IMPROVING THE FITTINGNESS OF SOIL LINES AND THE DYNAMIC RANGE OF VEGETATION INDICES BY AVIRIS BAND POSITIONING SELECTION

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1. INTRODUCTION

In general, conventional vegetation indices are based on the soil line concept, a linear relationship between the red (R) and the near-infrared (NIR) spectral response. These indices have been used in a wide range of applications, including the monitoring of vegetation at a global scale and the estimate of canopy parameters such as the green biomass, the leaf area index, and the absorbed photosynthetically active radiation (Tucker, 1979; Asrar et al., 1984; Chen, 1996). However, the nonexistence of a unique soil line, i.e., that encompasses all soil types, tend to introduce soil background noise in the results derived from these applications, as demonstrated in several articles (Huete et al., 1985; Huete, 1989). Besides soil background effects, vegetation index determinations are also affected by other factors such as the atmospheric influence and the Sun-view geometry (Myneni and Asrar, 1984; Epiphanio and Huete, 1995). Such problems justify the existence of numerous indices proposed to minimize the influence of these factors and to improve comparatively the performance of the normalized difference vegetation index (NDVI), the most frequently used vegetation index in global vegetation studies. Examples of NDVI variants include the soil-adjusted vegetation index (SAVI) (Huete, 1988) and the atmospherically resistant vegetation index (ARVI) (Kaufman and Tanré, 1992), which produce different dynamic ranges in relation to the conventional NDVI.

Furthermore, the effects of band positioning and bandwidth on vegetation index determinations have been discussed in recent publications. As indicated in Table 1, orbital multispectral sensors acquire data in R and NIR bands with very different spectral positioning and bandwidth. According to Guyot and Gu (1994), band positioning has to be considered when distinct multisensor images are analyzed. Teillet et al. (1997) have indicated enhanced sensitivity of the NDVI to variations in the width of the R band. By using laboratory reflectance spectra of tropical soils, Galvão and Vitorello (1998) have shown that a better representation of a general soil line is produced when the NIR band is positioned at the shorter wavelengths in the 750-1100 nm range. Also, an increase in the dynamic range of the NDVI or in the contrast between green vegetation and other scene components is obtained with the NIR band around 750 nm, and the R band placed close to the chlorophyll absorption interval (660-680 nm) (Galvão et al., 1999; Galvão et al., 2000).

In this article, the influence of band positioning on the fittingness of the soil line representing tropical soil types that occur in an area of agricultural activities in central Brazil is reviewed by using AVIRIS data collected during the SCAR-B mission in 1995. The results are also presented for the broad-band sensors listed in Table 1. Better-fitted soil lines means minimization of the soil background effects on the vegetation index determination. In this context, the impact of the position of narrow R-NIR pair of AVIRIS bands on the dynamic range of indices such as NDVI, SAVI and ARVI is discussed, and the results are compared with those obtained from the soil line analysis. By extending the dynamic range of these indices to a maximum through an adequate band positioning, it is possible to increase the discrimination of more vegetation types, notwithstanding the fact that discrimination will also be dependent on the radiometric sensitivity of the observing instrument.

Table 1. Red (R) and near-infrared (NIR) nominal bandpasses of some orbital sensors. The difference between the centers of the R and NIR bands is also indicated.

	R BAND (nm)			NIR BAND (nm)			
Sensor	*Interval*	*Width*	*Center*	*Interval*	*Width*	*Center*	*Center Difference*
MSS/Landsat 5	600-700	100	650	800-1100	300	950	300
AVHRR/NOAA 11	580-680	100	630	725-1100	375	912	282
TM/Landsat 5	630-690	60	660	760-900	140	830	170
HRV/SPOT 3	610-680	70	645	790-890	100	840	195
MODIS/EOS	620-670	50	645	841-876	35	858	213

2. METHODOLOGY

AVIRIS data were collected in 224 contiguous bands of less than 10 nm of width, in the 400-2500 nm range, for an area of crops located in central Brazil (19°53'S-53°45'W). The time of data acquisition (August 1995) corresponds to the peak of the regional dry season. The nominal spatial resolution is of 20 m, and the solar elevation angle of 56°. The AVIRIS radiance data were converted into surface reflectance through the use of a MODTRAN-based method (Green, 1991) that minimizes the effects of scattering and absorption by several atmosphere constituents.

In the dataset, many spectra of pixels associated with areas of supposedly exposed soils are affected at some extent by residues of senescent biomass (e.g., litter) that subdue the appearance of the 2200-nm absorption band due to clay minerals. A subset of 40 extreme pixels was chosen from the inspection of a scatter plot of the relationship between the R-NIR TM-simulated bands from AVIRIS data. The selected pixels represent two soil types composed of Latossolo Vermelho-Escuro (LE) and Podzólico vermelho-Amarelo. The former is a dark-red soil with greater amounts of iron oxides and overall lower reflectance than the latter, a red-yellowish soil. Details on the physicochemical characteristics of these soils can be found in Pizarro (1999).

First, soil line parameters and statistics (slope, intercept, coefficient of determination, and residual mean square values) were evaluated from the AVIRIS reflectance spectra of the selected pixels by setting a narrow R band at a constant positioning and shifting the center, at 10 nm intervals, of narrow NIR bands. The same strategy was used for a fixed NIR band. These results were then compared with those obtained with the R and NIR bands of the sensors listed in Table 1.

In a second step, the scatter plot was again used for the selection of reference spectra of green vegetation and soil. Vegetation index values (NDVI, SAVI, and ARVI) were calculated for these two reference spectra by changing the relative position of the AVIRIS R-NIR narrow bands, and simulating the nominal intervals of the broad-band sensors listed in Table 1. In the calculation of SAVI and ARVI, values of 0.5 and 1 were chosen, respectively, for the L (the canopy background adjustment factor) and γ (the weighting of the blue band to correct aerosol effects) parameters, as suggested by Huete (1988) and Kaufman and Tanré (1992). The blue AVIRIS band used in the ARVI equation was positioned at 470 nm. Variations in the dynamic range of these indices, as a function of band positioning, were evaluated by calculating the difference between the vegetation index curves of green vegetation and soil. The greater the difference, the higher the dynamic range of the index, and consequently the better the contrast among scene components.

3. RESULTS AND DISCUSSION

Figure 1 shows the scatter plot of the relationship between the AVIRIS-simulated TM3 (R) and TM4 (NIR) band reflectances of the TM/Landsat 5. In this figure, LE and PV indicate, respectively, the average response for Latossolo Vermelho-Escuro and Podzólico Vermelho-Amarelo, whereas GV represents the green vegetation of the riparian forest. Thus, 40 pixels around the LE and PV position in the scatter plot were chosen in the evaluation of the band placement effects on the soil line parameters. AVIRIS mean reflectance spectra representative of LE and PV, and of GV are shown in Figure 2, in which the characteristic absorption band due to clay materials can be clearly observed in the soil spectra around 2200 nm.

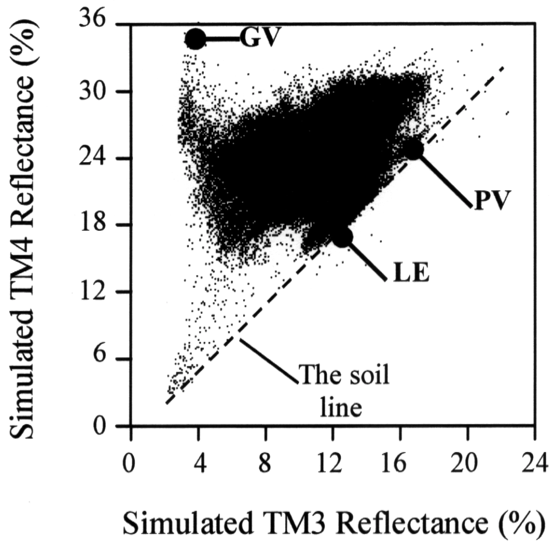


Figure 1 - Scatter plot from AVIRIS-simulated red (TM3) and near-infrared (TM4) band reflectances from TM/Landsat 5. GV represents the reference response of the green vegetation (riparian forest). LE and PV indicate, respectively, the average soil response of Latossolo vermelho-Escuro and Podzólico vermelho-Amarelo, along a soil line with a slope of 1.45.

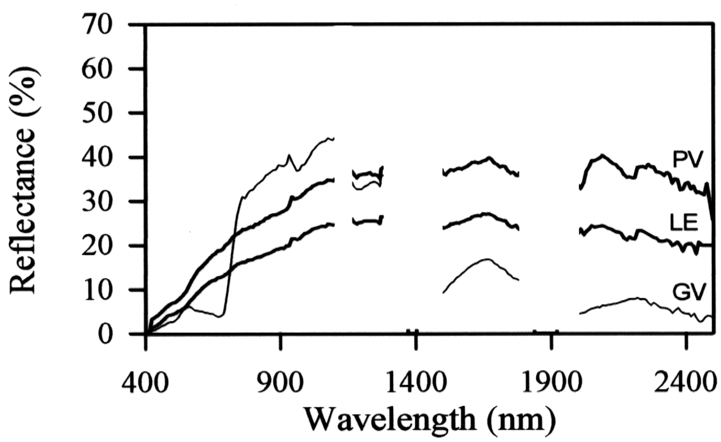


Figure 2 - AVIRIS reflectance spectra of the green vegetation (GV) of the riparian forest, and of two soil types (Latossolo Vermelho-Escuro - LE; Podzólico Vermelho-Amarelo - PV). Spectral intervals centered around 1400 and 1900 nm indicate strong atmospheric absorption. The over-corrected water vapor feature around 1140 nm is not shown for a better graphic representation.

Figure 3 shows the variations of the line slope, coefficient of determination and of the residual mean square error values for the relationship between a fixed narrow NIR AVIRIS band at 750 nm, the shortest wavelength of the near-infrared plateau in vegetation spectra, and variable R band positioning. On the other hand, Figure 4 displays the results for a fixed narrow R AVIRIS band at 677 nm, the wavelength around the chlorophyll absorption in the vegetation spectra, and variable NIR band placement. In Figure 4, the results are also presented for the relationships between the simulated R-NIR bands of the sensors listed in Table 1, and plotted at their NIR band centers.

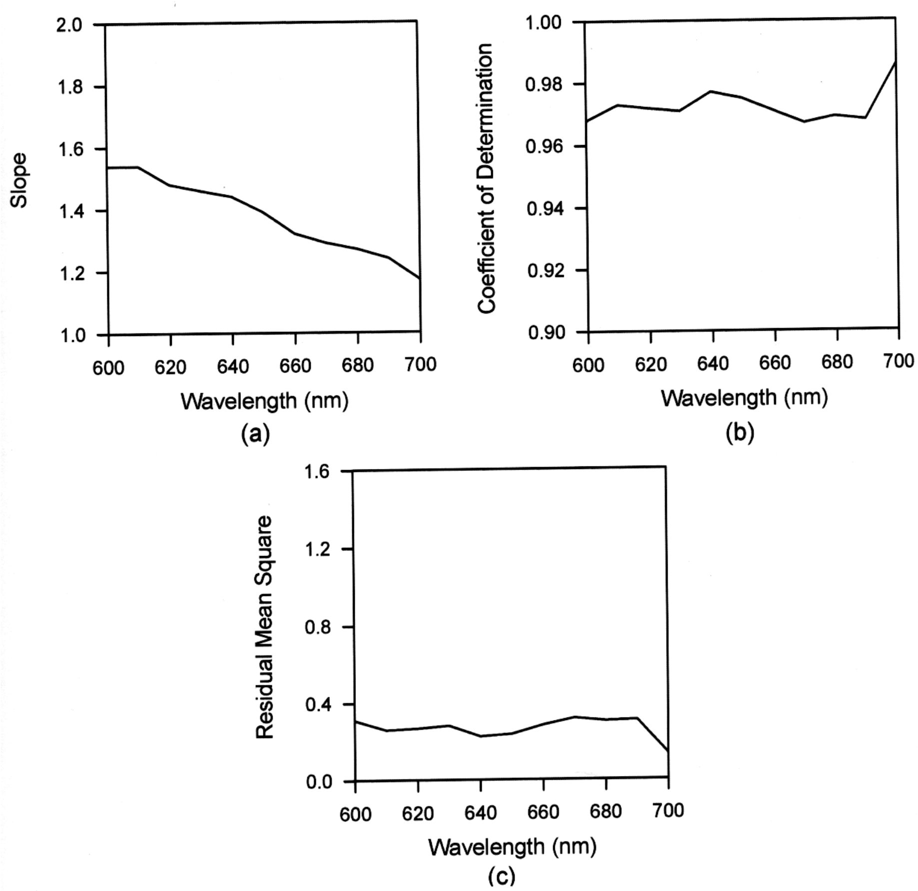


Figure 3 - Variations in the slope values for a general soil line determined with the use of 40 pixels related to Latossolo Vermelho-Escuro (LE) and Podzólico Vermelho-Amarelo (PV) are shown in (a), for a fixed 10-nm AVIRIS NIR band centered at 750 nm, and a variable R band positioning. In (b) and (c), the results are presented for the coefficients of determination and for the residual mean square errors of fitting.

As visualized from both figures, the general soil line resulting from the spectra of 40 pixels of LE and PV tends to present line slope values closer to one with the convergent displacement of the R and NIR bands towards longer and shorter wavelengths, respectively. Furthermore, the NIR band shifting towards shorter wavelengths (Fig. 4) produces significantly lower residual mean square errors and slightly better values of coefficient of determination. These results are in agreement with those obtained by Galvão and Vitorello (1998) with laboratory reflectance spectra of several soil types from southeastern Brazil.

Thus, a better-fitted general soil line is obtained with the R-NIR bands positioned at a smaller distance to each other. As a result, in comparison with MSS/Landsat 5 and AVHRR/NOAA 11, HRV/Spot3, MODIS/EOS, and TM/Landsat 5 tend to present better-adjusted soil lines and, consequently, to minimize soil background influences on vegetation index measurements.

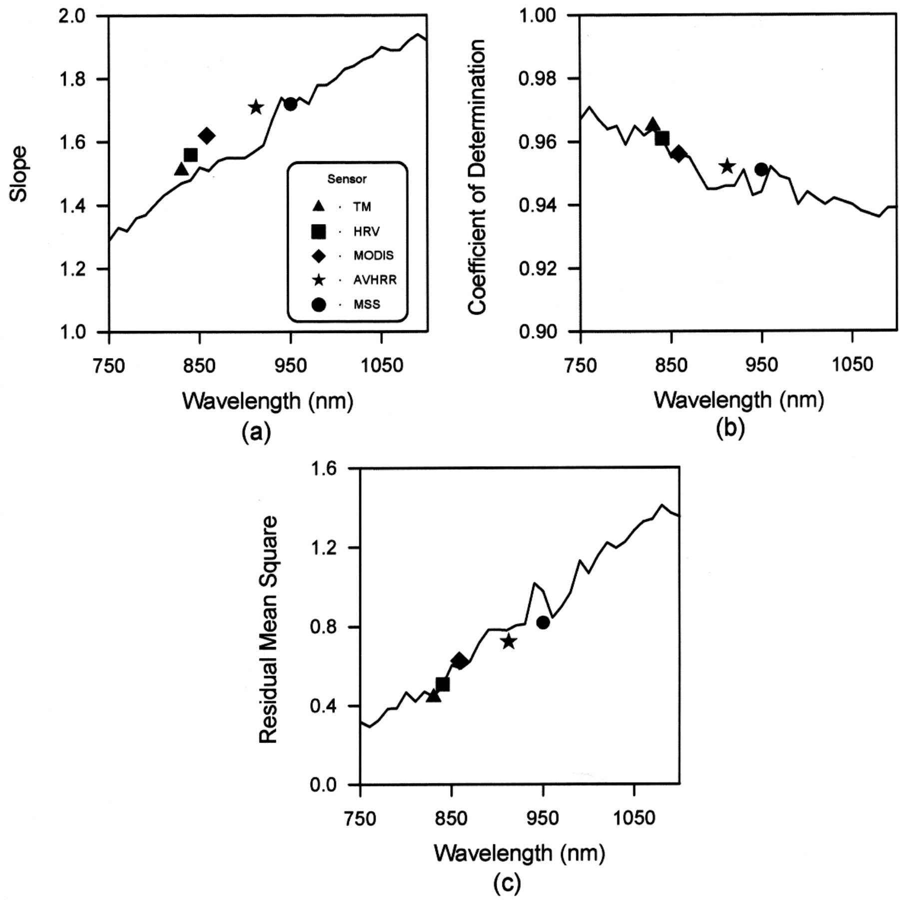


Figure 4 - Variations in the slope values for a general soil line determined with the use of 40 pixels related to Latossolo Vermelho-Escuro (LE) and Podzólico Vermelho-Amarelo (PV) are shown in (a), for a fixed 10-nm AVIRIS R band at 677 nm, and variable NIR band positioning. In (b) and (c), the results are presented for the coefficients of determination, and for the residual mean square errors of fitting. The symbols indicate the results obtained with the R and NIR bands of the sensors listed in Table 1, which are presented at their NIR band centers.

To demonstrate the impact of band positioning on the dynamic range of vegetation indices, Figure 5 displays the contrast between the GV and soil, as expressed by the difference between their vegetation index curves (e.g., $NDVI_{GV}$ minus $NDVI_{Soil}$). The vegetation index curves have been calculated with the use of the GV spectrum of Figure 2, and of a soil spectrum with intermediate response between the LR and PV curves of the same figure. In Figure 5a, the results are presented for a fixed narrow NIR AVIRIS band at a constant positioning (750 nm), and variable narrow R bands. In Figure 5b, the R band is fixed at 677 nm, while the NIR band has variable positioning.

As observed in Figure 5, the dynamic range of the indices increases from SAVI to ARVI. In the R interval (Fig. 5a), the spectral contrast between GV and soil increases towards longer wavelengths up to 690 nm, followed by a substantial contrast decrease produced as a result of the insertion of the R band into the red edge domain of the vegetation spectrum. In the NIR interval (Fig. 5b), the contrast increases with the shifting of the NIR band towards shorter wavelengths up to 750 nm, especially for NDVI and SAVI, and decreases again as a consequence of the red edge effect. The red edge effect is stronger in the R band than in the NIR. The results for SAVI show a lesser dependence of the contrast on NIR band positioning. According to Galvão et al. (1999), bandwidth is not important if the R and NIR bands are not inserted into the red edge domain.

The NDVI results for the sensors in Figure 5b indicate that the contrast tends to increase from AVHRR/NOAA 11 and MSS/Landsat 5 to MODIS/EOS, HRV/Spot 3, and TM/Landsat 5. The same trend is observed for the other indices. In comparison with the other sensors, AVHRR and MSS show a greater distance between their R-NIR band centers, and have the R or NIR bands inserted into the red-edge domain (690-750 nm interval), as verified in Table 1.

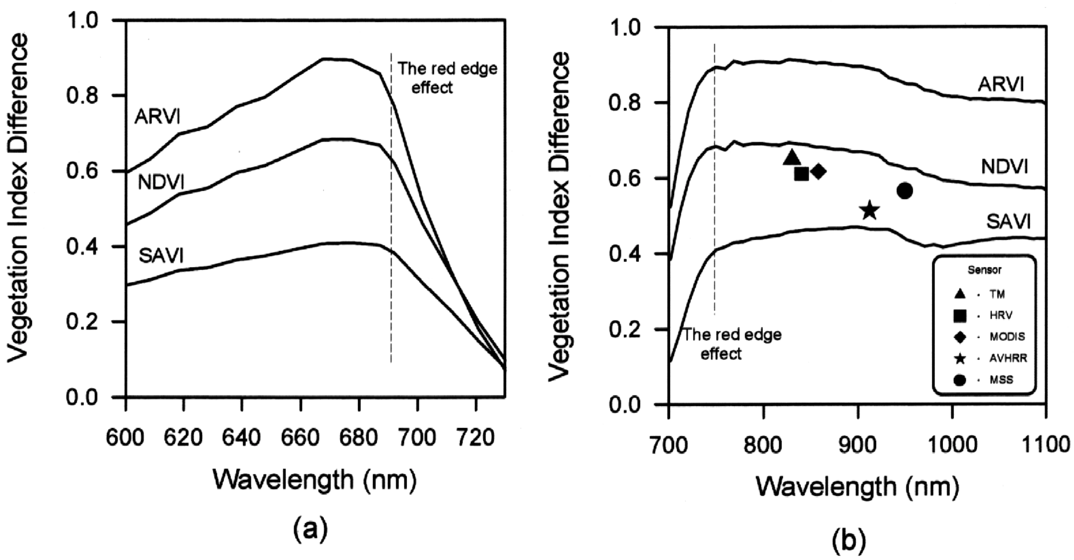
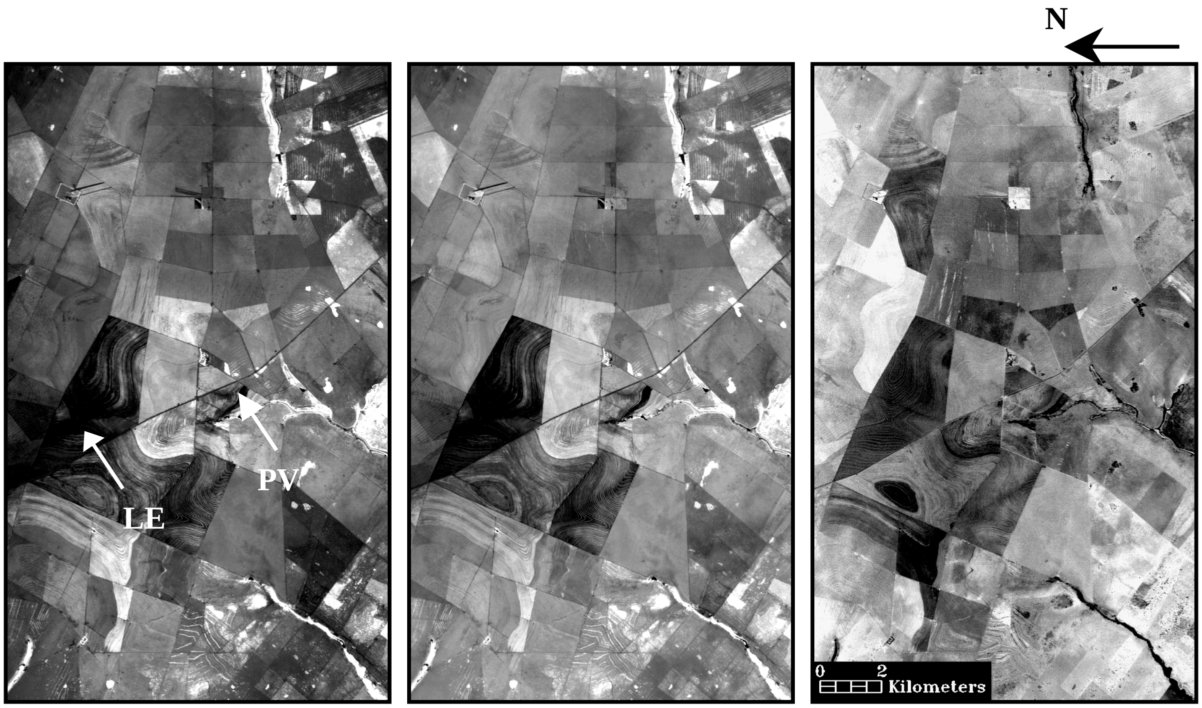


Figure 5 - Variations in the dynamic range of vegetation indices as a function of band positioning. In (a), the spectral contrast between green vegetation and soil, as expressed by their vegetation index difference curves, is presented for a narrow NIR AVIRIS band fixed at 750 nm, and variable R band placement. In (b), the R band is positioned at 677 nm. The NDVI results calculated with the R and NIR bands of the sensors listed in Table 1 are shown in (b) at their NIR band centers. In both figures, the vertical dashed line indicates the limits of the red edge effect, which tends to subdue the spectral contrast between green vegetation and other scene components.

To give an idea of the impact of the NIR band positioning on vegetation index measurements in the study area, Figure 6 displays NDVI images obtained with the R band at a constant position (677 nm), and the NIR bands at extreme locations at 750 nm (Fig. 6a) and 1100 nm (Fig. 6b). Figure 6c shows the NDVI difference image (6b minus 6a) where dark pixels indicate smaller NDVI differences or areas of lesser impact of the NIR band positioning on NDVI measurements, which include mainly the GV along the drainage streams (riparian forest) with NDVI differences of less than 0.15. Areas with shades of gray correspond to the GVof emerging crops and soils with NDVI differences between 0.15 and 0.23. The greatest NDVI differences (brighter pixels), as a function of band positioning, are associated with areas of senescent biomass, which can reach values of 0.35.



(a) (b) (c)

Figure 6 - NDVI images obtained with the R band at a constant position (677 nm), and the NIR band at extreme locations at 750 nm (a) and 1100 nm (b). The NDVI difference image (b minus a) is shown in (c). Areas from where pixels have been selected to compose the general soil line analysis are indicated in (a).

4. CONCLUSIONS

It is generally accepted that an ideal vegetation index must be applicable at a global scale to enhance vegetation characteristics while minimizing the undesirable influence of other factors such as the soil background and atmospheric effects. However, the results of this paper have shown that, independently of the selected vegetation index to reach such goal, an increase in its dynamic range and in the quality of the soil lines can be obtained by band positioning. The R band should be placed around the chlorophyll absorption interval (660-680 nm) and the NIR band positioned at shorter wavelengths in the 750-1100 nm interval. The strongest effects of band positioning to subdue the contrast between green vegetation and other scene components result from the insertion of the NIR, and especially R band, into the red edge domain. From the simulation of the nominal intervals of the broad-band sensors analyzed in this study, the best results were obtained for TM, HRV and MODIS, whereas the worst results were provided by AVHRR and MSS.

This study confirms the fact that vegetation indices derived from data collected by different sensors are not directly comparable. This is especially true in areas of crops or of strong seasonal rainfall contrast (e.g., tropical savannas), where the impact of band positioning on the dynamic range of the indices tend to be enhanced in the dry season because of the predominance of senescent biomass.

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