Transformed Difference Vegetation Index (TDVI) for Vegetation Cover Mapping

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Abstract: In this study, we present a new vegetation index, the TDVI: *Transformed Difference Vegetation Index*. This index shows the same sensitivity as the *Soil Adjusted Vegetation Index* (SAVI) to the optical proprieties of bare soil subjacent to the cover. It does not saturate like NDVI and SAVI and it shows an excellent linearity as a function of the rate of vegetation cover.

1. INTRODUCTION

The monitoring of Earth vegetation cover involves the utilization of vegetation indices as a radiometric measure of the spatial and temporal patterns of vegetation photosynthetic activity. Vegetation indices play an important role in the derivation of biophysical parameters, such as percentage of vegetation cover, leaf area index, absorbed photosynthetically active radiation (APAR), production the rate of the biomass, etc. Their interest lies in the detection of changes in land use and the monitoring of the seasonal dynamics of vegetation on regional and/or global scales. As reported in the literature, several indices have been developed for various applications and under quite specific conditions [1]. However, the use of these indices to characterize vegetation cover can be limited by various physical effects that affect the signal at the sensor, namely: drift of the sensor radiometric calibration [2], atmospheric effects [3], topographical effects [4], effects of the optical properties of the bare soil subjacent to the vegetation cover [5], bi-directional effects [6], spatial and spectral characteristics of the sensors [7] and, finally, problems of saturation and linearity [8]. These factors increase or decrease reflectances in the red and near infrared spectral bands and, consequently, limit the detection of vegetation cover changes using vegetation indices, which causes errors in the interpretation and the analysis of the results. The majority of these problems can be corrected for remote sensing imagery or *in situ* measurements before the derivation of vegetation indices. However, the problems of saturation and linearity are weaknesses that result from the design and the analytical formulation of the vegetation indices. In this study, we present a new vegetation index, the TDVI: *Transformed Difference Vegetation Index*. The potential of this index is evaluated by comparing it to the *Soil Adjusted Vegetation Index* (SAVI) [9], which minimizes artefacts caused by the optical properties of bare soil, and to the *Normalized Difference Vegetation Index* (NDVI)[10], with respect to linearity and saturation problems. To achieve our goal, spectroradiometric measurements were acquired above a forest cover with various degrees of defoliation, a cotton field with various percent covers [11], and several bare soils with various optical properties. All of the spectroradiometric measurements were resampled in the solar-reflective spectral bands of the Landsat-7 Enhanced Thematic Mapper Plus (ETM+).

2. MATERIALS AND METHODS

In this study, spectroradiometric measurements were acquired above a forest stand (Balsam Fir) with various degrees of defoliation (0, 30, 50, 75 and 100 percent). The age of the trees considered varies from 30 to 35 years, the height from 6 to 8 m, and the diameter of the crown from 2 to 3 m. The spectra were acquired in September when the herbaceous vegetation understorey is in senescence. Thus, it is assumed that no photo-synthetically active vegetation was present below the trees measured. Moreover, we obtained nadir spectra for 42 bare soil sites, including various soil types (fine silica clay and sand), levels of humidity (wet, fairly wet and dry) and roughness (rough, fairly rough and smooth). The measurements were carried out with a portable GER-3700 spectroradiometer (350 to 2500 nm). To take into account bi-directional reflectance effects of the target, which depend on both illumination angle and viewing angles, measurements measurements were made on both sides of Noon using a vertical view direction.

All of the spectroradiometric measurements were resampled in the solar-reflective spectral bands of the Landsat-7 ETM+. Other spectroradiometric measurements were acquired above cotton fields at different stages of development with various percent covers using a Barnes modular multispectral radiometer. Percent green cover was estimated from 35-mm slides obtained simultaneously from a camera mounted to the radiometer. A detailed description of this experiment can be found in the reference [11]. The following vegetation indices were calculated (L = 0.5, ρ_r = reflectance in the red channel, and ρ_{nir} = reflectance in the near-infrared channel):

$$NDVI = (\rho_{nir} - \rho_{red})/(\rho_{nir} + \rho_{red}) \qquad (1)$$

$$SAVI = (1 + L)(\rho_{nir} - \rho_r)/(\rho_{nir} + \rho_{red} + L) \qquad (2)$$

$$TDVI = 1.5 * \left[(\rho_{nir} - \rho_r) \Big/ \sqrt{\rho_{nir}^2 + \rho_r + 0.5} \right] \qquad (3)$$

3. ANALYSIS AND DISCUSSION

When a new index is documented in the literature, it is normally validated using a unique and limited data set, making claims of its superiority straightforward. In the context of this study, we considered two cover types (forest and cotton) and 42 bare soils with varying optical properties. Data were measured by different operators, in different environments. Forest data were collected at an experimental site that has been used since 1976 to develop the remote-sensing techniques applied in the evaluation of defoliation caused by the spruce budworm on Cape Breton Island, Nova Scotia, Canada. The data on cotton were collected at the U.S. Department of Agriculture experimental station in Phoenix.

Fig. 1 shows that, independently of the properties of bare soil, its nature and surface condition, the TDVI effectively minimizes the impact of bare soil subjacent to the cover. In the case of bright and dry soil, artefacts can result in errors of approximately 28 % in NDVI and 12% in SAVI and TDVI. However, soil that is wet or darker in colour causes an error of approximately 10 % in NDVI and SAVI, but less than 5 % in TDVI. The average quadratic error for all the soils is approximately 14 % for NDVI and 7 % for SAVI and for TDVI (Fig. 2). However, when we look at an entire scene, without distinguishing between the nature and surface condition of the soils depicted, the TDVI normalizes the effect of soils as well as, and sometimes better than, SAVI (Fig. 1).

If we consider the two types of vegetation cover (forest and cotton), Figures 3 and 4 demonstrate that the dynamic range of NDVI and SAVI saturate differently, depending on the cover type. In fact, for a percent cover of 100 % the SAVI saturates at a value of 60 % in the case of forest vegetation and 80 % in the case of cotton, demonstrating the sensitivity of this index to the structure of the cover and to plant type. The NDVI shows non-linear behaviour in the case of both cotton and forest cover. Moreover, its dynamic range saturates at a value of 80 % in the case of forest vegetation and 90% in the case of cotton. This saturation is seen above a percent cover of about 70 %, regardless of plant species. It should also be pointed out that when the cover is sparse or moderately dense (less than 50%), its density is overestimated by the NDVI and correctly estimated by the SAVI and TDVI. Figures 3 and 4 show that the TDVI, which does not saturate and which displays excellent linearity, occupies the middle ground between these two indices in particular when cover is higher than 50 %. For both cotton and forest cover, it behaves ideally in terms of estimating percent ground cover independently of cover structure and density, while minimizing artefacts caused by the optical properties of bare soil.

4. CONCLUSION

In this study, we present a new vegetation index, the TDVI (*Transformed Difference Vegetation Index*). If all the radiometric problems (drift of the sensor, atmospheric effects, etc.) can be corrected for remote sensing imagery or *in situ* measurements, the TDVI performs better than NDVI and SAVI. It does not saturate like NDVI or SAVI and it shows an excellent linearity as a function of the rate of vegetation cover, and shows the same sensitivity as the SAVI to the optical proprieties of bare soil subjacent to vegetation cover.

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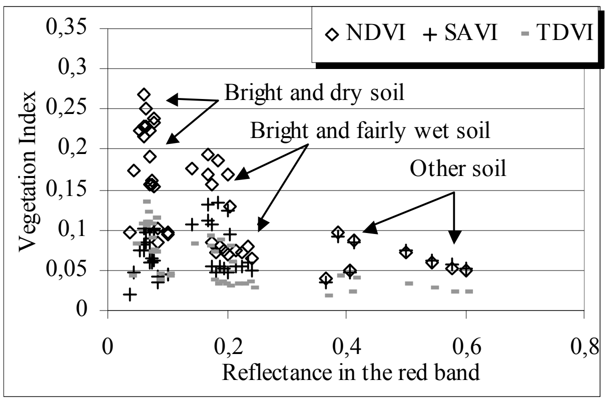

Fig. 1: Sensitivity of vegetation indices to the various optical properties of bare soil backgrounds.

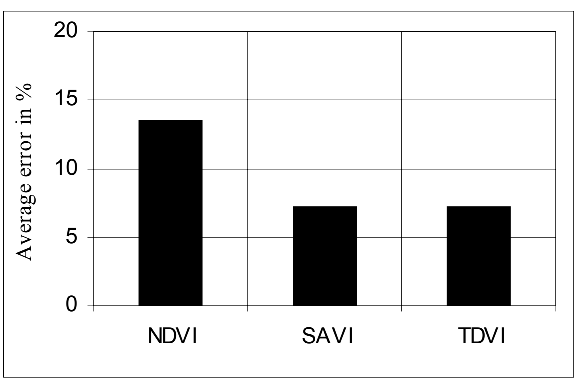

Fig. 2: Average error caused by the noise of bare soil on vegetation indices.

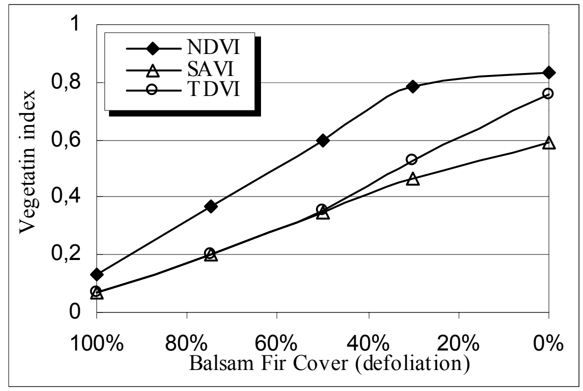

Fig. 3: Sensitivity of vegetation indices to percent forest defoliation.

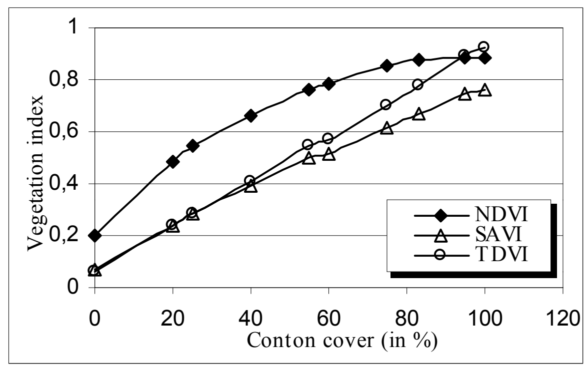

Fig. 4: Sensitivity of vegetation indices to percent cotton cover.