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WINTER WHEAT CROP STATE ASSESSMENT, BASED ON SATELLITE DATA FROM THE EXPERIMENT *SPOT-5 TAKE-5*, UNMANNED AIRIAL VEHICLE *SENSEFLY eBee AG* AND FIELD DATA IN *ZLATIA* TEST SITE, BULGARIA

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Key words: *SPOT 5 Take 5, SenseFly eBee Ag, NDVI, Winter Wheat, Physiological State*

Abstract: *this article presents the first results from the agricultural application of satellite time series data from the SPOT5/HRG XS in Zlatia Test Site (ZTS), Bulgaria. Those time series were acquired within the SPOT 5 Take 5 experiment, which was carried out between April and September 2015 as an initiative of CNES and ESA. The main objective of the study is to perform spatial analysis and assessment of the winter wheat physiological state in three test fields using time series of satellite NDVI imagery from SPOT5/HRG XS (product level L2A). The crop state is assessed using a qualitative scale with three levels: poor, satisfying and good condition. This division was based on NDVI threshold values determined during this study using the method natural breaks classification. Assessment maps are prepared for three winter wheat phenological stages: stem elongation, milk development and dough development. Field experiment was carried out on 8 and 9 June 2015 to verify the maps. Image of the test fields was acquired using the specialized unmanned aerial system for mapping senseFly eBee Ag. In addition were performed phenological observations, biometrical measurements and plant samples were collected from nine sampling plots to assess the actual state of the crops. The NDVI values from both eBee Ag/S110NIR and from SPOT5/HRG2 XS pixels have been classified using natural breaks method in three NDVI ranges, corresponding to three classes of crop state (poor, satisfying and good). Those classes coincide entirely with the ground observations of the physiological crop state established during the field campaigns. The results from the study carried out in ZTS show that the high spatial and temporal resolution of the SPOT 5 Take 5 image dataset substantially increase the potential for monitoring of winter wheat and assessment of its state at local level.*

АНАЛИЗ НА СЪСТОЯНИЕ НА ПОСЕВИ ОТ ЗИМНА ПШЕНИЦА НА БАЗАТА НА СПЪТНИКОВИ ДАННИ ОТ *SPOT-5 TAKE 5*, ИЗОБРАЖЕНИЯ ОТ *SENSEFLY eBee AG* И ПОЛЕВИ ИЗМЕРВАНИЯ НА ТЕСТОВИ УЧАСТЪК „ЗЛАТИЯ“, БЪЛГАРИЯ

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Ключови думи: *SPOT 5 Take 5 , senseFly eBee Ag, NDVI, зимна пшеница, състояние на посевите*

Резюме: *В настоящата статия са представени първите резултати свързани с използване на спътникови времеви серии от сензора SPOT5/HRG2_XS за земеделски приложения на територията на* *тестови участък (ТУ) „Златия“, България. Те са получени по време на експеримента SPOT 5 Take 5 който е осъществен в периода април-септември 2015 г. по инициатива на CNES и ESA. Основана цел на изследването е да се извърши пространствена оценка и анализ на състоянието на посеви от зимна пшеница на три полета разположени на територията на ТУ „Златия“ с използване на спътникови времеви серии от NDVI изображения генерирани от сензора SPOT5/HRG2_XS (продукт ниво L2A). Състоянието на посевите е оценено на 3 степени – лошо, удовлетворително и добро на базата на установени в процеса на изследването праговите стойности на NDVI за всяка от тях. Съставени са оценъчни карти за три от фазите на развитие на зимната пшеница - вретенене, млечна и восъчна зрелост. За верифициране на съставените карти на 08 и 09.06.2015 г. е осъществен полеви експеримент. Извършено е заснемането със специализирана безпилотна система за въздушно картографиране senseFly eBee Ag. Проведени са и наземни фенологични наблюдения, биометрични измервания и събиране на растителни проби от 9 елементарни площадки за оценка на реалното състояние на посевите. За трите полета е изградена гео-база данни. Установено е, че стойностите на NDVI на пикселите от изображенията NDVI eBee Ag/S110NIR и NDVI SPOT5/HRG2 XS, съответстващи на местоположението на елементарните площадки, изцяло попадат в границите на праговите стойности на индекса, отговарящи на трите изследвани състояния на посевите.*

Резултатите от проведените изследвания на ТУ „Златия“ показват, че високата пространствена и времева разделителна способност на изображенията получени от експеримента SPOT 5 Take 5 повишават значително потенциала за извършване на мониторинг на посеви от зимна пшеница и оценка на тяхното състояние на локално ниво.

Introduction

Large number of documents in the common agricultural policy of the European Union (EU), are intended to rule and regulate the use of satellite imagery to control the agricultural practices, to assess the crop state of agricultural fields and to predict their yields. With the launch of Sentinel-1A in 2014, starts the EU program for Earth observation – Copernicus [http://copernicus.eu]. On 23 June 2015 the satellite Sentinel – 2A was launched with temporal resolution of 10 days, operating in 13 spectral channels, with spatial resolution of 10 m, 20 m and 60 m. After the launch of Sentinel – 2B, planned for 2016 is expected that satellite imagery with this type of characteristics to be acquired every 5 days. Centre National d'Etudes Spatiales (CNES) and the European Space Agency (ESA) have initiated the project *SPOT 5 TAKE 5* [https://earth.esa.int/web/…] in 2015 before the launch of Sentinel – 2A. The project goal was to change the orbit of the satellite SPOT 5, to the intended orbit of Sentinel – 2 in order to generate imagery with 5 days temporal resolution mimicking Sentinel – 2 imagery. In December 2014, ESA have opened a call for project proposals for test areas around the world, where dense time-series of satellite imagery will be acquired and made available for experiments and the data processing cost will be funded by ESA's Earthnet program. Space Research and Technology Institute (SRTI) and the Institute of Soil Science, Agro-Technology and Plant Protection “Nikola Pushkarov” (ISSAPP) proposed a territory in North-West Bulgaria – Zlatia Test Site (ZTS), the test site was accepted together with other 150 test areas around the world [http://www.cesbio.ups-tlse.fr/…]. In the period between April and September 2015 field data collection campaigns in ZTS were carried out. The imagery acquired during the *SPOT 5 TAKE 5* experiment are preprocessed by THEIA Land Data Centre. The satellite imagery was available in two types of products L1C (Ortho-rectified images expressed in top of atmosphere reflectance) and L2A (Ortho-rectified images expressed in surface reflectance with a cloud and cloud shadow mask). During the vegetation period in 2015, over ZTS are acquired 21 satellite images, with 12 of them with relatively low cloud cover. In this paper are presented the results from the first experiment conducted during the summer in 2015. The main goal of the experiment is to perform spatial analysis and assessment of the winter wheat physiological condition in three agricultural fields in ZTS. NDVI time series are generated using the sensor SPOT5/HRG2_XS. The crop condition was assigned in one of the three classes: poor, satisfying and good condition, using NDVI threshold values. The threshold values are determined with natural breaks classification.

Study area

Winter wheat (Triticum aestivum) is traditionally grown in Bulgaria. There is substantial amount of research dealing with the spectral characteristics of this crop and its ecological and physiological features [Kancheva R. et al 2013]. In Bulgaria, satellite vegetation indices have been broadly used for

mapping the physiological state of winter wheat and other agricultural crops [Roumenina E., et al 1989, 2000, 2011, 2013, 2014, 2015; Vassilev V. et al 2014].
The study area investigated during the field experiments comprises of three agricultural fields, located in North – West Bulgaria, near the village of Kneja, municipality Pleven. This area is one of the most extensive agricultural regions in Bulgaria and the Danube plain, with average elevation of 136 m. The remarkable fertility of this territory is mostly due to the soil type – typical chernozem. The test fields are sown with the cultivar *Enola,* 4 cm deep, with norm of 26 kg/dka. The spatial analysis and assessment of the test fields are performed in the period April – July 2015, during the experiment *SPOT 5 TAKE 5.* In the beginning of the project, the crop is in phenophase stem elongation on 15 April 2015 and the end of the project coincides with the harvest on 10 and 11 July 2015.

Methods and data

It is vital for the farmers to have in-time estimates of local crop condition anomalies within the fields. This information enables taking on-time decision making and prevents such cases and supports sustainable usage of the agricultural resources. Different technologies are applied for controlling and crop condition assessment: ground data collection equipment with high accuracy but very time and resource consuming; unmanned aerial vehicles, airplanes and satellite imagery. The current article satellite derived information from the experiment SPOT 5 TAKE 5 was used a data source. Based on image processing and analysis in ArcGIS environment, crop condition maps are composed for winter wheat for three fields in the studied period. For validation of the achieved results sub-satellite ground measurements were conducted between 07-09.06.2015. Crop condition assessment was based on: ground phonological information, biometric measurements, collection of plant tissue samples conducted in the Institute of Maize in Knezha. During the experiments a unmanned aerial vehicle senseFly eBeeAg was used. All collected data during the experiments were included in the ArcGIS geodatabase.

Multispectral Satellite and aerial imagery

The spatial resolution and winter wheat crop condition analysis in the studied fields in based on multispectral satellite imagery from SPOT5/HRG2 XS (product L2A) collected from the SPOT 5 TAKE 5 experiment. They have 4 spectral bands at the following wavelengths: 1) λλ 0.50 – 0.59 µm; 2) λλ 0.61 – 0.68 µm; 3) λλ 0.79 – 0.89 µm и 4) λλ 1.58 – 1.75 µm. The spatial resolution is 10 meters. Nine cloud free images were processed, acquired in the period between 19.04.2015 – 13.07.2015.

The Canon S110 camera was used for the image acquisition with the specialized unmanned aerial vehicle equipment senseFly eBee Ag. The camera has the following spectral bands: 1) λλ 0.52 – 0.59; 2) λλ 0.58 – 0.67 и 3) λλ 0.80 – 0.90. In order to get spatial resolution of 10 cm/pixel for the images the UAV flight height of 286 m is set.

Ground data collection

Crop calendar information was obtained from a local farmer including the following information: previous sown crop, date of sowing and harvest, beginning and end date of all major phenonological stages of the crops, achieved yield, date and type of the agricultural treatments, date of fertilizing, herbicides and insecticide treatments.

During the conducted sub-satellite experiments on 08-09.06.2015, information for 9 sampling units with size $1m^2$ within the studied fields was collected: crop phenophase, LAI, height and density of the crop canopy, soil moisture and GPS measurement. The collected plant tissue samples ware evaluated in the laboratory for quantity of fresh biomass, dry matter, chlorophyll content, caronines and total nitrogen content.

Building-up a spatial Geodatabase

A geodatabase for all three studied fields was created in UTM WGS84 projection including:

- Collected sampling data for each field including: accurate location, soil properties, crop calendar;
- Raw multispectral imagery from: 1) SPOT-5/HRG2 XS (product L2A) and 2) eBee Ag/Canon S110 NIR camera

- Ground collected data and laboratory measurement;
- Processed information layers from the conducted analysis.

The crop condition assessment was applied utilizing the Normalized Difference Vegetation Index (NDVI)

(1) NDVI = (ρNIR - ρRed) / (ρNIR + ρRed)

Where, където:

ρNIR – **near** infrared reflectance values
ρRed – **red** reflectance values

The NDVI index is presented first in the work of Rouse et al, 1973 and it is the mostly applied vegetation index ever since for satellite vegetation monitoring. The NDVI values traditionally lies between -1 and +1. The NDVI index can be generated with vast amount of satellite imagery with different spatial resolution, which have available spectral bands in the red and NIR portion of the electromagnetic spectrum (*0.55-0.75 μm*) and (*0.75-1.0 μm*), respectively [P. Sellers, C. Turker et al., 1994]. The algorithm for calculating the NDVI is implemented in most of the dedicated software's for image processing. The index is mostly used for vegetation season dynamics evaluation for example monitoring the season analysis and condition of crops.
The procedure for image processing includes the following stages:

1) Orthorectified imagery creation from the eBee Ag/Canon S110 NIR camera;
2) NDVI generation from SPOT 5/HRG XS and the eBee Ag/Canon S110/NIR camera;
3) Applying crop mask only for the selected crop fields;
4) Applying 15 m buffer within the border of the fields;
5) Aggregation of the unmanned aerial vehicle to the spatial resolution of the satellite images from the experiment SPOT 5/HR2 XS to 10 meters.
6) Applying of natural jerks classification algorithm (*Jenks' Natural Breaks Algorithm*) [Jenks G., 1967] to the selected winter wheat fields with 4 classes. This algorithm determines the borders from preliminary determined classes is based on natural data grouping of the images and differentiate between the class values the best way possible. For each class a threshold values are determined which resembles the best grouping of values. This enables to minimize the variations of the NDVI values. Three crop condition classes are defined for the winter wheat: poor condition, satisfactory and good condition. One additional class is defined not occupied with winter wheat cover. Winter wheat crop condition maps are composed and the area occupied by each class is calculated.

Results and Discussions

The winter wheat condition determined by the NDVI threshold values is constantly changing during the vegetation season (Figure 1.) From the moment the winter wheat is sown they start to accumulate biomass and the values of the index start to increase. At milk dough phenophase the accumulated biomass is at its peak, and afterwards the values start to decrease towards the end of the vegetative season. The lower values of the vegetation index is evidence for occurring stress situation, which in most cases is due to pest infestations or bad soil moisture conditions.The average values of the NDVI derived from SPOT 5/HRG2 XS for the three studied fields for all images varies between 0.20-0.85 (Figure 1).

Using the vegetative crop calendar and the average values analysis of the NDVI/SPOT 5/HRG2 XS (Figure 1.) three acquisitions dates were selected: 19.04.2015, 08.06.2015 and 08.07.2015. Threshold values are determined for these dates and crop condition maps were created (Figure 2, 3, 4).

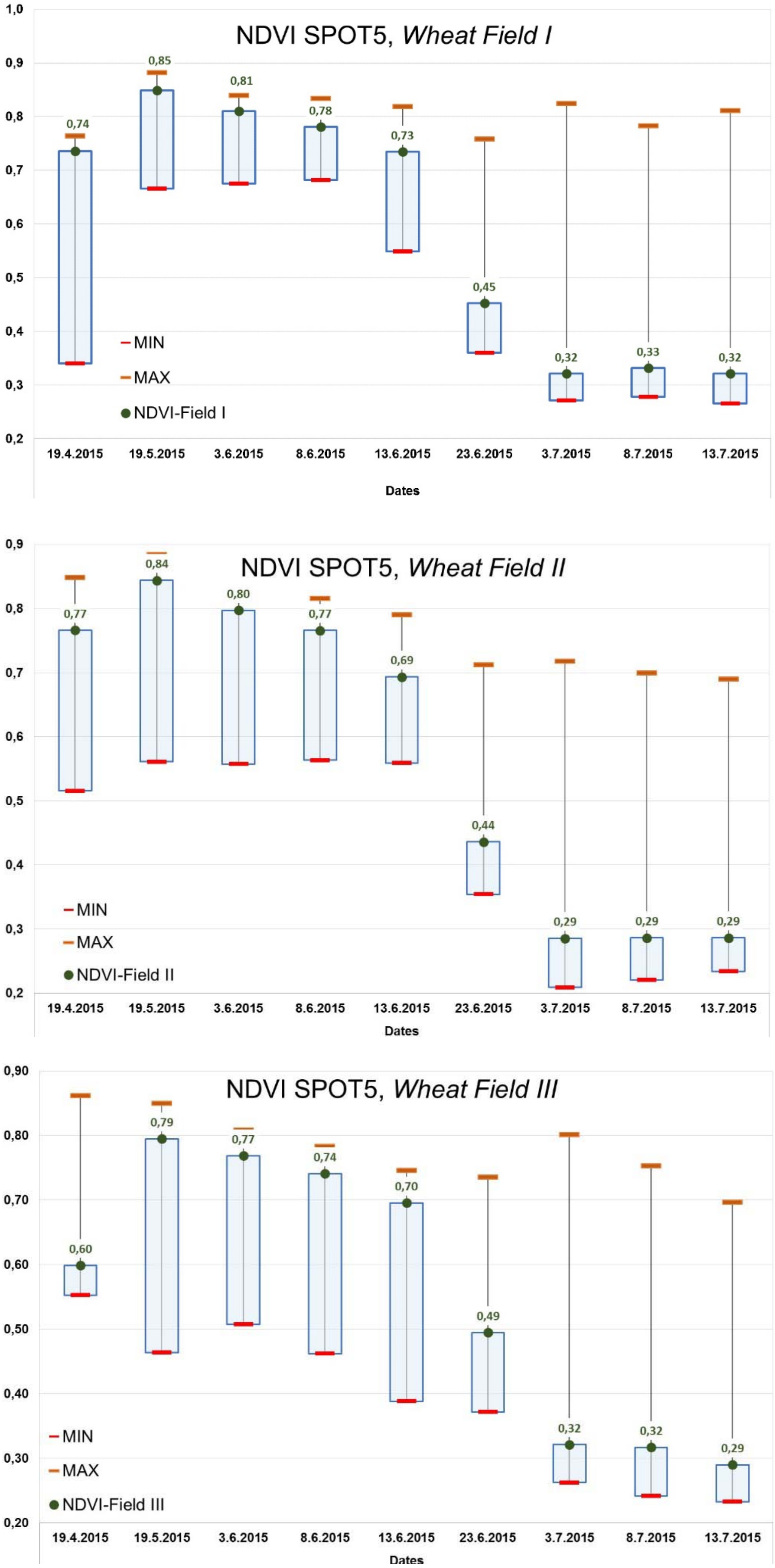


Fig. 1. Mean, maximal, and minimal NDVI from the *SPOT 5*/HRG2 XS over the studied winter wheat fields for the period 19.04.2015 – 13.07.2015.

Table 1. Threshold NDVI values for the SPOT 5 HRG2 XS sensor

Date	Phenophase	Condition	NDVI Threshold values
19.04.2015	Stem elongation	Poor	0,34 - 0,58
		Satisfying	0,59 - 0,75
		Good	0,76 - 0,86
08.06.2015	Milk Dought	No winter wheat areas	0,35 - 0,59
		Poor	0,6 - 0,7
		Satisfying	0,71 - 0,75
		Good	0,76 - 0,82
08.07.2015	Maturity	Weeds	0,49 - 0,7
		Poor	0,35 - 0,48
		Satisfying	0,3 - 0,34
		Good	0,22 - 0,29

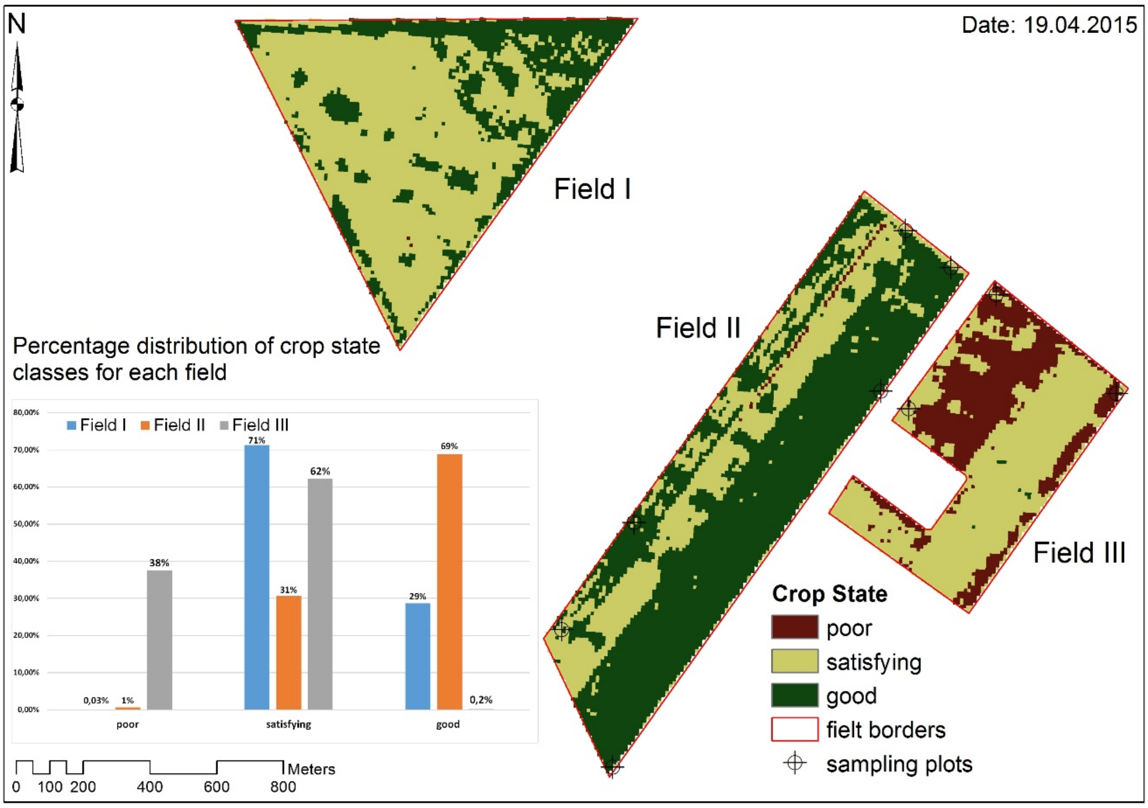
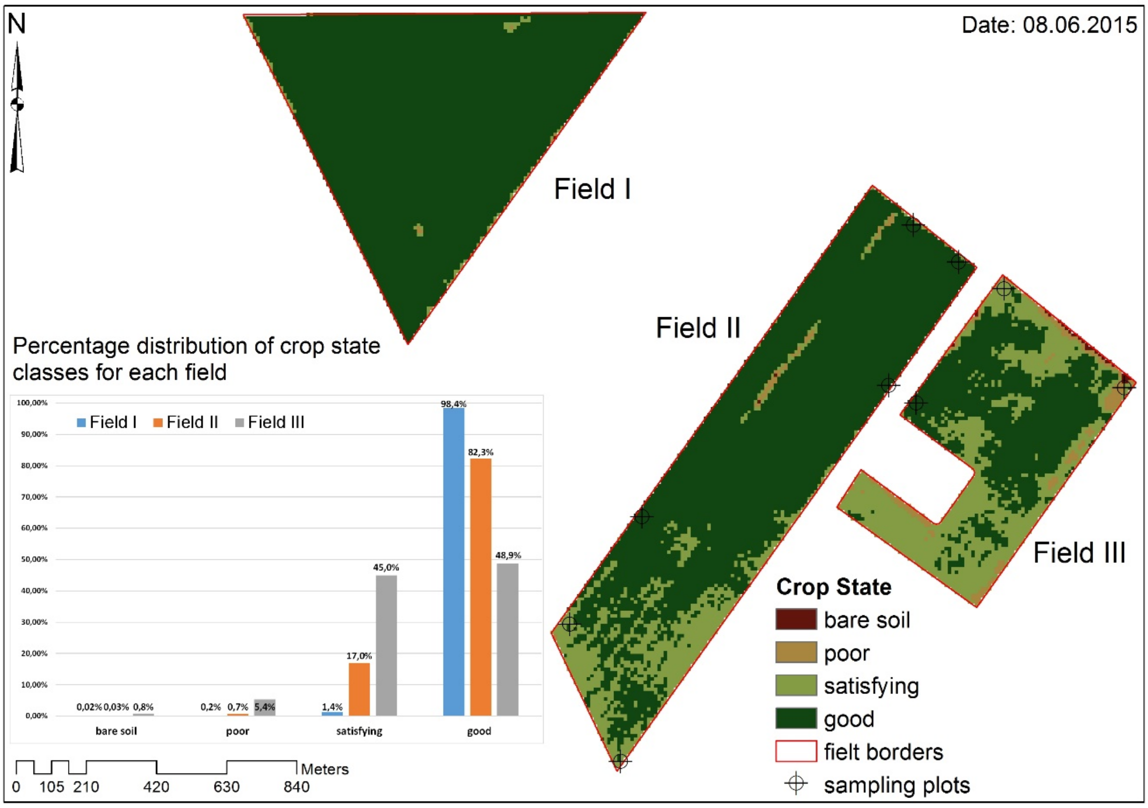
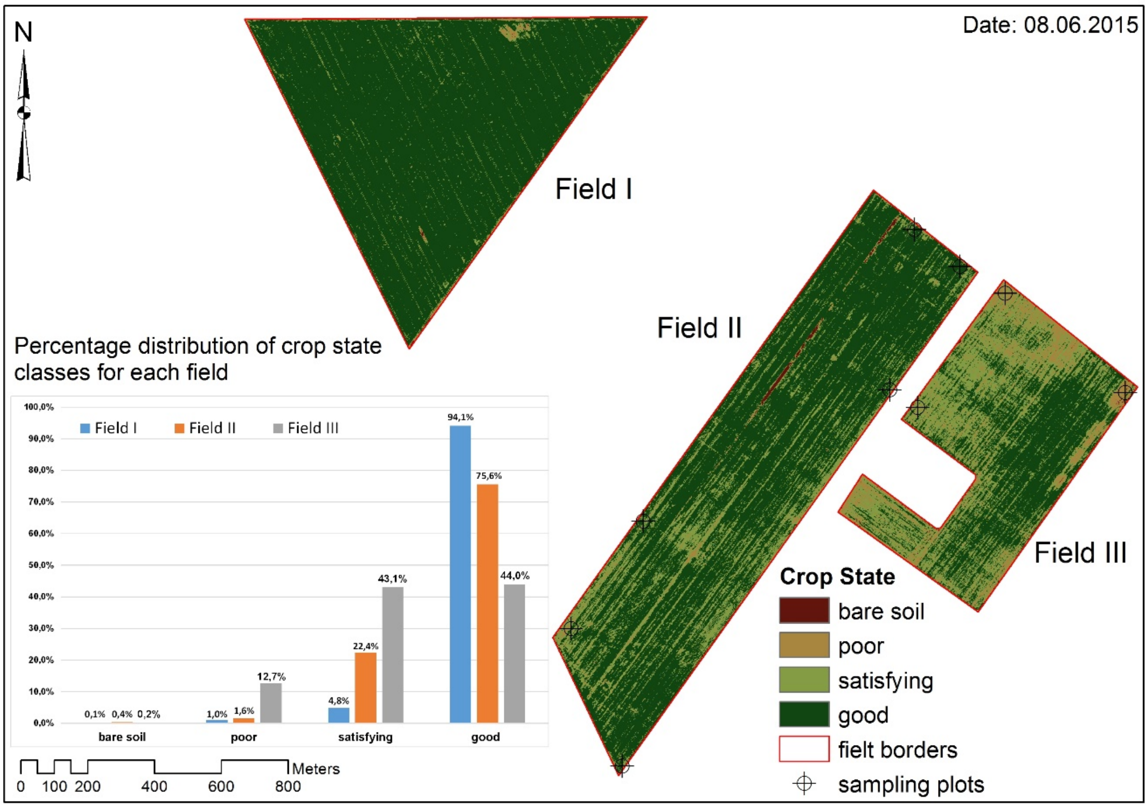


Fig. 2. Winter wheat crop state assessment map for 19.04.2015 produced using a classification of NDVI image from the *SPOT 5/HRG2_XS* sensor



а)



б)

Fig. 3. Winter wheat crop state assessment map for 08.06.2015 produced using a classification of NDVI image from: a) the SPOT 5/HRG2_XS sensor, and b) the eBee Ag/Canon S110NIR camera.

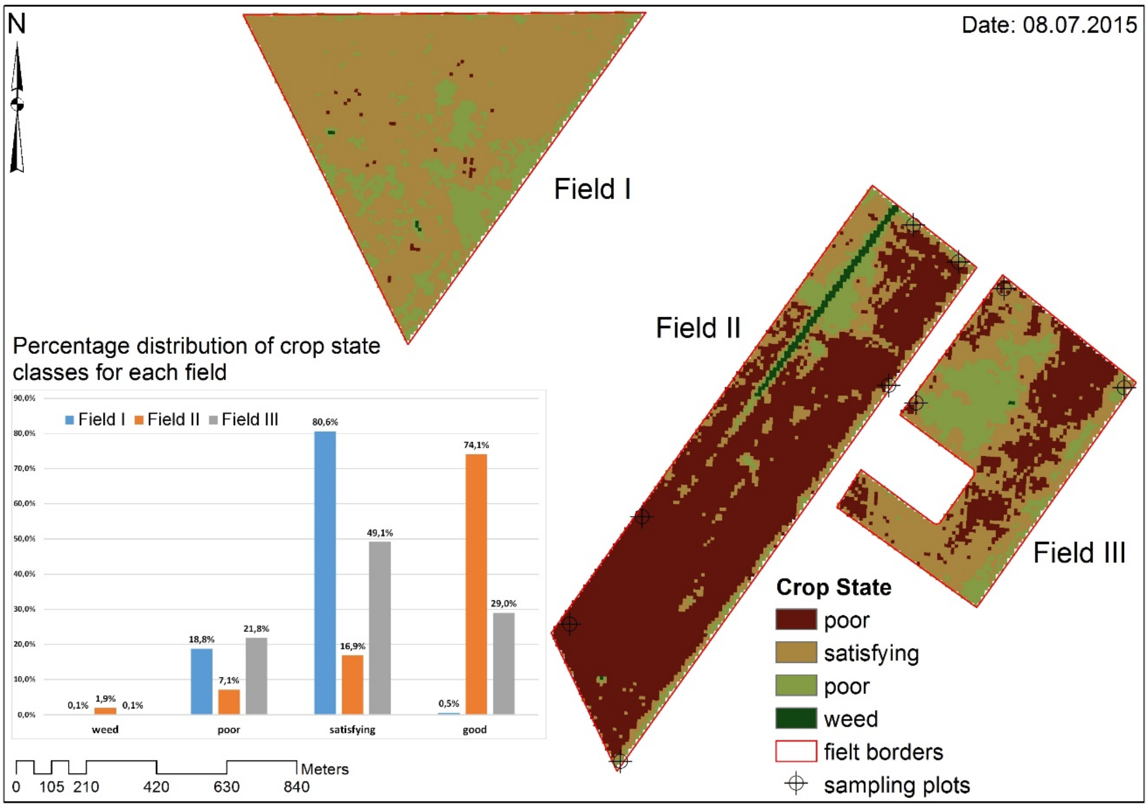


Fig. 4. Winter wheat crop state assessment map for *08.07.2015 produced using a classification of NDVI image from the SPOT 5/HRG2_XS* sensor

It is evident from the generated maps that the winter wheat is growing not evenly over the three fields. On all three fields the sowing dates were at the optimal time for this region. The first and second fields were sown on 07 and 08.11. 2014, and the field three was sown on the 23.11. 2014. The first two fields head towards winter at the stem elongation phenophase, while the third field was at emergence phenophase at that time. The areas with winter wheat at stem elongation phenophase are characterized with high threshold values (Table 1). Because of late development some parts of the fields with low NDVI values were assigned to satisfactory condition. They occupy 71% of the total area of field I ad 62% of the total area of field II. In the worst condition is field III, occupying 38% of the total area. On the 19.04.2015 the field was treated with insecticide for Eurigasther integriceps with pest population between 3-8 individuals for 1 m^2. The following formula was used for NDVI change evaluation:

(2) $$\Delta NDVI = (NDVI_2 - NDVI_1)/(NDVI_2 + NDVI_1)$$

Where $NDVI_2$ is the average values of the NDVI for every field at milk dough phenophase and $NDVI_1$ – average values of NDVI for each field at stem elongation phenophase [P'yankov S., et al., 2009]. A map was generated based on the NDVI change values (Figure 5). The NDVI values for field III are the highest, where evolution of the crop condition was observed.

On 08.06.2015 the winter wheat was at milk dough phenophase, which started on 30.05.2015. The good condition in the fields I and II is occupying 83% of the total area (Figure 3 a), whereas field III the percentage of good condition is 48% of the total area. The same situation can be observed when using the eBee Ag/S110 NIR (Figure 3 b).

Based on the analysis of the NDVI threshold values (Table 2.) it was estimated that the classes satisfactory and poor condition from the NDVI eBee Ag/S110NIR are with low values with wide range compared to data extracted from the satellite imagery. There is a big difference between the threshold values of the class no winter wheat cover (0.11 – 0.46) from the eBee SPOT5/HRG2 XS and (0.35 – 0.59) derived from NDVI SPOT5/HRG2 XS. More research is necessary to investigate this issue in more detail.

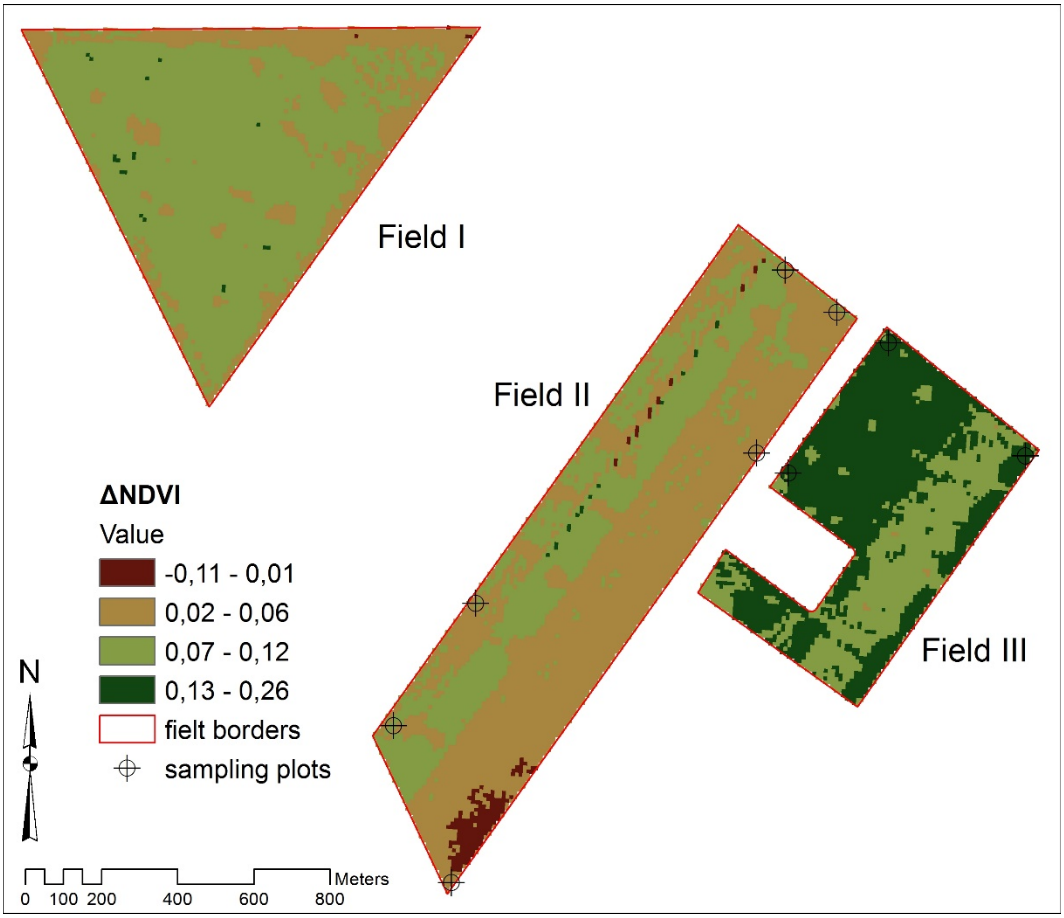


Fig. 5. Map of the change in NDVI values (ΔNDVI) between phenological stages stem elongation and milk dought

Validation process using the ground collected data

When comparing satellite derived NDVI at local level it is obligatory to take in consideration the border between the soil and vegetation cover, which can have different index values. Validation procedures are required to be accomplished using ground collected data. In many articles such as [C.Tucker, P. Sellers, 1986; M. Gandhi et al., 2015] consider the NDVI index as a indicator for the environment processes dynamics such as vegetation cover productivity. These authors share the opinion that the NDVI is an integral indicator of the vegetation activity.

Table 2. Results from the field measurements on 8 and 9 June 2015 for winter wheat state assessment and NDVI threshold values.

Parameter	**Crop state**		
	Poor	**Satisfying**	**Good**
Crop height (*cm*)	62	78	83
Canopy coverage (*%*)	51	80	90
Aboveground biomass - (*kg/0.75 m^2*)	1.1	1.5	1.7
Dry matter (*%*)	91.62	91.61	90.26
Chlorophyll a+в (*mg/g fresh biomass*)	3.7	4.8	5.6
Carotenoides (*mg/g fresh biomass*)	0.72	0.86	0.94
Total nitrogen (*N*) content in the dry sample (*%*)	1.57	1.98	1.91
Soil moisture VWC % mean	10.9	11.9	10.5
NDVI threshold - eBee Ag/S110NIR	0.47 – 0.64	0.65 – 0.70	0.71 – 0.86
NDVI threshold - SPOT5/HRG2 XS	0.60 – 0.70	0.71 – 0.75	0.76 – 0.82

The present article utilizes the information from a sub-satellite experiment conducted on the 08 and 09.06.2015, for evaluating the actual winter wheat condition. Ground data was collected for 9 sampling points within fields II and III. SPOT 5/HRG2 XS image acquired on 08.06.2015 was used for the experiment over Zlatia test site. Three sampling units were selected representing areas with poor condition, four representing satisfactory condition and two with good condition. The collected ground data for each sampling unit is summarized in Table 2.

The NDVI values derived from the eBee Ag/S110 NIR and SPOT 5/HRG2 XS are correlated with the threshold values from the sampling units.

Conclusion

The conducted experiment in Zlatia test site shows that the better spatial and temporal resolution from the SPOT 5 TAKE 5 experiment enhance the potential for better crop monitoring and evaluation of their accurate condition at local scale.

The winter wheat condition evaluated based on the threshold values of the NDVI both from SPOT 5/HRG2 XS and NDVI eBee Ag/S110 NIR, over the vegetative season gives opportunity to conduct both quantitative and qualitative assessment on field level.

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