percent vegetation cover in the visible region and a direct relation in the infrared region; whereas, on the dark-toned background, the effect of increased vegetation cover was significant only in the infrared region.

From the regression curves generated from the regression analysis, it appears possible to predict percent cover from reflectance curves; however, more work is needed to fully explain the many variables involved.

## PREFACE

This study was conducted under Project 4A161102B52C, Task C, Work Unit 0010, "Indicators of Terrain Conditions."

The objectives were to evaluate the spectral reflectances from two soils as affected by different amounts of vegetative cover and to determine the minimum percent vegetative cover that would significantly alter the spectral return of these two soils.

The authors wish to express their appreciation to Mr. Scott Meeks, Research Institute, U.S. Army Engineer Topographic Laboratories (USA-ETL) for his technical assistance in the field and laboratory work.

The work was performed during 1980 under the supervision of Dr. J.N. Rinker, Team Leade-- Center for Remote Sensing; and Mr. M. Crowell, Jr., Director, Research Institute.

COL Edward .. Wintz, CE was Commander and Director and Mr. Robert P. Macchia was Technical Director of the Engineer Topographic Laboratories during the study period.

CONTENTS

## ILLUSTRATIONS

ILLUSTRATIONS (Continued)

# VEGETATIVE COVER EFFECTS ON SOIL SPECTRAL REFLECTANCE

## INTRODUCTION

High Altitude aerial photography and LANDSAT imagery taken over arid shrublands and grasslands shows little, if any, indication of the presence of vegetation. The vegetation is so widely spaced that what one sees, or records, is mostly the soil between the plants. When standing on the ground, however, and looking over an area, even an insignificant amount of vegetation can be obvious. Because vegetation cover is sparse as compared to the vast expanse of bare soil and because arid soils are highly reflective, it can be difficult to detect the presence of vegetation using remote sensing techniques.

Nevertheless, remote sensing procedures can be of great help in mapping vegetation in arid lands. The successful use of the procedures depends on an awareness and an understanding of many complicating factors. For example, when a given field of view, such as that of LANDSAT, contains more than one kind of material, the resulting spectral reflectance from the field of view will be an average of the components. Thus, one must know something about the spectral reflectance characteristics of the plants, the shadows, the soils, and the areas that each of them occupies in any given field of view. The spectral reflectance also depends on the nature of the incoming light, which, in turn, depends on location, season, time of day, and the nature of the atmosphere. The spectral reflectance characteristics of a plant depend on the species, size, age, leaf shape and orientation, crown shape, and spectral returns of the leaves (both sides) as well as of other tissue, such as stems and bark. These are some of the variables that must be kept in mind when evaluating airborne or satellite imagery.

Condit showed that conditions affecting soil reflectance include soil texture, color, and soil moisture.[1] Vegetation poses even more of a problem owing to extensive three-dimensional and temporal variations. The differences in height, leaf angle, leaf type, crown shape, and color, as well as seasonal differences, all affect the reflectance. The importance of color

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[1] H.R. Condit, "The Spectral Reflectance of American Soils." *Photogram. Engin. and Rem. Sens.* 955–966, 1970.

differences within a single plant was demonstrated using variegated leaves in which the green portion was found to have high reflectance in the infrared and low in the visible region; whereas, the white portion of the same leaf was highly reflective throughout the visible and infrared.[2] The differences in spectral response between green and chlorotic vegetation was used by Gausman to monitor chlorotic grain sorghum using LANDSAT I imagery.[3]

The interaction between soil and vegetation reflectance has been reported by Colwell.[4] Forested areas with grass-covered soils had higher infrared reflectance than a forest of similar type on a bare rock rubble soil. Soil color/vegetation interaction effects demonstrated that the total reflectance of a light-toned soil with a grass cover was higher than that of a dark-toned soil with the same grass cover.[5]

Reflectance models for the interaction of plant canopy and soil have been developed by Allen and Richardson; Suits; and Chance and Le Master.[6,7,8] These models address only a partial canopy cover. A two-dimensional model developed by Jackson, et al. addresses the complete canopy and considers other plant characteristics such as height/width ratio, spacing, shade, orientation, and seasonality.[9]

The purpose of the present study was to conduct a simple experiment to evaluate the effects of vegetation cover on the reflectance, of two soil types and to determine the percent cover required to alter sufficiently the background reflectance to detect the vegetation.

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[2]E.B. Knipling, "Physical and Physiological Basis for the Reflectance of Visible and Near Infrared Radiation From Vegetation." *Rem. Sens. of Environ.* 1:155–159, 1970.

[3]H.W. Gausman, A.H. Gerbermann, and C.L. Wiegand, "Use of ERTS–1 Data to Detect Chlorotic Grain Sorghum" *Photogram. Engin. and Rem. Sens.* 16(2): 177–179, 1975.

[4]J.E. Colwell, "Vegetation Canopy Reflectance." *Rem. Sens. Envir.* 3:175–183, 1974.

[5]Ibid.

[6]W.A. Allen and A.J. Richardson, "Interaction of Light With a Plant Canopy." *Journ. Optical Soc. Amer.* 58(8):1023–1028, 1968.

[7]G.H. Suits, "The Calculations of the Directional Reflectance of a Vegetational Canopy." *Rem. Sens. of Environ.* 2:117–125, 1972.

[8]J.E. Chance and E.W. LeMaster, "Suits Reflectance Models for Wheat Cotton. Theoretical and Experimental Tests." *Applied Optics* 16(2):407–412, 1977.

[9]R.D. Jackson, R.J. Reginato, P.J. Pinter, Jr., and S.B. Idso, "Plant Canopy Information Extraction From Composite Scene Reflectance of Row Crops." *Applied Optics.* 18(22):3775–3782, 1979.

## METHODS AND MATERIALS

Two test plots were constructed, each 1.9 meters square; one was filled with light-colored, clean, gravelly, medium sand, and the other, with a commercially available dark, organic loam potting soil (figure 1).

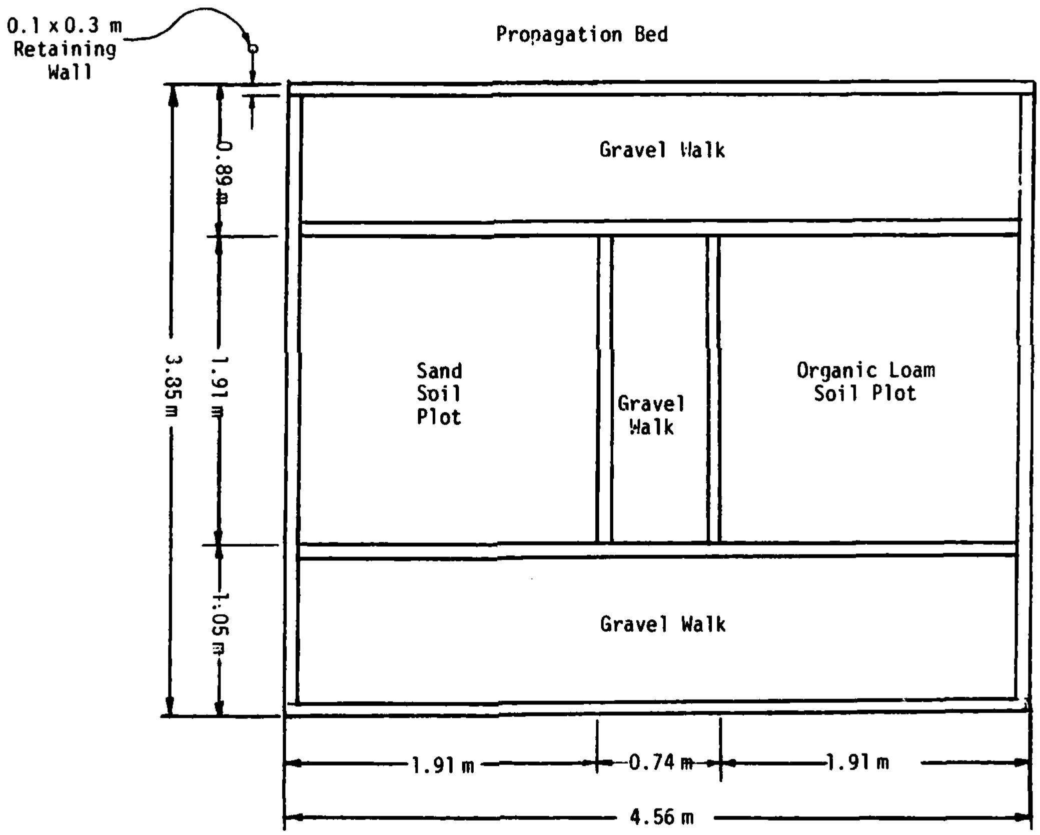


FIGURE 1. Plan View of the Test Site.

The plant species used in this study were marigold (*Targetes*, sp.) and silver lace dusty miller (*Cineraria*, sp). These species were selected because of their rapid growth, dense canopy, seasonal growth characteristics, and color.

*Targets:*

Light-toned soil – clean, gravelly, medium sand;
Munsell color: 2.5Y 9/2, dry

Dark-toned soil – commercial potting mixture organic loam;. 49.6% wt loss on ignition of oven dry sample;
Munsell color: 7.5 YR 2/0, moist

Green plants – marigold (*Targetes* sp.); Munsell color: 7.5 GY 4/4

Gray plants – dusty miller (*Cineraria* sp.); Munsell color: 10 GY 8/1

Radiometer: – EG&G Mdl 550/555 Spectroradiometer system with monochromator Mdl 555–61 and field of view adapter Mdl 555–73–15.
Calibration to NBS Standard Lamp No. A301A, certificate No. 555-2b–B1267–1.

Plants, 10 centimeters (cm) tall, were planted in plastic pots, 16.5 cm in diameter by 15 cm and cultured for 30 days. All flower buds were removed during the experiment. The cross-section diameter of the plant canopy at the beginning of the experiment was approximately that of the pot diameter, although there were some variations.

The marigolds were divided into two sets of 150 pots, one set for the sand soil plot, and the other for the organic loam soil plot. The dusty miller plants were used for a limited number of reflectance measurements on both soil conditions. Prior to each data collection, pots containing the marigolds were placed in the test plot in the 12 by 12 pot matrix to form the 100 percent vegetative cover condition (hereafter called the 100 percent reflectance cover). Soil was carefully placed around each pot so that only sunlit and shadowed plants and soil formed the target in the field of view (FOV).

The potted marigolds were removed randomly from the matrix to produce the desired cover class; 100, 80, 60, 40, 20, 10 and 0 percent. The position of each pot removed from the matrix was recorded, and the percent vegetative cover was calculated from the number of pots in the FOV. As each pot was removed, the void in the soil surface was filled with soil. Reflectance measurements of the dusty miller were made for several vegetative covers that were less than 40 percent. The desired vegetative cover was achieved by clustering the potted dusty miller plants in the center of the monochromator's FOV.

Spectral measurements were made over 400 to 1100 nm, in 10-nm increments, using a spectroradiometer system. Each scan required about 4 minutes to complete. The monochromator was attached to a scaffold so that it looked vertically downward and was centered on the test plot. The height of the monochromator was 583 cm above each test plot. The FOV was 153 cm in diameter at the test plot surface. A plumbline was used for centering the monochromator over each test plot (figure 2). A plan view of the monochromator and test plot arrangement is shown in figure 3. The spectroradiometer was interfaced with a Hewlett Packard Model 9830 calculator for automatic data recording and processing. A schematic of the automatic data collection and processing system is shown in figure 4.

A 15-cm-square magnesium carbonate block reference target was positioned normal to the sun and was viewed at an incident angle less than 10°. The reflectance of each vegetation-soil target was calculated as a percentage of the magnesium carbonate reference. An Eppley radiometer and a strip chart recorder were used to measure and record total solar illumination during the scanning periods. Measurements were made on clear days between 1030 and 1430 hours local standard time on 13, 14, 17, and 22 June 1980. The reflectance data for each day were normalized to each other using normalization coefficients that were calculated by dividing the maximum solar illumination measured for a spectral scan by the measured solar illumination during a scan.

The percent cover was varied by removing the potted plants from the FOV in the test plot. The vegetative cover in each target was calculated from the pot surface area in the FOV. This percent cover calculation was evaluated by comparing the reflectance curve (Rm) measured *in situ* with a predicted reflectance curve (Rp) for a selected cover class on the organic loam soil. The predicted percent covers for the vegetation-organic loam soil targets were calculated using equation (1).

$$Pc = (Rm - Rs) / (Rv - Rs) \times 100\% \qquad (1)$$

Where Pc = predicted cover, Rm = measured reflectance for a target with an unknown percent cover, Rs = measured reflectance for the organic loam soil, and Rv = measured reflectance for the 100 percent vegetative cover for a selected wavelength. Predicted covers were calculated from reflectances in the bandpasses centered at 800, 850, 900 and 950 nm. The four predicted cover values were averaged. The predicted reflectance curve was calculated using equation (1), the mean Pc value, and the measure reflectance for the soil and vegetation. Chi-square analysis of the Rm and Rp curves was made to determine significance at the 95 percent level of confidence.

The percent cover calculations for the various dusty miller-organic soil targets were also evaluated using these procedures. Polynomial regression analysis of relationships between percent reflectance and percent cover was done for each soil and each vegetation cover for the 10-nm bandpasses centered at 450, 550, 680 and 850 nm. The effects of vegetation on the soil's reflectance for the four LANDSAT bands; 4(500-600 nm), 5(600-700 nm), 6(700-800 nm) and 7(800-1100 nm) were evaluated. The percent cover and reflectance relationships were analyzed using polynomial regression analysis. The relative brightness of the target on a scale of 0 – 100 in each LANDSAT band was used in this evaluation.

The minimum percent cover causing a significant difference between the reflectance of the bare soil and that of the vegetation-soil target will vary by spectral region, when the reflectance contrast between the soil and the vegetation varies. The reflectance of a vegetation-soil target was calculated using equation (1) for each 10 nm bandpass in the visible (400 700 nm), infrared (800-1000 nm) and visible–IR (400-1000 nm) regions. Chi-square analysis determined the significance of any difference between the two reflectance curves in any of the three regions at the 95 percent level of confidence and 25, 20 and 55 degrees of freedom respectively. Through an iterative process, the percent cover was determined for the vegetation-soil target having a reflectance curve significantly different from that of the bare soil.

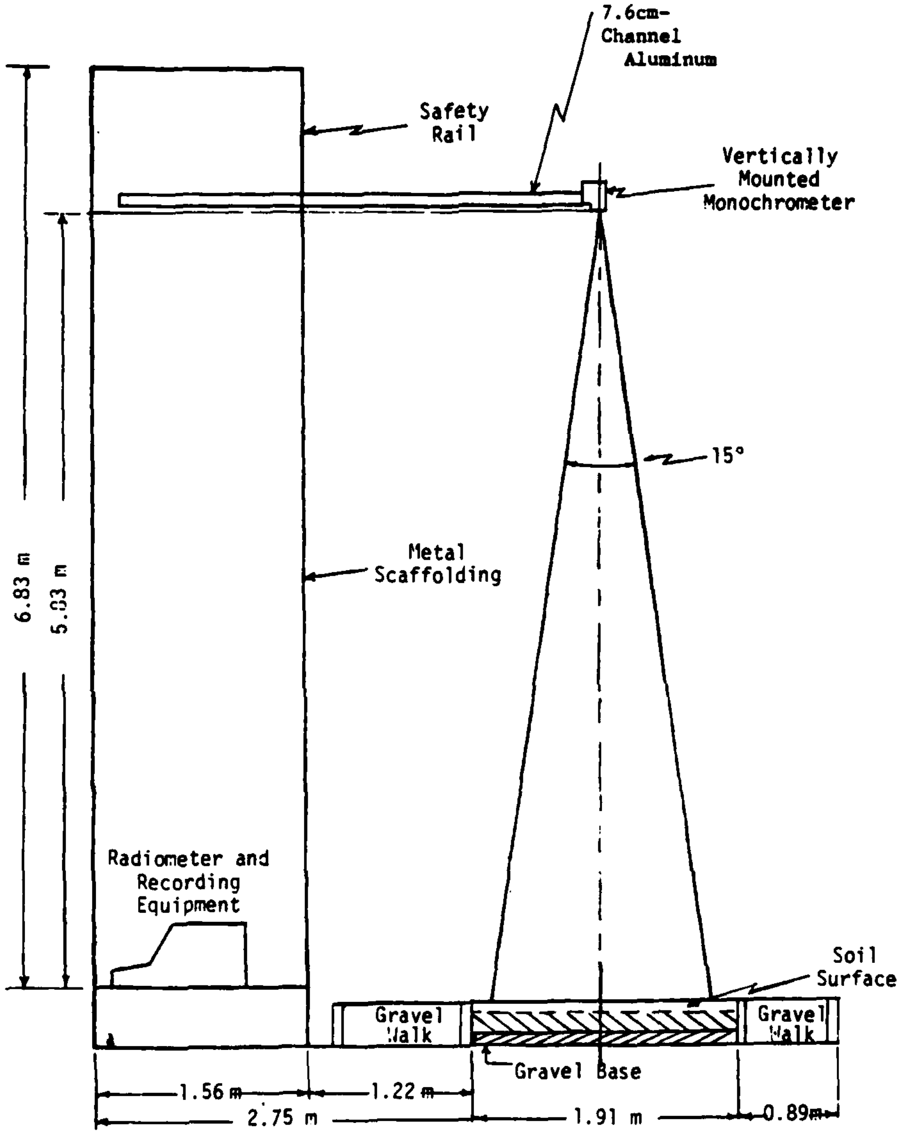


FIGURE 2. A Schematic Side View of the Monochrometer Position Over a Test Plot.

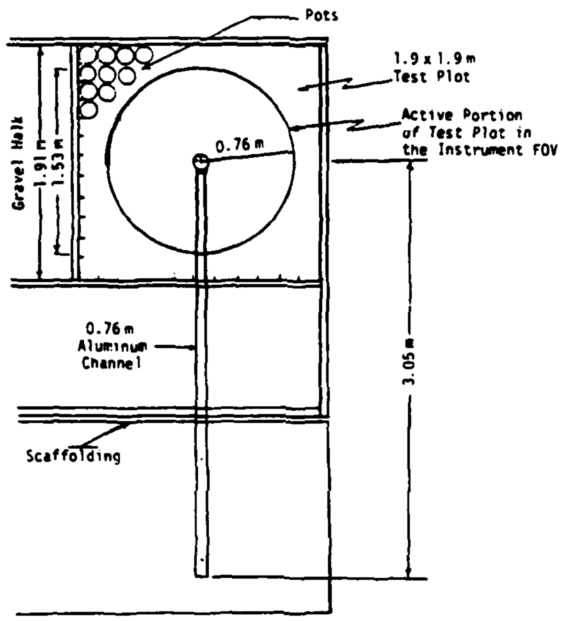


FIGURE 3. A Schematic Plan View (Partial) of the Monochrometer Position Over a Test Plot.

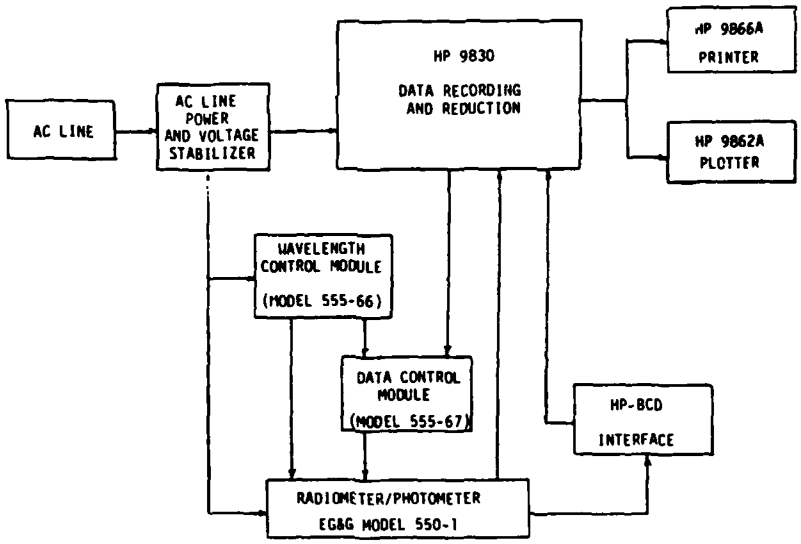


FIGURE 4. Schematic for an Automated Spectroradiometer System for Making Field or Laboratory Measurements.

## RESULTS

**Solar Illumination.** Total solar illumination ranged from 1 3 to 1.6 langleys (5.4 to 6.7 joules per square meter) during the recording periods. The lowest solar illumination occurred at the beginning of the measurement period, about 1030 to 1100 hours, and the maximum occurred between 1230 and 1300 hours.

**Vegetation on Sand Soil.** The reflectance curves for marigold, dusty miller, and sand soil show that the two vegetative covers can be differentiated from the sand soil in both the visible and infrared regions, except in the 720 to 750 nm region where the reflectance curves of the sand and vegetation cross (figure 5).

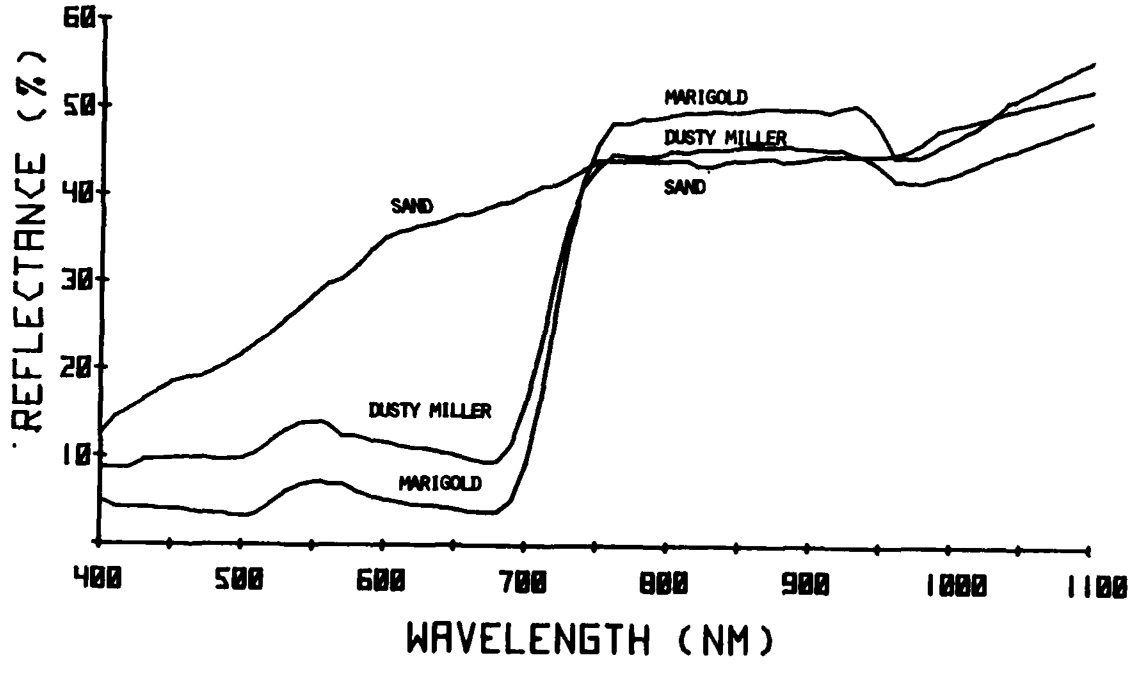


**FIGURE 5. Measured Reflectance Curves for Sand Soil, Marigold and Dusty Miller.**

The sand soil had a higher reflectance in the 400 to 690 nm region than the 100 percent marigold and a lower reflectance in the 750 to 1100 nm region (figure 5). In the 400 to 680 nm region, the differences between the bare soil and marigold ranged from 10 to 36 percent, and in the 750 to 1100 nm region the differences were less than 10 percent. The greatest reflectance contrast between the marigold cover and the bare soil was in the 650 to 680 nm region.

The target reflectance varied inversely with the percentage cover in the 400 to 680 nm region, i.e. as the percent vegetative cover increased, the reflectance from the target decreased (figure 6). In this region, the reflectance curves for the marigold-sand soil targets with 18 percent cover were more similar in shape and slope to that of the 100 percent vegetative cover target than they were to the reflectance curve of the sandy soil. In the 750 to 1100 nm region, the target's reflectance varied directly with the percent cover. Targets with 75 to 100 percent cover differed less than 3 percent in their reflectance, and targets with less than 28 percent cover were only slightly more reflective than the bare soil.

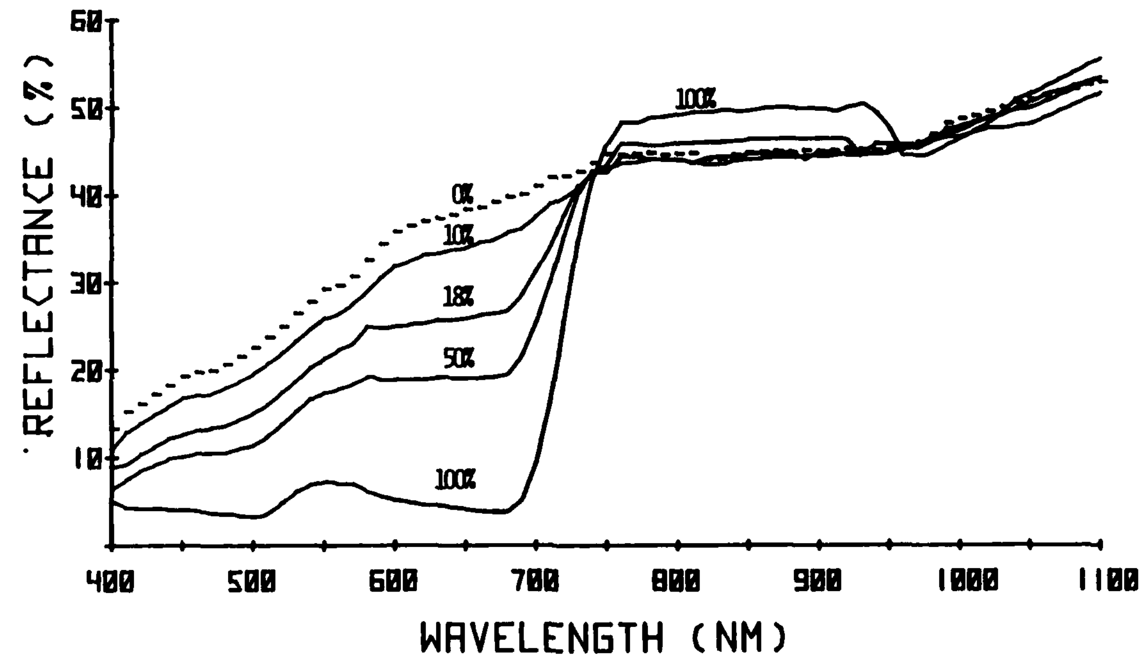


FIGURE 6. Reflectance Curves for Sand-Marigold Targets With Different Vegetative Covers.

The relationships between the percent cover and the percent reflectance were described for the 10 nm bandpasses centered at 450, 550, 680, and 850 nm using polynomial regression analysis (figure 7). These curves show the inverse relationships between the percent cover and the percent reflectance in the visible region and the direct relationship in the IR region. Strong correlations between reflectance and percent cover were found at 550 and 680 nm, $R^2$ = 0.87 and 0.93, respectively. The slope of the regression curve for the 850 nm bandpass indicates that the reflectance-cover relationship at this bandpass is not very strong.

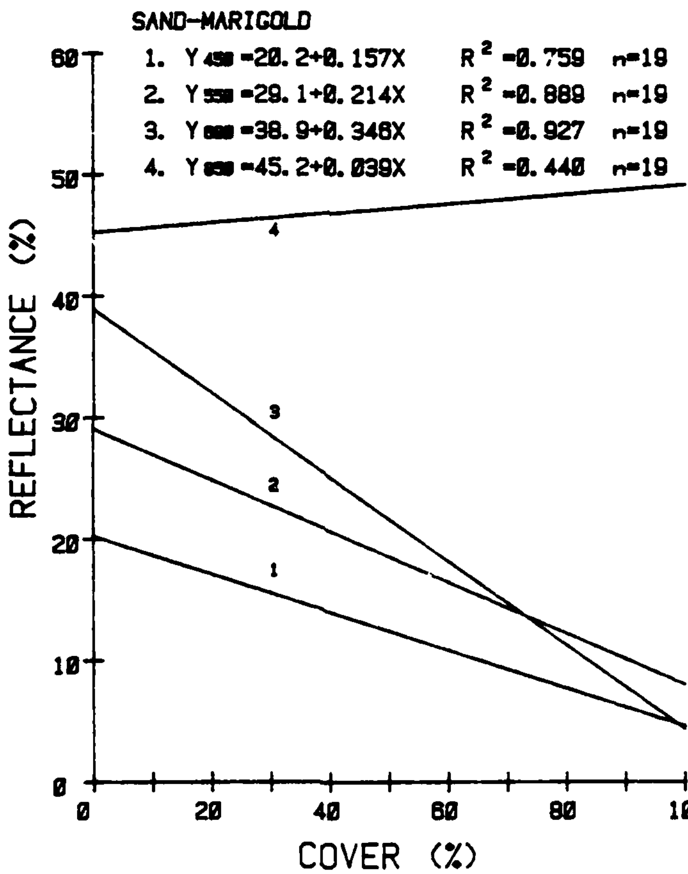


FIGURE 7. Regression Curves for Reflectance at 450, 550, 680 and 850 nm and Precent Cover of Sand-Marigold Targets.

The reflectance curves in figure 6 show that the introduction of any vegetation to the sand soil plot created a new vegetation-soil target with its own reflectance characteristics. The influence of vegetation is seen in the visible region for those vegetation-soil targets with $\geqslant$ 10 percent cover. Chi-square analysis found significant differences (at the 95 percent level of confidence) between reflectance in the 400 to 1100 nm region for the bare sand soil and the targets with $\geqslant$ 35 percent cover.

The reflectance curves for the sand soil and the dusty miller targets were similar to those for the marigold-sand soil targets in that the greatest difference in reflectance was between 400 to 680 nm, and the least, between 750 to 1100 nm. These differences ranged from 4 percent at 400 nm to 30 percent at 680 nm and from 2 to 3 percent in the 750 to 1100 region (figure 8).

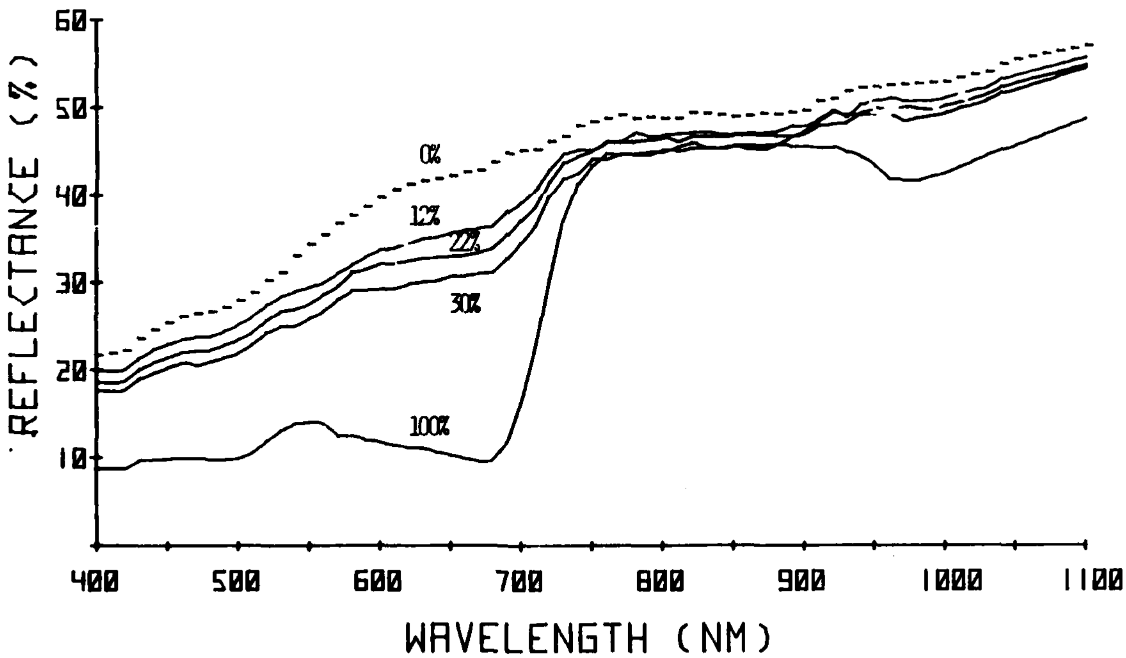


**FIGURE 8. Reflectance Curves for the Sand-Dusty Miller Targets Different Vegetative Covers.**

The reflectance curves for the 100 percent dusty miller cover and sand soil in figures 5 and 8 were calculated from two sets of reflectance measurements. Comparing the two dusty miller reflectance curves and the two sand soil reflectance curves shows that in the IR region the dusty miller had higher reflectance than the sand soil in figure 5, but was less reflective than the sand soil in figure 8. Chi-square statistical analysis of the two curves revealed no statistical difference at the 95 percent confidence level. Even so, the evaluation of the reflectance-cover relationship from these data is dependent on whether the reflectance of the dusty miller was greater or less than the sand soil. In the visible region, dusty miller and sand soil reflectance curves had the same relative position to each other, although the contrast between the two curves varied for the two measurements days.

The reflectance-cover relationships were the same for both sets of curves. The dusty miller cover on the sand soil was varied between 0 and 30 percent. The reflectance curves in figure 8 show an inverse relationship between the reflectance of dusty-miller-sand soil targets and the percent cover in the visible and IR regions, i.e. target reflectance decreased with increased cover.

The reflectance curves for the targets with 12 and 22 percent cover, although displaced, were similar to the reflectance curve of the bare soil. The target with 30 percent cover was substantially different from the bare soil and was more like that of the 100 percent dusty miller cover.

Polynomial regression analysis of the percent reflectance and percent cover describes the inverse relationship between reflectance and cover for the 10 nm bandpasses at 450, 550, 680 and 850 nm wavelengths. The slope of the regression curves shows a good correlation between percent cover and reflectance at 450, 550 and 680 nm, $R^2 = 0.81, 0.91$, and 0.96 respectively (figure 9). The relationship at 850 nm was slightly inverse.

The reflectance curves in figure 8 show that the dusty miller vegetation can alter the sand reflectance at all cover values. Chi-square analysis found significant difference between the reflectance of sand soil and the dusty-miller-sand targets with 30 percent cover in the 400 to 700 nm region at the 95 percent level of confidence.

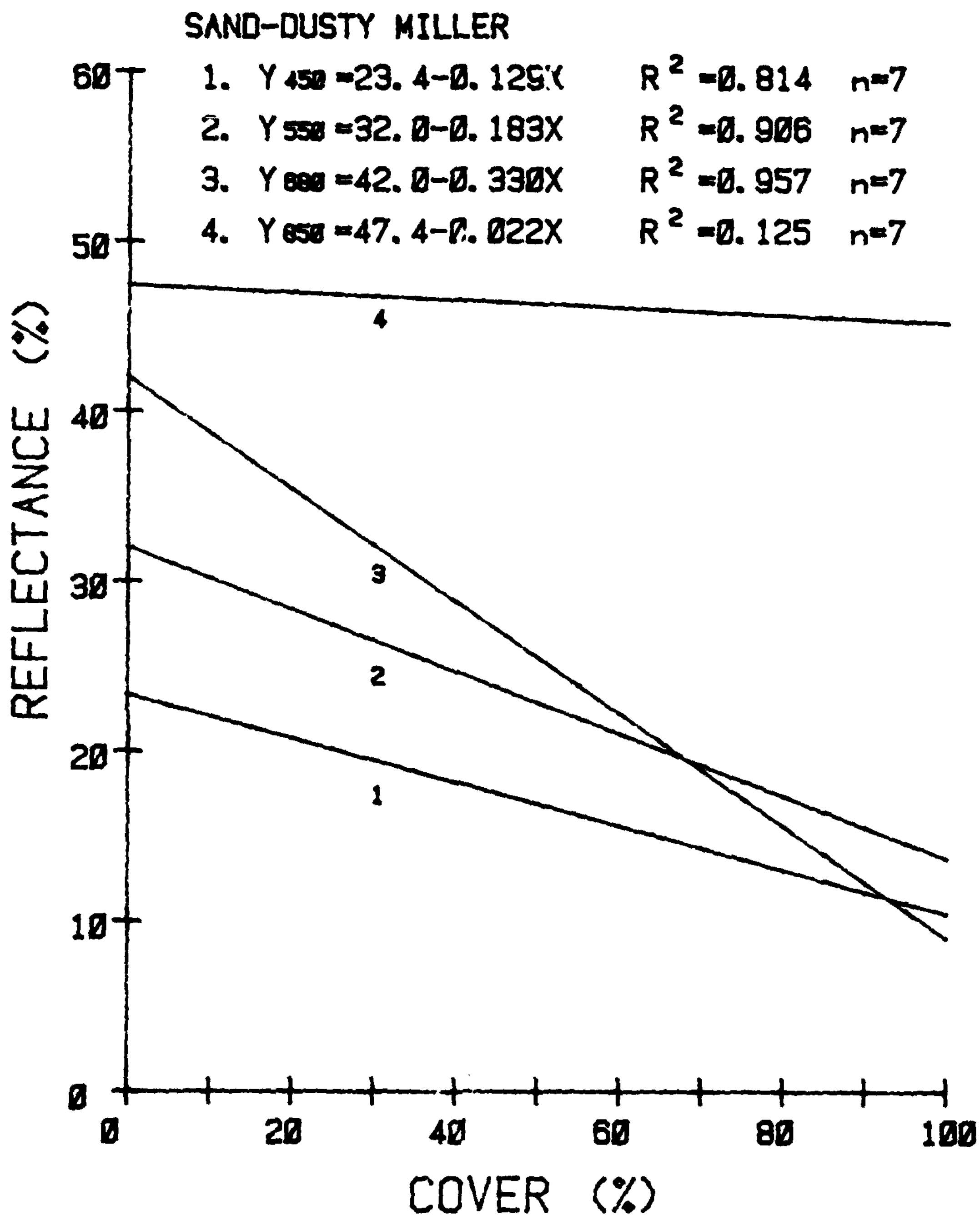


FIGURE 9. Regression Curves for Reflectance at 450, 550, 680 and 850 nm and Percent Cover of Sand-Dusty Miller Targets.

**Vegetation On Organic Loam Soil.** The reflectance curves for the marigold, dusty miller, and organic loam soil show that these targets can be differentiated from each other, but not equally in the visible and infrared regions (figure 10). The reflectance contrasts between the soil and the two vegetation types were less than 5 percent in the visible and about 30 percent in the infrared region.

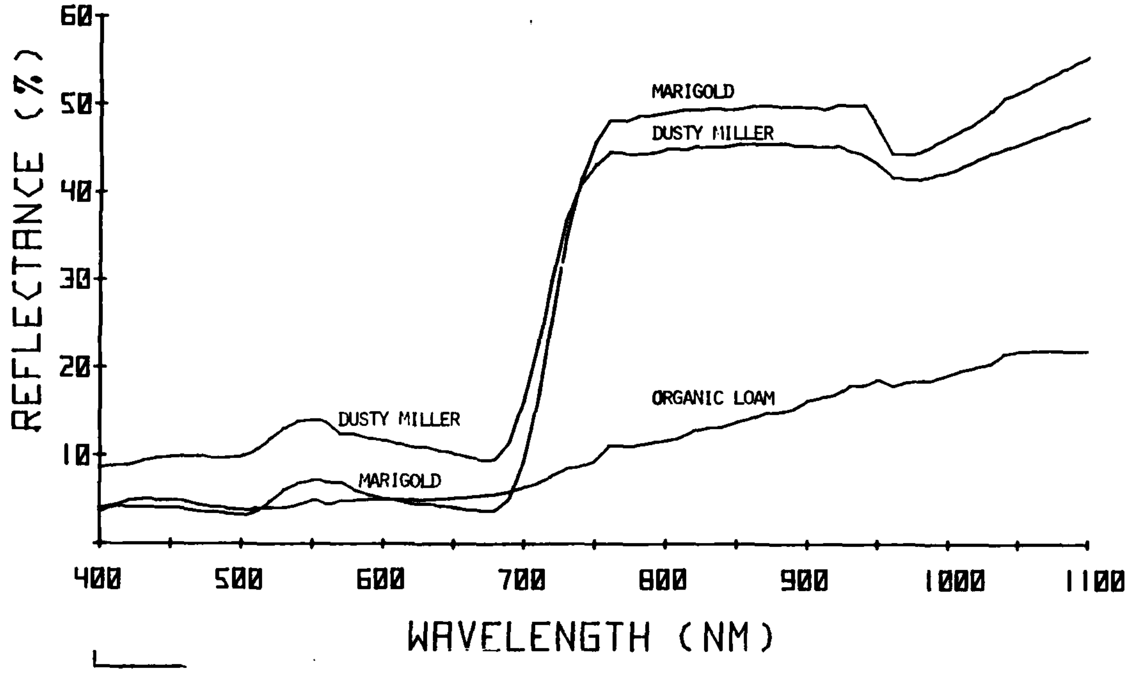


**FIGURE 10. Reflectance Curves for the Organic Loam, Marigold and Dusty Miller.**

The spectral reflectance curves for the marigold and bare organic loam soil (0 percent cover) are shown in figure 11. These curves differed by less than 5 percent in the visible region, where the marigold was slightly more reflective than the organic soil. The reflectance of the marigold was less than the organic soil in the 650 to 680 nm region because of the chlorophyll absorbtion. The reflectance contrasts between the marigold and organic loam in the 400 to 690 nm region were too small for positive differentiation between the targets.

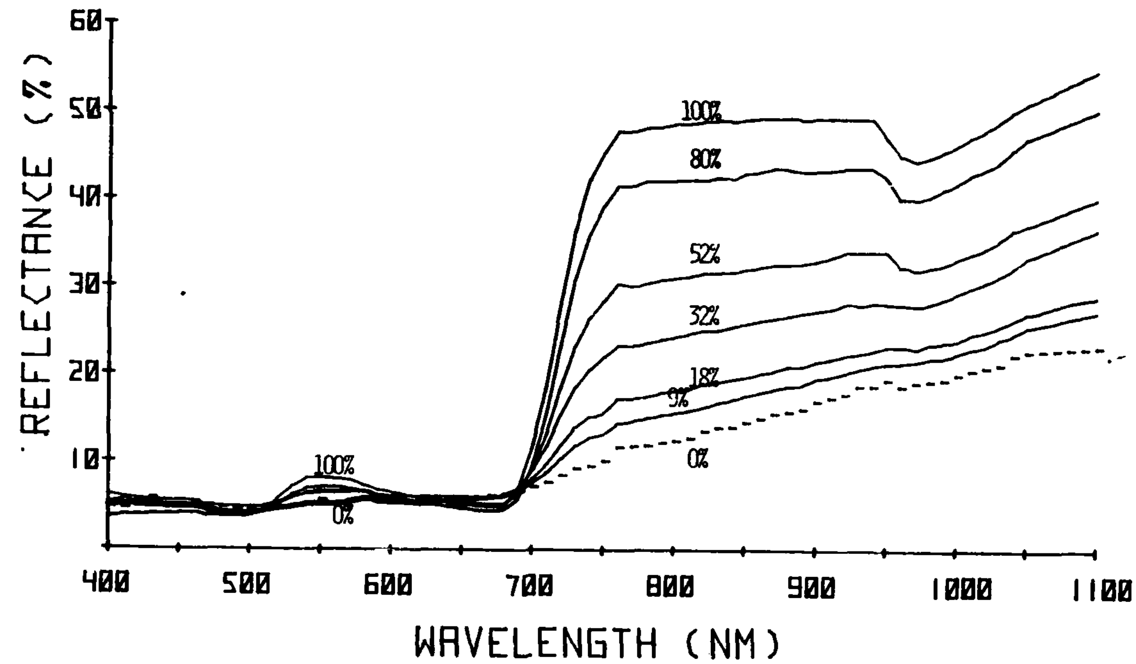


**FIGURE 11. Reflectance Curves for Organic Loam-Marigold Targets With Different Vegetative Covers.**

Varying the marigold cover on the organic soil substantially changed the reflectance characteristics of the target area, particularly in the near IR region. A direct relationship exists between percent cover and percent reflectance of the marigold-organic loam soil targets. Polynomial regression analysis of the relationship between percent cover and percent reflectance in the visible region, 450, 550, and 680 nm, shows that a small variation in reflectance was associated with a large change in percent cover (figure 12). The reflectance in the near IR region (850 nm) was directly related to the percent cover, $R^2 = 0.99$ The regression curve of this relationship shows the ratio of percent reflectance to percent cover was about 2:5.

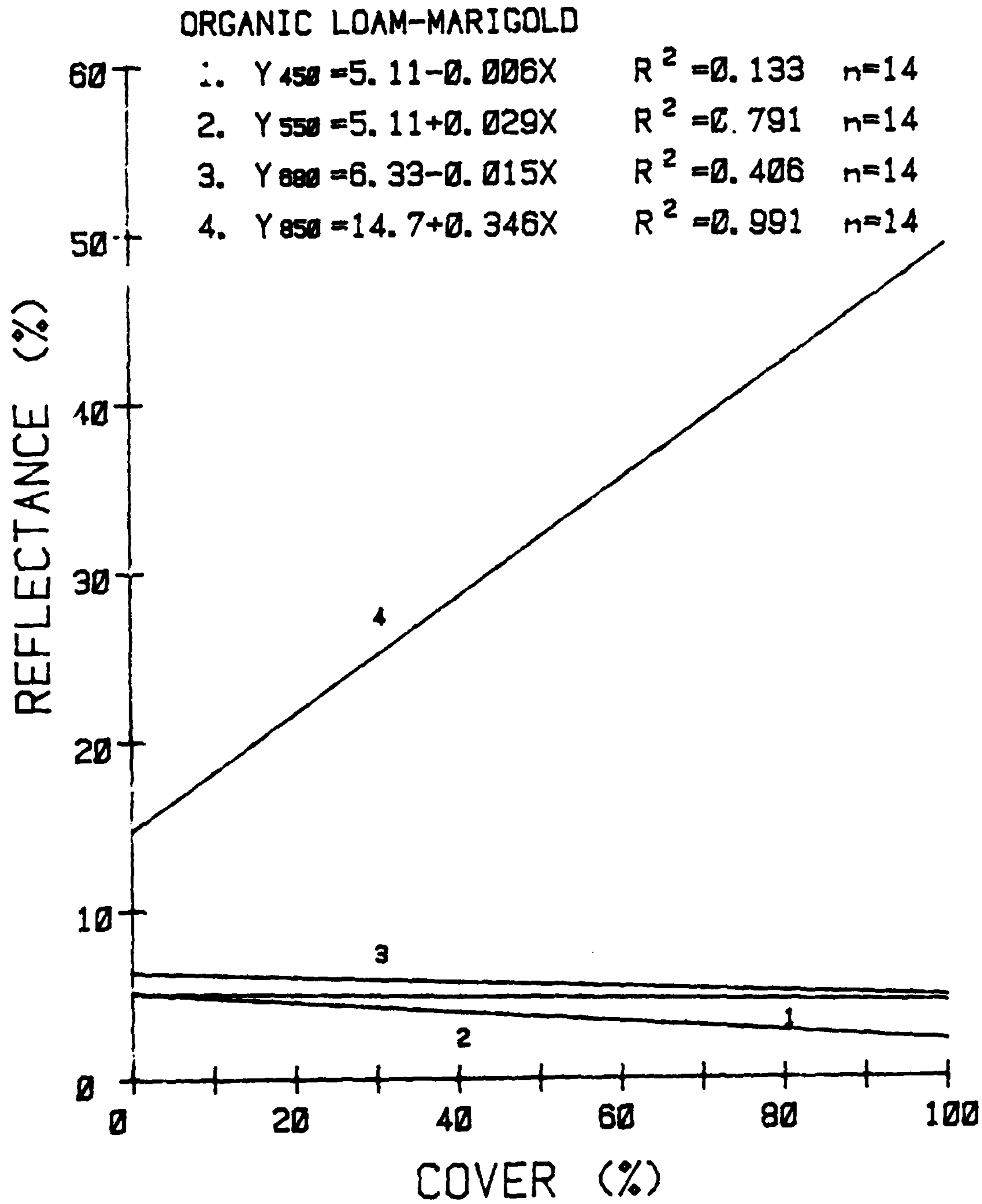


FIGURE 12. Regression Curves for Reflectance at 450, 550, 680 and 850 nm and Percent Cover of Organic Loam-Marigold Targets.

Chi-square analysis of the infrared reflectance (800 -- 1000 nm) differences revealed a significant difference (at 95 percent level of confidence) between the soil and marigold-organic loam targets with ⩾ 12 percent cover.

The reflectance curves for the dusty miller (100 percent cover) and the dark-toned organic loam soil (0 percent cover) show the dusty miller had 10 to 15 percent greater reflectance than the organic loam soil in the 400 to 690 nm region, and about 40 percent greater reflectance in the 780 to 1100 nm region. Increasing the vegetative cover on the organic loam soil increased the reflectance at all wavelengths in the 400 to 1100 nm region.

The reflectance curves of the dusty miller and the organic loam soil targets with 5, 16, and 35 percent cover are shown in figure 13. These curves differed by only 3 to 4 percent in the 400 to 690 nm region, but by 10 to 15 percent in the 800 to 1100 nm region.

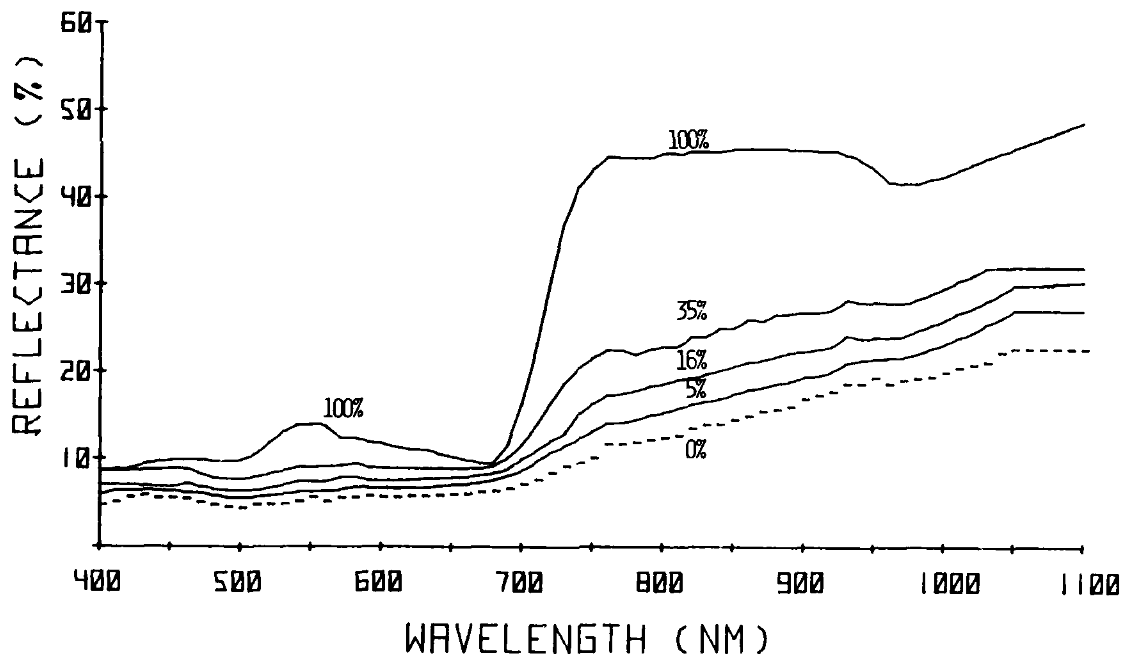


**FIGURE 13. Reflectance Curves for Organic Loam Soil-Dusty Miller Targets With Different Vegetative Cove. .**

Regression analysis of the percent reflectance and percent cover shows a direct relationship (figure 14). The regression curve shows that large changes in cover resulted in only small increases in target reflectance in the 400 to 690 nm region, but in the 750 to 1100 nm region, the ratio of reflectance to cover was 3:10.

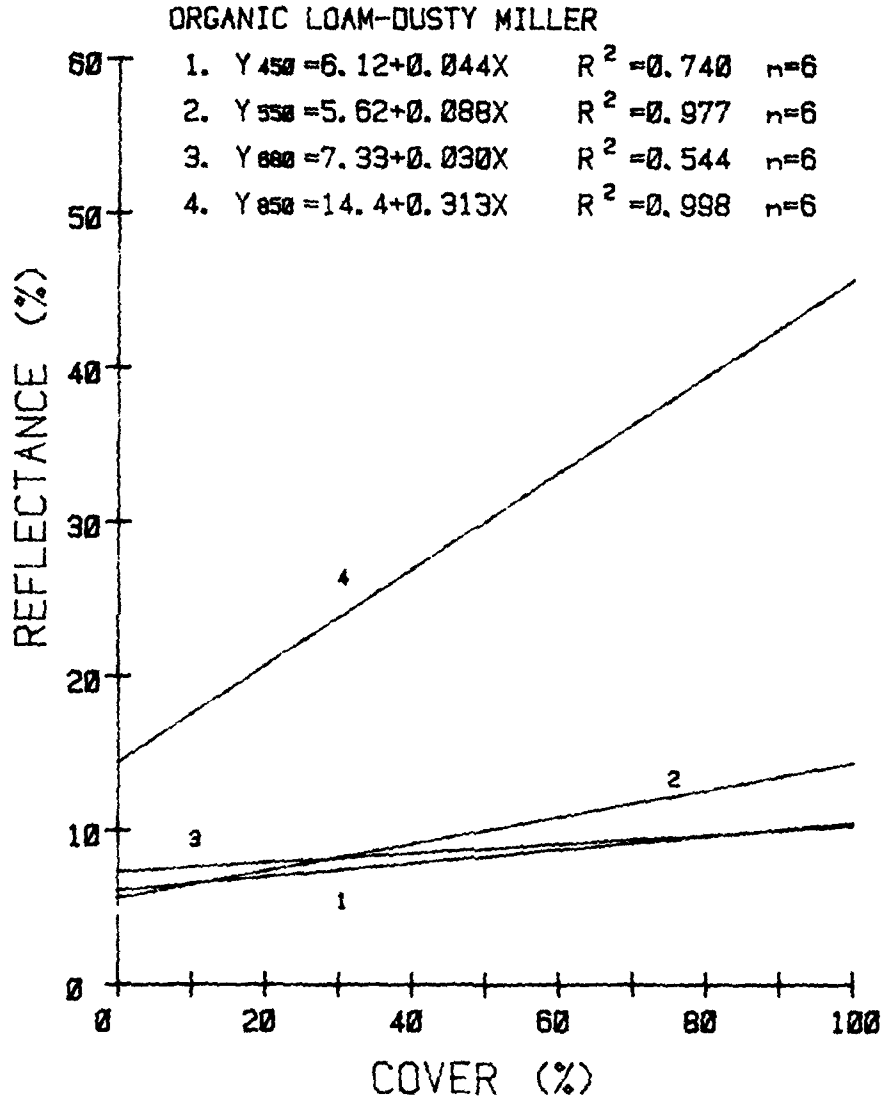


FIGURE 14. Regression Curves for Reflectance at 450, 500, 680 and 850 nm and Percent Cover of Organic Loam-Dusty Miller Targets.

Comparing the reflectance curves in figure 13 shows that the target with 5 percent cover was substantially different from the reflectance curve of the organic loam soils. Chi-square analysis of the differences between the reflectance in the 800 to 1000 nm region for the organic loam soil and the dusty-miller-organic loam soil targets revealed that the reflectance of a dusty-miller-soil target with 19 percent cover was significantly different from that of the organic loam soil at the 95 percent level of confidence.

**Soil and Vegetation Reflectance Characteristics on LANDSAT Bands.** The target's relative brightness corresponding to the four LANDSAT bands was calculated for the various marigold and soil targets. Polynomial regression analysis was used to evaluate the relationships between the brightness of each band and the percent cover (figures 15 and 16, respectively).

The reflectance in the LANDSAT bands was highly correlated with cover in the sand-marigold targets. Inverse relationships were found between reflectance in bands 4, 5, and 6 and percent cover, and a direct relationship was found between reflectance and cover in band 7. The slopes of the regression curves show that the soil (0 percent cover) and the vegetation (100 percent cover) could be readily differentiated in LANDSAT bands 4, 5, and 6 because there was substantial reflectance contrast between soil and marigold. The slope of the regression curve for band 7 was small, indicating the small reflectance contrast between sand and marigold in this spectral region.

The regression curves for the marigold and the organic loam show little correlation between reflectance and cover in bands 4 and 5, $R^2$ = 0.55 and 0.04, respectively; but in bands 6 and 7, reflectance and cover were directly correlated, $R^2 = 0.99$. The slopes of the regression curves show that bands 6 and 7 could be used for differentiating the organic loam and the marigold cover because of the substantial change in target reflectance associated with moderate changes in percent cover. Band 7 provides the best spectral region for monitoring vegetative cover on the dark-toned soils because of the greater reflectance contrast between soil and vegetation than that found in the other three LANDSAT bands.

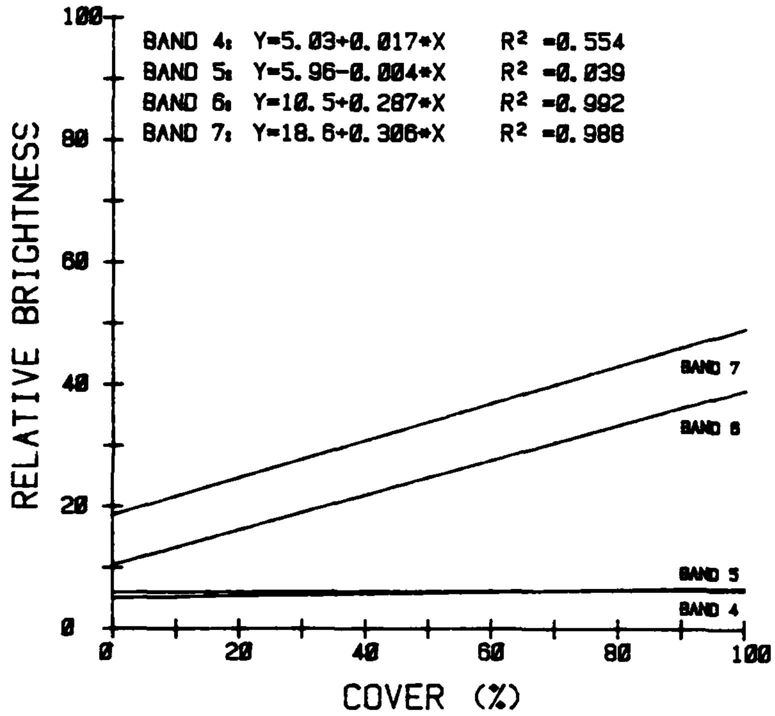


FIGURE 15. Regression Curves of the Percent Cover in the Sand-Marigold Targets Against Total Reflectance in LANDSAT Bands 4, 5, 6 and 7.

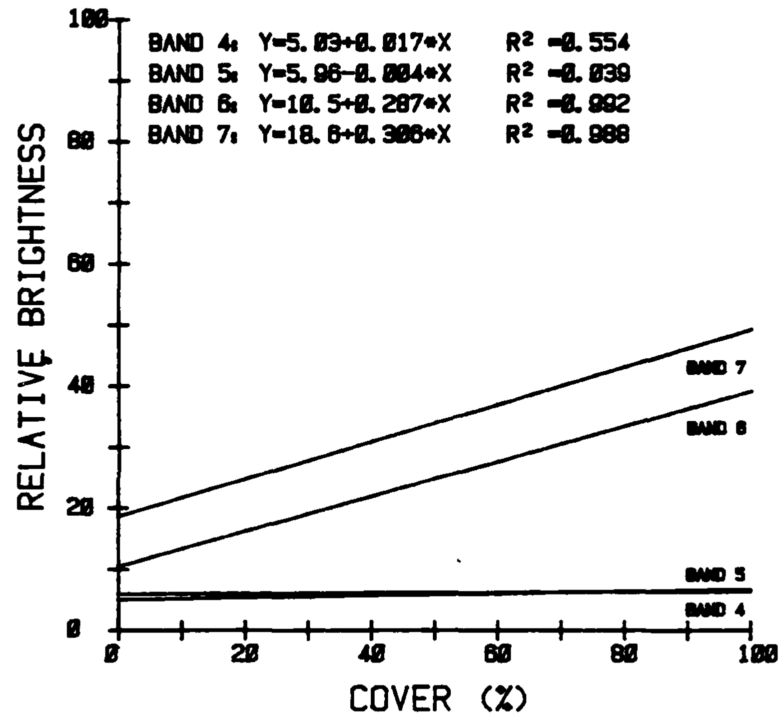


FIGURE 16. Regression Curves of the Percent Cover in the Organic Loam-Marigold Targets Against Total Reflectance in LANDSAT Bands 4, 5, 6 and 7.

Chi-square analysis revealed that the percent cover in the vegetation-soil targets whose significantly reflectance was different from the soil's reflectance varied by spectral region, soil type, and vegetation. This difference was predictable considering the contrast between vegetation and soil reflectance. In the 400 to 1100 nm region, the sand soil reflectance was significantly different from targets with 25 percent marigold or 30 percent dusty miller cover; whereas, the organic soil reflectance was significantly different from targets with 20 percent marigold and 19 percent dusty miller cover. Because the vegetative effects were not uniform throughout the 400 to 1100 nm region, the percent cover in targets having reflectance significantly different from the soil's reflectance varied with the reflectance contrast between the soil and vegetation conditions. In the visible region, 400 to 700 nm, targets with marigold covers of 25 percent had reflectance curves that were significantly different from the reflectance of the sand but were not significantly different from the organic soil targets. For the dusty miller, which had a lesser reflectance contrast with the sand soil than the marigold, targets with dusty miller cover of 30 percent had reflectance curves that were significantly different from the sand reflectance; whereas, targets with 23 percent cover were not significantly different from the organic loam reflectance curve.

In the near IR region (800 to 1000 nm), the small reflectance contrast between the sand soil and the vegetation necessitated a large vegetative cover before a significant change in reflectance was found. For the marigold-sand targets, there was no statistical difference between the reflectance curves of the dusty miller, 100 percent cover, and the sand soil, 0 percent cover. The organic loam soil and two vegetation types had large reflectance contrasts in the near IR. Targets with 15 percent marigold or 19 percent dusty miller had IR reflectance curves that were significantly different from the organic loam reflectance.

Polynomial regression analysis shows a highly correlated linear relationship ($R^2 = 0.97$) between the IR reflectances at 800, 850, 900, and 950 nm and the percent cover (figure 17). This linear relation shows reflectance in the IR region can be used for estimating percent vegetative cover.

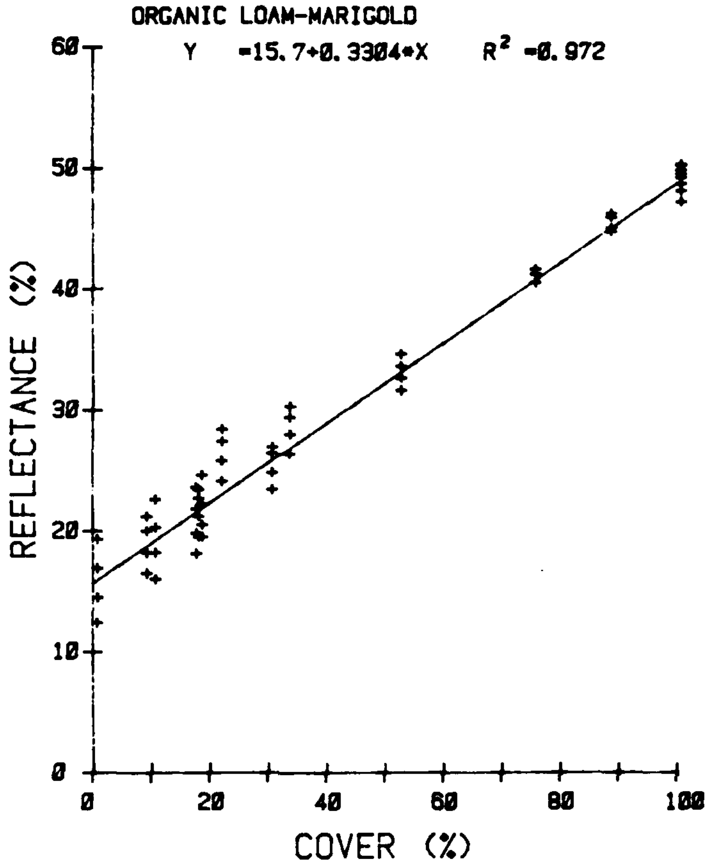


FIGURE 17. **Regression Curves for the Relationship Between Reflectance at 800, 850, 900 and 950 nm and Percent Cover.**

This relation was used to estimate cover and to compute a predictive reflectance curve (Rp). The measured reflectance, RM, and calculated reflectance, Rp, curves for the marigold-organic loam targets, and curves for the dusty miller-organic soil targets are shown in figures 18 and 19. The differences between the Rm and Rp curves were mostly less than 2 percent. Chi-square analysis did not show a significant difference between the Rm and Rp curves at the 95 percent level of confidence.

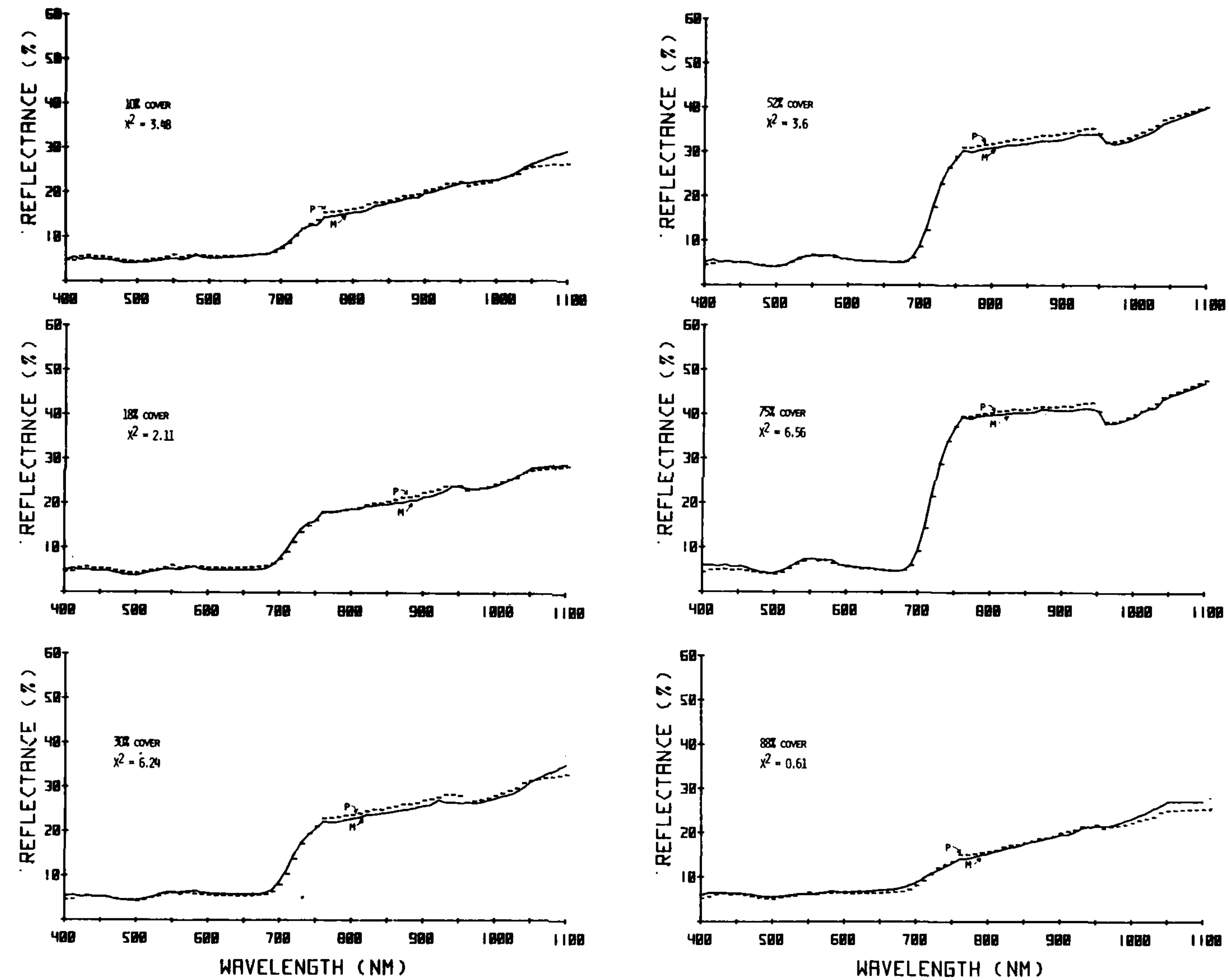


FIGURE 18. Reflectance Curves of Organic Loam Soil-Marigold Targets With Different Percent Covers.

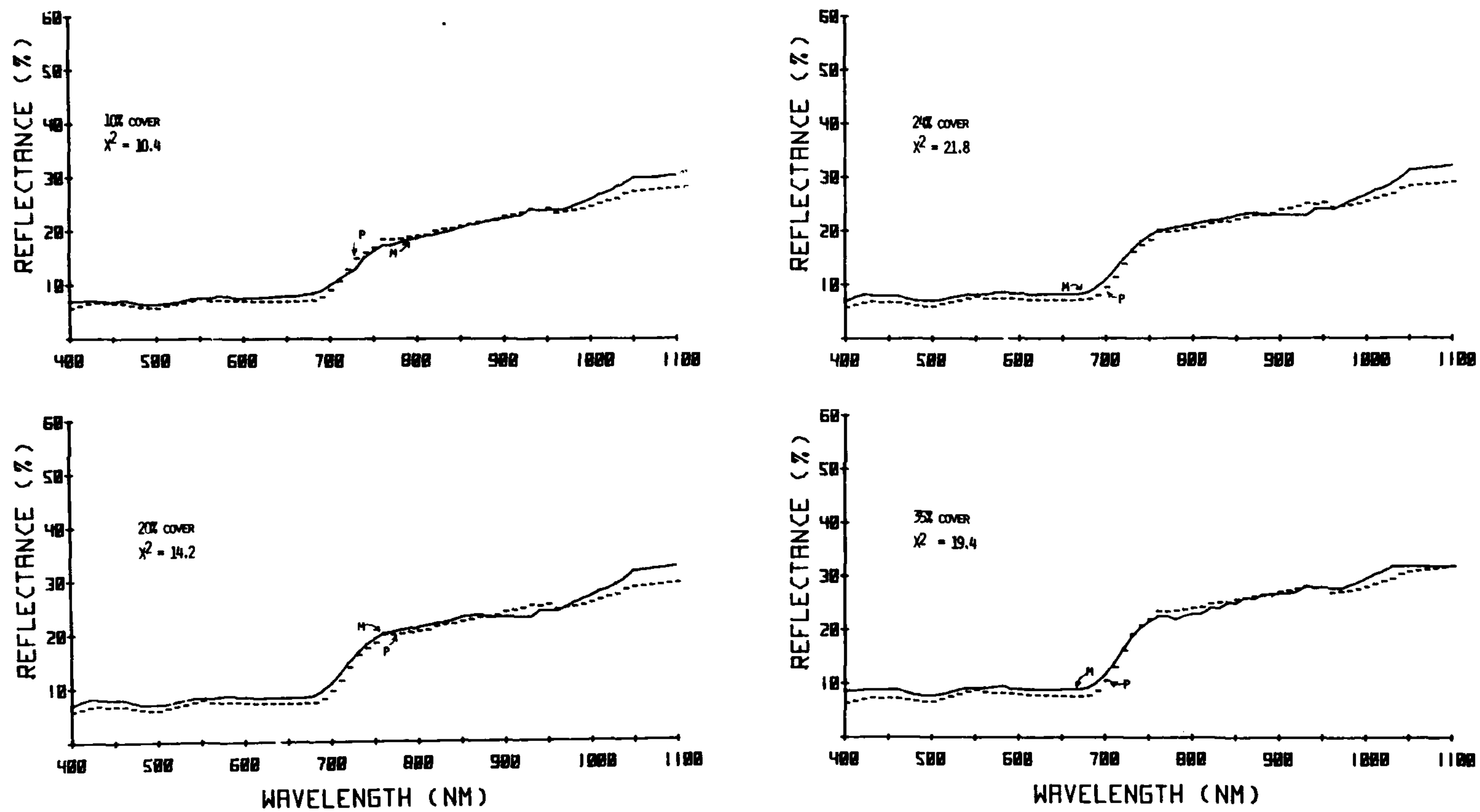


**FIGURE 19. Reflectance Curves of Organic Loam Soil-Dusty Miller Targets With Different Percent Covers.**

The calculated cover values for the marigold-sand soil targets were evaluated by comparing the Rm and Rp curve (figure 20). For those targets with intermediate covers – 18 to 50 percent – large differences were found in the 400 to 680 nm region but only small differences were found in 700 to 1100 nm region. Targets with percent cover outside the 18 to 50 percent range had Rp curves very similar to their respective Rm curves. The differences between the Rm and Rp curves in the visible region were probably caused by shadows cast on the bare soil, which reduced the amount of fully illuminated bare soil in the FOV. The random removal of potted plants from the FOV apparently distributed the voids in the plant canopy, thereby increasing the shadowed soil surface area. The data in figure 20 indicate a substantial shadow effect on the target's reflectance and show plant distribution-shadow relationships, particularly on highly reflective soil.

The covers for the predicted curves in figure 20 were calculated using equation (1). The infrared reflectance of the Rp curve was calculated, and the curve emperically fitted to the Rm curve in this region. The percent cover achieving this fit was used to calculate the 400 to 1100 nm Rp curve using equation (2),

$$Rp_n = (Rm_n^{100} \ X \ Pc) + (Rm_n^0 \ X \ (1 - Pc)) \tag{2}$$

where Pc is the predicted percent cover. The Pc values underestimated cover because of the inherent error associated with the Rm curves, which included a shadow component. Even so, comparing the visible portions of the measured and predicted curves shows that the measured curves were less than the predicted curves in the visible region for targets $>$ 18 percent and $<$ 75 percent. The close fit of the measured and predicted curves for targets with $<$ 18 percent and $>$ 75 percent cover (used in computing the various Rp curves) indicates that they were reasonable estimates of cover. The higher visible reflectance shown in the Rp curve compared to the Rm curve for targets with 18 to 75 percent cover shows the effect of shadow on target reflectance.

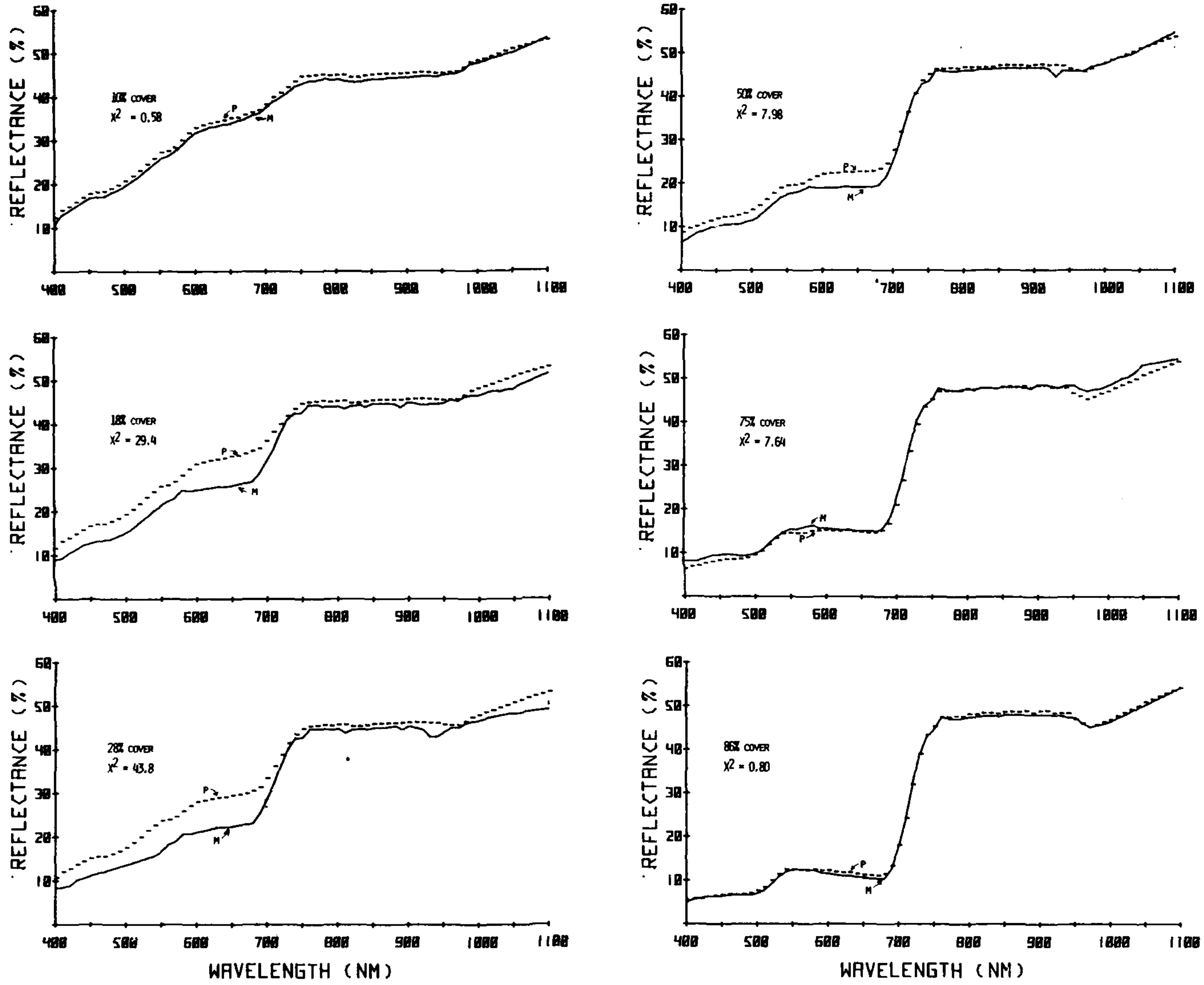


FIGURE 20. Reflectance Covers for Sand Soil-Marigold Targets With Different Percent Covers.

Interpretuation of the reduced reflectance in Rm curves for evaluating cover depends on the spectral region. A lower reflectance can indicate: (1) a greater vegetative cover because of the inverse relation of cover and reflectance in the visible region or (2) a smaller cover because of the direct relation of cover and reflectance in the infrared region. In the visible region, reflectance from shadowed areas would be scattered radiation that is reflected at an intensity much less than that reflected from a sunlit surface. Infrared radiation is not reflected from shadowed areas, which would decrease the reflectance and make the shadows "seen" by the monochromator indicative of soil, given the infrared reflectance-cover relationships for the marigold-sand targets. The two curves indicate a limitation in predicting intermediate vegetative cover using known soil and vegetative reflection curves without considering the shadow effects.

## DISCUSSION

The reflectance characteristics of the sand and organic loam soil were affected by adding any vegetation to the plots. Changes in reflectance were greatest in those spectral regions where large reflectance contrasts were found between the vegetation and the soil. For example, both the green colored marigold and the gray colored dusty miller readily altered the sand soil reflectance in the visible region as well as the organic soil's reflectance in the near IR region. When the vegetation and the soil had small reflectance contrasts, large changes in percent cover were needed to produce even slight changes in reflectance. This was apparent for the marigold on the organic soil in the 400 to 700 nm region, and for the dusty miller on the sand soil in the 700 to 1100 nm region.

The reflectance contrast between vegetation and soil is important for the monitoring of vegetative cover or evaluating crop vigor. Differentiation between crop and soil would be impossible, or at least severely limited, when there is low reflectance contrast. The low contrast between soil and vegetation could explain why some desert and semidesert plants are not readily detectable and other species are easily detected. The effects of the vegetation on target reflectance were not uniform throughout the 400 to 1100 nm spectrum.

In the 400 to 700 nm region, an inverse relationship was found between the percent reflectance from the sand-vegetation targets and the percent cover, either marigold or dusty miller. In this same spectral region, direct relationships were found between the reflectance from the organic loam soil-dusty miller targets, but not for the marigold-organic loam soil targets. In the IR region, the target reflectance was directly related to the percent marigold cover on both the sand and the organic loam soil. Reflectance from the sand-dusty miller targets was not related to the dusty miller cover because of the low reflectance contrast between the sand and dusty miller. These results were similar to those reported by Colwell and Holben for green vegetation on a light-toned soil.[10,11]

The results of this study can be used to interpret different types of aerial photography and LANDSAT imagery for evaluating vegetative cover. When using panchromatic photography, the association is often made that gray tone levels are directly proportional to the percent cover or soil conditions within the scene. The data presented here show that gray tone differences can be used for making reasonable approximation of cover on uniform, light-toned soils; however, for uniform, dark-toned soils, using photo tones would depend on the vegetation color, as both direct and inverse relationships can be made between photo tones and vegetative cover. On color infrared photography, direct or inverse photo tone/color-vegetative cover relationships are also possible, depending on the soil and vegetation reflectance characteristics in the green-IR spectrum. The intensity of the red on the IR photography could be related to the percent vegetative cover. However, vegetation types with reflectance similar to the soil's reflectance would make the differentiation of vegetation and soil difficult on the color IR imagery.

For the LANDSAT imagery, the image tone-cover relationships were also highly dependent on the reflectance characteristics of the soil. Regression analysis of the green vegetative cover on high and low reflective soils in the four LANDSAT bands showed the correlation between cover and reflectance were not the same for both soil types (figures 15 and 16).

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[10] J.E. Colwell, "Vegetation Canopy Reflectance." *Rem. Sens. Envir.* 3:175–183, 1974.

[11] B.N. Holben, C.J. Tucker, and Cheng-Jeng Fan. "Spectral Assessment of Soybean Leaf Areas and Leaf Biomass." *Photogram. Engin. and Rem. Sens.* 46(5):651–65, 1980.

Green vegetation on highly reflective soils varied inversely with reflectance in the (bands 4, 5 and 6) and varied directly with reflectance in the IR region, (band 7). For dark-toned soils, the reflectance was only slightly correlated with cover in the visible region (bands 4 and 5) and was highly and directly correlated with cover in the IR region (bands 6 and 7). Target reflectance in LANDSAT band 6, in which the transition from the visible to IR region occurs, could vary either directly or inversely with percent cover, depending on whether the soil had high or low reflectance. Because both soil conditions can occur in the same LANDSAT scene, the cover-reflectance relationships limit the use of band 6 for predicting cover or bare soil. In unknown areas without some ground truth of the area, it would be impossible to determine how the image tones were related to precent cover. The regression curves for LANDSAT bands 4, 5, and 7 can be used for monitoring cover, but only where there is sufficient reflectance contrast between vegetation and soil.

Although adding any vegetation to the soil changed the soil's reflectance characteristic, the cover needed to bring about this change was dependent on the reflectance contrast between soil and vegetation in the visible and IR regions. The percent cover needed for the changes varied with the reflectance contrast, which is illustrated by the marigold and dusty miller covers on the two soil types. These changes were caused by 35 percent marigold cover in the 400 to 1100 nm region, but 25 percent marigold cover and 30 percent dusty miller cover were needed in the 400 to 700 nm region.

These statistics are further supported by the slopes of the various regression curves calculated for selected wavelengths and the LANDSAT bands. These curves show that when high reflectance contrast exists between soil (0 percent cover) and vegetative cover (100 percent), smaller vegetative covers are needed to cause significant changes in the soil reflectance characteristics than when small reflectance contrasts exist between soil and vegetation. The regression analysis presented in this study describes the relationships between cover and reflectance and indicates that, within some limits, cover can be calculated from soil and vegetation reflectance measurements. These estimated values have limited use for highly reflective soils with incomplete plant canopies because the shadowed soil surface would have reduced reflectance in the visible region, which would cause an over estimation of plant cover.

The interaction of the soil and vegetation reflectance measured in this study shows the necessity for considering soil and vegetation reflectance characteristics and the reflectance contrast between different soils and vegetation types during any photographic or image analysis.

## CONCLUSIONS

1. Changes in vegetation cover on a soil surface altered the target's spectral reflectance in a predictable manner. The measured reflectance curve of each soil-vegetation target was intermediate and proportional to the reflectance curves of the soil (0 percent cover) and the vegetation (100 percent cover).

2. The reflectance and cover relationships were highly dependent on the reflectance contrast between the soil and vegetation. In the visible region, both marigold and dusty miller covers on the sand soil were inversely related with reflectance. In the infrared region, the soil-vegetation and reflectance was directly related to the marigold cover, but not to the dusty miller cover. In the visible region, the organic loam-vegetation targets show little correlation between reflectance and marigold cover, and a direct relation with the dusty miller cover. In the infrared region, reflectance was directly related to the percent marigold or the dusty miller cover on the organic loam soil.

3. The percent vegetative cover that significantly altered the reflectance curve of either the sand soil or organic loam soil was dependent on the spectral region and on the reflectance contrast between the soil and vegetation.

4. Spectral regions permitting the best differentiation between the soil and vegetation targets were different for each soil and vegetation type. For the sand soil targets, the visible region was better than the infrared region. In the infrared region, the marigold could be differentiated from sand soil, but the gray-colored dusty miller was not easily discriminated. For the organic loam soils, the infrared region permitted a better separation of soil and vegetation than the visible region.

5. Regression analysis showed that reflectance and cover varied in a predictable manner on the LANDSAT bands. The differentiation of vegetation and soil on each band requires sufficient reflectance contrast between the vegetation and soil components in order to facilitate their separation. The reflectance-cover relationships in LANDSAT band 6 varied inversely on dark-toned soil and directly on light-toned soils. These opposing relationships essentially curtail using image tone on band 6 imagery for assessing cover and bare soil conditions.

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