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Beyond NDVI-Spectral indexing of biomass

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ABSTRACT

The use of both terrestrial and satellite sensors often lacks the specific knowledge that makes them more effective. There are many reasons for this, one of them is agricultural digitalization to facilitate data availability and shortened automatic spectral indexing, but interpretation requires special remote sensing and agricultural knowledge. The absence of this complex knowledge, will result in misleading or incorrect solutions and on the other hand the existing technical possibilities cannot be exploited by the farmers. The application and calculation of the wide and narrow band channel VIs were presented on two agricultural test areas. The purpose of this publication is to briefly introduce the technical capabilities of vegetation indices based on a Hungarian test site and thereby reduce potential misinterpretation.

1. Introduction

Crop monitoring is an equally important task and tool for all crop growers. Remote sensing-based crop monitoring is a universal tool for all the players of the agro-business (farmers, traders, insurers) as they can find the field health monitoring, climate impact analysis, fertility management and crop yield modeling tools at a one-for-all Platform. The satellite or near-field spectral vegetation index is most often used in this process.

There are more than two hundred other spectral indices besides NDVI (Normalized Difference Vegetation Index), that are widely used to analyze vegetation pattern and generally agro-environmental conditions (Nagy et al., 2018).

Every index is basically a special spectral combination of the sensor-measured band reflectance properties (chlorophyll content, water content, pigment, etc.) at 2 or more wavelengths that reveals particular characteristics of vegetation.

The optimal applicability of vegetation indices highly depends on their developing methodologies. Most indices have been developed for Earth observation, so they have been tested and validated on the sensors of a given satellite (e.g. Landsat, SPOT, Sentinel family). The selection of satellite sensor validation areas was fundamentally dependent on the interests of the project participating countries (Haboudanea et al., 2004). Therefore, the small countries in Central Europe have never been included in the Carpathian Basin area in initial sensor testing programs. However, in recent decades, huge amounts of data have been collected and several successful projects have been completed to investigate the agricultural applicability of remote sensing data in this Central European region, but the original development opportunities of space technologies, were always missed due to lack of financial resources. The first Hungarian aerial hyperspectral imaging programme took place within the framework of the HYSENS project in 2002 (Kardeván et al., 2003). Water quality and vegetation were

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analysed based on early results of the flight campaign (Jung, Kardeván & Gläßer 2007). From 2007, hyperspectral images were taken by an AISA DUAL (Eagle and Hawk) airborne hyperspectral camera system installed and operated in joint venture by Mechanization Institute of Agricultural Ministry and the University of Debrecen. The Eagle camera takes images in the visible and near-infrared range (400- 970 nm), while Hawk operates in the middle infrared range (970-2500 nm) with 498 spectral channels. Airborne hyperspectral imagery provides the potential for more accurate and detailed information extraction than it is possible with any other types of broadband, remotely sensed data. Precision agriculture requires spatially correct image data to control different field technologies. In this case, an important point was to develop the effective flight campaign to produce highly accurate high ground and spectral resolution data. Hyperspectral narrow-band indices are more sophisticated measures of general quantity than the traditional satellite broadband indices. Many of these indices are currently unknown in agricultural practice or under-used. In our study, the potential of AISA EAGLE airborne hyperspectral sensor data to create a narrowband vegetation indices distribution map of agricultural fields was evaluated.

Beyond the general aims, the purpose of this publication is to briefly introduce the technical capabilities of vegetation indices based on a Hungarian test site and thereby reduce potential misinterpretation.

2. Material and methods

2.1. Data acquisition and processing

Hyperspectral VI test site was a winter wheat site, close to Siófok city (UL Geo 18º 0' 0.26" E; 46º 54' 3.14" N); (spectral interval 400-970 nm, average bandwidth 2.9 nm, spatial resolution: 0.5 m). The total area was 20 ha (Figure 1). The hyperspectral images were taken by an AISA EAGLE airborne hyperspectral imaging spectrometer. AISA is a dual sensor system, which provides seamless hyperspectral data in the full range from 400 to 970 nm (Burai, & Tamás 2004).

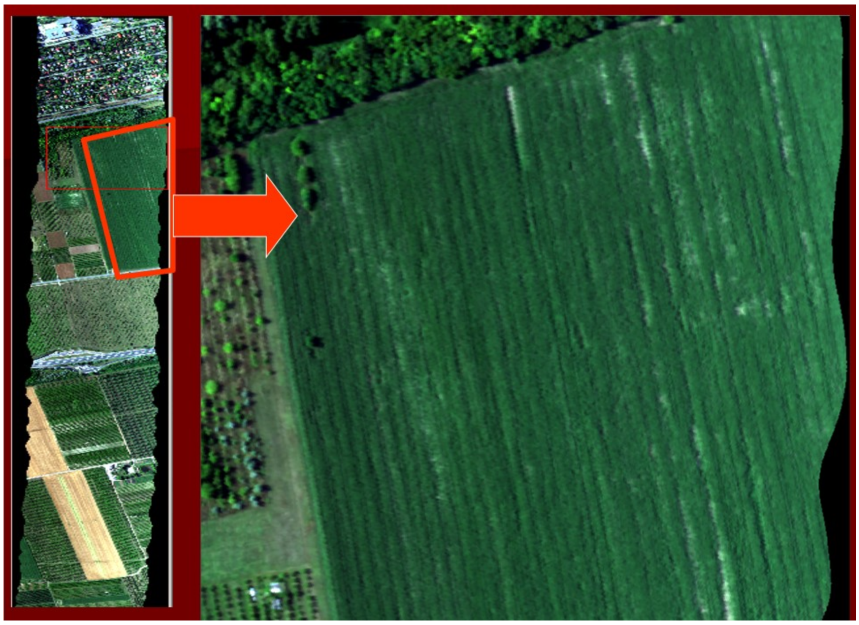

Figure 1. The test site was a winter wheat field near Siófok

The schematic steps of the hyperspectral image processing were the following: 1) Aerial and land image taking. 2) Radiometrical and geometrical corrections. 3) Noise filtering and data decrease. 4) Choosing the objective spectrum. 5) Classification. 6) Interpretation. 7) Checking (Burai & Tamás, 2004). Steps 1 and 2 were made with the CaliGeo (radiometric and geometric corrections), while for steps 3 to 6, ENVI 5.3 raster based remote sensing software and ArcGIS 10.5 GIS environment were applied. Below, steps 2, 5 and 6 as the most crucial ones of the whole process will be reported.

2.2. Vegetation indices

Widely used Vegetation Indices (VIs) are combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. Earth observation satellites use wide spectral channels so the vegetation indices use these channel combinations. Hyperspectral narrowband indices are more sophisticated measures of general quantity than the traditional satellite broadband indices. In this study, calculation and application of broad band VIs and narrow band VIs were evaluated. Indices under mentioned were calculated:

NDVI- Normalized Difference Vegetation Index, SAVI- Soil Adjusted Vegetation Index, MSAVI- Modified Soil Adjusted Vegetation Index, EVI- Enhanced Vegetation Index, GCI- Green Chlorophyll Index, SIPI- Structure Insensitive Pigment Index, NBR - Normalized Burn Ratio and ΔNBR-Delta Normalized Burn Ratio, mSR 705- Modified Red Edge Simple Ratio, VOG-1,2- Vogelmann Red Edge Index 1, 2, PRI- Photochemical Reflectance Index, CRI1,2- Carotenoid Reflectance Index, ARI1,2- Anthocyanin Reflectance Index 1 and WBI-Water Band Index. The formulas of calculated vegetation indices are summarized in Table 1.

Table 1. The formulas of applied spectral vegetation indices

Broad band VIs	**Narrow band VIs**
NDVI= (NIR-RED)/(NIR+RED)	$mSR_{705} = \frac{\rho_{750} - \rho_{445}}{\rho_{7050} + \rho_{445}}$
SAVI = (($\lambda_{NIR} - \lambda_{Red}$) / ($\lambda_{NIR} + \lambda_{Red}$ + L)) x (1 + L)	$mNDVI_{705} = \frac{\rho_{750} - \rho_{705}}{\rho_{750} - \rho_{705} - 2\rho_{445}}$
$MSAVI = \frac{1}{2}\left[2\lambda_{800} + 1 - \sqrt{(2\lambda_{800} + 1)^2} - \sqrt{8(\lambda_{800} - \lambda_{670})}\right]$	$VOG1 = \frac{\rho_{740}}{\rho_{720}}$ $VOG2 = \frac{\rho_{734} - \rho_{747}}{\rho_{715} + \rho_{726}}$
ARVI = (λ_{NIR} – (2 * λ_{Red}) + λ_{Blue}) / (λ_{NIR} + (2 * λ_{Red}) + λ_{Blue})	$PRI = \frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}}$
EVI = 2.5 * (($\lambda_{NIR} - \lambda_{Red}$) / (($\lambda_{NIR}$) + (C1 * λ_{Red}) – (C2 * λ_{Blue}) + L)	$CR1 = \left(\frac{1}{\rho_{510}}\right) - \left(\frac{1}{\rho_{550}}\right)$
GCI = (λ_{NIR}) / (λ_{Green}) – 1	$CR2 = \left(\frac{1}{\rho_{510}}\right) - \left(\frac{1}{\rho_{700}}\right)$
SIPI = (λNIR – λBlue) / (λNIR – λRed)	$ARI1 = \left[\left(\frac{1}{\rho_{550}}\right) - \left(\frac{1}{\rho_{700}}\right)\right]$
NBR = ($\lambda_{NIR} - \lambda_{SWIR}$) / ($\lambda_{NIR} + \lambda_{SWIR}$)	$ARI2 = \rho_{800}\left[\left(\frac{1}{\rho_{550}}\right) - \left(\frac{1}{\rho_{700}}\right)\right]$
ΔNBR= PrefireNBR-PostfireNBR	$WBI = \frac{\rho_{900}}{\rho_{970}}$

3. Results

3.1. Application of broad band VIs

Nowadays the use of the broadband NDVI index is one of the most widespread vegetation index out of broadband VIs. During the last decades, substantial efforts were taken in improving the Normalized Difference Vegetation Index (NDVI) to reduce saturation impacts when dense canopy is closed and in developing new indices aiming to compensate for soil background influences (Figure 2).

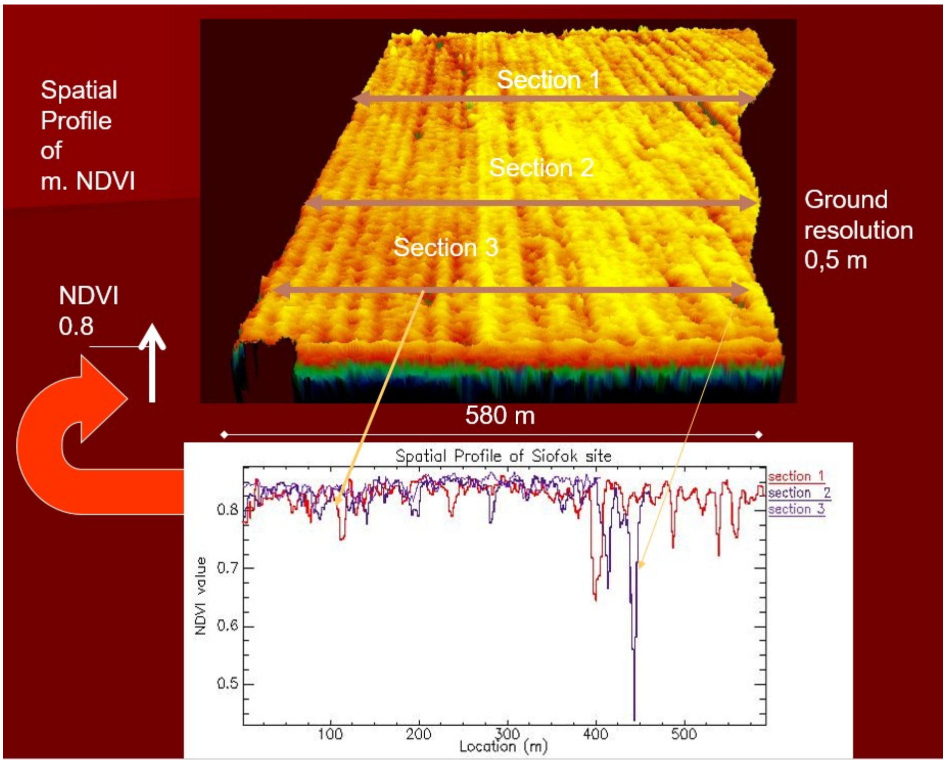

Figure 2. Cross section of spectral and physical space of winter wheat

The Soil Adjusted Vegetation Index (SAVI) was designed to minimize soil brightness influences. Huete (1988) added a soil adjustment factor L to the equation of NDVI in order to correct for soil noise effects (soil color, soil moisture, soil variability across region, etc.), which tend to impact the results. L values range between -1 and 1, depending on the amount of green vegetation present in the area. To run the remote sensing analysis of areas with high green vegetation, L is set to zero (in which case SAVI index data will be equal to NDVI); whereas low green vegetation regions require L=1. to use: for analysis of young crops; for arid regions with sparse vegetation (less than 15% of total area) and exposed soil surfaces (Figure 3). Huete (1988) suggested an optimal value of L= 0.5 to account for first-order soil background variations.

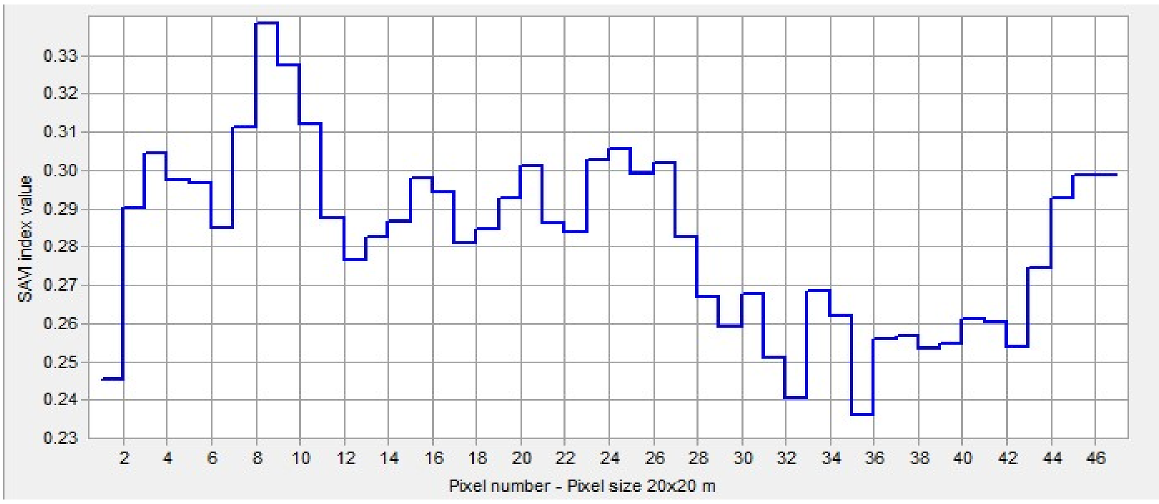

Figure 3. Cross section of Soil Adjusted Vegetation Index Index of winter wheat

Attempting to improve SAVI with regard to the differences in soil background, (Qi, et al. 1994) developed an improved SAVI (MSAVI) with a self-adjustment factor L that does not appear in the formulation of MSAVI.

The Atmospherically Resistant Vegetation Index (ARVI) is the first vegetation index, which is relatively prone to atmospheric factors (such as aerosol). The formula of ARVI index invented by Kaufman & Tanre (1992) is basically NDVI corrected for atmospheric scattering effects in the red reflectance spectrum by using the measurements in blue wavelengths. Compared to other indices, ARVI agriculture index is also more robust to topographic effects, which makes it a highly effective monitoring tool for tropical mountainous regions often polluted by soot coming from slash-and-burn agriculture. An atmospherically resistant vegetation index (ARVI) is proposed and developed for remote sensing of vegetation from the Earth Observing System (EOS) MODIS sensor. The same index can be used for remote sensing from Landsat TM and the EOS-HIRIS sensor. The index takes advantage of the presence of the blue channel (0.47.+or-0.01 μm) in the MODIS sensor, in addition to the red (0.66+or-0.025 μm) and the near-IR (0.865+or-0.02 μm) channels that compose the present normalized difference vegetation index (NDVI) (Kaufman & Tanre 1992). The data source was used to evaluate regions with high content of atmospheric aerosol (e.g. rain, fog, dust, smoke, air pollution).

The Enhanced Vegetation Index (EVI) was invented by Liu & Huete (1995) to simultaneously correct NDVI results for atmospheric influences and soil background signals, especially in areas of dense canopy. The value range for EVI is -1 to 1, and for healthy vegetation it varies between 0.2 and 0.8. EVI contains coefficient C1 and C2 to correct for aerosol scattering present in the atmosphere, and L to adjust for soil and canopy background. Traditionally, for NASA's MODIS sensor (which EVI index was developed for) C1=6, C2=7.5, and L=1 (Figure 4). When to use: for analyzing areas of agricultural region with large amounts of chlorophyll (such as virgin forests), and preferably with minimum topographic effects (not mountainous regions).

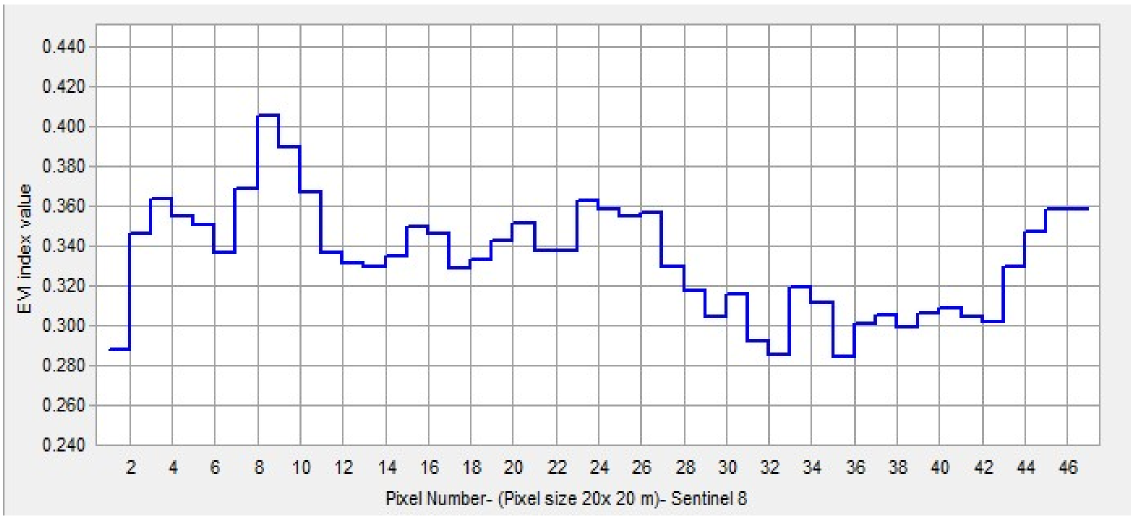

Figure 4. Cross section of Enhanced Vegetation Index of winter wheat

In remote sensing, the Green Chlorophyll Index (GCI) is used to estimate the content of leaf chlorophyll in various species of plants. The chlorophyll content reflects the physiological state of vegetation; it decreases in stressed plants and can therefore be used as a measurement of plant health.

Better prediction of chlorophyll amount with the GCI vegetation index can be achieved by using satellite sensors that have broad NIR and green wavelengths. The main fields of applications are monitoring the impact of seasonality, environmental stresses,and applied pesticides on plant health (Xue & Su, 2017).

The Structure Insensitive Pigment Index (SIPI) is good for analysis of vegetation with the variable canopy structure. It estimates the ratio of carotenoids to chlorophyll: the increased value signals of stressed vegetation.

Most researchers used high SIPI values (increased carotenoids and decreased chlorophyll) which are often applied as an indicator of plant disease, which is associated with loss of chlorophyll in plants.

SIPI can be used for monitoring plant health in regions with high variability in canopy structure or leaf area index, for early detection of plant disease or other causes of stress (Bannari, Morin, Bonn & Huete 1995).

By definition, it is the Normalized Burn Ratio (NBR) that is used to highlight burned areas following fire. The equation of NBR vegetation index includes measurements at both NIR and SWIR wavelengths: healthy vegetation shows high reflectance in NIR spectrum, whereas the recently burned areas of vegetation highly reflect in the SWIR spectrum. NBR fire index has become especially important in the past years as extreme weather conditions (regional drought) cause significant increase in wildfires destroying forest biomass (Escuin, Navarro & Fernández, 2008).

To perform NBR vegetation index calculation, one needs a raster image containing the near infrared and shortwave infrared bands that may be a satellite image collected by Landsat 7, Landsat 8, MODIS, etc. The range of values is between 1 and -1.

It is a common practice to assess burn extent and severity with the relative differenced NBR (delta Normalized Burn Ratio), which has shown the highest response to landscape changes caused by fire. It is a difference between the NBR calculated from an image of an area before the fire and NBR calculated from an image taken immediately after the burn. The range of values < -0.25 - > 0.66 from High post-fire regrowth to High-severity burn categories.

Additionally, there’s the NBR Thermal 1 index, which includes the Thermal band to enhance NBR and provide more accurate differentiation between the burned and unburned land. Although the typical use of NBR index for forestry is detection of active fires and analysis of burn severity, it can also be used for monitoring of agricultural vegetation survival after the burn.

3.2. Calculation and application of narrow band VIs

Narrowband greenness VIs more sophisticated measures of general and vigor of green biomass than the broadband VIs. Hyperspectral data or special LIDAR data give the opportunity to the utilization of vegetation indices based on narrow spectral channel data.

The Modified Red Edge Simple Ratio (mSR 705) index is a modification of the traditional broadband SR index. It differs from the standard SR because it uses bands in the red edge and incorporates a correction for leaf specular reflection. Applications include precision agriculture, forest monitoring, and vegetation stress detection. The value of this index ranges from 0 to 30. The common range for green vegetation is 2 to 8 (Datt 1999). The actual numbers of the winter wheat test site were: mean =11,14; max. = 18,7; min. = 1,55.

The Red Edge Normalized Difference Vegetation Index (NDVI705) is intended for use with very high spectral resolution reflectance data. Applications include precision agriculture, forest monitoring, and vegetation stress detection. This VI differs from the NDVI by using bands along the red edge, instead of the main absorption and reflectance peaks. The NDVI 705 capitalizes on the sensitivity of the vegetation red edge to small changes in canopy foliage content, gap fraction, and senescence. The value of this index ranges from -1 to 1. The common range for green vegetation is 0.2 to 0.9 (Sims & Gamon 2002). The actual numbers of the Winter wheat test site were: mean =0,83; max. = 0.87; min. = 0,17.

The Vogelmann Red Edge Index (VOG1 and VOG2) is a narrowband reflectance measurement that is sensitive to the combined effects of foliage chlorophyll concentration, canopy leaf area, and water content. Applications include vegetation phenology (growth) studies, precision agriculture, and vegetation productivity modeling (Vogelmann, Rock, & Moss, 1993). The value of this index ranges from 0 to 20. The common range for green vegetation is 4 to 8. The actual numbers of the winter wheat test site were: mean =2,59; max. = 2,84; min. = 1,33.

The Photochemical Reflectance Index (PRI) is a reflectance measurement that is sensitive to changes in carotenoid pigments (particularly xanthophyll pigments) in live foliage (Gamon, Penuelas, & Field, 1992). The actual numbers of the Winter wheat test site were: mean =0.016; max. = 0,07; min. = -0,05.

Carotenoid pigments are indicative of photosynthetic light use efficiency, or the rate of carbon dioxide uptake by foliage per unit energy absorbed. As such, it is used in studies of vegetation productivity and stress. Applications include vegetation health in forests, and agricultural crops prior to senescence. The value of this index ranges from -1 to 1. The common range for green vegetation is -0.2 to 0.2. Stress-related pigments include carotenoids and anthocyanins, which are present in higher concentrations in weakened vegetation. Carotenoids function in light absorption processes in plants, as well as in protecting plants from the harmful effects of high light conditions. The Carotenoid Reflectance Index 1-2 (CRI1-2) is a reflectance measurement that is sensitive to carotenoid pigments in plant foliage. Higher CRI1 values mean greater caratenoid concentration relative to chlorophyll (Gitelson, Zur, Chivkunova & Merzlyak, 2002). The common range for green vegetation is from 1 to 11. CR2 provides better results in areas of high carotenoid concentration. The actual numbers of the winter wheat test site were: mean =6,99; max. = 8.7; min. = 4.58.

Anthocyanins are water-soluble pigments abundant in newly forming leaves and leaves undergoing senescence. The Anthocyanin Reflectance Index 1 (ARI1) is a reflectance measurement that is sensitive to anthocynanins in plant foliage. Increases in ARI1 indicate canopy changes in foliage via new growth or death (Gitelson, Merzlyak & Chivkunova, 2001). The ARI2 is a modification of the ARI1 which detects higher concentrations of anthocynanins in vegetation. The value of these indices ranges from 0 to more than 0.2. The common range for green vegetation is 0.001 to 0.1. The actual numbers of the winter wheat test site were: mean =0.00012; max. = 0,0009; min. = 0,000086.

Water Band Index (WBI) is defined by the following equation (Champagne, Pattey, Bannari & Stratchan, 2001). Water content is an important quantity of vegetation because higher water content indicates healthier vegetation that is likely to grow faster and be more fire-resistant. The Water Band Index (WBI) is a reflectance measurement that is sensitive to changes in canopy water status. As the water content of vegetation canopies increases, the strength of the absorption around 970 nm increases relative to that of 900 nm. The common range for green vegetation is 0.8 to 1.2. Applications include canopy stress analysis, productivity prediction and modeling, fire hazard condition analysis, cropland management, and studies of ecosystem physiology. Actual numbers of winter wheat test site were: mean =1,032; max. = 1,129; min. = 0,87.

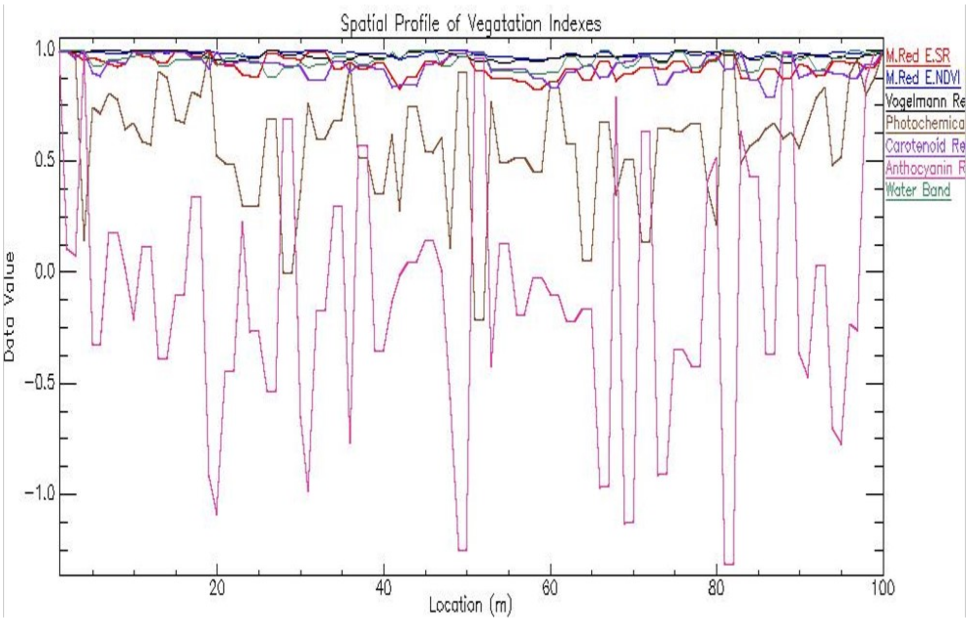

Figure 5. Cross sections of the applied narrow band VIs which was covered by winter wheat

Based on the indices there are several spots with different spectral feauter referring to the heterogeneity of the vegetation which can contribute to a better identification of management zones in precision agriculture.

3. Conclusion

The optimal applicability of vegetation indices highly depends on their developing methodologies. The Earth Observation satellites available today use wide spectral channels that scan large geographic regions. Although the number of satellite sensor channels and ground resolution are increasing, and satellite data are available in better temporal resolution, these properties remain below the spatial and temporal resolution of airborne hyperspectral imaging. However, in precision agricultural applications, the two survey modes are complementary in space and time. In order to compare the values obtained, it is necessary to know how to calculate them, the validation and the applicability of the used EM spectra. Some indices can be spectrally matched, such as NDVI and $NDVI_{705}$, while other indices have completely different purposes, contributing to a better identification of management zones in precision agriculture.

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