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AD A119714

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER ETL-R039	2. GOVT ACCESSION NO. AD-A119 714
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Effects of Ground Cover and Leaf Area on the Spectral Reflectance of Vegetation-Soil Target	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Melvin B. Satterwhite and Ponder Henley	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer Topographic Laboratories Ft. Belvoir, VA 22060	12. REPORT DATE 23 Sep 82
	13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

spectral reflectance
leaf area index
vegetation-soil
remote sensing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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For the vegetation-organic loam targets, the percent cover and LAI varied directly with the target reflectance in the green (520-600 nm) and the infrared

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Results show that the major change in reflectance of vegetation-soils was related more to the change in percent cover. For less than 100 percent cover, the LAI varied directly with percent ground cover. A change in LAI produced less change in target reflectance than did a change in percent cover. Once the canopy is closed, i.e., 100 percent cover, variation in LAI had little effect.

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EFFECTS OF GROUND COVER AND LEAF AREA ON THE SPECTRAL REFLECTANCE OF VEGETATION-SOIL TARGETS

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ABSTRACT

The relations between spectral reflectance, percent ground cover, and leaf area index (LAI) for vegetation-soil targets were evaluated for green vegetation against either a light-toned sand and a dark-toned organic loam soil. The percent ground cover and LAI were calculated for the ground area in the radiometer's field of view. The spectral reflectances of the different targets were measured in the 400 to 1100 nm region.

For the vegetation-organic loam targets, the percent cover and LAI varied directly with the target reflectance in the green (520-600 nm) and the infrared (700-1100 nm) regions, but varied inversely with reflectance in the red region (650-700 nm). For the vegetation-sand targets, the percent cover and LAI varied inversely with reflectance in the visible region and directly in the IR region.

Results show that the major change in reflectance of vegetation-soils was related more to the change in percent cover. For less than 100 percent cover, the LAI varied directly with percent ground cover. A change in LAI produced less change in target reflectance than did a change in percent cover. Once the canopy is closed, i.e., 100 percent cover, variation in LAI had little effect.

INTRODUCTION

Aerial photography and Landsat imagery taken over arid shrublands and grasslands often show little, if any, evidence of vegetation. The vegetation can be widely spaced and what is recorded is mostly the soil between the plants. When standing on the ground, even a sparse vegetation can be obvious. Because the vegetative cover is small compared to the vast expanse of bare soil and because arid soils are usually highly reflective, it can be difficult to detect the presence of vegetation using remote sensing techniques.

Vegetative cover and leaf area index are two parameters used in describing vegetation. Cover is the percentage of the ground surface covered by vegetation when viewed vertically and therefore cannot be greater than 100 percent. Leaf area index is the ratio of the total leaf surface area to the sample area. A plant having a total leaf area of 2.0 square meters in a sampling area of 1 square meter would have a LAI of 2.0. Other plant characteristics such as phyllotaxy, leaf angle, crown size, crown shape, and plant spacing can affect the leaf area index.

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These factors can create LAI values greater than 1.0 without achieving canopy closure. A vegetative target with an average of three leaf layers could have substantial bare soil exposed between plants or have holes in the canopy that are not present in canopies with four or more leaf layers. Plant reflectance in the visible and near IR has been related to LAI in laboratory studies (Meyer, 1966; Allen and Richards, 1968). Maximum reflectance was achieved in the visible region with two stacked leaves and in the near IR with six to eight stacked leaves. The reflectance in the red region varied inversely with the LAI, while IR reflectance varied directly, however, the soil background must be taken into consideration (Daughtery, 1980; Holben, 1980; Tucker, 1979).

Any amount of vegetative cover can affect the reflectance of a soil background, but the effects vary with the reflectance contrast between the soil and the vegetation. When the contrast is large a small amount of vegetation can significantly change the overall reflectance while a low contrast requires large amounts of vegetation cover to produce a noticeable change (Satterwhite, 1981, 1982).

Although cover and leaf area index are directly related, their respective effects on the the spectral reflectance of vegetation-soil targets can vary substantially, particularly when there is high reflection contrast between the soil and the vegetation.

OBJECTIVE

The purpose of this study was to evaluate the effects of vegetative cover and leaf area index on the reflectance characteristics of soil-vegetation targets.

METHODS AND MATERIALS

Two 1.9 x 1.9 meter plots, one of which was filled with dark-toned organic loam soil and the other with a light-toned clean gravelly medium sand, were used as the target backgrounds. Geranium (Geranium sp.) was used for the vegetative cover. The plants were cultured in 16.5 cm diameter plastic pots until they had achieved the desired crown diameter and height. All flower buds were pruned from the plants during the study.

An EG&G spectroradiometer system, model 550/555, with a 15° field of view, was used for measuring the target radiance in the 400 to 1100 nm region in 10 nm increments. The monochromator was mounted vertically and centered over each test plot. A 15 cm square magnesium carbonate block was used as the standard reference target. Measurements were made on clear days between 1030 and 1430 local standard time.

Excised geranium leaves were placed in a layered arrangement on either a sand or organic loam soil. The leaves were large enough that each filled the field of view (FOV). The first leaf layer placed on the soil background created a target with 100 percent cover and LAI = 1.0.

Additional leaves placed in the FOV varied the LAI from 1.0 to 4.0, while the percent cover remained constant. After each leaf was placed in the FOV, the target's spectral reflectance was measured. The percent vegetative cover and leaf area were also varied by placing a single plant in the FOV and selectively clipping leaves from the plant canopy. After each leaf clipping, the spectral radiance of the resultant vegetation-soil target was measured and the percent reflectance in each 10 nm bandpass was calculated. The percent cover in each target was determined from measurement of the plant canopy area on a photo taken at nadir. The canopy area was scaled as a percentage of the FOV. The leaf area was determined using a LICOR, model 3100, area meter. The leaf area index (LAI) of each target was determined using the radiometer's FOV as the basis for computing the ground sample area. Attempts were made to reduce the leaf area in the plant canopy while maintaining a constant canopy size. The cover-LAI relations were evaluated using polynomial regression analysis.

RESULTS

The leaf area and the cover area in the targets varied directly with each other. Increased leaf area produced greater vegetative cover and a larger number of leaf layers in the canopy (Figure 1). The increase in leaf area produced a greater leaf area within the plant canopy and small increases in the canopy size. The leaf area to cover area ratio increased from 1.5 at a cover of 200 cm^2 to 2.4 at a cover of 700 cm^2. The spectral reflectance curves for the target in which excised geranium leaves were placed in a layered arrangement in the FOV are shown in Figure 2. These curves show that the layering of up to four leaves had no or little effect on the visible reflectance of either soil condition. In the infrared region, reflectance varied with the number of leaf layers up to the fourth layer. Additional leaf layers did not substantially increase the target's reflectance. Reflectance of the sand soil targets was greater than that of the organic loam soil with the same number of leaf layers. This difference ranged from 10 to 20 percent.

Spectral reflectance data, 400 nm to 1100 nm, were recorded for vegetation soil targets in which the vegetative cover and leaf area were varied. The spectral reflectance curves for the geranium-sand soil targets are shown in Figure 3 and the geranium-organic loam soil targets in Figure 4. The spectral reflectance contrast between the sand soil and the geranium was largest in the visible region. The reflectance varied inversely with the percent cover in the visible region. In the IR region, the target's reflectance varied directly with the percent cover. The IR reflectance contrast between the geranium and soil was less than was observed in the visible region. The spectral curves of the geranium and the bare organic loam soil show less than 10 percent difference in the visible region with the vegetation being slightly more reflective. In the 650-700 nm region, the vegetation was less reflective than the organic soil because of chlorophyll absorption. In the infrared region, reflectance contrast between geranium and organic soil was quite large, ranging from 30 percent to 40 percent. Varying the vegetative cover on the organic soil substantially changed the target's spectral reflectance characteristics, particularly in the near IR region. A direct relation was found between the percent cover and target reflectance.

The spectral curves for the geranium-soil targets show that the introduction of green vegetation to either the sand or organic loam soil will create a new target with its unique spectral reflectance characteristics. The percent cover bringing about a significant change in the soil spectral signature was dependent, in part, on the reflectance contrast between the vegetation and the soil, and the spectral region under consideration. In those spectral regions with large reflectance contrasts between vegetation and the soil, less cover was required to cause a significant change in soil spectral reflectance than where the reflectance contrast was small. The minimum cover of geranium significantly affecting the spectral reflectance of either soil type is summarized in Table 1.

TABLE 1
PERCENT VEGETATIVE COVER
SIGNIFICANTLY CHANGING A SOIL'S SPECTRAL REFLECTANCE*

SOIL TYPE	SPECTRAL REGION (nm)		
	450-700	800-1000	450-1100
	COVER (%)		
Sand Soil	17	98	20
Organic Loam Soil	NA	22	22

*Values significant at the 95% level of confidence

The leaf area effects on the spectral reflectance of geranium-soil target are shown by the reflectance curves in Figures 2, 3, and 4. The separation of the cover and LAI effects on the target's reflectance were not entirely successful because of the direct nonlinear relation between cover and leaf area. The changes in the target reflectance that could be associated with LAI were found in the visible region where the leaf area index and spectral reflectance varied inversely. The IR reflectance constrast between the vegetation and sand soil was often too small to be of much use in evaluating the LAI-reflectance relations. Some reflectance differences were associated with the LAI values of targets with LAI more than 2.0.

Reflectance curves for the geranium-organic loam soil targets show that the reflectance contrast was large enough in the green region to separate some targets, while other visible regions did not permit target separation. The

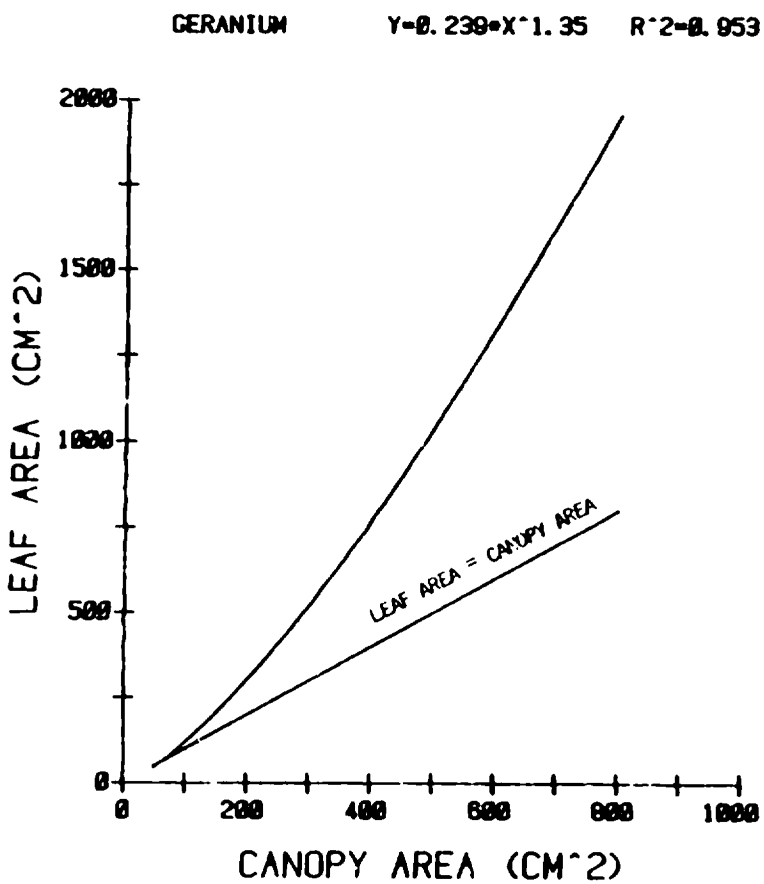

FIGURE 1. LEAF AREA AND COVER AREA RELATIONS FOR GERANIUM PLANTS.

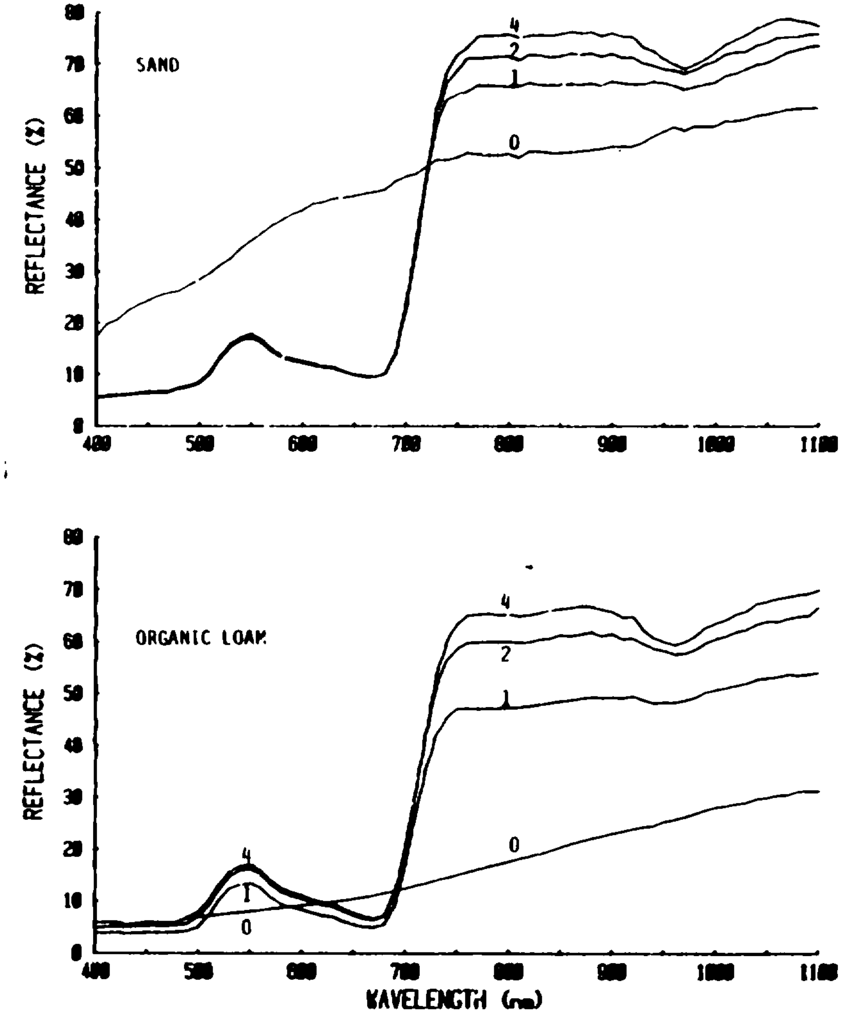

FIGURE 2. SPECTRAL REFLECTANCE CURVES FOR LAYERED GERANIUM LEAVES ON TWO SOIL CONDITIONS.

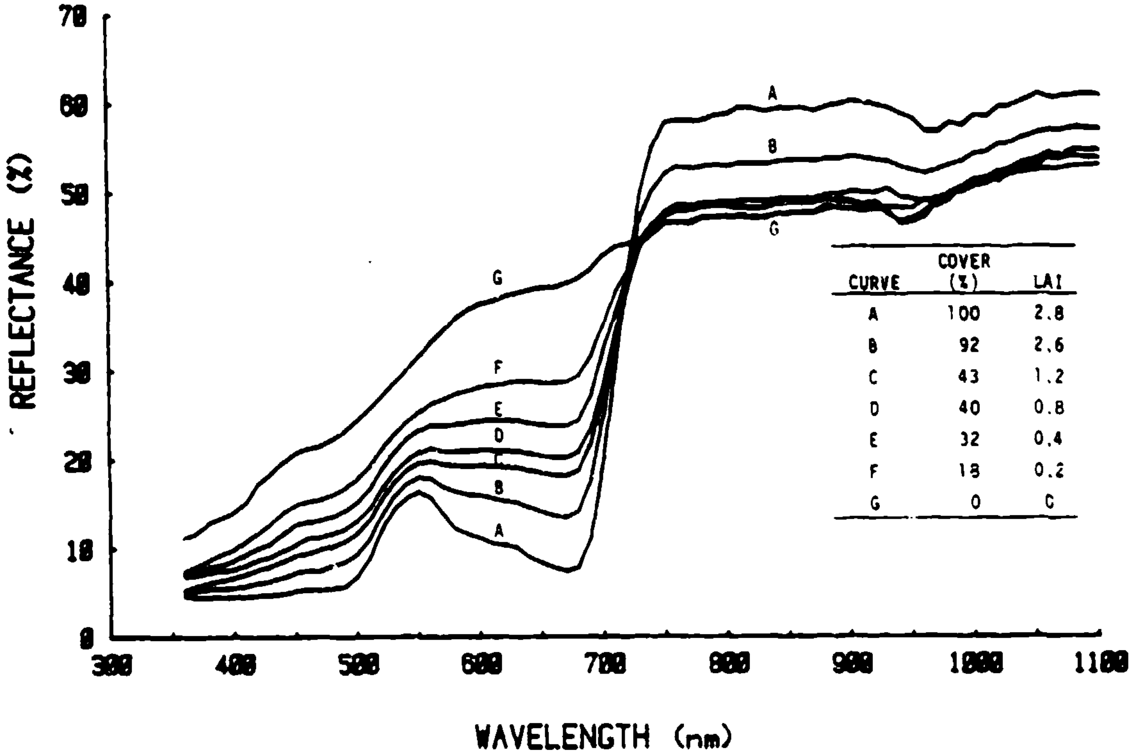

FIGURE 3. SPECTRAL REFLECTANCE CURVES FOR GERANIUM-SAND SOIL TARGETS WITH DIFFERENT PERCENT COVER AND LEAF AREA INDICES. EACH CURVE IS THE AVERAGE OF TWO SPECTRAL CURVES.

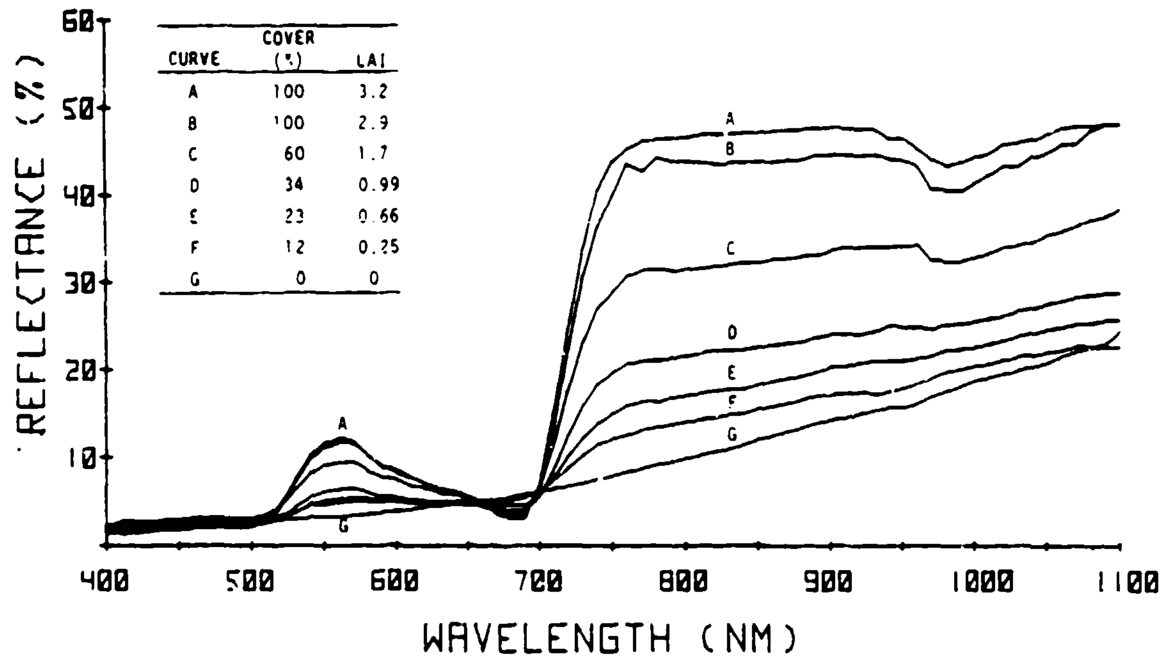

FIGURE 4. SPECTRAL REFLECTANCE CURVES FOR GERANIUM-ORGANIC LOAM SOIL TARGETS WITH DIFFERENT COVERS AND LEAF AREA INDICES.

large reflectance constrast in the near IR region permitted the differentiation of all targets (Figure 4). These curves show the major reflectance difference between targets was associated with cover differences, while LAI differences had less of an effect on reflectance. Two geranium-organic loam targets with LAI of 2.9 and 3.2 and 100 percent cover had similar IR reflectances, 43 percent and 45 percent, respectively.

A constant plant canopy area was maintained while varying the leaf area by clipping leaves from the canopies of for five geranium-organic loam soil targets. The percent cover in these five targets ranged from 57 to 60 percent, while the LAI ranged from 0.93 to 1.73 (Table 2). The difference in infrared reflectance varied was about ± 1 percent of the mean for the 800, 850, and 900 nm bandpasses, although the leaf area index had varied 85 percent. The canopy cover, leaf area, index and IR reflectance for these five targets indicate the small effect of the in-canopy multiple layered leaves on the infrared reflectance. This effect is also shown by the reflectance differences between curves A and B in Figure 4. The spectral curves of the five targets were similar in the IR region, therefore, only curve C has been presented in Figure 4.

DISCUSSION

Target reflectance is related to percent vegetative cover and leaf area index. These relations form a basis for using spectral reflectance measurements for monitoring these vegetative parameters. The manner in which the vegetation and background surfaces affect the spectral reflectance measured by the sensor is crucial for their use. The reflectance contrast between vegetation and soil is important for the monitoring of vegetative cover or evaluating crop vigor. Differentiation between vegetation and soil could be 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.

Leaf growth that increases the number of leaf layers in the plant canopy and the canopy size increased the in-canopy leaf area faster than the canopy area. The ratio of leaf area to canopy area was not constant but increased directly with canopy size, ranging from 1.5 to 2.4.

The effects of the vegetation on target reflectance were not uniform throughout the 400-1100 nm spectrum. In the visible region, an inverse relation was found between the percent reflectance from the vegetation-sand targets and the percent cover. In the IR region, the target reflectance was directly related to the percent cover on the sand and the organic loam soil. These results were similar to those reported by Holben (1980) and Satterwhite (1981) for green vegetation on a light-toned soil.

Separation of the cover and LAI effects in these spectral regions was not always possible because of their direct relation. The reflectance curves for vegetation-soil targets show no difference in the visible reflectance for the targets with one to four leaf layers and 100 percent cover (Figure 2). This is similar to the results reported by Meyers, et al (1968). The differences in visible spectral reflectance between the geranium-soil targets must have resulted from cover differences (Figures 3 and 4). The slope and shape of these reflectance curves show that they are proportional to the percentages of soil and vegetation comprising the target.

In the infrared region, the reflectance contrasts between the vegetation and soil were large enough to discriminate reflectance gradients with cover or LAI. The plant growth pattern complicated the separation of the cover and LAI effects on the target's IR reflectance, in that a portion of the infrared reflectance is associated with reducing the bare soil component while other portions are related to the plant canopy segments with multiple leaf layers. An apportionment of the reflectance difference between cover and LAI may not be possible but an estimate can be made using the reflectance curves for the bare soil and that for a single leaf layer. This could set the infrared reflectance for a hypothetical canopy with uniformly distributed leaves, LAI of 1.0 and cover of 100 percent. A target with infrared reflectance greater than the threshold curve could indicate a closed canopy with multiple leaf layers. It could also indicate an incomplete canopy with less than 100 percent cover. The lower IR reflectance from the soil would be compensated by the infrared reflectance from those canopy segments which have more than one leaf layer, e.g., Curve B in Figures 3 and 4. As the percentage of soil in the FOV decreases and the LAI becomes larger, the percentage of the target's infrared reflectance originating from the canopy segments with more than one leaf layer would also increase.

The data presented in Table 2 show that a substantial LAI change did not change the infrared reflectance. The target's IR reflectance was apparently determined by the reflectance contrast between the canopy and the soil, and the percentage of each in the FOV. The greater IR reflectance from the multiple leaf layer segment was apparently not a substantial component in comparison to the reflectance contrast between soil and vegetation. This is shown by the contrast between the spectral curves for the one and two leaf layer targets (Figure 2). Thus, increase reflectance could result from multiple leaf layers, but the magnitude of this compliment was not measurable for these targets.

TABLE 2
INFRARED REFLECTANCE FOR GERANIUM-ORGANIC LOAM TARGETS WITH VARYING PERCENT COVER AND LAI

Target Number	Leaf Area Index	Cover (%)	Wavelength (nm) 800	850	900
			Reflectance (%)		
14	1.73	60	31.6	32.5	33.8
23	1.47	59	33.3	34.2	35.1
24	1.28	58	32.7	33.7	35.0
25	1.12	58	32.4	33.2	34.7
26	0.93	57	31.0	32.1	33.3
Mean	1.31	58	32.2	33.1	34.4

Because of canopy geometry and phyllotaxy, the leaf area usually increased faster than the canopy area for the species used in this study. The leaf area/canopy area relation can be greater than one, but averaging the leaf area over a sensor's FOV or the sample area can substantially reduce these values, particularly when the individual canopies have not coalesced. Multiple leaf layers within the canopy would be averaged over the sensor's FOV thereby reducing the LAI ratio with IR reflectance for targets with less than 100 percent cover. The portion of the leaf area effect having the largest effect on the target would be that associated with crown enlargement or increased cover. The leaf area increase associated with multiple leaf layers could produce significant change in the target IR reflectance once the critical threshold IP reflectance coincident with the 100 percent cover was attained. Targets with 100 percent cover could have larger IR reflectance associated with multiple leaf layers.

Plant growth can be monitored using various spectral regions, particularly the near infrared spectra, but unless substantial cover differences are coincident with plant growth, the reflectances may differ only slightly. The reflectance of coalescing plant canopies can be an apportioned ratio of the reflectance of the plant canopy, the soil and the background materials. During those growth periods when the canopy LAI is less than 1.0, little measurable difference may be found between the spectral signatures of the vegetation-soil targets, unless the amount of exposed soil in the target has been substantially changed by increased vegetative cover.

CONCLUSIONS

1. Changes in cover on a soil surface altered the target's spectral reflectance in a predictable manner.

2. A direct relation between cover and leaf area was described for geranium. The total leaf area within the plant canopy increased faster than the cover area.

3. In the visible region, vegetative cover was the primary factor effecting the reflectance of vegetation-soil targets, while leaf area index had little or no effect. Multiple layers of leaves produced little or no increased visible reflectance beyond that achieved by a single leaf layer.

4. The percent cover significantly altering the soil's reflectance curve depended on the spectral region and the reflectance contrast between the soil and vegetation.

5. Vegetative cover and multiple leaf layers affected the infrared reflectance of geranium-sand and geranium-organic loam soil targets.

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