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A Soil-Adjusted Vegetation Index (SAVI)

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A transformation technique is presented to minimize soil brightness influences from spectral vegetation indices involving red and near-infrared (NIR) wavelengths. Graphically, the transformation involves a shifting of the origin of reflectance spectra plotted in NIR-red wavelength space to account for first-order soil–vegetation interactions and differential red and NIR flux extinction through vegetated canopies. For cotton (*Gossypium hirsutum* L. var DPL-70) and range grass (*Eragrostis lehmanniana* Nees) canopies, underlain with different soil backgrounds, the transformation nearly eliminated soil-induced variations in vegetation indices. A physical basis for the soil-adjusted vegetation index (SAVI) is subsequently presented. The SAVI was found to be an important step toward the establishment of simple "global" models that can describe dynamic soil–vegetation systems from remotely sensed data.

Introduction

Numerous spectral vegetation indices have been developed to characterize vegetation canopies. The most common of these indices utilize red and near-infrared canopy reflectances or radiances in the form of ratios (normalized difference and ratio vegetation indices: see Tucker, 1979) or in linear combination (perpendicular vegetation index; Richardson and Wiegand, 1977). These indices have been found to be well correlated with various vegetation parameters including green leaf area, biomass, percent green cover, productivity, and photosynthetic activity (Colwell, 1974; Hatfield et al., 1984; Asrar et al., 1984; Sellers, 1985). Limitations, however, exist as a result of atmospheric influences and soil substrate differences. Atmospheric turbidity generally inhibits reliable measures of vegetation and may delay the detection of an onset of stress in canopies (Slater and Jackson, 1982; Jackson et al., 1983). Uncorrected atmospheric effects are also a problem in multitemporal studies where atmosphere-induced variations on canopy spectra exceed those due to vegetation development.

Soil background conditions exert considerable influence on partial canopy spectra and the calculated vegetation indices. Soil brightness influences have been noted in numerous studies where, for a given amount of vegetation, darker soil substrates resulted in higher vegetation index values when the ratio vegetation index (RVI = NIR/red) or the normalized difference vegetation index [NDVI =(NIR − red)/(NIR + red) = (RVI − 1)/(RVI + 1)] were used as vegetation measures (Colwell, 1974; Elvidge and Lyon, 1985; Huete et al., 1985). Huete et al. (1985) also found an opposite soil brightness influence on the perpendicular vegetation index (PVI) such that brighter soils resulted in higher index values for a given quantity of incomplete vegetation cover. Thus, in areas where there are considerable soil brightness variations resulting from moisture differences, rough-

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ness variations, shadow, or organic matter differences, there are soil-induced influences on the vegetation index values.

Soil influences on incomplete canopy spectra are partly due to a dependency of the soil background signal on the optical properties of the overlying canopy (Jackson et al., 1980; Lillesaeter, 1982; Heilman and Kress, 1987; Huete, 1987). Differences in red and NIR flux transfers (Kimes et al., 1985; Sellers, 1985; Choudhury, 1987) through a canopy result in a complex soil–vegetation interaction, which makes it difficult to subtract or correct for soil background influences. A vegetated canopy will scatter and transmit a significant amount of NIR flux towards the soil surface, irradiating the soil underneath as well as in between individual plants. The soil subsequently reflects part of this scattered and transmitted flux back toward the sensor in a manner dependent upon the optical properties of the soil surface. By contrast, red light is strongly absorbed by the uppermost leaf layers of the canopy, and irradiance at the soil surface is limited to that received directly from the sun and sky through canopy gaps.

Heilman and Kress (1987) and Huete (1987) investigated the differential rates of radiant flux penetration in incomplete cotton canopies and found the spectral response reflected from the soil surface to mimic that of green vegetation. Thus, regardless of the vegetation index tested, the soil-reflected signal was indistinguishable from that of the vegetation. The soil component rendered vegetation indices "soil-dependent" because its magnitude varied with the reflectance properties of the underlying soil.

Huete et al. (1985) found that the sensitivity of vegetation indices to soil background was greatest in canopies with intermediate levels of vegetation cover (50% green cover). With low vegetation amounts, there isn't enough vegetation to impart a canopy-scattered, soil-reflected signal while, at very high vegetation densities, there isn't enough soil signal emerging from the canopy to be of significance. At intermediate levels of vegetation, however, significant scattering and transmission of NIR flux through the canopy produces a soil-reflected spectral signal that strongly resembles vegetation spectral signatures. The purpose of this study was to model the soil brightness dependency of partially vegetated canopy spectra in order to develop a simple "global" vegetation index that could account for dynamic soil–vegetation spectral behavior and which could be related to significant biophysical plant parameters.

Approach

In general, most vegetation indices rely on the existence of a "soil line" in red and NIR wavelength space, i.e., there is a principal axis of soil spectral variation extending outward from the origin with increasing brightness. Since most soil spectra fall on or close to the soil line, and since the intercept of such a line is close to the origin, RVI and NDVI values of bare soils (ratios) will be nearly identical for a wide range in soil conditions. Similarly, since the PVI utilizes this line of soils as a baseline, bare soil PVI values will also be nearly identical for most soil conditions. A secondary axis of soil variation (the width of a "global" soil line) may be significant in certain cases and may hinder the detection of low amounts of vegetation (Huete et al., 1984). Such secondary soil influences are most noticeable with red and yellow colored soils (Kauth and Thomas, 1976).

Figure 1 depicts lines of constant vegetation amounts (isolines) as predicted by the ratio and orthogonal indices. The ratio indices are graphically displayed by vegetation isolines of increasing slopes diverging out from the origin while orthogonal-index isolines remain parallel to the soil line. The explanation offered by the two types of indices are contradictory with each other in describing soil–vegetation spectral behavior. As an example, a partial canopy over a dry soil background (A) is shown in Fig. 1. If the soil background were to become wet, a vegetation isoline bounded by dry and wet soil conditions would be formed. In order for the RVI and NDVI to effectively normalize such a background change, the vegetated pixel would have to shift directly toward the origin (B), following an isoline of constant RVI and NDVI values. The PVI, however, would require the pixel to shift along an isoline parallel to the soil line (C) so that both the wet- and dry-soil vegetated pixels maintain a constant PVI value (equidistant to the soil line).

Huete et al. (1985) and Huete and Jackson (1987) utilized ground-measured spectra collected over a series of cotton (*Gossypium hirsutum* L. var DPL-70) and range grass (*Eragrostis lehmanniana* Nees) canopies to study vegetation isolines in NIR–red wavelength space. The isolines were obtained by alternately inserting soil trays of different soil types

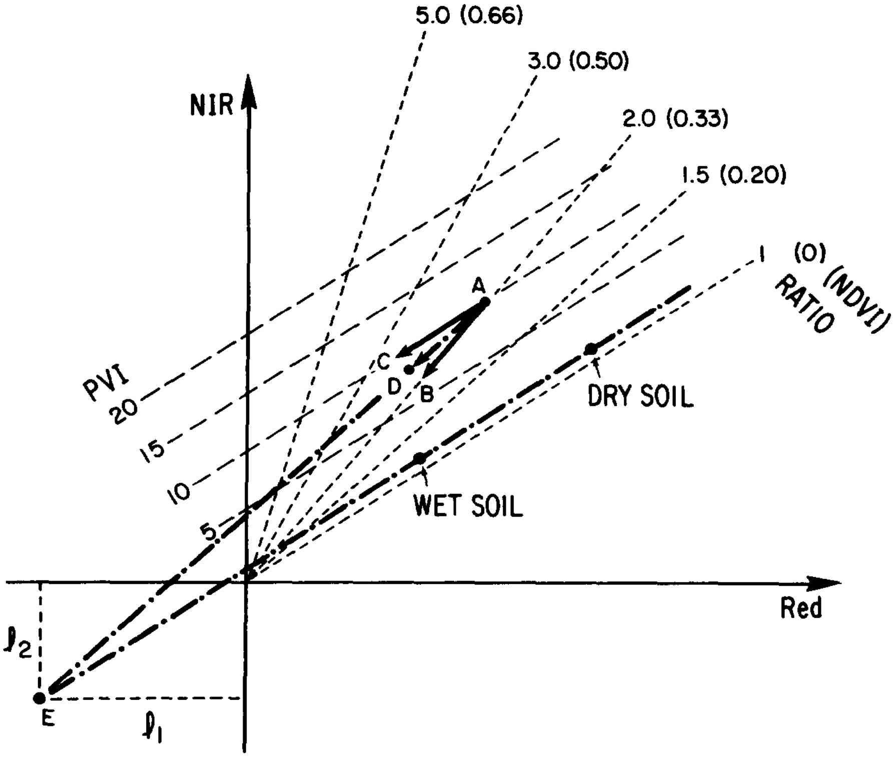

FIGURE 1. Vegetation spectra isolines in NIR–red wavelength space as predicted by the ratio-, normalized difference-, and perpendicular-vegetation indices.

and moisture condition underneath the vegetated canopies. The soils included a i) bright, yellowish-brown Superstition sand (sandy, mixed, hyperthermic Calciorthid), ii) a high-iron, red Whitehouse sandy clay loam (fine, mixed, thermic Ustollic Haplargid), iii) a brown Avondale loam (fine-loamy, mixed, hyperthermic Typic Torrifluvent), and iv) a dark, organic-rich Cloversprings loam (fine-silty, mixed Cumulic Cryoboroll). Converting to reflectance factors (referenced to a $BaSO_4$ panel), they found vegetation isolines to possess NIR–red wavelength slopes in between those of the ratio- and orthogonal-based isolines (Fig. 2; point D in Fig. 1). The individual cotton and grass spectral isolines followed a pattern of increasing slopes and NIR intercepts with higher vegetation densities. The isolines neither converged at the origin (as required by the RVI and NDVI) nor maintained slopes identical with the soil line (a PVI requirement). This same soil–vegetation spectral behavior has been verified with various canopy radiant transfer models including the SAIL model (S. Goward, personal communication), the two-stream hemispherical model of Seller's (1985) and the directional radiative transfer model utilized by Choudhury (1987).

Soil brightness influences are prevalent in partially vegetated canopies because the ratio-based and orthogonal-based vegetation indices fail to predict the behavior of vegetated pixels as they migrate away from the soil line. If vegetation isoline behavior does not agree with that predicted by spectral vegetation indices,

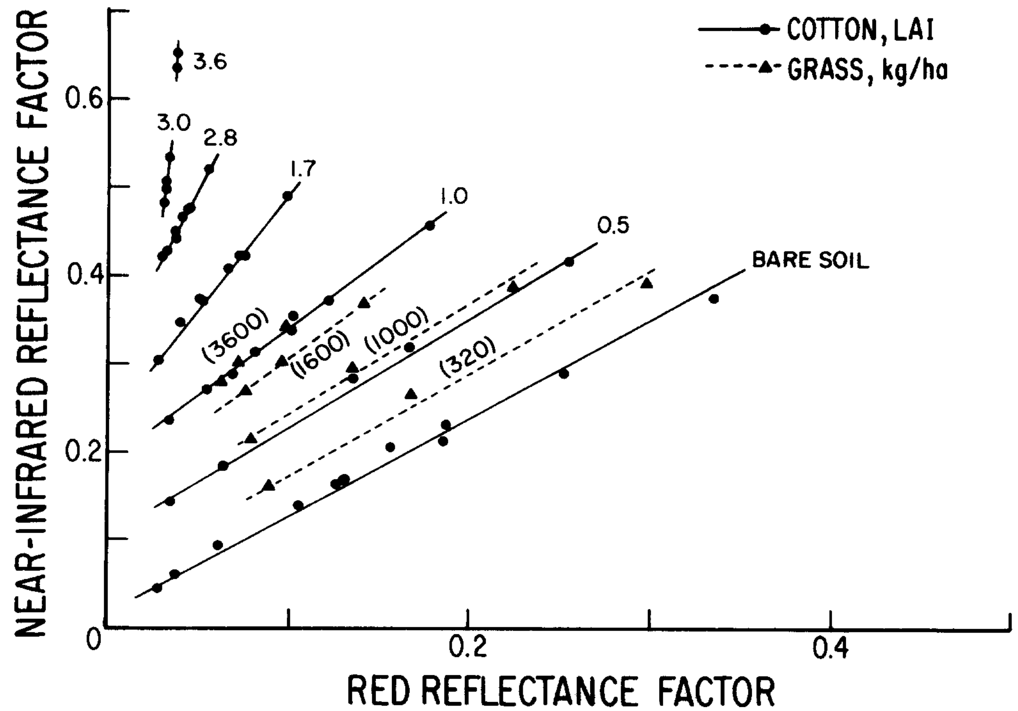

FIGURE 2. Observed vegetation isolines for various canopy densities of cotton and grass with differing soil background conditions. Numbers in parenthesis represent grass phytomass.

then different soil backgrounds under constant vegetation amounts will produce different spectral index values. Thus, in Fig. 1, as the soil darkens upon wetting, the PVI value of the wet soil-vegetated pixel (D) is lower than that of the dry soil (A) while the wet pixel RVI and NDVI values exceed those of the dry soil. This agrees with the soil brightness influences encountered in other experimental studies (Colwell, 1974; Elvidge and Lyon, 1985).

Vegetation isoline behavior may be graphically modeled by shifting the NIR–red space origin toward an approximate isoline convergence point (E in Fig. 1). This would describe a situation whereby the isolines increase in slope and intercept with increasing vegetation development (Figs. 1 and 2). Vegetation isolines do not actually converge to one common point as convergence is partly a function of vegetation density (LAI). However, a first-order approximation may be obtained by shifting the origin to a point where intermediate densities of vegetation converge with the soil line.

In this study, soil–vegetation spectral behavior is first modeled graphically through adjustment of the NIR–red wavelength space origin to various isoline convergence points. Shifting the origin toward negative values is equivalent to adding a constant, l, to the red and NIR reflectance data such that the adjusted RVI and NDVI become

$$(\mathrm{NIR}+l_2)/(\mathrm{red}+l_1) \qquad (1)$$

and

$$[(\mathrm{NIR}+l_2)-(\mathrm{red}+l_1)]/[(\mathrm{NIR}+l_2)+(\mathrm{red}+l_1)], \qquad (2)$$

respectively. Since the soil line has a slope close to 1, the adjustment factors, l_1 and l_2, would be nearly equivalent. Shifting the red and NIR data equally ($l_1 = l_2$) and utilizing the NDVI format, Eq. (2) reduces to

$$[(\mathrm{NIR}-\mathrm{red})/(\mathrm{NIR}+\mathrm{red}+L)], \qquad (3)$$

where $L = l_1 + l_2 = 2l$. Thus, a soil adjusted vegetation index (SAVI) would only involve an addition of a constant, L, to the denominator of the NDVI equation. However, in order to maintain the bounded conditions of the NDVI equation (NDVI can vary from -1 to $+1$), a multiplication factor $(1+L)$ is needed in Eq. (3) such that

$$\mathrm{SAVI} = [(\mathrm{NIR}-\mathrm{red})/(\mathrm{NIR}+\mathrm{red}+L)] \times (1+L). \qquad (4)$$

Results

Utilizing a light-colored (Superstition sand) and a dark-colored (Cloversprings loam) soil, the soil-induced range in spectral index values were assessed for various L values (Fig. 3). L was varied from 0 to 1, and from 1 to 100 in order to analyze the effect and sensitivity of NIR–red data space translation on vegetation index improvement and to determine whether a single optimal L value may be applied to a wide range in vegetation densities. Each shaded area in Fig. 3 depicts vegetation index variations from a constant amount of vegetation over the two soil backgrounds. At $L = 0$, the behavior of the NDVI is shown with the width of the shaded area representing light to dark soil variations. As the adjustment factor (or shift in origin) is increased, a continual decrease in soil-induced variations occurred for low vegetation amounts (LAI = 0–0.5), and, at $L = 1$, soil influences nearly disappeared in these canopies. With a higher vegetation density (LAI = 1), the optimal adjustment was found at $L = 0.75$ as soil influences reappeared at higher "L" values. With even higher vegetation densities optimal "L" values decreased to smaller values. The optimal adjustment factor was found to be linearly correlated with LAI ($r = -0.990$).

The adjustment factors from 1 to 100 are presented to approximate the PVI concept, i.e., L goes to infinity (no convergence of isolines). As seen in Fig. 3, higher "L" values caused the soil noise problem to reappear and gradually increase, producing a soil brightness problem opposite that of the ratio indices; i.e., before the optimal "L" was reached, the darker soil caused the top boundary of the shaded curve, while beyond the optimal "L," the light-colored soil background defined the upper portion of the shaded areas. At the optimal "L," light and dark soil substrates produced the same index value. This explains why the ratio indices, which have an adjustment factor ($L = 0$) that is less than the optimal, result in soil brightness influences opposite those of the PVI, which has an adjusted origin much greater than the optimal.

The optimal "L" values differed with vegetation density as a result of the nonuniform convergence of isolines in NIR–red wavelength space (Fig. 2). It

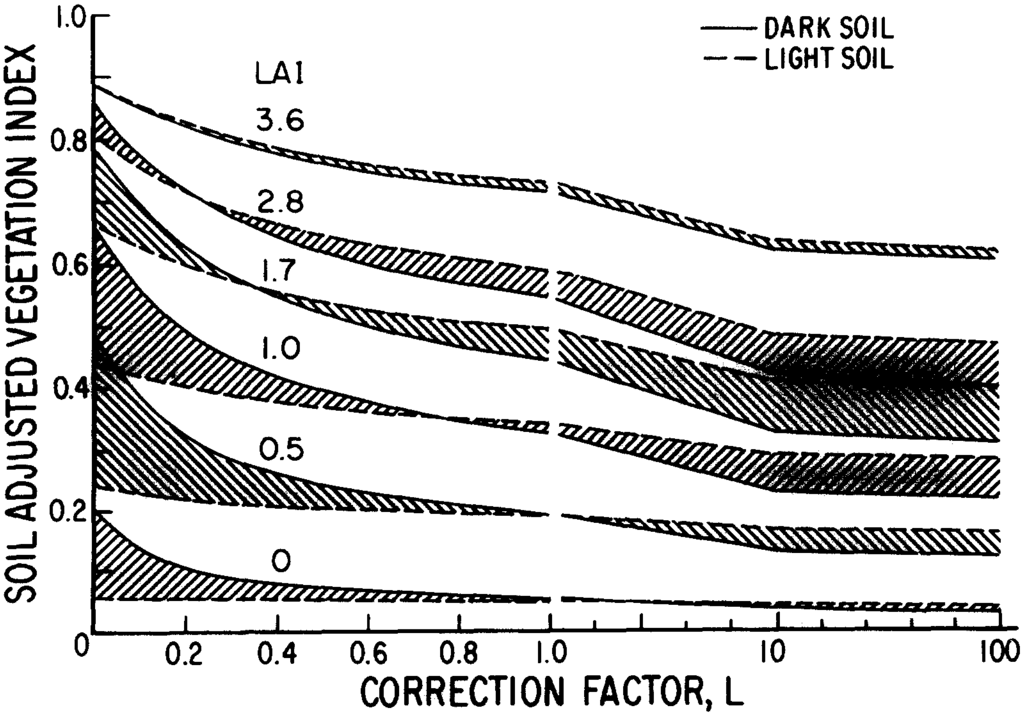

FIGURE 3. Light and dark soil influences on the SAVI values of cotton as a function of the shifted origin correction factor.

seems apparent from Fig. 3 that there may actually be two or three optimal adjustment factors depending on whether one wishes to analyze very low vegetation densities ($L = 1$), intermediate vegetation densities ($L = 0.5$), or higher densities ($L = 0.25$). However, for any adjustment factor from 0.25 to 1, soil influences were considerably reduced in comparison to the NDVI and PVI, which demonstrated the greatest soil problems. An adjustment factor for intermediate vegetation amounts ($L = 0.5$) should offer a spectral index superior to the NDVI and PVI for the entire range of vegetation conditions studied here. A comparison of the SAVI ($L = 0.5$) with the NDVI and PVI is shown with a plot of respective vegetation index values vs. LAI (Fig. 4). In this plot, eight soil conditions (four soil types in wet and dry condition) were used to vary the soil background. The SAVI substantially reduced soil-induced variations and improved the linearity between index and LAI in comparison to the NDVI and PVI. Although there was a loss in the amplitude of the vegetation index signal between the NDVI and the SAVI, vegetation discrimination and soil noise levels were considerably improved.

The apparent loss in vegetation index response is worth noting because the use of the SAVI, instead of the NDVI, may result in a lowered vegetation index signal, particularly in studies involving a single soil type. As can be seen in Fig. 4, a good, although curvilinear, relationship exists between the NDVI and LAI for any specific soil background. It is only in global data sets and when data are com-

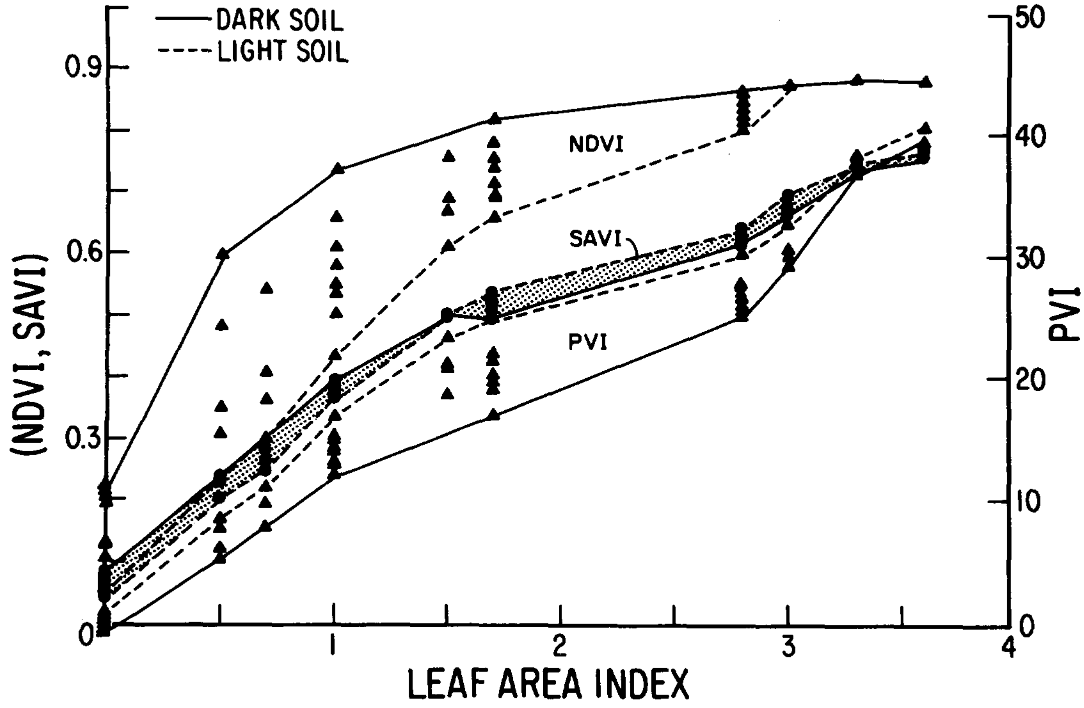

FIGURE 4. Vegetation index response and soil variations of the NDVI, SAVI ($L = 0.5$), and PVI as a function of cotton leaf area index.

pared across different soil types that the NDVI suffers from soil problems which the SAVI is capable of minimizing. The relationship between NDVI and LAI is very soil-dependent, as seen by the considerable range in NDVI values for a constant vegetation density (NDVI varied from 0.24 to 0.60 for LAI = 0.5 and from 0.44 to 0.74 for LAI = 1). The equivalent variations with the SAVI were 0.21–0.24 (LAI = 0.5) and 0.38–0.40 (LAI = 1). Consequently, it appears that a single L value may be all that is needed to model soil–vegetation spectral behavior from sparse to dense canopies. Furthermore, the exact location of the shifted origin does not appear to be crucial (Fig. 3).

Figure 5 is another way of expressing what a translated origin does to the soil–vegetation reflectance data set. The SAVI has produced vegetation isolines more nearly independent of the soil-induced variations as measured, in this case by the red reflectance of the composite, canopy signal. Note that a decrease in red composite spectra, due to darker soils, caused a significant increase in the NDVI. The NDVI appeared to be as sensitive to soil darkening as to vegetation development. The SAVI ($L = 0.5$) also successfully minimized soil variations in both the grass (erectophile) and the cotton (planophile) canopies.

Theoretical Basis

The slope and intercept of vegetation isolines in NIR–red wavelength space may be related to the optical properties of the canopy medium. Several studies have dealt with radiant flux dynamics in partially vegetated canopies (Jackson et al., 1979; Norman and Welles, 1983; Verhoef, 1984; Kimes et al., 1985). These models are oriented toward predicting canopy-reflected radiances by characterizing the complex geometrical, structural, and optical leaf properties of a vegetation canopy. The purpose of the following analysis is not to model canopy optical behavior, but to examine radiant transfer at the soil surface. This is done through an analysis of the canopy-attenuated spectral irradiance at the soil surface.

Radiant flux transfer through the canopy medium may be evaluated by Bouguer's law:

$$E_s(\lambda) = E_0(\lambda)\exp[-k(\lambda)m] \quad (5)$$

$$T(\lambda) = \exp[-k(\lambda)m], \quad (6)$$

where E_0 is the global (diffuse + direct) irradiance entering the canopy medium, E_s is the irradiance at the soil surface after passing through a canopy optical path length m, k is the extinction coefficient, km is the extinction optical thickness (dimensionless), T is transmittance through the canopy medium, and λ is wavelength (Iqball, 1983). By using LAI as the optical depth parameter (m), canopy extinction becomes the slope obtained in plotting $-\ln(T)$ against LAI.

Huete (1987) obtained canopy transmittance values for the cotton data set presented here by separating the reflected radiance of soil–cotton mixtures into a vegetation spectral component and a soil-dependent spectral component:

$$D_m(\lambda) = E_0(\lambda)R_c(\lambda) + E_0(\lambda)R_s(\lambda)T^2(\lambda), \quad (7)$$

where the measured canopy signal D_m is

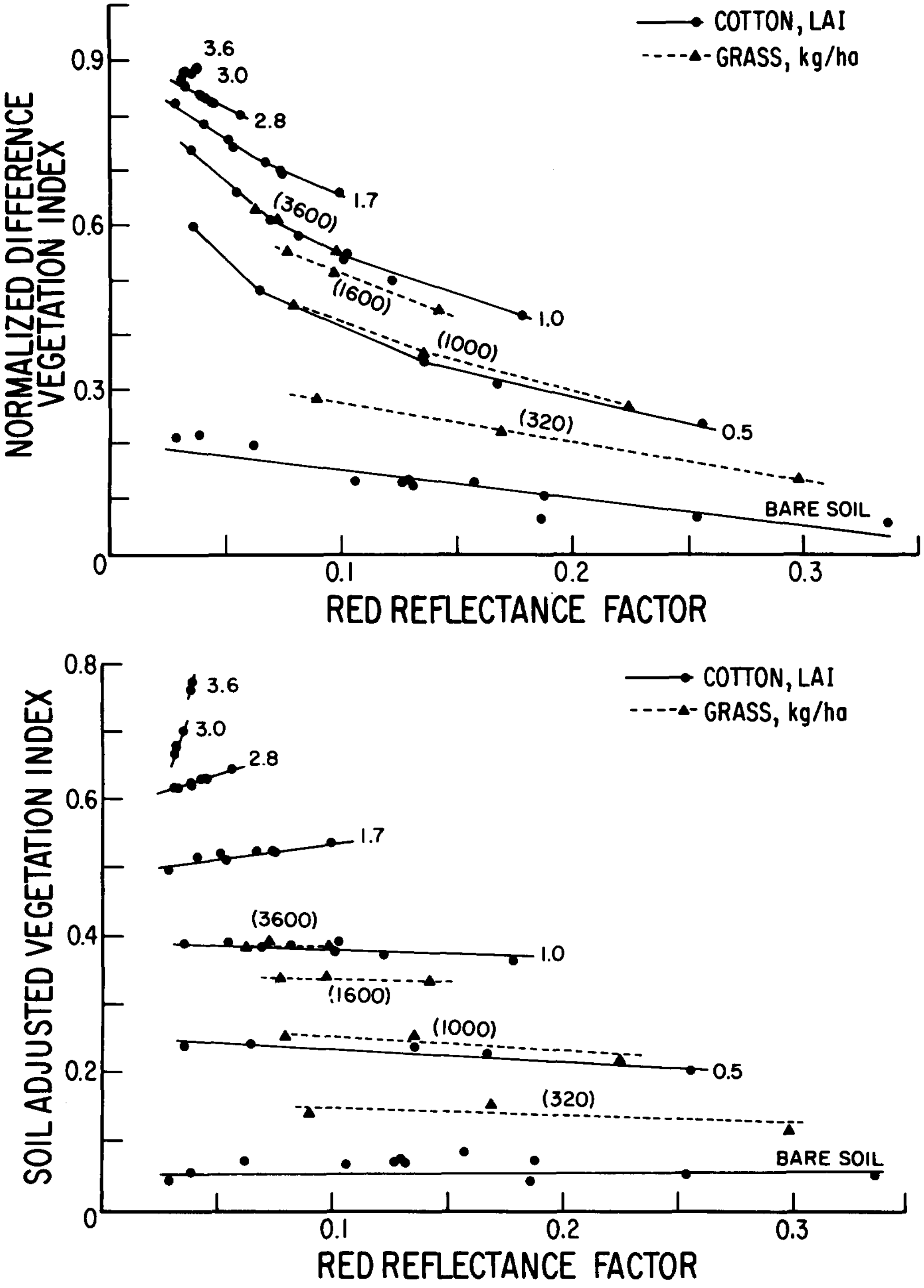

FIGURE 5. NDVI (part A) and SAVI ($L = 0.5$, part B) response as a function of red canopy reflectance for various canopy densities of grass and cotton.

equal to the sum of i) the vegetation component $E_0 R_c$, which is the irradiance directly reflected by the vegetation, and ii) the soil-dependent component $E_0 R_s T^2$, which is the product of global irradiance E_0, by soil reflectance R_s, by the downward and upward global transmittance through the canopy, T^2. All radiant energy interacting with the soil background forms the soil-dependent signal from the canopy. The vegetation component represents the reflected canopy radiance which would be measured if a "zero" reflecting soil background were underneath the canopy. This spectral response is free of soil influences and may be related to LAI through some constant B, which encompasses the scattering coefficients and inclination angles in canopy radiant transfer models:

$$R_c(\lambda) = B(\lambda)\mathrm{LAI}. \qquad (8)$$

Equation (7) is based on single-order spectral interactions between soil and vegetation components. Decomposition of NIR canopy spectra via eigenanalysis showed that first-order soil–vegetation interactions accounted for 99.996% of the spectral variance with a residual standard deviation of 0.37% reflectance (Huete, 1987). Utilizing Eqs. (6)–(8), one can derive the slope behavior of vegetation isolines in NIR–red wavelength space:

$$\begin{aligned} &D_m(\lambda)/E_0(\lambda) \\ &\quad = R_m(\lambda) = B(\lambda)\mathrm{LAI} \\ &\qquad + R_s(\lambda)\exp[-2k(\lambda)\mathrm{LAI}], \qquad (9) \end{aligned}$$

where measured canopy reflectance $(R_m = D_m/E_0)$ is the sum of the vegetation and soil-dependent components. Combining the red and NIR versions of Eq. (9) with a soil line equation [Eq. (10)] results in an equation for the slope of vegetation isolines (M_{vi}) in NIR–red wavelength space:

$$R_{s(\mathrm{NIR})} = R_{s(\mathrm{red})} M_s + I_s \qquad (10)$$

and

$$M_{\mathrm{vi}} = M_s \exp[2(k_{\mathrm{red}} - k_{\mathrm{NIR}})\mathrm{LAI}]. \qquad (11)$$

M_s and I_s are the slope and NIR intercept of the soil line equation. Equation (11) shows that the slope of a vegetation isoline is dependent on the slope of the soil line, LAI, and the difference in red and NIR canopy extinction. The following generalizations can be made:

1. If $\mathrm{LAI} = 0$, Eq. (11) reduces to the soil line slope.
2. If $k_{\mathrm{red}} = k_{\mathrm{NIR}}$, the slope of the isolines remain constant and equal to the soil line slope.
3. If $k_{\mathrm{red}} > k_{\mathrm{NIR}}$ (a photosynthetically active canopy), the flux transfer difference is positive, and the slope of the isoline becomes greater than the soil line slope.

Thus, it is the difference between red and NIR extinction through a vegetated canopy that determines the slope behavior of an isoline and the subsequent soil influence. The greater the difference between red and NIR extinction, the steeper the isolines become. The extinction (k) values for the cotton experimental data set were 0.46 for red light and 0.23 for NIR flux (Fig. 6). Inserting these values into Eqs. (9)–(11) results in a vegetation isoline slope ($\mathrm{LAI} = 1$) which converges with the soil line at $(-0.26, -0.24)$. This results in approximately equal x- and y-axis shifts (0.25 reflectance units) identical with the graphical solution [$L = 0.5$ in Eqs. (1)–(4)].

In order to obtain a complete NIR–red wavelength space equation for a vegetation isoline, an intercept term would also have to be computed. This term would depict the shift away from the soil line as a function of vegetation density and is related to the vegetation component, B LAI, described in Eq. (9). A more rigorous radiative transfer model, which is outside the scope of this study, would be needed to describe the optical/scattering properties of the vegetation component. The primary interest in this study was to analyze and model the soil-dependent component in Eq. (9). In brief, however, a vegetation component equation would describe the NIR and red spectral behavior of varying amounts of vegetation with a hypothetical "zero reflecting" soil background. The inclusion of a reflecting soil background would then cause the canopy response to shift in the positive red and NIR directions forming an isoline with a slope described by Eq. (11). The slope is dependent on the soil line, LAI, and canopy flux transfers, while the shift is soil-independent.

Discussion

The transformation technique presented in this study is an important step toward the establishment of simple global models that can adequately describe dynamic soil–vegetation systems. Graphically, the transformation involves a shifting of the origin of reflectance spectra plotted in NIR–red wavelength space to

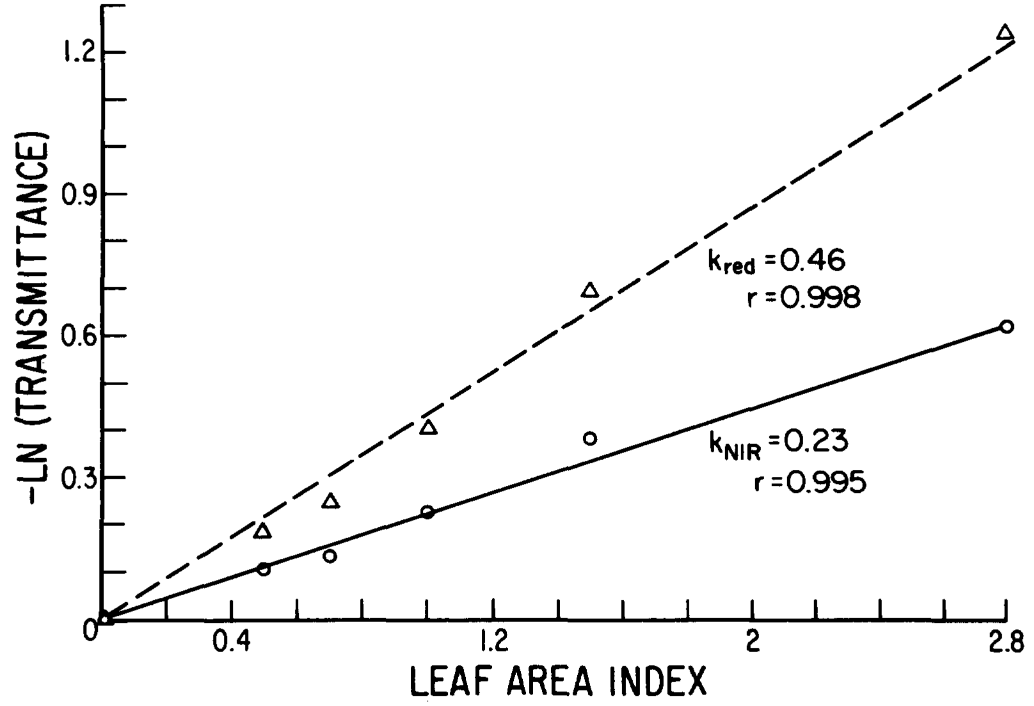

FIGURE 6. Relationship among canopy transmittance, extinction, and cotton leaf area index for red and NIR wavelengths.

account for first-order soil–vegetation interactions and differential red and NIR extinction through vegetation canopies. The SAVI is also a method by which spectral indices may be refined or "calibrated" so that soil substrate variations are effectively normalized and are not influencing the vegetation measure. Based on the ground-collected grass and cotton data utilized in this study, the optimal adjustment factor varied with vegetation density; however, a single adjustment factor ($L = 0.5$) was shown to reduce soil noise considerably throughout the range in vegetation densities.

The optimal adjustment was found to vary with vegetation density in a predictable manner. As the vegetation density became greater, the adjustment factor became lower. Thus, with prior knowledge of vegetation densities, one may choose the best correction term. The more common situation, however, involves no prior knowledge of LAI, but it may still be possible to use an iterative procedure, based on initial vegetation index values, to refine the SAVI. In this study, the adjustment factor of $L = 0.5$ was found to reduce soil noise problems substantially for a wide range in LAI values.

The ideal adjustment factor does not remain constant because the nature of soil–vegetation interactions varies with canopy closure. At low densities, there is little soil–vegetation interaction as red and NIR penetration through the canopy are nearly equal, with most of the flux reaching the soil surface coming from direct solar and sky irradiance. Soil and vegetation behave as additive components rendering the orthogonal indices, with parallel isolines, as the best predictors of soil–vegetation behavior. As the amount of vegetation increases, the difference between red and NIR penetration to the soil surface increases, causing the slope of the isolines to increase and the orthogonal indices lose their ability to describe soil–vegetation behavior. Only with the highest vegetation densities do isoline slopes become steep enough to approximate the ratio indices. Thus, for vegetation conditions between sparse and dense canopies, neither the ratio nor the orthogonal indices can adequately describe incomplete canopy spectral behavior.

Although, the SAVI ($L = 0.5$) successfully minimized soil noise in the two architecturally different canopies tested here (broad-leaf cotton and narrow-leaf grass), further field studies would be needed to ensure SAVI applicability on a global basis. Radiant flux transfers through natural ecosystems involve a mixture of several plant species. The arrangement of different plant species, along with their morphologies and densities, will determine the composition and magnitude of soil surface irradiance and hence the contribution and influence of the soil-dependent canopy signal. The limitations of the SAVI thus need to be analyzed over several vegetation biomes and agricultural situations. The results of this study as well as those of canopy radiant transfer equations, however, suggest that the NDVI and PVI are seriously affected by soil variations and that almost any adjustment (especially at L from 0.5 to 1) would improve remotely sensed vegetation interpretations.

There are several other orthogonal-based vegetation indices which are also affected by the results presented here. As with the PVI, all orthogonal indices are based on the premise that radiant flux extinction through a canopy is wavelength-independent, thereby producing parallel vegetation isolines. Thus, the four-band (MSS) green vegetation index (Kauth and Thomas, 1976), the six-band (TM) green vegetation index (Crist and Cicone, 1984), and the *n*-space indices (Jackson, 1983) all assume that soil, vegetation, and other spectral features are noninteracting components which can be added in some linear combination. All of these spectral techniques result in soil brightness effects similar to that shown here with the PVI.

The results presented here are based on NIR–red reflectance space. The orientation of the soil line and hence the vegetation isolines will differ when radiances are used instead of reflectance factors or when satellite-dependent digital counts are used. Differences in red and NIR filters among sensors as well as the nature of satellite calibration will also affect the isoline slopes and position in NIR–red wavelength space. However, the basic premise that there exist soil brightness influences on incomplete vegetation spectra and that these influences can be minimized remain. It is only the red and NIR (and other wavelengths) adjustment factors that will differ in terms of units and magnitudes, especially if the soil line does not intercept close to the origin. The influence of the atmosphere will also have to be tested on the SAVI as will the influence of sun angle and viewing geometries.

Detection of low amounts of vegetation will still be restricted by a second soil noise factor which was not considered here. The "width" of the global soil line (secondary axis of soil variation) will inhibit the discrimination of low amounts of vegetation from certain soils since their respective pixels will occupy similar positions in NIR–red wavelength space. The SAVI will not reduce this secondary source of soil variation as only soil line orientation problems and soil brightness (dark to light-colored soils) effects on vegetation isolines are modeled. Soils with high chromas, such as red or yellow-colored soils, often deviate the most away from the soil line and project themselves into "green vegetation" space. This type of soil noise may possibly be minimized through the use of soil-specific spectral indices, through prior stratification of data sets or images, or through the use of additional wavelengths for improved soil discrimination.

The soil background is a major surface component controling the spectral behavior of all but the most dense vegetation canopies. Soil variations occur within small field plots as well as over broad landscape units (volcanic areas, alluvial soils, clays, and sands). Since soil surfaces are also temporally dynamic (moisture, organic inputs, erosion, and cultivation), an understanding of soil spectral properties and its behavior and interactions with plant life and water are crucial to the development of global earth models.

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