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CROP MONITORING USING SPOT-VGT NDVIs S10 TIME-SERIES PRODUCT FOR NORTHEAST BULGARIA

Vassil Vassilev, Eugenia Roumenina

Space Research and Techlology Institute – Bulgarian Academy of Sciences
e-mail: vassilev_vas@space.bas.bg

Abstract

The objects of this investigation are the major crops in the Northeast region of Bulgaria, namely winter wheat, winter barley, oilseed rape, sunflower and maize. The article covers the subject of crop monitoring at regional scale with low-resolution and high revisit time Earth Observation (EO) product. The study is focusing on processing and interpretation of Normalized Difference Vegetation Index (NDVI) time-series for crop monitoring, with three different objectives: crop identification, crop phenology estimation, and crop anomaly events detection. The crop identification process was assessed using similarity value analysis between the NDVI crop values from SPOT-VGT NDVIs S10 product and the high-resolution satellite images for a test site in the region of interest. Knowledge of crop phenology was used for vegetation growth parameters extraction from the temporal profiles. To detect the crop anomaly events, correlation between the average yield for the major cultivated crops and the highest reached NDVI values of the identified crops was done with confidence level of 95%, the relevant r values are ≥0.75 and ≤-0.75 for five variables. The results show high correlation (r) for winter barley at r + 0.99, sunflower and oilseed rape cultivars have equally high values at r + 0.84. Winter wheat has a good correlation with r + 0.65, while maize cultivars have positive correlation at r + 0. 37. The presented investigation shows the significant potential of using low spatial resolution satellite data for crop monitoring at regional scale in conjunction with agro-phenological information derived from the National Institute of Meteorology and Hydrology (Bulgarian Academy of Sciences), high-resolution images for accuracy assessment and yield statistics. This research contributes for a successfull application and elaboration of the existing JRC MARS methodology.
The continuity of time-series vegetation monitoring is assured by the launch of PROBA-V mission in 2013 as a successor of SPOT-Vegetation.

1. Introduction[1]

Satellite Remote Sensing (RS) provides synoptic, objective and relatively homogeneous data which can be geographically and temporally registered. Therefore, RS is an efficient tool for providing standard, high quality information on agriculture, evenly over broad-scale territories. The Monitoring Agriculture with Remote Sensing (MARS) project of the European Union was established in order to define and demonstrate how RS can be used operationally to supplement, interpret, and standartize agricultural statistical data provided by conventional techniques [1,2]. Satellite RS techniques have been proven to be effective and useful in broad-scale agricultural surveys such as: Large Area Crop Inventory Experiment (LACIE) project in the USA and MARS project in Europe [3,4]. These projects such as LACIE and Crop Identification Technology Assessment for Remote Sensing (CITARS) demonstrate the capabilities of RS for crop inventory and forecasting [5,6]. Currently, the Group of Earth Observation (GEO) is intergrating a Global Crop Monitoring initiative called GEOGLAM [7].

Crop identification during the growing season is a major challenge for forecasting crop production as well as for controlling area-based subsidies in the European Union member states [6]. The basis for separation one crop from another is the supposition that each crop species has a unique visual appearance and spectral signature on the image. However, separating these species may be difficult because of variations in soil properties, fertilization, pest condition, irrigation practices, planting dates, as well as intercropping, and tillage practices [8]. Vegetation types can be characterized using their seasonal variations in the Normalized Difference Vegetation Index (NDVI) time-series, which include a series of images, acquired each 10-days and showing the crop development dynamics. For example, the winter wheat phenophases like tillering and flowering as well as harvest, can be successfully identified using sensors with different spatial resolution in various band combinations and severe ground surveys,

[1] Abreviations used:
NIMH-BAS – National Institite of Meteorology and Hydrology-Bulgarian Academy of Sciences
MARS - Monitoring Agriculture with Remote Sensing
LACIE - Large Area Crop Inventory Experiment
CITARS - Crop Identification Technology Assessment for Remote Sensing

including collecting information for defining training samples for the supervised classification [9,10]. A number of different methods have been developed during the last two decades to discriminate crop types using data from NDVI and from the Advanced Very High-Resolution Radiometer (AVHRR). These methods employ a variety of different approaches including temporal profiles of crop phenology manifested in the NDVI [11,12], and classification of multi-temporal data [13,14], which can be applied on variously managed crop areas worldwide.

The purpose of this case study comprises of crop monitoring at a regional scale (Northeast Bulgaria), and it includes the following tasks:

(1) Identification of the major crops (winter wheat, winter barley, sunflower and maize) using cluster analysis method upon a 10-day SPOT-VGT NDVIs S10 time-series product with low spatial resolution of 1000 m by extracting summarized agro-phenological information and NDVI values derived from high-resolution satellite images.

(2) Onset recognition of the crop growing period, length of the reproductive growth period and the entire crop growing season for the winter and summer crops for each studied year. Knowledge of crop phenology was used for vegetation growth parameters extraction from the temporal profiles.

(3) Crop anomaly events detection using yearly NDVI time-series cluster analysis and quantative data.

2. Materials, methods and data used

The study area is the North-East Bulgaria region, which includes the following regions: Targovishte, Shumen, Varna and Dobrich. The area represents intensively cultivated area sowed mostly with cereals and sunflower. This territory is one of the main agricultural regions of the country. The geology is presented mainly by Miocene limestone, clay and marl covered subsequently by loess. The area is part of the European-continental climatic province of the temperate climatic belt. Climate is moderately warm with no distinctive dry season. Mean annual air temperature is 10.2°C. The maximum precipitation is in June and the minimum – in February, with overall annual precipitation of around 540 mm. Due to the carbonate bedrock, i.e limestone, marl; the hydrographic network is represented by intermittent streams. The main soil types are chernozems from the zonal ones and fluvisols from the azonal ones. Figure

1. Study area

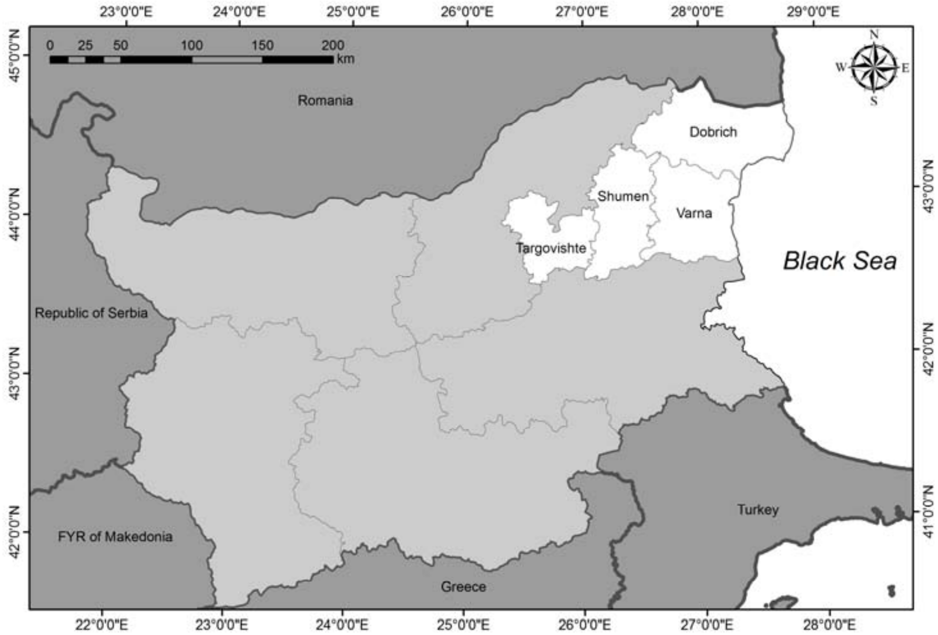

Fig. 1. Study area

The major crops winter wheat, winter barley, sunflower and maize on the arable territory of the Northeast region of Bulgaria are investigated in the present case study.

The satellite data used herein was provided by the Agri4cast Action at the Monitoring Agricultural Resources Unit (Joint Research Centre, Ispra, Italy). The data set includes five time-series (2007-2011) with 36 stacked 10-day NDVI maximum value composites for each year from 01 January until 31 December. The NDVIs S10 smoothed actual product was registered by the low spatial resolution (1000 m) of SPOT-VGT sensor. Thus, totally 180 low resolution satellite images were used for the present case study. Then, agro-phenological ground data was collected from the monthly open access bulletins (available at www.meteo.bg) by National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences (NIMH-BAS).

High-resolution satellite images are used to complement the crop identification process. The satellite images choosen for that purpose are: SPOT-4 HRVIR sensor, with 4 multispectral bands with 20 m spatial resolution and 1 panchromatic band with 10 m spatial resolution. The spectral portions are the following: green band - 0.50 – 0.59 μm; red band - 0.61 – 0.68 μm; near infrared band - 0.78 – 0.89 μm; shortwave infrared band - 1.58 – 1.75 μm and the panchromatic band - 0.48 – 0.71 μm. The temporal resolution of the SPOT-4 satellite is 26 days and has 60 km scene width. Additionally, three LANDSAT-5 TM satellite images were used as well. The spatial resolution of each image is 30 m. in the visible and infrared bands and 120 m. in the thermal bands. The spectral portions of the bands are the following: blue band - 0.45 – 0.52 μm; green band - 0.52 – 0.60 μm; red band - 0.63 – 0.69 μm; near infrared band - 0.76 – 0.90 μm; shortwave infrared and middle infrared bands - 1.55 – 1.75 μm; 2.08 – 2.35 μm and thermal band - 10.40 – 12.50 μm. The temporal resolution of the LANDSAT-5 TM satellite is 16 days and the scene width is 185 km. All of the chosen high-resolution satellite images are situated in a test site part of the Northeast region of Bulgaria, where ground data was collected and are selected to correspond to a major phenological stage of crop development for the agricultural year 2011.

The most commonly used RS vegetation index for agricultural applications is the NDVI, expressed by the following formula: $NDVI = (NIR-VIS)/(NIR+VIS)$, where VIS and NIR stands for the spectral reflectance measurements acquired in the visible red and near-infrared regions, respectively [15]. NDVI is a commonly used space-observed measure of the chlorophyll activity. It ranges typically from 0.15 (bare soils) to 0.80 (dense vegetation).

An arable mask was applied, which was aggregated to the spatial resolution of the SPOT-VGT NDVIs S10 product using information from CORINE 2000 database [16]. The Northeast region of Bulgaria was cropped and images were stacked on yearly basis (2007-2011) (one file compiles 36 bands, repsesenting the 36 decades of the year).

The *k*-mean and Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithms are the most frequently used ones in RS. The ISODATA algorithm was selected in this study because it allows different number of clusters, while the *k*-mean algorithm assumes that the number of clusters is known a priori [17,18,19]. Unsupervised ISODATA classification with five classes was used on the individual yearly stacked images in ERDAS Imagine software, based on the temporal syntheses generated in the previous stage. The arable territory of the Northeast region of Bulgaria was divided into five clusters based on the time-profile differences of their NDVI values using this approach. As a result of the above classification five clusters were defined and the analysis was conducted by extracting the mean NDVI values for each decade for every cluster separately. As a result yearly NDVI time-series profiles were created.

The developing stages used in the present investigation for winter crops are: (1) sowing; (2) emergence; (3) tillering; (4) heading; (5) flowering; (6) grain filling periods (milk and dough development); (7) ripening; and (8) harvest. On the other hand, the developing stages for spring crops include: (1) sowing; (2) vegetative; (3) flowering; (4) grain filling; (5) ripening; (6) maturity; and (7) harvest.

The crop identification process was accomplished using the time-series cluster analysis, summarized agro-phenological information derived from the monthly bulletins that include the most important information such as: phenological stage and the agro-technical threatments throughtout each decade of the growing season for the major cultivated crops. Additionally, high resolution satellite images were utilized in order to identify the major crops. Thus, the maximum NDVI values for the major phenological stages for winter and spring crops were extracted both from the low-resolution product and high-resolution satellite images. The high-resolution satellite images are acquired in the agricultural year 2011, which is labeled as normal in a test site where ground data was collected. This will help identify the major cultivated crops on the low-resolution SPOT-VGT NDVIs S10 product for the whole 5 years.

Knowledge of crop phenology was used for vegetation growth parameters extraction from the temporal profiles. An approach partly based on Reed et al. (1994) was applied to identify the moment when the NDVI exhibits a sudden increase that can signal the onset of significant photosynthetic activity. The seasonal duration of the entire crop growing season, measured in decades, was derived by subtracting the time of onset of greenness from the time of the end of season. After that, the smoothed data were used to identify the maximum NDVI value for the growing season for each crop. Finally, the onset of the crop growing period, length of the reproductive growth period and the entire crop growing season for the winter and spring crops for each studied year were identified using the time-series cluster analysis profiles as reference and measured in decades of the year.

Crop anomaly events detection was performed in order to investigate the capabilities of the low resolution satellite product for detecting the ground observed anomaly events using yearly NDVI time-series data. Additionally, the quality of the anomaly was assessed using quantative data. Since, the anomaly events have their serious impact on the NDVI values and consequentily on the yield figures a correlation analysis was conducted. Correlation between the average yield figures of the major cultivated crops (winter wheat, winter barley, sunflower, maize and oilseed rape) for the region derived from official statistics and the maximum NDVI values reached for each crop for the five year period was extracted.

3. Results and discussions

3.1. Identification of the major crops using SPOT-VGT NDVIs S10 satellite product

A consideration amongst the five year period studied using the ground data show some anomaly events such as: (1) bad overall agro-phenological conditions with low yield figures (2007); (2) most favourable conditions in agro-phenological aspect with highest yield in 20 years (2008); and (3) meteorological conditions delayed the harvest effecting both the NDVI values and yield figures (2010); These considerations now will be assessed applying the remote sensing data.

The following crops: (1) mixed crops; (2) winter wheat; (3) winter barley; (4) sunflower; and (5) maize; were identified to be predominantly cultivated for each of the classes (1-5) using as reference the time-series cluster analysis, summarized agro-phenological information for the choosen years (2007-2011) was prepared, but for formatting ussues only the information between may and october is presented in (Table 1) and maximum NDVI values for the identified crops derived from high-resolution satellite images.

Time-series cluster analysis profiles for each of the identified crops for the five year period were created, in order to evaluate similarity between the profiles (Figure 2). The class that makes exception is the class mixed crop, which shows no consistency and aggrement between the five yearly profiles and clearly presents a mixture of cultivars, which in consequens has large vegetative period spreading from 8th decade to the 30th decade (Figure 2). Therefore, the class was assigned to be a mixed crop class, rather than identifying a single crop. Althought, for the crop anomaly event detection section, where quantitative data will be introduced, oilseed rape yield figures will be assigned to this class. For the other crop classes identified namely winter wheat, winter barley, sunflower and maize a similarity between the time-series cluster analysis profiles was observed for the studied years (Figure 2). The variety amongs the other crop profiles is due to agrometeorological conditions experienced in each individual year.

Table 1. Agro-phenological summary data from the monthly NIMH-BAS bulletins

Month / Year	May	June	July	August	Sept.	Oct.
2007	High temp. Low soil moisture content. WW and WB shortening of phases - flowering. M. vegetative, 3-9 leaf. S. vegetative, 2-4 leaf.	2: M. - vegetative S. - flowering 1: WB. harvest 2-3: WW. harvest; Fruit trees - pick	Drought conditions, 2-3: M. grain filling (milk dough)	1: intensive rainfall 2-3: M. grain filling (dough dev.)- 3: late hybrids grain filling (milk dough dev.) Low yield figures.	Intensive rainfall 2: M. late hybrids end their dev. 1: late harvest due to rainfall 3: WB.WW Sowing. 2-3: grape vintage	Good soil moisture content. WW - emergence (1–2 leaf), third leaf Late sowing of winter crops
	May	**June**	**July**	**August**	**Sept.**	**Oct.**
2008	Late sowing of spring crops. 1- emergence (3–5 leaf), S – vegetative, 2–4 leaf. 2- M vegetative - flowering 3- WW, WB- grain filling (milk dev.) 3- S – flowering	> biomass of spring crops. 1- WB grain filling (dough dev.) 2- WW and WB – ripening., R. - flowering. 2- S –flowering 3- stress. 3-M flowering 2- WB. harvest 3- WW. harvest	2- shortening of phases spring crops. M. – grain filling 2- Early hyb.grain filling (milk dough). 3 – S. and M. grain filling (dough dev.) 3- S. ripening. 3- 100% WB. harvest and 95% WW.	Hot and dry 1- fast dev. M. grain filling (dough dev.) 2- S – beginning of ripening 3- S. harvest.	1- Drought 2- rainfall 1-2- average late hyb.M. ripening - maturity 1-2- S. harvest 100%, M. early hyb.	1-rainfall Late sowing 2-3- increase emergence, 1–3 leaf. 3- emergence 2-3 increase sowing rate, 80% -WW, 50% -WB
	May	**June**	**July**	**August**	**Sept.**	**Oct.**
2009	Low soil water content	3- rainfall. 1 – WW milk dev., WB – dough dev. 2- 3 – WW WB. Rip. and	1-good water content 2-3- drought 3- S. –	2-3- drought 2- M- maturity. 2- late M. – grain filling, ripening 3	1-3 late M. maturity 1- S. end of harvest 2-3- M. harvest	Good water cont. .2- rainfall – late sowing 3-

	1-yellow.2-3-(shortening) Flowering and grain filling 3-end of sowing late hyb. M.	maturity. 3-M.S. veg., flowering phase. 2-harvest WB, 2-3 –WW	flowering, grain filling 3-late M – flowering, early - grain filling, ripening	– S. harvest		emergence 3-Sowing 75-80% of W crops
	May	**June**	**July**	**August**	**Sept.**	**Oct.**
2010	1-2- M. – vegetative (3–5–7 leaf), S. vegetative 2–4 leaf.1-flowering 2- mass flowering 3WW, WB. Flowering, grain filling.3-WB. Mass grain filling (milk dough) 3-S. M.> biomass 3-S. flowering.	1-2 WW. From milk to dough dev. 3-M. and S. max biomass flowering and grain filling 3-early hyb. Grain filling 3- WB. harvest Rainfall - low grain quality	1-slow dev. M.S.flowering to grain filling S. grain filling (dough dev) 3-WW. harvest	Drought 1-S. ripening. Late hyb. M. grain filling (milk to dough dev.) 3 – S. mass low arable land maturity 2-harvest WW. 3-S. harvest and early hyb. M. 3-deep soil plowing	2- average late hyb. M. ripening and late hyb. Dough dev. 2- S. maturity 3-rainfall delay harvest of spring crops. Emergence of early rapeseed, WW and WB.3 - sowing mass	2, 3-emergence. 2-rainfall delay sowing of winter crops.
	May	**June**	**July**	**August**	**Sept.**	**Oct.**
2011	1-WW.WB. heading and beg. Flowering. 1- M. vegetative 3-5-7 leaf. S. vegetative 2-leaf. 3-WW. WB flowering and beginning grain filling. 1-late sowing of spring crops.	1-WW, WB., milk dev. 1 – WB. Ripening maturity.1-R. - ripening. 1-high biomass spring crops. 2-WW. Dough dev. 2-S. (south) beg. Flowering 2-3-WB. harvest	1-WW. dough dev. 1-M. early hyb. Flowering, aver. Early hyb. And late hyb. Vegetative. 3-aver.early M. grain filling and early dough dev. 3- S. beg. Ripening. End WB. Harvest and 85% WW.	1-2- late hyb. Beg. Milk dev. 2-S. mass ripening and maturity.3-aver. Late hyb. Dough dev. And late hyb. Milk dev. 3- S. end of dev.	Dry month. 2-1- aver. Late hyb. M. dough dev. Ripening 2- end S. harvest 2-harvest of early and average hyb. M. 3-sowing WW, WB. At places.	3- sowing winter crops 3-emerg. 3-R. mass emergence 2- rainfall obstruct from sowing of WW and WB. 3-increase cereals area.

List of abbreviations used in Table 1. 1, first decade; 2, second decade; 3, third decade; WB, winter barley; WW, winter wheat; R, rapeseed; S, sunflower; M, maize

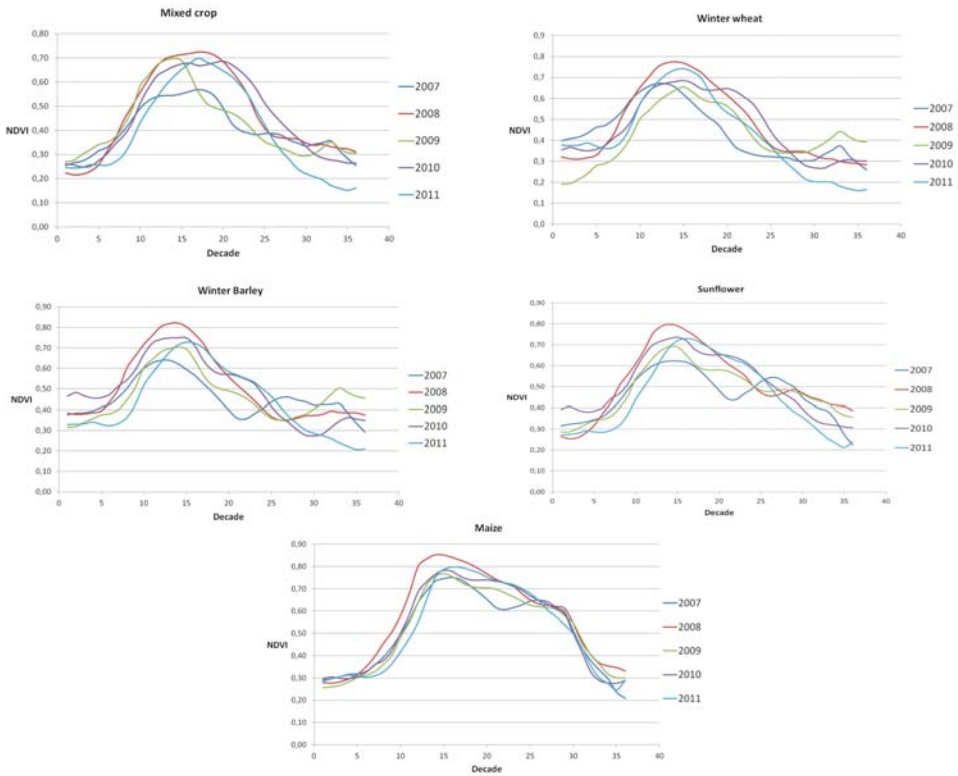

Fig. 2. NDVI time-series cluster analysis profiles for the identified crops (2007-2011)

Supervised classification with the maximum likelihood classifier algorithm was applied on the high-resolution images using as reference the field data to identify the training samples for each crop on the selected images and assess the crop identification process on the SPOT-VGT data. Thus, after the crop identification process, accuracy assessment was applied on the three crop identification classifications to evaluate the accuracy. Overall classification accuracy for the SPOT-4 HRVIR image was 87.62%; and for the LANDSAT-5 TM images in the range 82-94% overall accuracy. Afterwards, the maximum NDVI values were derived from these images for the major identified crops in order to compare them with the values derived from the representative decades of the SPOT-VGT NDVIs time-series data. The SPOT-4 HRVIR image is acquired on 24.03.2011, when winter crops are at heading phenophase, while sping crops are either at beginning of vegetative phase, still bare soil or not sown. The highest NDVI value for the

SPOT-4 image is 0.50 for winter wheat, while for SPOT-VGT NDVIs S10 is 0.47 (Figure 3.).

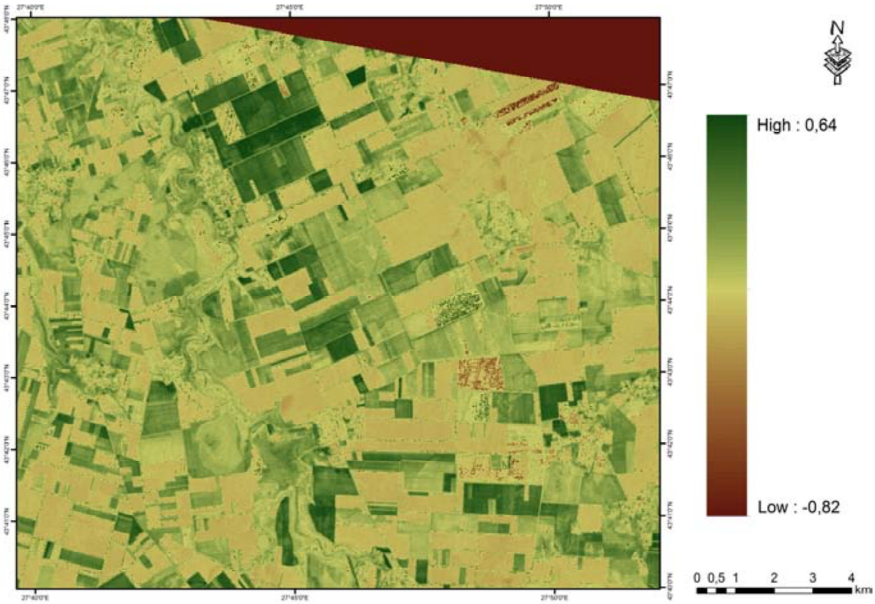

Fig. 3. NDVI image derived from SPOT-4 HRVIR sensor, acquired on 24.03.2011

The first LANDSAT-5 TM satellite image is acquired on 29.05.2011, when the winter crops are at flowering and grain filling phenophases, while spring crops are at vegetative phase of their development. The maximum NDVI from the LANDSAT-5 TM is 0.74, while from the SPOT-VGT product it is 0.72 (Figure 4.).

The second LANDSAT-5 TM satellite image was acquired on 21.06.2011, when winter crops are at ripening and dough development stage, while spring crops are at flowering phenophase. At this stage of the agricultural year there is big similarity observed, because the values for winter wheat are 0.64 from LANDSAT image and 0.63 from SPOT-VGT product. The sunflower class is with 0.67 NDVI from the high-resolution image and 0.70 from SPOT-VGT product. The identified maize class show close values with 0.76 NDVI from LANDSAT image, while from SPOT-VGT product at 0.79 (Figure 5.). Additionally, the third LANDSAT-5 TM satellite image acquired on 08.08.2011 was introduces, where winter crops are already harvested, but spring crops are at ripening and maturity phenophases. The sunflower values are at 0.57 from LANDSAT and 0.50

from SPOT-VGT, while for maize cultivars at 0.61 and 0.65, respectively (Figure 6.).

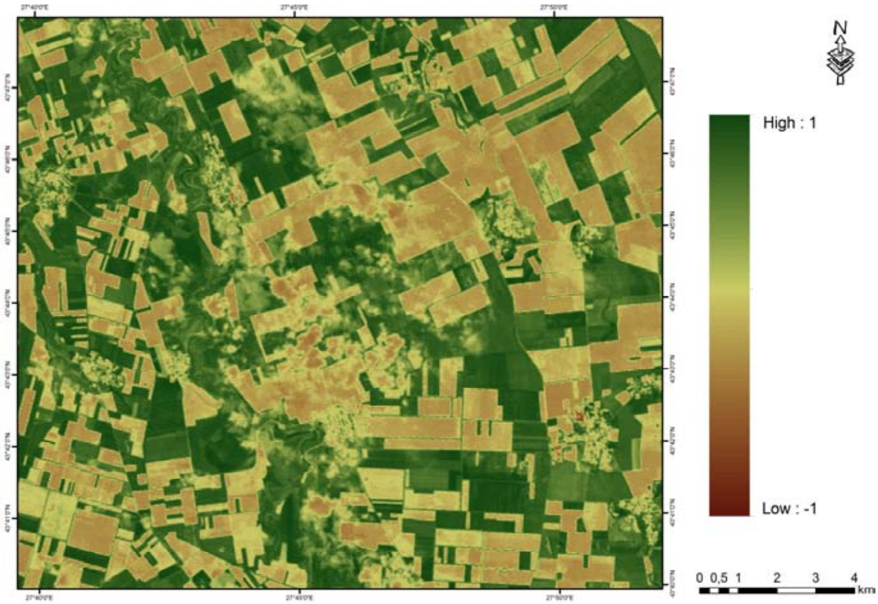

Fig. 4. NDVI image derived from LANDSAT-5 TM sensor, acquired on 29.05.2011

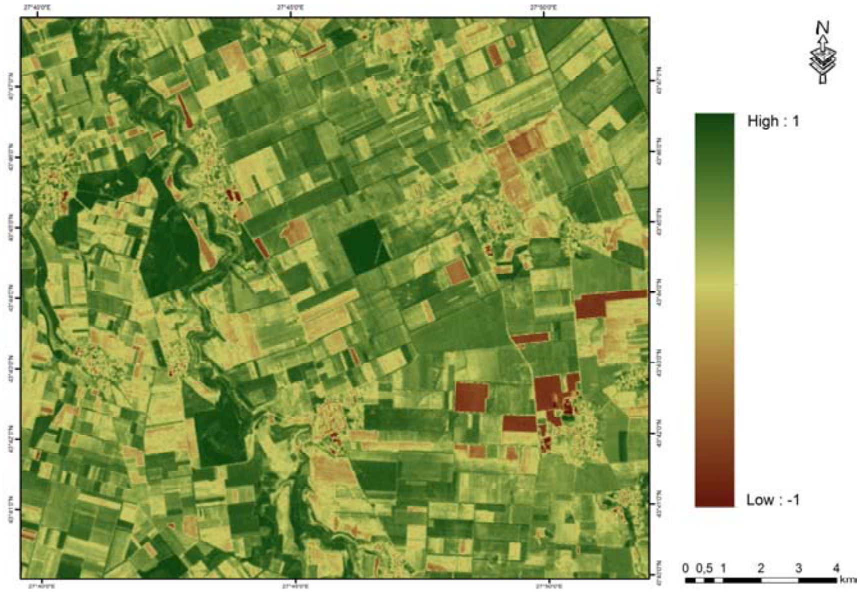

Fig. 5. NDVI image derived from LANDSAT-5 TM sensor, acquired on 21.06.2011

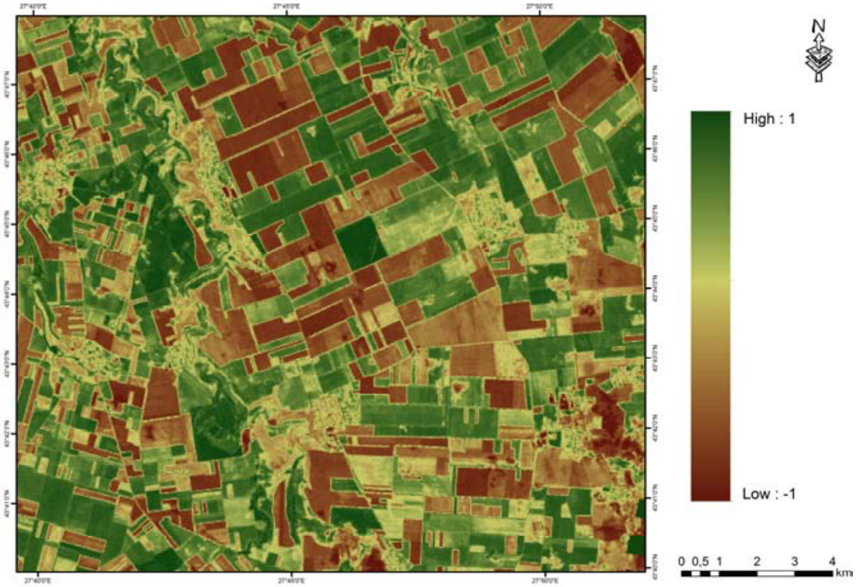

Fig. 6. NDVI image derived from LANDSAT-5 TM sensor, acquired on 08.08.2011

3.2. Identifying the onset of the growing period, length of the reproductive growth period and the entire growing season for the crops

The results obtained in this section are partly based on the Reed et al. (1994) approach. Additionaly, knowledge of crop phenology was used for vegetation growth parameters extraction from the temporal profiles. The onset of the crop growing period, maximum NDVI values reached, length of the reproductive growth period and entire crop growing season are extracted using the NDVI time-series cluster analysis profiles for the identified crops (2007-2011) presented in Figure 2 for comparison.

The mixed class identified has onset of the crop growing period raging from the 1^{th} decade of 2007 till the 7^{th} decade of 2011. The maximum NDVI values are from 0.56 to 0.72 between 14 and 20 decade for the five years period. The length of the reproductive growth period for the mixed class is between 5-7 decades. The entire crop growing season ranges from 25 to 35 decades in the five year period. Hence, the above data indicate that the class represents a mixed crop cluster.

The winter wheat class shows onset of the crop growing period for the 5-year period which starts from the 1^{th} decade of 2007 to 7^{th} of 2011. The maximum NDVI for the class winter wheat is in the range 0.70 - 0.80 within 14^{th} and 15^{th} decades. The length of the reproductive growth period is between 6 and 9 decades and the entire crop growing season ranges between 20 and 25 decades.

The winter barley class reveals onset of the crop growing period from the 3th decade of 2007 to 7th decade of 2011. The maximum NDVI is in the range 0.63 - 0.82 between 13th -16th decades. The length of the reproductive growth period is between 7 and 9 decades while, the entire crop growing season is between 21 and 25 decades.

The sunflower class shows onset of the crop growing period from the 3th decade of 2008 to 7th decade of 2011. The maximum NDVI values reached for the five year period is between 0.62-0.80 in the range of 14th - 17th decades. The length of the reproductive growth period is between 8 and 10 decades and the entire crop growing season for the sunflower cultivars is 22 and 27 decades.

The maize class revelas onset of the growing period from the 5th decade of 2008 to 7th decade of 2011. The maximum NDVI reached is between 0.78 and 0.85 in the 14th decade for 2008 and 16th decade for 2007. The length of the reproductive growth period is between 8 and 10 decades while, the entire crop growing season is between 25 and 28 decades.

In addition, the start of the growing season, end of growing season, maximum NDVI values reached for winter crops and maximum NDVI values reached for spring crops was prepared in a figure based on ground data and farmers inquires for the year 2011 (Figure 7).

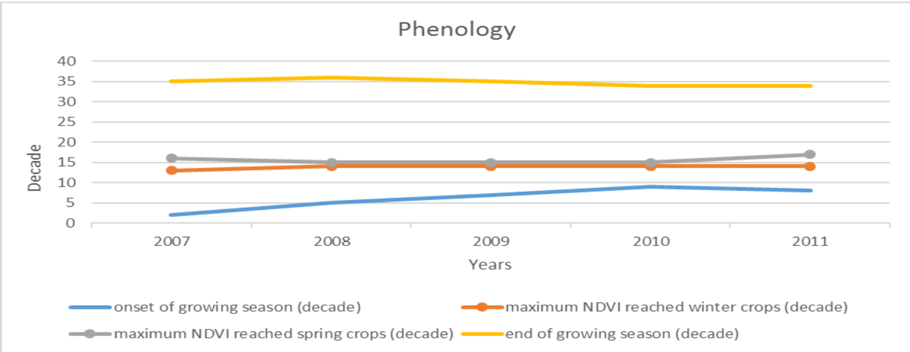

Fig. 7. Crop phenology parameters extraction

Hence, the above data reveals that overall there is similarity in the length of the reproductive growth period and the entire crop growing season between the winter crops (wheat and barley) and spring crops (sunflower and maize) depending on experienced anomalies. The crop phenology results show good relation between the parameters derived from ground and remote sensing data.

3.3. Crop anomaly events detection using yearly cluster NDVI time-series image analysis and quantative data

The agro-phenological information together with the agro activities done for each 10-day period are extracted from the monthly bulletins and implemented in the crop anomaly events detection using yearly NDVI time-series cluster analysis derived from the SPOT-Vegetation NDVI product. The quality of the crop anomaly events detection was assessed using quantative data. Yield figures for the major crops for the five year period derived from official statistics from the Bulgarian Ministry of Agriculure and Foods and making correlations with the maximum NDVI values reached for the growing season. The time-series cluster analysis is given below.

3.3.1. Analysis of 2007

The year was characterized as anomalous. The winter crops at the beginning of the year were ahead of their development by 45 days. The crops were at tillering in February and in heading phenophase in March. Shortening of the phenophase periods were observed due to bad agrometeorological conditions in May. As a result the yield from both winter and spring crops were low. The harvest of the late maize cultivars was delayed because of intensive rainfall in the beginning of September.

The identified winter wheat and barley classes exhibited NDVI values above 0.38 for the first decade (Figure 8a). Such values are a clear indication of winter crops. The cultivars of winter wheat and barley reached their maximum NDVI values of 0.67 and 0.64, respectively, at the end of April (11-12th decade) at flowering stage (Figure 8a). Afterwards, in the middle of May the winter crops were in grain filling and ripening development stages. Finally the harvest of the winter barley fields at maturity stage took place in the beginning of June (16th decade), while the fields sown with winter wheat were harvested at the end of June (17th and 18th decade). The maize and sunflower classes identified showed the highest NDVI values in June (16-17th decade), which corresponds to flowering development stage with NDVI values at 0.75 for maize and 0.62 for sunflower. The harvest of the late maize hybrids was delayed due to intensive rainfall. As a result of that high NDVI values up to 0.61 (Figure 8a) were observed until mid September (25-26th decade).

The winter wheat class occupies large areas in the Northeast part of the region, while the spring crop classes are mostly situated in west and south parts of the studied region (Figure 8b).

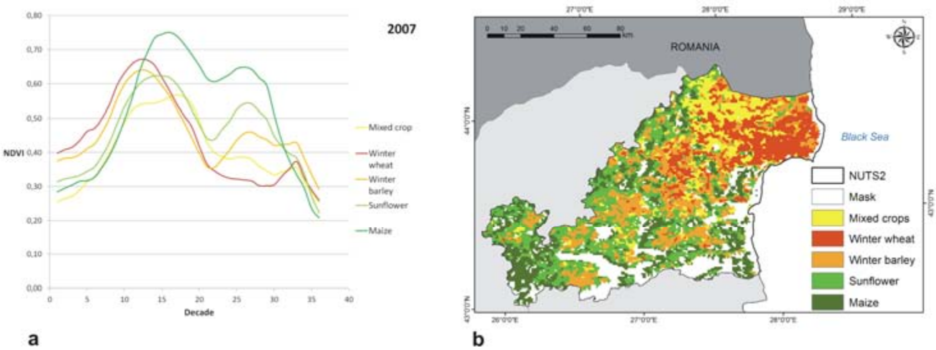

Fig. 8. a) NDVI cluster time-series cluster analysis profiles for 2007
b) Cluster map of actual NDVI values for 2007

3.3.2. Analysis of 2008

The year was characterized as favorable in terms of the agrometeorological conditions and the applied agrotechnical measures. Thus, the average crop yield figures were the highest for the past 20 years.

The identified winter crop classes reflected very accurately the occurred late onset of tillering and heading phenophases in the beginning of March due to the late snow melt (Figure 9a). Then winter crop classes reached their peack of vegetative biomass at flowering stage in the end of April and beginning of May. Exceptionally high NDVI values were reached - 0.82 for winter barley and 0.77 for winter wheat because of the extraordinary good agrometeorological conditions observed. Winter wheat cultivars were at dough development, while winter barley were at maturity stage in mid June (17th decade), which accommodated better crop identification. The harvest was conducted at the end of June for winter barley, while for winter wheat it took place in the beginning of July. The spring crops were at their highest biomass accumulation at the beginning of June with NDVI values at 0.79 for sunflower and 0.85 for maize. The maize cultivars kept high NDVI values until September, due to the development of late maize hybrid.

Winter crop classes occupy northeast part of the region, while the spring crops are distributed in the west and south parts of the region (Figure 9b.)

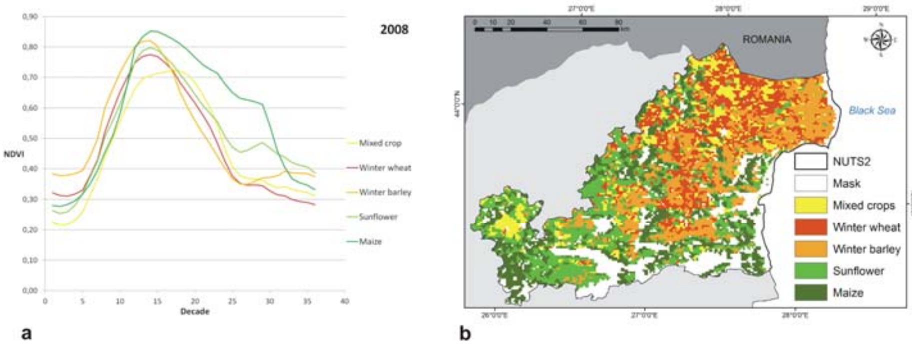

Fig. 9. a) NDVI cluster time-series cluster analysis profiles for 2008
b) Cluster map of actual NDVI values for 2008

3.3.3. Analysis of 2009

The year was described as normal considering the agrometeorological conditions. The identified winter crop cultivars were at tillering and heading phenophases in their majority in March. Then in the end of April and beginning of May (14-15^{th} decade) the winter crops were at flowering stage. At that point the maximum accumulated green biomass was reached with NDVI values for winter barley - 0.70 (14^{th} decade) and for winter wheat - 0.65 (15^{th} decade). The harvest of the winter barley occurred in the middle of June (17^{th} decade), while in the 18^{th} decade was the harvest of the winter wheat. This information accommodates better crop identification process. The spring crops reached their maximum of accumulated green biomass in June (15^{th} -16^{th} decade) at flowering phenophase. The NDVI values were 0.69 for sunflower and 0.77 for maize. In September the late maize hybrids still kept high NDVI values - 0.61. Winter crops that were already sown at that point started their development from 0.30 NDVI in September and by the end of the year in tillering phenophase were at 0.50 NDVI values (Figure 10a).

The winter crops and mixed crop clusters occupy Northeast part of the region, while the sunflower class is mainly in the rest of the region covering the central and southwest part of the area studied (Figure 10b).

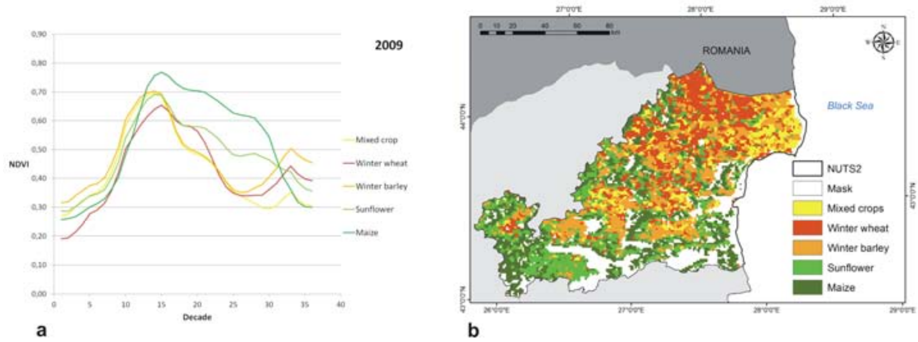

Fig. 10. a) NDVI cluster time-series cluster analysis profiles for 2009
b) Cluster map of actual NDVI values for 2009

3.3.4. Analysis of 2010

The year was considered unfavourable because of bad agrometeorological conditions which delayed the harvest and as a consequence affected the grain quality and yield values.

The identified classess experienced a slight increase of NDVI values due to relatively high temperatures, which kept the vegetative state of the winter crops in the beginning of year. Afterwards, in the middle of the month the temperatures decreesed rapidly, which returned the crops to dormancy. Nevertheless, this anomalies were clearly identified using the NDVIs S10 time-series cluster analysis profiles (Figure 11a). Until the beginning of March, when the vegetative state of the winter crops was renewed, low NDVI values were experienced. At that point the NDVI values of winter crops were at 0.35-0.43 and in tillering and heading phenophases. The highest green biomass accumulated at the beginning of May at flowering phenophase with values 0.69 for winter wheat and 0.75 for winter barley. Winter barley cultivars were at grain filling (dough development) stage, while winter wheat cultivars were at milk development in the end of May (15th decade). Winter crops experienced high NDVI values up until the end of July (21th decade) because of intensive rainfall delayed harvest was observed. On the other hand the spring crops reached their maximum green biomass accumulation at the end of May and the beginning of June at flowering phenophase, with NDVI values for sunflower at 0.74 and maize at 0.78. The bad agrometeorological conditions delayed harvest of spring crops as well. Finally, sunflower cultivars were harvested in September, while the late maize hybrids in October (Figure 11a).

The winter crops are distributed in the Northeast part of region, while the rest of the region was occupied by a combination of mixed crop class, sunflower and maize (Figure 11b).

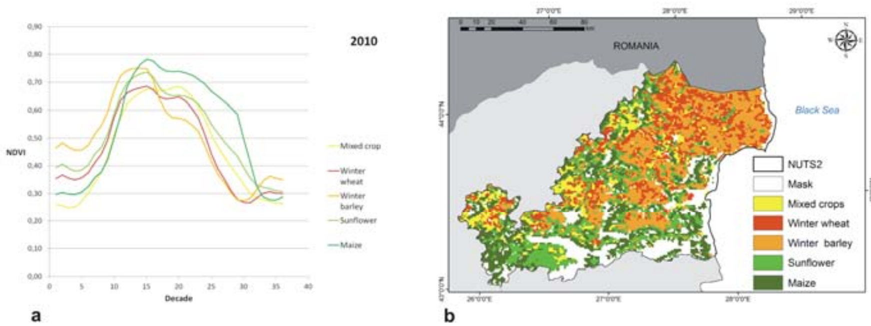

Fig. 11. a) NDVI cluster time-series cluster analysis profiles for 2010
b) Cluster map of actual NDVI values for 2010

3.3.5. Analysis of 2011

The year was characterized as normal for all cultivated crops. The winter crops started the year with NDVI values in the range 0.33-0.38. Winter crops were at heading phenophase in the beginning of April. Winter crop classes reached their maximum accumulated green biomass in May (14^{th} decade) with NDVI values at 0.74 for winter wheat and 0.73 for winter barley (Figure 12a). Winter crops were harvested in the end of June and beginning of July. The sunflower class reached its maximum NDVI values in mid June (17^{th} decade) with NDVI values at 0.72. The maize class reached NDVI values of 0.80 at the end of June (18^{th} decade). The class maintained high values of up to 0.72 (Figure 12a) until the 23^{th} decade of the year.

The winter wheat and mixed crop classess occupy North and Northeast parts of the region. Sunflower cultivars were present in the central parts of the region, while maize cultivars were sown in the south part (Figure 12b) where highest altitudes of the region can be observed.

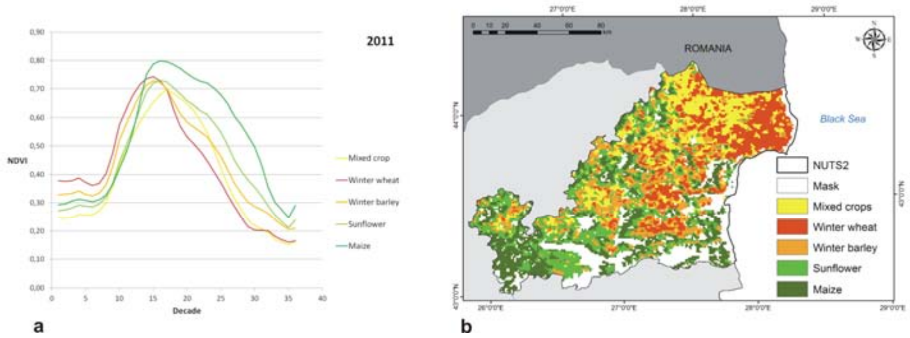

Fig. 12. a) NDVI cluster time-series cluster analysis profiles for 2011
b) Cluster map of actual NDVI values for 2011

Additionally, for quality assessment a correlation process was prepared. Correlation between the average yield figures for the region derived from official statistics for the major cultivated crops (winter wheat, winter barley, sunflower and maize) and the maximum reached NDVI values from the time-series analysis for the five year period with confidence level of 95%, the relevant r values are ≥0.75 and ≤-0.75 for five variables was accomplished. For the mixed crop class the yield figure that was taken from official statistic was the one from oilseed rape, since presumably that cultivar have some big parts in that class (Table 2). The correlation results show that, there is high correlation (r) between the yield and highest NDVI values for winter barley at r + 0.99, sunflower and oilseed rape have equally high values at r + 0.84. Winter wheat has a good correlation with r + 0.65, while maize cultivars have positive correlation at r + 0. 37 (Table 3.).

Table 2. Statistics for derived average yield and maximum NDVI values

Average Yield (kg/dca)	**2007**	**2008**	**2009**	**2010**	**2011**
Winter wheat	253.5	472.5	344.9	411.6	362
Winter barley	283.4	421.8	345.7	374.2	340
Maize	101.2	406.6	415.3	598.6	626
Sunflower	95.7	198.8	185.6	209.3	210
Rapeseed	182.7	276.1	221.8	277.8	257
Maximum NDVI reached	**2007**	**2008**	**2009**	**2010**	**2011**
Rapeseed	0.56	0.72	0.69	0.68	0.69
Winter wheat	0.68	0.78	0.65	0.68	0.73
Winter barley	0.64	0.82	0.71	0.75	0.72
Sunflower	0.62	0.79	0.69	0.74	0.72
Maize	0.75	0.85	0.76	0.78	0.80

Table 3. Correlation analysis for the major cultivated crops

Correlation	Winter wheat	Winter barley	Maize	Sunflower	Oilseed rape
R^2	0.65	0.99	0.37	0.84	0.84

4. Conclusions

Identifying the possibility of crop monitoring at regional scale using time-series of SPOT-VGT NDVIs S10 vegetation product in an intensively cropped area in Northeast Bulgaria was investigated in this case study. The study applying SPOT-VGT NDVIs S10 satellite product for crop monitoring including the following tasks: crop identification, crop phenology estimation and crop anomaly events detection covering intensively cropped area (Northeast Bulgaria). The crop identification process was assessed using similarity value analysis between the maximum NDVI values derived from the low-resolution SPOT-VGT NDVIs S10 product and the high-resolution satellite images for a test site in the region of interest. The article shows similarity in the length of the reproductive growth period and the entire crop growing season between the winter crops (wheat and barley) and spring crops (sunflower and maize) depending on experienced anomalies. The crop phenology results show good relation between the parameters derived from ground and remote sensing data. The crop anomaly events detection was quantified using correlation between the average yield for the major cultivated crops and the highest reached NDVI values of the identified crops show high correlation for winter barley at r^2 0.99, sunflower and oilseed rape have equally high values at r^2 + 0.84. Winter wheat has a good correlation with r^2 + 0.65, while maize cultivars have positive correlation at r^2 + 0. 37. The applied methodology proves that the low resolution satellite images with high-revisit period are an ideal solution for crop monitoring on large arable territories. However low resolution satellite vegetation products must always be supported and used in combination with agro-phenological ground data, quantative data and some high-resolution satellite images for better crop monitoring results. Although, the SPOT-VGT sensor successfully retired on 01.06.2014 the continuitity of such low resolution data for time-series vegetation monitoring is assured by the launch of PROBA-V mission in 2013.

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References

1. M e y e r-R o u x, J., P. V o s s e n. The first phase of the MARS project, 1988–1993: overview, methods and results. In: Official Publications of the E.U., Luxembourg (Ed.), Report EUR 15599 EN. Conference on the MARS project: Overview and prospectives, Belgirade, 1994, 33-79.
2. D e W i n n e, P. 2004. Les Besoins de la Direction Generale VI: Agriculture. In: Office for official publications of the E.U., Luxembourg (Ed.), Report EUR 15599 EN, 2004. Conference on the MARS project: Overview and prospectives, Villa Carlotta, Belgirate, Lake Maggiore, Italy, 17-22 (in French).
3. P i t t s, D. E., G. B a d h w a r. 1980. Field size, length, and width distributions based on LACIE ground truth data. Remote Sensing of Environment, Volume 10, Issue 3, 201-213.
4. C o h e n, Y., M. S h o s h a n y. 2002. A national knowledge-based crop recognition in Mediterranean environment International Journal of Applied Earth Observation and Geoinformation, 4, 75- 87.
5. M a c D o n a l d, R. 1984. IEEE Transaction on Geoscience & Remote Sensing, GE-22, 473-481.
6. B l a e s , 2005. Efficiency of crop identification based on optical and SAR image time series. Remote Sensing of Environment, 96 352 – 365.
7. G E O 2013. Progress on GEOGLAM Implementation First steps towards implementation 2013-2014 Phase I and II. 28th Executive Committee – 16-17 July 2013.
8. R y e r s o n, R. A., P. J. C u r r a n , P. R. S t e p h e n s. 1997. Agriculture. In: Philipson W.R. (Ed.) Manual of Photographic Interpretation. 2nd ed. Americal Society for Photogrammetry and Remote Sensing, Bethesda, MD, 365-397.
9. T o w n s h e n d, J., J u s t i c e C., L i W., G u r n e y C., M c M a n u s J. 1991. Global land cover classification by remote sensing: present capabilities and future possibilities. Remote Sens Environ, 35, 243-255.
10. V a s s i l e v, V. 2013. Crop Identification Using Satellite Images and Vegetation Products. PhD thesis work. Prof. Marin Drinov Academic Publishing House. pp. 154 ISBN 978-954-322-633-7. (In Bulgarian).
11. D e F r i e s, R., M. H a n s e n , J. T o w n s h e n d. 1995. Global discrimination of land cover types from metrics derived from AVHRR pathfinder data. Remote Sens Environ, 64 (3), 209-222.

12. R e e d, B. C., J. F. B r o w n, V a n d e r Z e e D., L o v e l a n d T. R., J. W. M e r c h a n t, D. O. O h l e n. 1994. Measuring phenological variability from satellite imagery. Journal of Vegetation Science, 5, 703-714.
13. B r o w n, J. F., T. R. L o v e l a n d, J. W. M e r c h a n t, B. C. R e e d, D.O. O h l e n. 1993. Using multisource data in global land-cover characterization: Concepts, requirements, and methods. Photogramm Eng Remote Sens, 59(6), 977-987.
14. L o v e l a n d, T. R., J. W. M e r c h a n t, J. F. B r o w n, D.O. O h l e n, B.C. R e e d, P. O l s o n , J. H u t c h i n s o n. 1995. Seasonal land-cover regions of the United States. Annals of the Association of American Geographers, 85, 339-355.
15. R o u s e, J., R. H a a s, J. S c h e l l, D. D e e r i n g. 1973. Monitoring vegetation systems in the Great Plains with ERTS. In: Third ERTS Symposium, 1973, NASA SP-351 I, 309-317.
16. B o s s a r d, M., J. F e r a n e c and J. O t a h e l 2000. CORINE land cover technical guide – Addendum 2000. Technical report No 40. European Environmental Agency EEA Copenhagen.
17. G r o o m, B. G., F u l l e r R. M., J o n e s A. R. 1996. Contextual correction: techniques for improving land-cover from remotely sensed images. Int J Remote Sens, 17, 69-89.
18. G a r c i a-C o n s u e g r a, J., G. C i s n e r o s. 1999. Establishing spatially continuous in a non-supervised way. In: Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS'99), 1999, Hamburg, Germany.
19. Y u a n, H., S. K h or r a m, , D a i X. L. 1999. Applications of simulated annealing minimization technique to unsupervised classification of remotely sensed data. In: Proceedings of the IEEE International Geoscience and Remote Sensing Symposium (IGARSS'99), 1999, Hamburg, Germany.

МОНИТОРИНГ НА ЗЕМЕДЕЛСКИТЕ КУЛТУРИ ЧРЕЗ ВРЕМЕВИ СЕРИИ ОТ SPOT-VGT NDVIs S10 ПРОДУКТ ЗА СЕВЕРОИЗТОЧНА БЪЛГАРИЯ

В. Василев, Е. Руменина

Резюме

Обект на настоящето изследване са основните отглеждани земеделски култури в североизточния район на България и по конкретно: зимна пшеница, зимен ечемик, рапица, слънчоглед и царевица. Целта на статията е мониторинг на земеделските култури на регионално ниво с дистанционни данни със ниска пространствена разделителна способност (ПРС) и висока времева разделителна спсобност (ВРС). Изследването е концентрирано върху обработка и интерпретация на времеви серии от Нормиран Разликов Вегетационен

Индекс с цел мониторинг на земеделски култури с три различни под-етапи на работа: разпознаване на земеделски култури, определяне на фенологични параметри и разпознаване на аномалните земеделски събития. Разпознаването на земеделските култури е оценена посредством сходство на стойностите на Нормирания Разликов Вегетационен продукт с ниска ПРС и тези извлечени от спътникови изображения с висока ПРС върху тестови участък разположен в района на изследване. Познания за фенологията на земеделските култури е използвано при определяне на фенологични параметри от времевите профили от данни. Разпознаване на аномалните земеделски събития е извършено с помощта корелация между средните стойности на добивите за основните култури и достигнатите през земеделската година максимални стойности на Нормираният Разликов Вегетационен Индекс за разпознатите култури за период от пет години (2007-2011) с праг на достоверност от 95% и значими стойности от ≥0.75 и ≤-0.75 за пет променливи. Резултатите показват висока корелация (r) за зимен ечемик r + 0.99, посевите на слънчогледа и зимна рапица са с еднакви стойности от r + 0.84. Зимната пшеница има добра корелация със стойности r + 0.65, докато посевите на царевица имат позитивна корелация от r + 0. 37. Представената методика доказва значителния потенциал при използването на спътниковите изображения с ниска ПРС за целите на мониторинг на земеделски култури на регионално ниво в допълнение с агро-фенологична информация извлечена от месечните бюлетини на Националния Институт по Метеорология и Хидрология към Българската Академия на Науките, спътникови изображения с висока ПРС и статистика за средните добиви за основните земеделски култури. Това изследване допринася за успешното приложение и внедряване на съществуващата методология на MARS отдела към Европейската Комисия и допълването и със агро-фенологична, изображения с висока ПРС и статистически данни за добивите. Продължаващото използане на данни с ниска ПРС с цел мониторинг на земеделските култури на регионално ниво е подсигурено с успешното изтрелване на микро спътника PROBA-V през 2013 г., продължение на мисията на SPOT-Vegetation.