MULTI, SUPER OR HYPER SPECTRAL DATA, THE RIGHT WAY FROM RESEARCH TOWARD APPLICATION IN AGRICULTURE

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ABSTRACT

Remote sensing provides opportunities for diverse applications in agriculture. For maximizing the utility of these applications, there is a need to choose the most efficient spectral resolution. Picking the optimal spectral resolutions (multi, super, or hyper) for a specific application is interconnected to other factors (e.g., spatial and temporal resolutions) of the utilized device. This work focuses mainly on the analysis of the effect of different and combined spectral resolutions throughout the research, towards practical implementation for wheat (as a crop model). Hyperspectral data can be examined as an entire spectrum in order to relate it to specific phenomenon or compare it to other spectra. No doubt, there is no need for hyperspectral data if a phenomenon can be detected by specific wavelengths. Nevertheless, hyperspectral data is valuable for identifying specific wavelengths as well as a basis for resampling data for simulating multi or super (above 10 bands) spectral sensors. In addition to the analysis of the entire spectrum, the effect of different resolutions can be analyzed and vegetation indices can be calculated by combining several bands or specific wavelengths that will be slightly modified by the different resolutions. The crop model, wheat, demonstrates applications based on different spectral resolutions. The applications that will be discussed in this work are: (1) evaluation of nutrients and water contents in plants, phenology, and LAI using quantitative statistical models and vegetation indices; (2) spectral separation between crop and weeds; (3) forecasting yield and yield quality; and (4) scaling up ground-level applications to airborne hyperspectral sensor or spaceborne superspectral satellites. Regarding costs and data processing procedure simplicity, we conclude that each application must be based on specific spectral bands/wavelength that should be picked ad hoc, hence, using an intermediate alternative as the superspectral resolutions should be considered as the selected way toward comprehensive application tool in agriculture.

Keywords: Remote sensing, multispectral, superspectral, hyperspectral, field crops, monitoring**.**

INTRODUCTION

Remote Sensing (RS) provides opportunities for diverse applications in agriculture. For maximizing the utility of these applications there is a need to choose the most efficient data acquiring system and its resolution. Three different systems for data acquisition are currently available based on their height - monitoring from the ground, air, and space. For more than 30 years, multispectral orbital land monitoring satellites have proved to provide very useful information for mapping natural resources over large areas with high to medium spatial resolution (1.5-50 m). Images were used for both in-field management, large scale management, or public policies. Selecting the optimal spectral resolutions (multi, super, or hyper) for a specific application is interconnected to factors (e.g., spatial and temporal resolutions) of the utilized acquisition system. The current work focuses mainly on the analysis of the effect of different and combined spectral resolutions throughout research, towards practical implementation for wheat (as a crop model).

MULTISPECTRAL REMOTE SENSING

RS has the potential of being an important contributor to site-specific management because of its ability to identify and characterize the spatial variability of the crop condition among fields and within a single field. Nowadays, most remote sensing sensors in use can be classified as multispectral (3-10 spectral bands) while data can be collected from ground platforms or from satellites. These sensors differ in many characteristics, but mainly in their spectral, spatial, and temporal resolutions (Table 1). Until the late 1990s, most commercial spaceborne sensors were characterized by low spatial resolution and few spectral bands. Thus, the use of RS technologies in agriculture had been limited mainly to large scale inventory and yield prediction. Hence, multispectral image interpretation was restricted to analyzing the false color composite, i.e., the NIR, red, and green spectral bands (respectively assigned to the red, green, and blue guns). Vegetation Indices (VI) that are usually based on multispectral data, are referred to combinations of two or more spectral bands, chosen to enhance the 'vegetation signal' and neutralize the 'background signal', enabling reliable spatial and temporal inter-comparisons of the corresponding biophysical variables (Thenkabail et al., 2004). The Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974) combines the reflectance of the near infrared (NIR) and red parts of the spectrum. NDVI has become the most well-known and used index to monitor changes in biomass, predicting crop yields, studying the condition of vegetation, or monitoring crop dynamics through remote sensing studies. The VI approach is also used by the on-the-go ground sensors such as GreenSeeker and CropCircle.

Table 1. Characteristics of multispectral sensors.

System	Spatial resolution (m[1])	Temporal resolution (days)	Spectral resolution (band no. & region[2])	Swath (km)
Ground				
GreenSeeker	0.6	on-the-go	2 VN	
CropCircle	0.25-2.5	on-the-go	2/3 VN	
Yara Hydro-N	3(6)	on-the-go	5 VN	
Spaceborne				
MODIS	250/500/1000	0.5	19 VNS	2330X10
Landsat TM & ETM	30	16	6 VNS	185
EO-1 ALI	30	16	9 VNS	37
ASTER	15/30	16	12 VNS	60
Spot 5	5/10/20	2-3	4 VNS	60
Formosat-2	8	1	4 VN	24
IKONOS	4	3	4 VN	11.3-13.8
Quickbird	2.5	1-3.5	4 VN	16.5
RapidEye	5	1	5 VN	77
WorldView-2	(1.8) 4.1	1.1-3.7	8 VN	16.4
VENμS (forthcoming)	5.3	2	11 VN	28
Sentinel-2 (forthcoming)	10/20/60	5	13 VNS	290

1: represent spatial ground cover by each sensor, or pixel size (satellite).
2: V=VIS, N=NIR, S=SWIR. Without thermal and panchromatic data.

Saturation Limitation

Multispectral information has serious limitations for in-farm management. Considering the large amount of knowledge gained during the past two decades about the plants specific spectral response to different factors at specific wavelengths, the lack of specificity represents one of today's' main limitation. This prevents multispectral remote sensing in taking a significant step forward into practical applications for in-farm management. One of the protruding examples corresponds to the limitation of the commonly used vegetation indices (e.g. NDVI, GNDVI, SAVI, Simple Ratio, etc.) for monitoring biomass development (e.g., leaf area index (LAI)) under high development conditions is referred to index saturation. As illustrated in Figure 1 (Pimstein, 2008), NDVI is sensitive to different variables (e.g., chlorophyll content, LAI, biomass) only during the early growth stages (Baret & Guyot, 1991, Buschmann & Nagel, 1993). However, in advanced stages when the crop has reached full coverage, the index becomes insensitive and therefore ineffective and useless. For field crop monitoring, this constraint limits the application of VI for site-specific management objectives, by not properly identify the crop condition precisely at the most important time of the season. For example, even in dry conditions, wheat can reach this LAI value less than 60 days after emergence, with other important stages of development still to come.

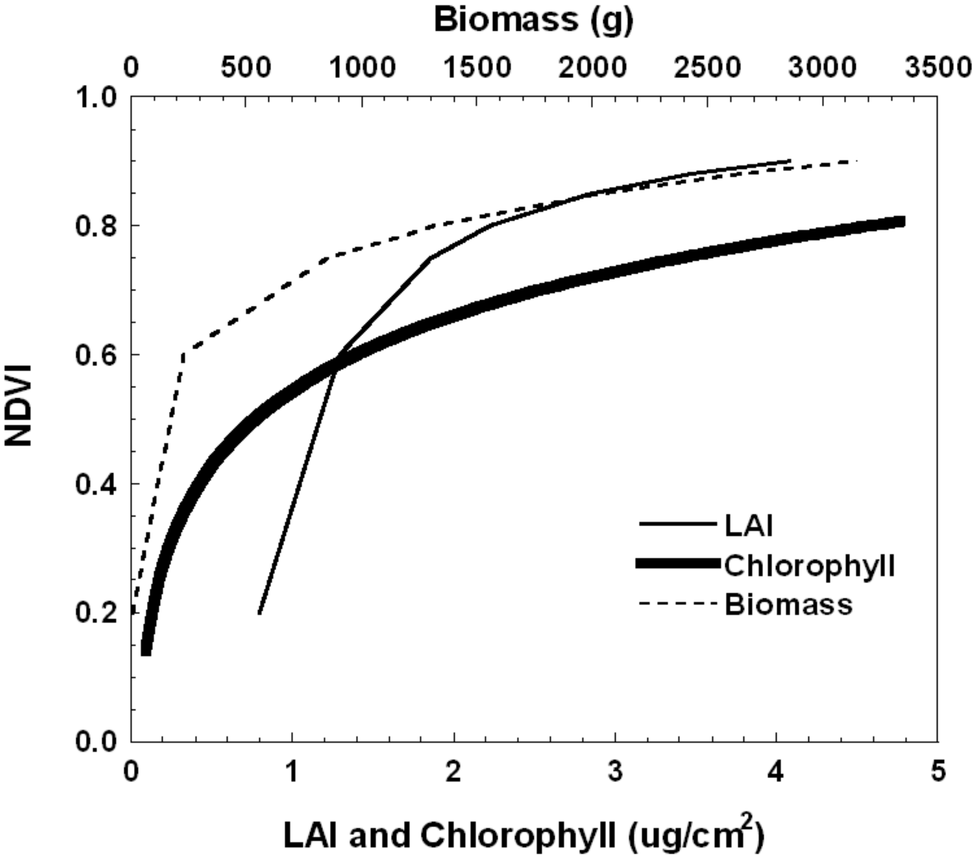

Fig. 1. NDVI as a function of LAI, chlorophyll content, and biomass. The chlorophyll data were multiplied by 10 for scaling (Pimstein, 2008)

Alternatively, other vegetation indices such as the Wide Dynamic Range Vegetation Index (WDRVI) and the Red-Edge Inflection Point (REIP), can effectively detect changes of the above-mentioned variables in under full cover conditions, especially for wheat (Gitelson, 2004; Herrmann et al., 2010). The red-edge is referred to the steep increase of reflectance between the red and NIR regions and marks the transition between photosynthetically affected region of the spectrum (chlorophyll absorption feature in the red region) and the region with high reflectance values at the NIR plateau, which are affected by plant cell structure and leaves layers. This feature enables a clear representation of chlorophyll absorption dynamics, illustrating a shoulder shifts towards longer wavelengths when the absorption increases (chlorophyll content increases), and a shift towards the shorter wavelengths with decreasing chlorophyll absorption (Moran et al., 2004). The importance of the red-edge bands leads the decision to include it in the newest satellite sensors, i.e. RapidEye, WorldView-2, VENµS, and Sentinel-2.

Lack of sensitivity

Lack of sensitivity is another major issue that limits the use of multispectral data. Although weed detection and site-specific weed management are very important and promising RS applications, most multispectral data cannot be applied for that purpose. Only where classification is very simple, weed or soil, multispectral data can be applied as implemented in the WeedSeeker system (http://www.ntechindustries.com/weedseeker-home.html). Therefore, this system is limited only to between rows in row crops fields. Weeds affecting the reflectance retrieved from wheat fields, but it can be only identified when they are clustered together in patches bigger than the sensor's spatial resolution. Nowadays, this cause abnormality spot in the RS image, however, it cannot be interpreted without addition data. Consequently, RS data are still not in use for site-specific weed management.

Another example where the lack of specificity of multispectral RS limits its role in in-farm management is its lack of possibility to identify specific absorption features that could help in monitoring other primary nutrients (e.g., potassium) that have not been possible to address by the RS community. Regarding the potassium and phosphorus correlation to reflectance, the problem is that it followed a similar pattern as the nitrogen correlation, suggesting some cross-correlation involving these elements (Pimstein et al., 2010). Therefore, only specific narrow bands can retrieve accurate quantitative information about the nutritional condition of wheat, other than nitrogen. Currently commercial multispectral sensors do not supply this capability.

Low spatial and temporal resolution

Most multispectral sensors that can supply data of more than 5 bands for wide swath have spatial and/or temporal low resolution (Table 1). The large MODIS pixel size prevents identification of any spatial variation within most fields. Hence, these data can be used mainly for taking regional scale decisions. Although Landsat and EO-1 ALI have pixel size of 30 m, they have been and probably will be used in the future for several agricultural applications. A Decision Support Systems (DSS) for local Israeli conditions (Negev-DSS) was developed for fertilization and agronomic management of wheat grown under semi-arid conditions (Bonfil et al., 2004). This DSS is beneficial for the farmer's profit since it optimizes the cultivating operations but also takes care of the environment through optimizing the use of fertilizers. To increase use availability, a new algorithm was build based on Landsat or EO-1 ALI data (Bonfil et al., 2009). However, for this kind of applications, sun-synchronous multispectral satellites as Landsat, limit their possibility of providing useful information by the simple fact that they might miss the date of interest (e.g. heading). Considering that Landsat revisit time is 16 days, the probability of taking an image on the required period of heading is very low. This is the reason why it has not been possible to validate the Negev-DSS during the last 5 seasons. Therefore, it is clear that this application could not be based on these low temporal resolution satellites.

HYPERSPECTRAL IMAGE SPECTROSCOPY

In light of the relationship between the reflected spectral response and the vegetation condition, RS scientists have developed analysis techniques that facilitate the use of specific ranges of the electromagnetic spectrum to retrieve information about the vegetation, and to map it. However, using multispectral data allows to retrieve from the spectra only pieces of the whole information, through the only few available broad or narrow bands.

Hyperspectral images have the possibility of identifying specific absorption features of the materials enclosed in the images, allowing accurate mapping of the included features. Imaging spectrometry or hyperspectral remote sensing (HSR) is an advanced technology that has attracted the attention of many professionals during the past decade. It provides high spectral resolution data (with the aim of providing near-laboratory quality reflectance or emittance) for each single picture element (pixel) from a distance (Goetz et al., 1985). This information allows the identification and recognition of objects based on the spectral absorption features of a specific chemical attribute, and enables, for the first time, quantitative RS of the Earth from space for several terrestrial applications. Allocating spectral information in a spatial domain provides a new dimension that neither the traditional point spectroscopy nor air photography (or multispectral images) can provide separately. The observation of detailed spectral information from every pixel in a given image opens up new frontiers in the RS science and industry.

Currently, HSR data cannot be collected from space, as the only sensor (Hyperion) has many limitations, especially a low signal-to-noise (SNR) ratio. However, the development of airborne HSR has seen a rapid and extended development during the last decade around the globe. The hyperspectral imaging spectrometer (AISA-Eagle and AISA-Hawk), the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) and others, has operated with great success. Airborne HSR have been upgraded every year to achieve more precise spectral and spatial resolutions with very high data quality. Point measurements can be collected at ground level, the Analytical Spectral Devices (ASD) FieldSpec Pro FR spectrometer in the range of 400-2400 nm is the most used sensor, but other sensors as Ocean Optics USB2000 radiometer can be used too.

Comprehensive work with ASD exhibit large variation in the reflectance at different development stages (Fig. 2). Each curve represents the average of many curves from that specific day, bearing variation that relates mainly to crop stand, water and water supply/content, etc. The temporal dynamics of the spectra, generally corresponds to parallel changes in the crop (Fig 3). The high hyperspectral data resolution enables retrieving the crop biomass, water status and nitrogen condition, as well as identify heading (Pimstein et al., 2007; 2009). Moreover, hyperspectral data can be used to develop new VI (Pimstein et al., 2009; 2010), enabling the development of new applicable multispectral devices thereafter.

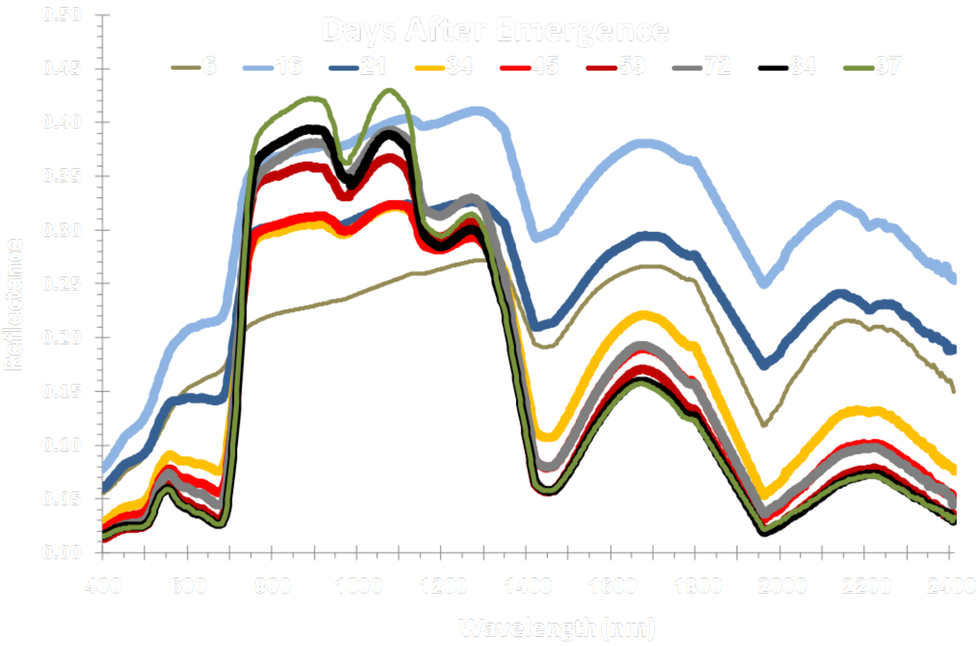

Fig. 2. Wheat canopy reflectance at different growth stages (Pimstein, 2007).

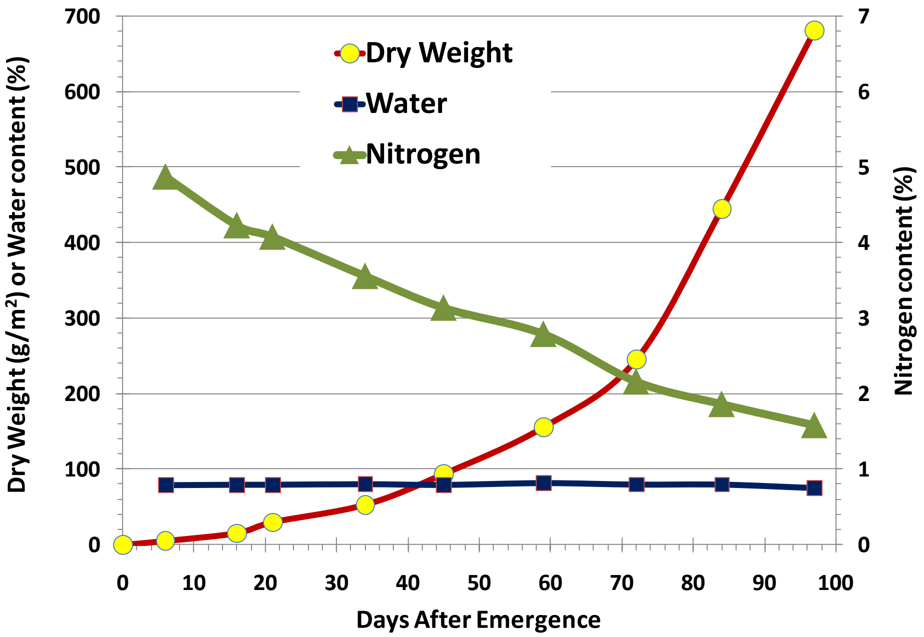

Fig. 3. Biomass, nitrogen, and water content in wheat canopy, from sowing to the grain filling period (Pimstein, 2007).

The capacity of retrieving the complete spectrum of the materials included in hyperspectral airborne images enables the performance of quantitative composition analyses of every pixel in the image. However, one of the limitations for agricultural applications corresponds to the need of large amount of calibration data in order to generate a reliable model to account for the vegetation status. Given the limited amount of resources and time availability during HSR campaigns, only a few samples may possibly be collected in the field for generating the respective models. Moreover, these samples usually do not cover the entire range of the biophysical parameters existing within and between fields, limiting the applicability of the model.

Ground spectral data (ASD) were used to supplement the ground truth data collected from ten hyperspectral images (AISA-ES) taken during the 2006/07 growing season in Israel. Beside correction for visual anomalies (e.g. striping), the images were radiometrically and atmospherically corrected applying in-flight calibration approach using ATCOR model (DLR, 2009). This approach adjusts the images radiometrically, apply atmospheric correction and generate reflectance images. The data were also transformed into derivatives and continuum removal domains for selecting the pre-processing method that could best fit for combining ground spectral with hyperspectral airborne data. Our results show that using a calibration model that is based on ground spectral measurements is not accurate for predicting the dry biomass and N-P-K nutritional crop status estimation from airborne data. Alternatively, significant improvement was achieved when the calibration model was based on samples that were collected from both ground spectral data and airborne hyperspectral images. Therefore, it is important to use all spectral population (field and airborne) to generate a robust and generic model to predict biochemical parameters of wheat crops. However, even after best procedure, running the Negev-DSS on the same area within a field, based on two different stripes (taken at the same flight) revealed different DSS accuracy (Fig. 4), emphasizing that more work must be carried out before basing applications on hyperspectral airborne images.

A total of 9 multispectral images from QuickBird, Landsat ETM+, and EO1-ALI platforms, together with 12 hyperspectral airborne images (AISA-ES) were acquired during heading time of 4 growing seasons (2005-2008) in Israel. In order to apply the Negev-DSS, characterization of the field crop water and nutrients status, and identify weeds infestation. All images were radiometrically and atmospherically corrected and transformed to relative reflectance domain. It was found that, due to the high level of complexity involved in the image interpretation, this data could only be used indirectly for supporting agronomic decision making. In addition, when considering satellite images, cloud coverage could prevent taking images at the specific heading time. Use of hyperspectral airborne images represent an alternative because of its flexibility regarding weather conditions, and because its possibility of better retrieving the crop biophysical parameters from the spectra. In this regard, chain processes for improving efficiency and consistency of atmospheric and radiometric corrections, together with accurate and applicable calibration models for the retrieval of the crop parameters, must be further developed before it would be able to base the Negev-DSS or other quantitative models upon HSR.

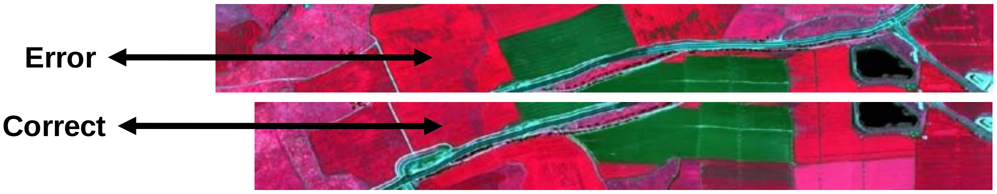

Fig. 4. Validation result of the DSS recommendations for a wheat field, done by synthetic Landsat 7 ETM+, EO1-ALI or VENμS bands resampled from AISA-ES.

SUPERSPECTRAL RESOLUTION

Regarding costs and data processing procedure simplicity, we conclude that each application must be based on specific spectral bands/wavelength that should be picked ad hoc, hence, using an intermediate alternative as the superspectral resolutions should be considered as the selected way toward comprehensive application tool in agriculture. The multispectral sensors can still be used for specific application that they enable although their low resolution (all types). We think that hyperspectral data will be used mainly for identify the important wavelength, and new VI development, while the main application based on RS will be based on superspectral data. One option is the forthcoming VENµS satellite. VENµS is joint mission of the Centre National d'Etudes Spatiales (CNES) in France and Israel Space Agency (ISA). Although this mission is convened as a demonstrated one, it has sophisticated characteristics, suitable for precision agriculture, namely, 12(11) narrow spectral bands in the visible and NIR region of the electromagnetic spectrum, a ground resolution of 5.3 m, two-day revisit periodicity, and a 30 degree tilting capability along and across its track. The band setting and two-day revisit periodicity should allow monitoring of vegetation state and dynamics (e.g., stresses as well as phenological changes). This goal can be achieved by a series of derived products, such as vegetation indices, LAI, red-edge position, and/or time series analysis. Resampling ASD data to VENµS bands yields very promising results in both Negev-DSS, characterization of the field crop water and nutrients status, and identify weeds infestation (Bonfil et al., 2009; Cohen et a., 2010; Herrmann et al., 2010; Shapira, 2008; Shapira et al., 2010). Hence it is expected that shortly after launch many applications would be validated, and the way for utilizing the data by the farmer will be open.

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