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ESTIMATING BIOMASS OF WINTER WHEAT USING NARROWBAND VEGETATION INDICES FOR PRECISION AGRICULTURE

Őszi búza biomassza mennyiségének becslése keskenysávú vegetációs indexek alkalmazásával a precíziós gazdálkodásban

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Abstract

An important part of wheat harvest planning is to have good understanding of the field where harvesting operation is to be conducted. Terrain characteristics influence biomass product. This information has been challenging to view of the area to be worked. Precision agriculture is about collecting timely geospatial information on soil-plant relations and prescribing an applying site-specific treatments to increase agricultural production and protect the environment. Precision farming should be applied in order to achieve sustainable agriculture. The development and implementation of site-specific farming has been made possible by combining geographic information systems (GIS) and hyperspectral remote sensing. In this research we introduce one existing problem that could be solved based on application of hyperspectral remote sensing. Digital images were taken by an Aisa EAGLE II hyperspectral sensor, which produced images with 253 contiguous bands (400-1000 nm), a spectral sampling of 2.5nm bandwidth, and a ground pixel size of 1m.

In our work narrowband vegetation indices (VI) were calculated from high resolution aerial hyperspectral images for estimating the biomass of winter wheat in an agricultural area. Narrow band's NDVI were computed for each combination of NIR and Red bands. Regression model was computed between NDVI's and field samples, where 625nm and 720nm bands produced the strongest relationship with biomass values ($n=9$, $R^2=0.762$, $p<0.05$).

Keywords: hyperspectral, vegetation index, biomass, remote sensing, precision agriculture

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Összefoglalás

A szántóföldi gabonatermesztés tervezésének fontos része a gazdálkodási terület megismerése. A területi jellemzők befolyásolják a biomassza produktumot. Ez az információ kihívást jelent a gazdálkodás területi tervezésében. A precíziós növénytermesztés összegyűjti az aktuális térinformatikai információkat a talaj-növény kapcsolatrendszeréről és meghatározza az alkalmazható helyspecifikus kezeléseket, amelyek növelik a mezőgazdasági termelés mértékét és a környezetet is védi. A precíziós gazdálkodás alkalmazható a fenntartható mezőgazdasági fejlődés elérése érdekében. A helyspecifikus gazdálkodási módszer kidolgozása és végrehajtása lehetővé tette a geoinformációs rendszerek (GIS) és a hiperspektrális távérzékelés ötvözését. Jelen kutatásban szeretnénk bemutatni egy olyan gyakorlati példát, amely megoldására távérzékelésből nyert információk segítségével kezelhetők. A felvételek AISA EAGLE II típusú hiperspektrális szenzorral készültek látható és közeli infravörös tartományban (400-1000 nm), 2,5 nm-es spektrális mintavételezéssel és 1 méter terepi felbontással, az így elkészült felvételek 253 db spektrális csatornát tartalmaztak. Munkánk során nagy felbontású légi hiperspektrális felvételekből számított keskenysávú vegetációs indexek (VI) segítségével következtettünk az őszi búza biomassza mennyiségére egy mezőgazdasági területen. A keskenysávú NDVI számításához a vörös-él számítást és az összes csatornakombinációt teszteltük a vörös és a közeli infravörös tartományokban a nedves biomassza-hozam becslésére. A legszorosabb regressziót a nedves biomassza és a mintaterület hiperspektrális felvétel pixelei között a 625nm vörös és a 720nm-es közeli infravörös csatornákból számított keskeny sávú NDVI alkalmazásával kaptuk.

Kulcsszavak: hiperspektrális, vegetációs index, biomassza, távérzékelés, precíziós mezőgazdaság

Introduction

The world's population is expected to double from its current level of 6-12 billions by the middle of the next century. The need for a high quality, reliable, sustainable, and environmentally friendly food source has become more imperative that ever. Wheat occupies the most planted areas and the highest trade value among cereal crops. (Gill et al., 2004). Many inputs and practices used by conventional farmers are also used in sustainable agriculture. The goal is to develop efficient biological systems, which do not need high levels of material inputs. Chemical inputs are seen by the public to be a primary cause of food contamination and environmental pollution arising from agriculture (Jolánkai et al., 2006). Field is not one uniform unit. In principle, all parameters and farming practices can be a part of a site-specific resource management (Bakhtiari – Hematian, 2003). The advantages and disadvantages of this technology highly depend on the heterogeneity of soil, the knowledge and attitude of the manager and the staff (Lencsés et al., 2014). Yield mapping provides information about the diversity within the field (Neményi et al., 2007).

GIS created by computing background makes possible to generate complex view about our fields and to make valid agro-technological decisions (Pecze, 2001). Geographical positioning with GPS or DGPS (Differential GPS) is essential for most site-specific practices that a specific action is recorded and positioned in order to use the information for future treatments. The global positioning system (GPS) makes possible to record the within field variability as geographically encoded data (Neményi et al., 2003). Yield monitors and maps form a very important part of a precision farming system. Yield is determined as a product of the various parameters being sensed (Shearer et al., 1999). The yield monitor which measures yield and gives information how yields vary within a field (DIGITAL GLOBE Corp, 2010).
Remote sensing provides consistent within and between field spatial variability across seasons in biophysical characteristics and yield that can be related to a crop model, making the decision-making approach feasible for precision-farming applications (Jones - Barnes 2000).By applying one of the most up-to-date type of optical remote sensing, i.e. airborne hyperspectral technology, due to the higher spectral and spatial resolution, compared to conventional airborne survey technologies (ortho and multispectral images), more detailed

information data can be obtained on a range of phenomena, layers and terrains of the Earth's surface. The scientifically-based planning and implementation of sustainable land use and rational soil management requires adequate information on the natural conditions and on the actual and/or potential impacts of human activities (Birkás, 2004). Today, an increasingly wide-spread application of hyperspectral airborne technology is witnessed in precision agriculture (Thenkabail, 2002; Ray et al., 2010) and among them several examples in Hungary are identified (Burai et al., 2009; Milics et al., 2008).
Hyperspectral remote sensing has opened up new possibilities for biomass estimates. There is growing evidence that imaging spectroscopy could improve the accuracy of satellite-based retrievals of vegetation attributes, such as biomass. Narrowband vegetation indexes (VIs) are based on much narrower spectral bands than their broadband counterparts, and contiguous spectral sampling allows examining specific absorption features and spectral regions which are typically not sampled by broadband sensors. It is common to search for the best band combinations for VIs iteratively (Mutanga and Skidmore, 2004; Thenkabail et al., 2004). This demonstrates the empirical nature of the VIs and the huge number of narrowband VIs that can be computed from imaging spectroscopy data. The Normalized Difference Vegetation Index (NDVI) is the most widely used vegetation index in recent decades. NDVI can provide relevant information on the distribution of plant species, plant growth patterns, and plant physiological status (Pettorelli, 2013).

The satellite sensor derived data to quantitatively and qualitatively assess within and between field variability of agricultural crops is increasingly becoming the single most important information source for precision farming. Site-specific information of agricultural crop conditions is essential for precision farming. Precision crop management requires spatial information on crop condition, biomass, and yield. The multispectral and hyperspectral data can be converted into quantitative and/or qualitative maps or information showing pixel by pixel variability for direct application in precision farming. (Moran et al. 1994)

Following the pre-processing the hyperspectral image, narrowband Normalised Differential Vegetation Indices (NDVI) were calculated from the red (620-680nm) and near-infrared (720-900nm) bands (Figure 1).

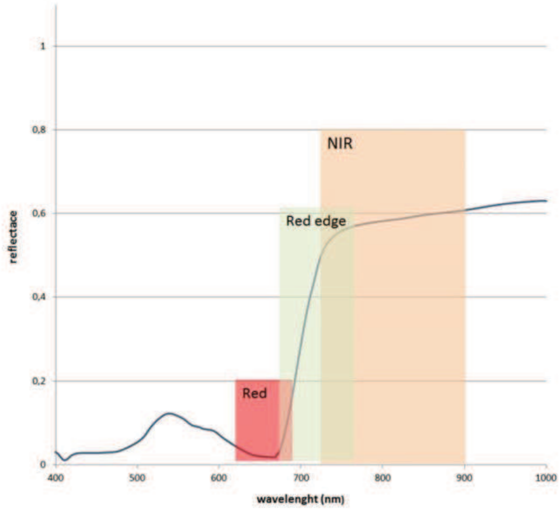

Figure 1. Region of Red (620-680 nm), Red Edge (680-780 nm) and NIR (720-900 nm) bands and a spectrum of vegetation

Therefore, we also assessed a set of narrowband VIs, which have been found useful in several previous studies. For testing the potential of airborne hyperspectral imagery to evaluate biomass, a heterogeneous winter wheat parcel provided an excellent possibility.
Precision agriculture technology has evolved in such a manner that it provides farmers with new and innovative ways to possibly improve profitability. One of these ways is a new approach to the application of liquid chemicals and other inputs known as automatic section control.

Materials and methods

Our study site is situated close to Gyöngyöspata (N 47°34' E 21° 6') in Northern Hungary. The total area of the study site is 32.83 hectares (Figure 2) where precision agricultural management is applied. Aisa EAGLE II type hyperspectral sensor was applied, which produced images with 253 contiguous bands (400-1000 nm), a spectral sampling of 2.5 nm bandwidth, and a ground pixel size of 1 m. The sensor was mounted to a Piper Aztec aircraft.

Figure 2. AISA Dual hyperspectral sensor set up in Piper Aztec aircraft

Data acquisition took place in good weather conditions from 10:50 to11:00 GMT, on 26th May, 2011. OxTS RT 3003 GPS/INS system was used to record the navigation data. Two images were recorded to cover the study area (Figure 3).

Figure 3. Position of study area (red contour line) in mosaic of hyperspectral images (RGB)

Intensive crop production is conducted at the sample area where the soil type is chernozem brown forest soil. In 2010, compared to the year-long average, a high amount of precipitation (866 mm) was experienced of which 248 mm fell between July and October when the land lacked vegetation cover (Figure 4).

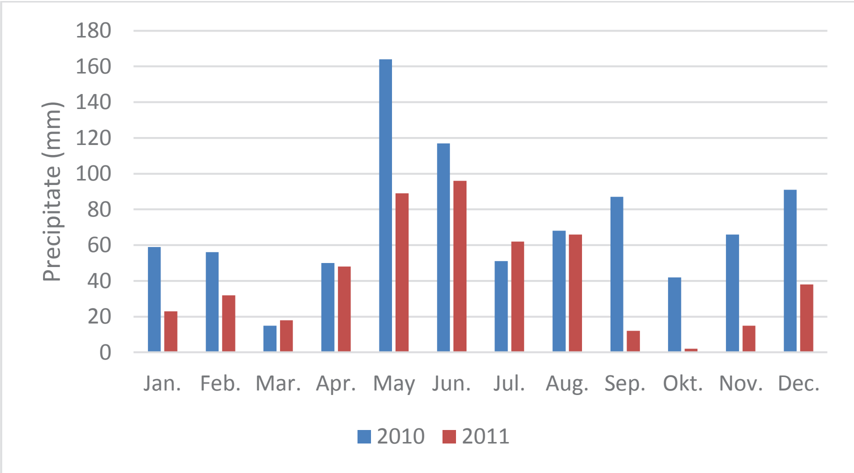

Figure 4. Precipitation on study site (2010 – 2011)

LAS data was processed in the UTM coordinate system (Zone 34 North UTM, WGS84) that was transformed to Hungarian National Projection (HD 72). A bare earth digital terrain model (DTM) was generated from LAS data at 0.5 m pixel resolution.
The discrete laser scanning data (Lidar) were collected with an airborne-mounted Leica ALS70 laser scanner on the 25th of April 2012. The scan swath was 874m and scan rate setting was 45,1kHz with “multi pulse in air mode” (MPIA) that produced 7 point/m^2 average point density.

The Lidar data was pictured in the UTM coordinate system (Zone 34 North UTM, WGS84) that was transformed to Hungarian National Projection (HD 72). A bare earth digital terrain model (DTM) was generated at 0.5 m pixel resolution. DTM was applied for geometric correction of hyperspectral image and to calculate slope map as well (Figure 5).

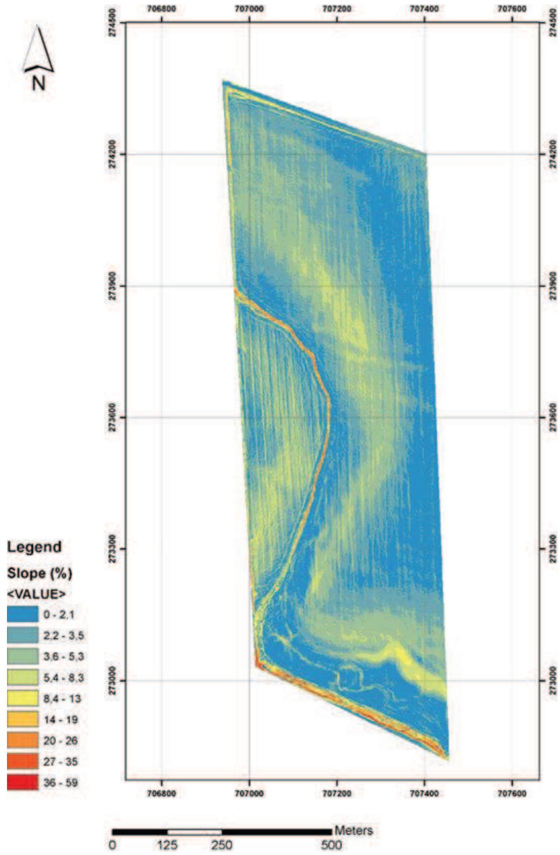

Figure 5. Classified slope (%) map was derived from digital terrain model (DTM) for study site

A push-broom typed Aisa Eagle II hyperspectral camera (www.specim.fi) was used at the whole sample area, which is capable of imaging in the visible and near-infrared (VNIR) region. (Figure 4) Image analysis was performed with the ENVI+IDL 4.7 software (http://www.ittvis.com/). At the study area, at 1m^2 sample spots, wet biomass mass and height were measured and their position was recorded by a sub-meter accuracy GPS device.

Vegetation Indices were computed by ENVI/IDL software.

a. Calculation of the NDVI

$$NDVI = \frac{(R_{NIR} - R_{RED})}{(R_{NIR} + R_{RED})}$$

R_{NIR}, R_{RED}: reflectance values of image
NDVI: narrowband normalized vegetation narrow band

b. Red Edge Position (REP) was calculated based on linear interpolation as described by Guyot et al. (1988). The REP of vegetation located around in the midpoint between the reflectance at the NIR plateau and the reflectance minimum at the chlorophyll absorption feature in the red.

Calculation of the reflectance at the infection point (R_{REP})

(1) $R_{REP} = (R_{670}+R_{780})/2$

Calculation of the Red Edge Position (REP)

(2) $REP = 700+40*((R_{REP}-R_{700})/(R_{740}-R_{700}))$

R_{670}, R_{700}, R_{740}, R_{780} are the reflectance values at 670,700,740 and 780nm

Results and discussion

The narrow band NDVI indices are most widely used in remote sensing (Pettorelli, 2013; Mutanga - Skidmore, 2004). Our study NDVI was computed for each combination of NIR and Red bands. Regression model was computed between NDVI's and field samples. (Figure 6) The NDVI from 625nm and 720nm produced the strongest relationship with biomass values (n=9, R^2=0.762, $p<0.05$).

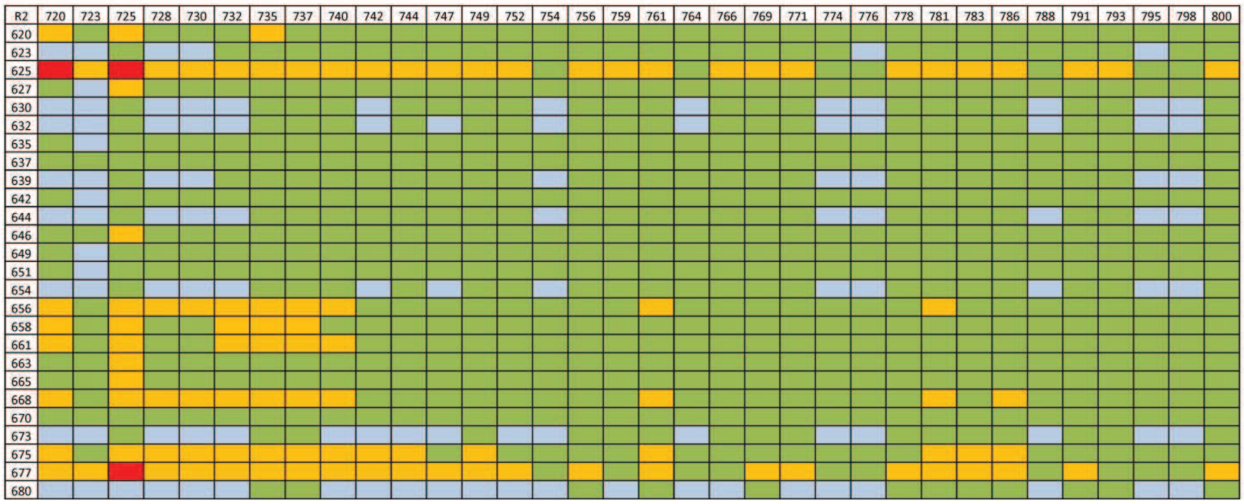

Figure 6. Regression was computed between Red (620-680nm) and NIR (720-800nm) bands. Colors represent the same group of regression values (red: R^2>0.7; orange: R^2: 0.6-0.7; green: R^2: 0,5-0.6; blue: R^2<0.5)

Furthermore regression also was computed between REP and biomass values which showed lower relationship (n=9, R^2=0.668, $p<0.05$). Narrow band's NDVI $_{(625nm,725nm)}$ was computed for all pixels of hyperspectral image (Figure 7).

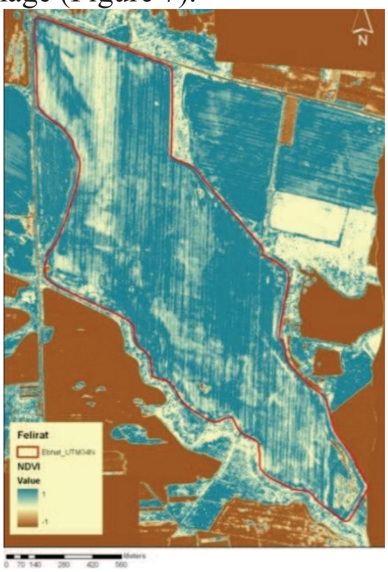

Figure 7. NDVI map of study site

By applying the equation for the entire sample area, a wet biomass map was developed (Figure 8). Wet biomass (kg/m^2) = 52.317$e^{NDVI(625,720)}$

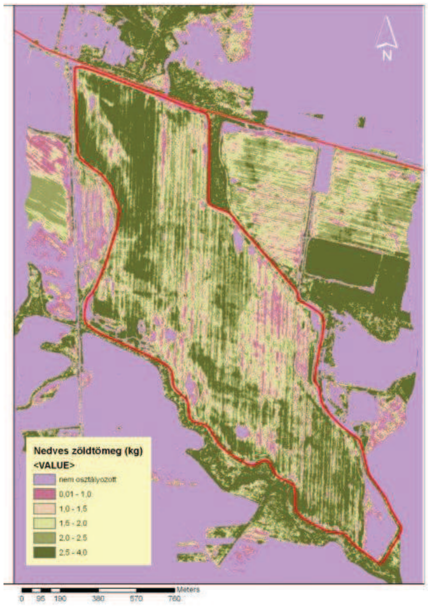

Figure 8. Wet biomass map of study site

Conclusions

Precision farming is a logical management tool for farmers. Data collected from soil sampling, yield monitoring, crop scouting, remote sensing, and satellite imaging are used to create maps. Many of these maps can be overlaid to look at interactions between yield, topography, fertilization and erosion. Yield monitors are detect and create site-specific map about volume of grain. This information is very important for the farmer before the harvest. Vegetation indexes would be useable information about crop yield before harvest.

The selected narrow band NDVI's and red-edge position were both found useful to describe wet biomass of winter wheat. Our result it clearly shows that the wet biomass could be estimated from both of narrowband NDVI and REP by exponential equations. Using the combination of 625nm and 720nm bands for NDVI produced the highest regression (n=9, R^2=0.762, $p<0.05$). However the relationship is strong between selected NDVI and biomass further analysis needs to extend it to general use of biomass evaluation of winter wheat.

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