

A Review of Vegetation Indices and Their Importance for Agricultural Observation

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ABSTRACT

Satellite and airborne remote sensing makes it possible to map vegetation cover and follow its changes across large regions. Vegetation indices (VIs), which are simple formulas built from a few spectral bands, offer a practical way of carrying out such assessments. This paper reviews basic and advanced indices together with the confounding factors that influence them: soil brightness, soil colour, atmospheric conditions, vegetation status and crop water status. Schemes for classifying the indices are described, reported relationships between VIs and forest biomass are summarised, and a filtering approach that extracts seasonal signals of NDVI and PRI from ground-based sensors is presented as a useful tool for crop monitoring.

Keywords: Biomass, reflectance, spectral composition, SRS, vegetation index

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INTRODUCTION

Remote sensing (RS) data cover wide areas repeatedly, which makes them well suited to mapping vegetation and monitoring how it changes with time. Detailed descriptions of the many vegetation indices, including the strengths and weaknesses of each, are available in [1], [2]. Indices are frequently combined to obtain a fuller picture of canopy condition, but because each one rests on its own formulation, its performance depends on the environment in which it is applied. In this review the indices are grouped according to the spectral bands they use, the bare-soil line, soil colour, atmospheric correction, soil brightness, vegetation status and crop water status.

Vegetation Indices

The radiation reflected and emitted by the Earth's surface carries spectral information about vegetation, soil and water. Remote sensing methods, models and indices are used to turn this information into quantities that can be interpreted. To apply RS to environmental problems, the scope and limitations of such assessments, and of vegetation indices in particular, have to be understood. By the mid-1990s more than forty indices had already been proposed [1]. The earliest were computed from raw satellite digital numbers (DN), without atmospheric correction, conversion to reflectance or sensor calibration. The first two, the Ratio Vegetation Index (RVI) and the Vegetation Index Number (VIN), are simple ratios built from the near-infrared (NIR) and red channels [1].

Ratio indices accentuate the contrast between soil and vegetation and are only weakly affected by illumination, but they respond to the optical properties of the soil. RVI

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is additionally affected by the atmosphere; it separates vegetation best at high cover and loses discriminating power when cover falls below about 50% [1]. The Normalized Difference Vegetation Index (NDVI) [3], [4] is used worldwide to assess vegetation condition and has been applied to rainfall-related studies in semi-arid regions and to agricultural crops [1]. Over dense canopies it is sensitive to viewing and illumination geometry, and it tends to overestimate vegetation cover early in the growing season and underestimate it towards the end [1].

Confounding Factors Affecting Vegetation Indices

The spectral behaviour of a canopy changes through time with factors that describe its condition, including plant age, water content, pest and disease attack, nutrient deficiency, canopy geometry, row spacing and orientation, and leaf distribution [1]. These are tied to the biology and structure of the vegetation. External disturbances come on top of them: the atmosphere, sun-sensor geometry, differences

in soil properties, wavelength, background brightness and colour, sensor characteristics and viewing conditions [1]. The subsections below deal with soil brightness, soil colour, the atmosphere, vegetation status and crop water status.

Soil Brightness

Ratio indices are more exposed to external disturbances than orthogonal indices, and neither group describes sparse vegetation adequately [1]. Where cover is sparse, the soil background lowers NIR reflectance and raises red reflectance. Using the four bands of the Landsat MSS sensor, Kauth and Thomas [5] derived four indices: the Green Vegetation Index (GVI), Soil Brightness Index (SBI), Yellow Vegetation Index (YVI) and Non-Such Index (NSI), each named after the quantity it is meant to capture. SBI and GVI are useful for characterising bare soil and vegetation, whereas NSI consists mostly of noise. YVI and NSI respond to haze and to atmospheric water-vapour absorption but are comparatively insensitive to changes in vegetation cover [1].

In red-NIR space, bare-soil pixels lie approximately along a straight line known as the soil line, which also helps to separate vegetation from soil. Vegetation pixels fall to the left of this line and water pixels to the right, and the denser the vegetation, the greater the distance between its pixels and the soil line [1].

The Perpendicular Vegetation Index (PVI) [6] is based on the difference between soil and vegetation reflectance in the relevant bands. Unlike ratio indices, its lines of equal value run parallel to the soil line instead of converging at the origin, so it takes bare soil into account. It nevertheless remains dependent on soil brightness, underestimating leaf area index over moist, dark soils, and it is a poor indicator of vegetation stress. Atmospheric path radiance changes PVI values by roughly 10-12% between clear and turbid conditions, although its sensitivity to soil brightness is still lower than that of ratio indices [1].

The Soil Adjusted Vegetation Index (SAVI) [7] was developed as a compromise between orthogonal indices such as PVI and ratio indices such as NDVI. It uses a soil adjustment factor that varies inversely with the amount of vegetation. The Modified SAVI (MSAVI) [8] was proposed to reduce the influence of bare soil further. The Transformed SAVI (TSAVI) [9] modifies SAVI by building the parameters of the soil line directly into the calculation, which gives it a more general character. SAVI and TSAVI are reported to be independent of sensor type and of variations in vegetation cover and soil background [1]. TSAVI has been used to detect low-cover vegetation when producing land-use maps for nonpoint-source erosion studies in a semi-arid watershed; it is a better indicator than NDVI at low cover and responds more strongly to senescent vegetation [1].

Soil Colour

Differences in soil colour seriously hinder the detection of low vegetation cover. The Redness Index (RI) was introduced

to correct vegetation indices for this soil-colour effect [10]. Information from the green channel is used to remove the soil-colour "noise": the slope k of the relationship between RI and the vegetation index (VI) gives a corrected index, VI^* , and the correction is reported to roughly double the sensitivity of the index [1].

The Atmosphere

The Atmospherically Resistant Vegetation Index (ARVI) [11] is made resistant to atmospheric effects through a self-correction of the red channel. Radiative-transfer simulations on natural and synthetic surface spectra under a range of atmospheric conditions indicate that ARVI has a dynamic range similar to NDVI while being about four times less sensitive to the atmosphere [1]. A green-channel variant of NDVI has also been proposed [12].

Vegetation Status

The Wide Dynamic Range Vegetation Index (WDRVI) [13] extends the useful range of NDVI by applying a weighting coefficient to NIR reflectance. It improves the response in high-biomass conditions ($LAI > 2$), but when biomass is low ($LAI < 1$) NDVI remains the better choice for classifying vegetation [2]. For estimating leaf chlorophyll, the Chlorophyll Absorption Ratio Index (CARI) was later refined into the Modified CARI (MCARI), which is more sensitive to leaf chlorophyll concentration [14]. A two-band enhanced vegetation index that does not require a blue band has also been developed [15].

Crop Water Status

Crop growth depends directly on plant water status and water supply. When soil water is insufficient, plants experience water stress, which reduces yield and, in severe drought, can lead to crop failure. Timely and accurate assessment of crop water status is therefore important for yield, growth and produce quality. Thermal infrared remote sensing has made it possible to measure canopy temperature and its variation over crop stands. These variations are linked to transpiration rate and stomatal conductance, so canopy and leaf temperature have been used to infer crop water status. To make canopy-temperature measurements comparable across conditions, the Crop Water Stress Index (CWSI) was developed [16].

Besides thermal measurements, the visible part of the spectrum can reveal water stress at an early stage. This approach relies on bands at wavelengths where photosynthetic pigments respond to stress. The Photochemical Reflectance Index (PRI) [17] is a stress index of this kind and has also been applied to detect disease symptoms. It is a normalized difference of reflectance at 531 nm and 570 nm, two bands influenced by the xanthophyll cycle, and it is closely related to the light use efficiency (LUE) of leaves; PRI therefore serves as a good proxy for leaf LUE. LUE is a key variable for estimating net primary productivity

(NPP), and accurate LUE measurements help in studying energy exchange and global climate change.

Classification of Vegetation Indices

Vegetation indices can be classified in several complementary ways. By the number of bands, there are indices combining two bands (red and NIR) and those combining three or four bands. By structure, they divide into ratio indices and orthogonal indices. Two-band ratio indices are simpler to use than those built from more complex band combinations, and the most widely used are VIN, RVI and NDVI. Orthogonal indices include the two-channel PVI, the four-channel GVI, a six-channel spectral index and the “n-dimensional” spectral index. They differ from ratio indices in that lines of constant greenness do not meet at the origin but run parallel to the soil line [1]. A further distinction separates indices that describe cover by its perpendicular distance from the bare-soil line (for example PVI and GVI) from those that use the slope (RVI, NDVI, SAVI, TSAVI) [1].

Indices can also be grouped into generations. First-generation indices (such as SBI and DVI) were derived empirically, with no allowance for atmospheric effects, soil brightness or soil colour, and were tied to a specific sensor and application, which limits their transferability to other regions. Second-generation indices (PVI, SAVI, TSAVI, TSARVI, ARVI, GEMI, MSAVI, AVI and NDVI, as grouped in [1]) were developed more recently with physical and mathematical reasoning supported by experiments and simulation; they are generally computed from reflectance values corrected for sensor and atmospheric effects [1], [18]. In spite of the many newer indices designed to handle soil behaviour, NDVI remains the most widely used in remote sensing applications.

Vegetation Indices and Forest Biomass

Satellite remote sensing offers a faster and more efficient route to biomass estimates for forest resource management than conventional field-based assessment, which is labour intensive and time consuming. Strong relationships between vegetation indices and biomass have been reported. In a study of the Western Ghats region of Maharashtra, RVI showed the highest correlation with above-ground biomass and was judged the most suitable index for that purpose. The likely reason is that these areas carry a large amount of photosynthetically active vegetation, where RVI responds well to the difference between red and NIR reflectance, so that it correlated better with biomass than the other indices. [Add the citation of the original Western Ghats biomass study here.]

Spectral Reflectance Sensors For NDVI and PRI

Spectral reflectance sensors (SRS) fixed close to the ground can support continuous monitoring of vegetation indices such as NDVI and PRI [19]. NDVI is mainly used to describe crop growth and phenology, while PRI was developed to monitor physiological status. The seasonal courses of both indices are therefore valuable information in a crop-monitoring system.

Capturing these seasonal patterns is difficult, however, because index values derived from canopy reflectance are strongly influenced by weather, particularly solar irradiance and precipitation. In addition, physiological status varies on a daily as well as a seasonal scale, unlike phenology and growth [19].

Ryu et al. [19] proposed a filtering method for extracting the seasonal signals of SRS-based NDVI and PRI in paddy rice, barley and garlic. The measurement accuracy of the SRS was first compared with that of portable spectrometers. Thresholds based on meteorological variables were then examined, and sunshine duration proved to be the most useful criterion for removing distorted index values. After processing on the basis of sunshine duration, the R^2 between the measured indices and the extracted seasonal signals rose by about 0.002-0.004 for NDVI and 0.065-0.298 for PRI, and the seasonal signals became noticeably clearer [19].

CONCLUSION

Vegetation indices are numerical measures of vegetation vigour. They are more sensitive to green vegetation than individual spectral bands, and they support land-use change monitoring, image interpretation, estimation of vegetation cover density, forestry, crop discrimination and crop forecasting. No vegetation index has a universal, fixed value: viewing conditions, the atmosphere, sensor calibration and characteristics, sun-sensor geometry, and soil colour and brightness all influence it. Mixed pixels containing vegetation together with other surfaces make interpretation harder still. Each environment has its own characteristics, and each index responds to green vegetation in its own way [1].

The development of vegetation indices can be seen in two phases. The first relied on linear combinations of raw digital numbers. The second is grounded in the physics of the interactions between electromagnetic radiation, the atmosphere, the vegetation canopy and the soil background, and it addresses many of the problems of the earlier phase, although some remain open. Second-generation indices are less sensitive to atmospheric effects and soil brightness than first-generation ones [1]. Indices derived from radiative-transfer simulations are more accurate under ideal conditions, but whether they retain the same sensitivity to vegetation cover with real satellite or airborne imagery is still unresolved, and only further experimental work can settle it and support an ideal index for specific applications. The most suitable index may also depend on the purpose of the study, the location and the forest type. Finally, extracting seasonal signals of NDVI and PRI, as described above, can strengthen agricultural monitoring systems by revealing seasonal changes in crop physiology and growth [19].

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