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CROP MONITORING OF 2011/2012 AGRICULTURAL YEAR FOR THE TERRITORY OF BULGARIA WITH THE USE OF MODIS NDVI PRODUCTS

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Keywords: *geo-information technologies, agricultural crops, NDVI, MODIS, SPOT VEGETATION*

Abstract: *The main objective of the study is to monitor crops for the 2011/2012 agricultural year with the use of MODIS and SPOT VEGETATION NDVI products and summary statistics of ground truth from the monthly bulletins of NIMH-BAS and NASA for the territory of Bulgaria. The hypothesis tested in the study is to see whether the satellite NDVI products will show similarities or will match the ground truth. In order to do so, the following tasks have been undertaken: a summary table for the agro-meteorological conditions with crop phenophases from NIMH-BAS monthly bulletins is prepared; NDVI anomalies maps from the multiannual average time-series of MODIS Terra have been used for the satellite segment of the monitoring; time-series curves extracted from SPOT VEGETATION NDVI products. The results from the study show that the continuous drought, which started at the end of June 2012 and beginning of July 2012, did not have significant effect on the yield of winter crops (5-9% less yield). Nevertheless, the severe drought has had an impact mainly on spring crops by shortening of their between-phase periods. Consequently, this highly affected their yield figures: (30% less) for maize and (56% less) for sunflower compared to the yield of the previous agricultural year 2010/2011.*

МОНИТОРИНГ НА СЪСТОЯНИЕТО НА ПОСЕВИТЕ НА ТЕРИТОРИЯТА НА БЪЛГАРИЯ ПРЕЗ 2011/2012 СТОПАНСКА ГОДИНА С ИЗПОЛЗВАНЕ НА MODIS NDVI ПРОДУКТИ

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Ключови думи: *геоинформационни технологии, земеделски култури, NDVI, MODIS, SPOT VEGETATION*

Резюме: *Основната цел на изследването е да се осъществи мониторинг на земеделски култури за стопанската 2011/2012 година с използването на MODIS NDVI спътникови продукти и обобщени наземни статистически данни от месечните бюлетини на НИМХ-БАН и НАСА за територията на България. Хипотезата, която се тества в проучването, е да се установят сходствата и съответствията на MODIS NDVI продуктите с наземната информация. За да направи това, са определени и извършени следните задачи: съставена е обобщена таблица за агрометеорологични условия с фенофазите от месечните бюлетини на НИМХ-БАН; съставени са карти на NDVI аномалии на основата на многогодишна времева серия от MODIS Terra; серия от мултитемпорални криви, извлечени от NDVI продукти от SPOT VEGETATION. Резултатите от изследването показват, че сушата, която започва в края на юни 2012 и началото на юли 2012, няма осезаем ефект върху добива на зимни култури (средно с 5-9% по-ниски добиви). Независимо от това, условията на суша въздействат главно върху пролетните култури чрез съкращаване на техните между-фазови периоди. Това силно повлиява върху стойностите на добивите от царевица (30% по-малко) и слънчоглед (56% по-малко) в сравнение с предходната 2010/2011 стопанска година.*

Introduction

Agricultural crops in Bulgaria may be generally sub-divided to summer and winter crops. Their development stages and phenophases are subject to influence of various, including unfavourable, meteorological conditions (frost, drought, soil over moisturizing, and strong wind) which create preconditions for crop damages. These changing conditions are monitored and assessed on a decadal basis and on a national, regional, or a global level. The monitoring is usually performed using data and products from low-resolution earth-observation satellites (Roumenina *et al*. 2013). The crop condition estimation and monitoring is also essential in making an empirical yield estimation using satellite derived products (Doraiswamy *et al.* 2004). Currently in operation, or scheduled for launch, are such low resolution satellite systems as NOAA-AVHRR, Envisat-MERIS, SPOT-VEGETATION, Terra/Aqua-MODIS, Landsat TM, GOSAT (IBUKI), GCOM etc. The actuality of the study is supported by the currently operational monitoring activities in the framework of several organizations and projects at: Food and Agricultural Organization (FAO); Global Information and Early Warning System (GIEWS); Monitoring Agricultural Resources (MARS) at the Joint Research Centre (JRC); Consultative Group on International Agricultural Research (CGIAR). The satellite monitoring of agriculture by earth observation satellites is also a backbone of GMES and GEOSS programmes (Future Brief: Earth Observation's Potential…, 2013).

The study subject is the territory of Bulgaria occupied by annual agricultural crops. The study objective is to perform a crop monitoring of 2011/2012 agricultural year for the territory of Bulgaria with the use of MODIS NDVI products. In order to achieve this - the following tasks were accomplished:

- to collect satellite and ground-based data for crop monitoring;
- to compare and analyze both datasets;

Data and methods

1. Data

The presented work employs two types of input data: 1) *satellite products* and 2) *ground-based data*.

Satellite products: The used satellite derived products for the viewers are SPOT-VGT and MODIS NDVI Terra, which is an anomaly product which gives the relative difference to the long-term average in percentage (%). Using this product one can estimate the delay or the advance of crop development compared to previous years. In presenting the maps a crop mask from GLOBCOVER 2009 was applied and the Admin level 3 was used.

Ground-based data: The ground data used was derived from the monthly bulletins of the National Institute of Meteorological and Hydrology (NIMH-BAS), where the information is summarized and presented in 3 decades for each month. This information serves mainly for defining the dates of occurrence and the magnitude and scale of the phenophases, crop status, crop development stage, drought, wet conditions to name but a few. As a result from the combination of the satellite data and the ground data, a comparative analysis was undertaken and an assessment of the 2011/2012 agricultural year was accomplished.

2. Methods

The methodology of the study is based on: online geo-information technologies; statistical methods; comparative analysis and interpretation of results. The methodological framework of the study is presented in Fig. 1.

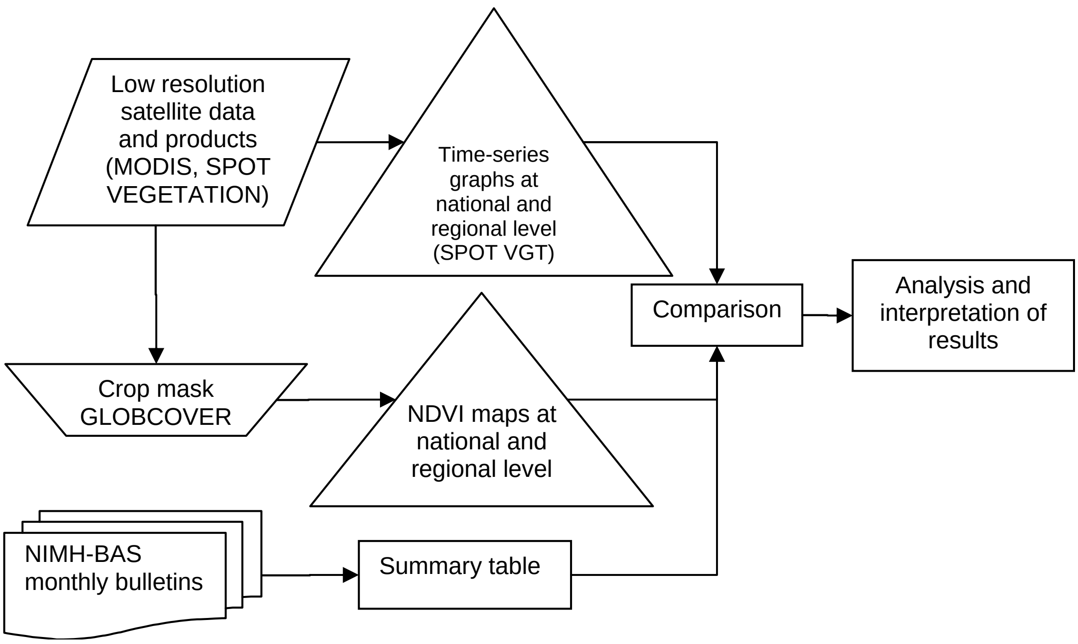


Fig. 1. Flowchart of the methodological framework.

2.2. MODIS Terra NDVI products

Normally, spectral vegetation indices, such as Normalized Difference Vegetation Index (NDVI), are used to study agricultural crops (Dadhwal, 2004; Doraiswamy *et al.* 2004). Its values are affected by most agricultural crop biometric characteristics, such as crop density, plant height, fresh and dry biomass, total area cover and more, as well as surface layer soil moisture (Roumenina *et al*. 2012). The NDVI index is considered also a direct indicator of plants' photosynthetic activity (Rouse *et al*. 1973; Tucker 1979). The NDVI is calculated by (1):

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

where NIR is the near infrared and RED is the red waveband.

2.3. Masking and deriving of the NDVI values from MODIS Terra NDVI products

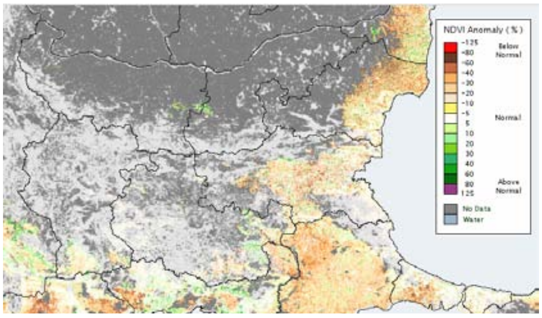
To be able to localize and discern the arable land on MODIS Terra scenes, a GLOBCOVER 2009 mask was applied (GLOBCOVER 2009, 2010). The test fields' mask was used as to derive the values of NDVI from the index images for each individual pixel, as to obtain the averaged values.

Results and discussions

The results and discussions below are presented on a month-by-month basis. The assessment of the agricultural crop status is based on a NDVI comparison with ground-measured data provided by NIMH-BAS.

1. January-February 2012

The intensive rainfall at the end of January and during the first two weeks of February 2012 significantly increased the field capacity (FC) of the soil. Frost kill is observed in some parts of East Bulgaria (NIMH-BAS monthly bulletin, January-February 2012). This statement is supported by the February's MODIS NDVI Terra anomaly map, where values of (20%)-(-40%), i.e. below the multiannual NDVI values, are observed, see Fig. 2 a) and Fig. 2 b).



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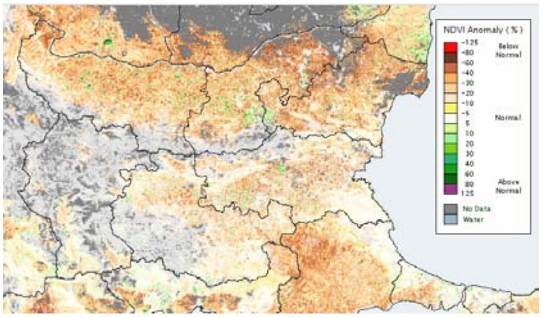

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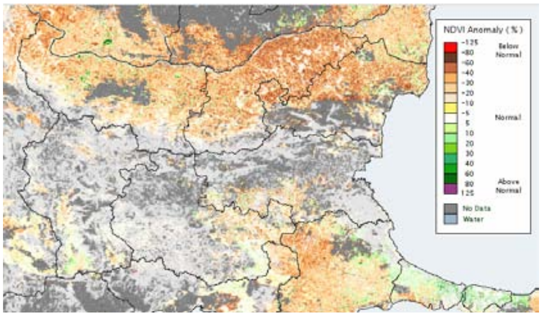
Fig. 2. NDVI anomaly maps from MODIS Terra products from a) 17-24.02.2012 and b) 25.02-03.03.2012. (data courtesy to USDA-FAS)

2. March 2012

The rainfall at the beginning of March 2012 was below the average for the month. In the beginning of spring the crops were in vegetative state and FC at the 2 meters layer was very good (85-90%). Renewal of the vegetative processes was seen during the second decade of the month. During the third decade the spring crops (sunflower and maize) were sown (NIMH-BAS monthly bulletin, March 2012). On the satellite anomaly maps for March 2012 the NDVI values are around the normal, see Fig. 3 a) and Fig. 3 b). Nevertheless, there are some territories in the North-West Bulgaria, where NDVI is +20% and +30% above the normal values. This probably was caused by the good FC of the soil in this period of the 2011/2012 agricultural year or due to the type of crops, i.e. rapeseed, at the greening places.



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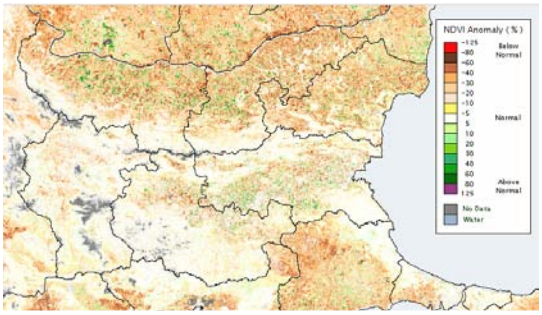
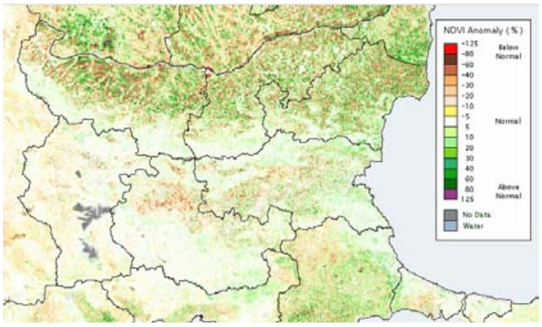


b)

Fig. 3. NDVI anomaly maps from MODIS Terra products from a) 04-11.03.2012 and b) 20-27.03.2012. (data courtesy to USDA-FAS)

3. April 2012

The rainfall, in some parts of North, Central, and East Bulgaria, was above the normal for the month, whereas in the South Bulgaria the rainfall amount was 50% below the months' normal. The lowest values of the FC were observed in the South-West Bulgaria. The first decade of April was characterized also with low levels of FC. In the second decade the FC values reached 80-85%, followed by a sudden decrease of FC during the third decade (NIMH-BAS monthly bulletin, April 2012). At that time the winter wheat and winter rapeseed cultivars were at *tillering* phenophase, while sunflower and maize are at *emergence* phenophase (NIMH-BAS monthly bulletin, April, 2012). Looking at the anomaly map derived from MODIS NDVI Terra it is confirmed that April 2012 was marked with some above the average NDVI, especially in the North Bulgaria. Its values were in the range of +20% to +60% above the normal, Fig. 4 a) and 4 b).

a)


b)

Fig. 4. NDVI anomaly maps from MODIS Terra products from a) 05-12.04.2012 and b) 21-28.04.2012. (data courtesy to USDA-FAS)

4. May 2012

During the first decade of May 2012, an unusual drought was observed in the North East and South Bulgaria. The maize and the sunflower were at *emergence* phenophase, while winter barley and winter wheat are at *grain filling* phenophase. During the second decade of May 2012 an above average rainfall (20-150 l/m^2) was measured in some places (NIMH-BAS monthly bulletin, May 2012). These were supported with hail conditions and strong winds gusts which caused damage to the crops and delayed their development. During the third decade of May 2012 in many parts of the country (West, Central, and South Bulgaria) full FC was reached. The anomaly map for May 2012 shows that the whole area of arable lands in Bulgaria features above average NDVI, i.e. from +40% to +60%, see Fig. 5 a) and Fig 5 b). This was optimal conditions for development of the winter crops, which at that time were in *maturity* phenophase. As it is seen from the analysis that follows this would not affect the figures of winter crop yield (winter wheat, winter barley, and winter rapeseed).

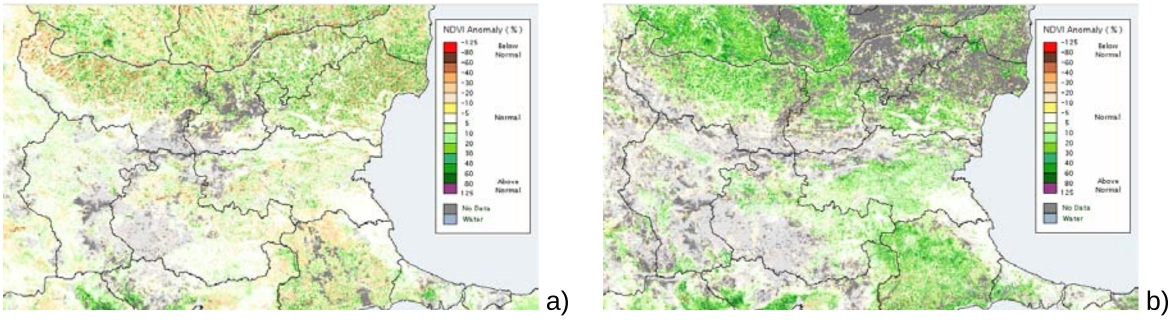


Fig. 5. NDVI anomaly maps from MODIS Terra products from a) 07-14.05.2012 and b) 23-30.05.2012. (data courtesy to USDA-FAS)

5. June 2012

During June 2012 (June is considered to be the rainiest month of the year) due to a lack of rainfall, a shortage of FC was observed in the East and South Bulgaria. During the first decade the winter barley was in *maturity*, winter wheat was in *ripening*, while the spring crops were in the *flowering* phenophases. During the second decade of June 2012 the winter crops were in *maturity* and *harvest* of the winter barley, while the winter rapeseed was in *ripening* phenophase (NIMH-BAS monthly bulletin, June 2012). During the third decade of June 2012 the early hybrids of maize grown under irrigated conditions were in *grain filling* and *flowering* phenophases, while the late hybrids of maize were in *vegetative* phenophase and the sunflower was in *flowering* phenophase. In some parts of the country harvest of the winter wheat was in progress. The NDVI anomaly map for June 2012 does not show any stress on the crop cultivars, but the drought conditions which had started at the beginning of June 2012 would have their consequences for the spring crops in the forthcoming months, see Fig. 6 a) and 6 b).

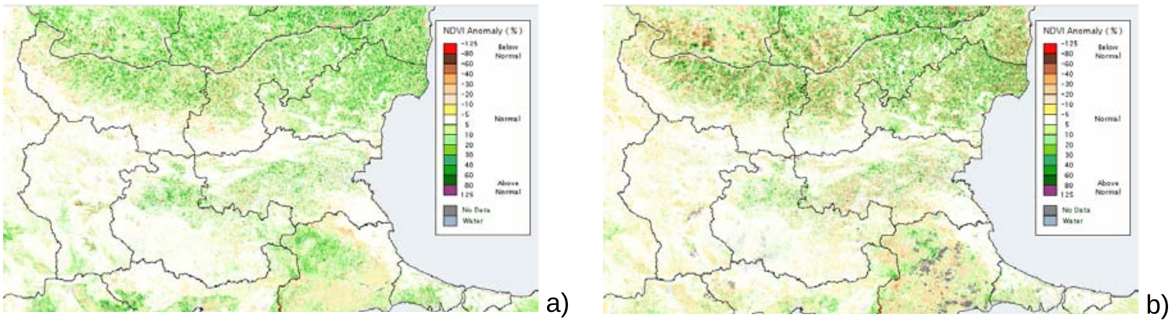


Fig. 6. NDVI anomaly maps from MODIS Terra products a) 08-15.06.2012 and b) 24.06-01.07.2012. (data courtesy to USDA-FAS)

6. July 2012

The dry spell in the month of July 2012 deepened the drought conditions which started in June 2012. The survival of the crops was highly dependent on irrigation. Severely damaged spring crops were observed in non-irrigated areas. Shortening of the between-phase periods was caused by the dry conditions as well (NIMH-BAS monthly bulletin, July 2012). During the first decade of July 2012, the maize was in *vegetative* and *flowering* phenophase, while sunflower cultivars were in *flowering* and *grain filling* phenophase. During the second decade of July 2012 the observed damages of spring crops increased. During the third decade of July 2012 the sunflower was well in advance in *grain filling* and *ripening* phenophases. Irrigated maize was in *maturity* phenophase. The dry conditions led to severe damages in the early hybrids of maize in the North-East Bulgaria, which were at *maturity* phenophase. Sunflower was also at *maturity* phenophase (two weeks earlier than anticipated). By the end of the month winter wheat harvest was in progress. The winter wheat yield was with high quality and good content of gluten (NIMH-BAS monthly bulletin, July 2012). The July 2012 NDVI anomaly map shows that NDVI was from -40% to -60% below the normal, which was caused by the continuing drought conditions, Fig. 7 a) and Fig. 7 b). Nevertheless some above close to normal values were observed in some parts of the North-East Bulgaria, but this might be attributed to permanently irrigated territories.

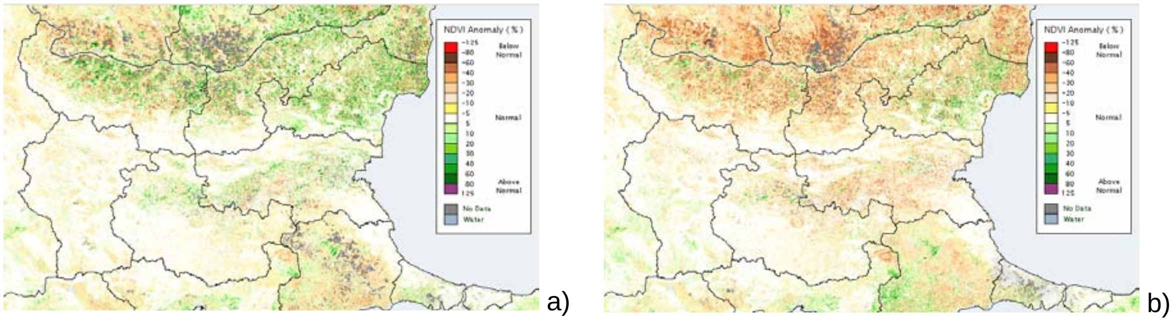


Fig. 7. NDVI anomaly maps from MODIS Terra products from a) 02-09.07.2012 and b) 18-25.07.2012. (data courtesy to USDA-FAS)

7. August 2012

During the first decade of August 2012 the rainfall in West Bulgaria increased significantly the soil moisture FC. Even though, during the second and third decades the lack of soil moisture affected the spring crops. Sunflower and the late hybrid types of maize were at *maturity* phenophase. About 50% of the territories occupied with sunflower and early hybrids of maize were harvested (NIMH-BAS monthly bulletin, August 2012). At the end of the month deep plowing was applied on the arable land. The NDVI anomaly map for August 2012 clearly shows that all the arable lands of Bulgaria was at a critical stage of their development, with values fallen well below the normal, i.e. -50% to -60%, see Fig. 8 a) and Fig. 8 b). This was not affecting the winter crops which were already harvested, but clearly made a big impact on spring crops (sunflower and grain maize).

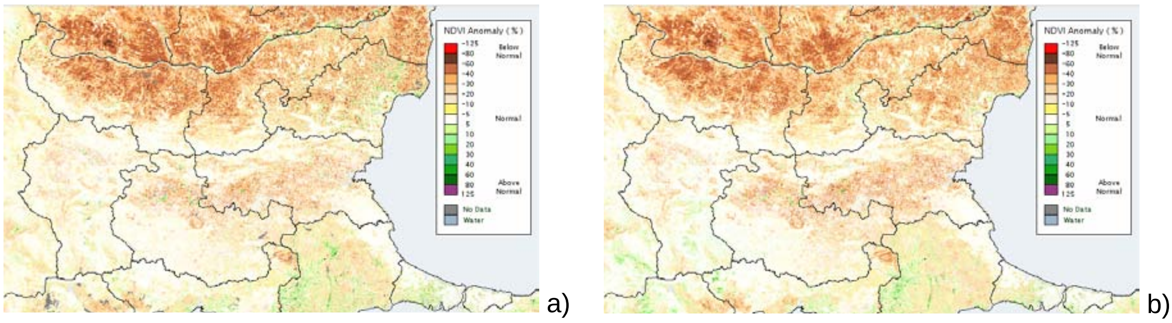
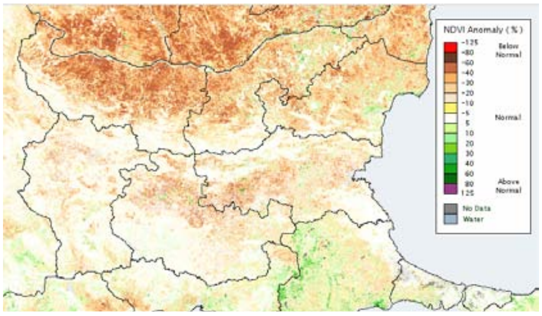


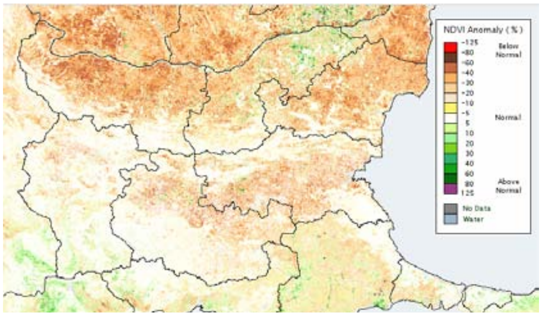
Fig. 8. NDVI anomaly maps from MODIS Terra products from a) 03-10.08.2012 and b) 19-26.08.2012. (data courtesy to USDA-FAS)

8. September 2012

The month was characterized with advanced development of the late agricultural crops. During the first decade the semi-late hybrids of maize was at *maturity* phenophase, while the late hybrids were at *beginning of maturity*. During the second and third decades the agricultural practices included sowing the early winter wheat, which finds them by the end of the month already at *emergence* phenophase. By the end of the month the harvesting of the sunflower was finished. The optimal periods for sowing the rapeseed were not followed (NIMH-BAS monthly bulletin, September 2012). The NDVI anomaly map for September 2012 shows no substantial change in the stress conditions for the crop cultivars, Fig. 9 a) and Fig. 9 b). During this time the sunflower cultivars were harvested which will be expressed by the yield figures when they are made available. Just some small parts in the North-East Bulgaria were experiencing above normal conditions, which is due to performing regular irrigation practices or sowing with different crop types.



a)

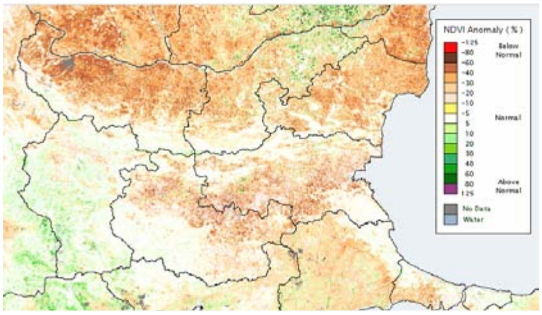


b)

Fig. 8. NDVI anomaly maps from MODIS Terra products from a) 04-11.09.2012 and b) 20-27.09.2012. (data courtesy to USDA-FAS)

9. October 2012

During the first decade of October 2012 a drastic decrease and complete depletion of soil moisture was observed. During the second and third decades of October 2012 the agricultural practices applied were sowing of winter crops. The heavy rainfall helped to accumulate normal amount of soil moisture in the agricultural crops which accounted for the normal development of winter wheat and winter barley at *emergence* and *tillering* phenophases (NIMH-BAS monthly bulletin, October 2012). In October 2012 the soil moisture conditions, in some parts of North Bulgaria, helped to improve the crop status as it is seen in the NDVI anomaly map, whereas in the North-West Bulgaria, where sowing of winter crops was observed are they were below normal state, Fig. 9 a) and Fig. 9 b).



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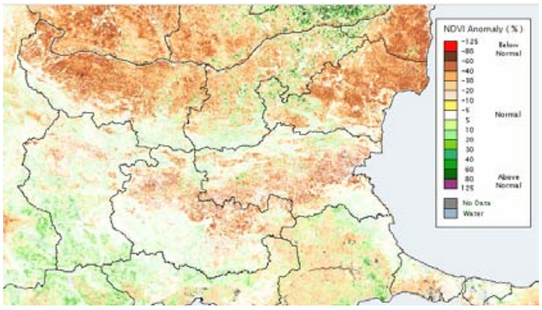

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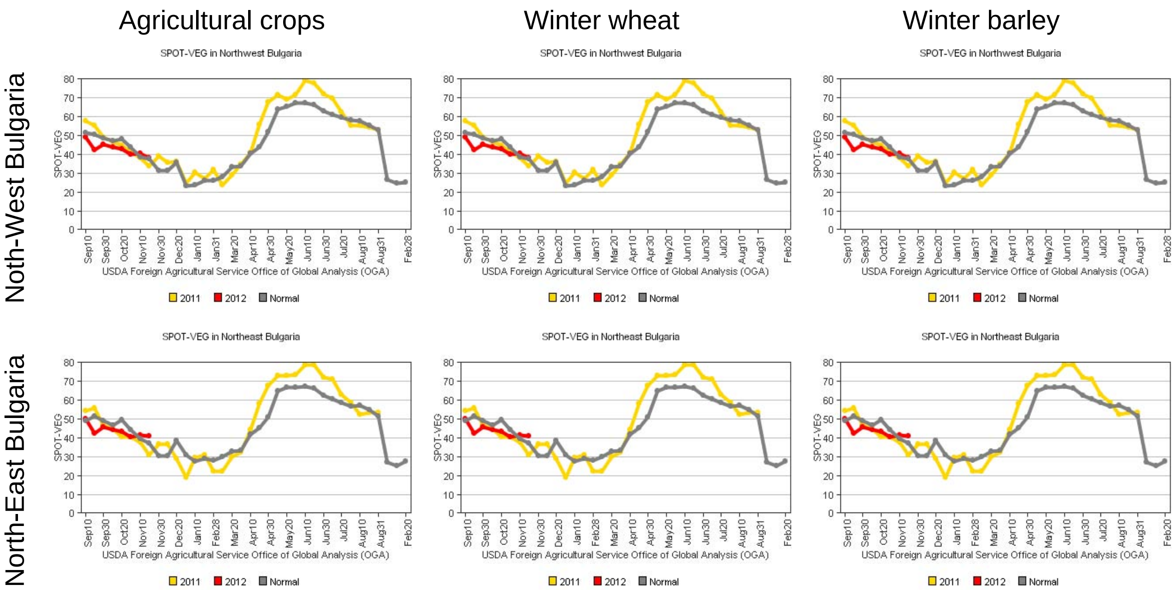
Fig. 9. NDVI anomaly maps from MODIS Terra products from a) 06-13.10.2012 and b) 22-29.10.2012. (data courtesy to USDA-FAS)

The analysis of these findings was detailed for winter wheat and winter barley by the time-series graphs derived from SPOT VEGETATION data, see Figure 10.



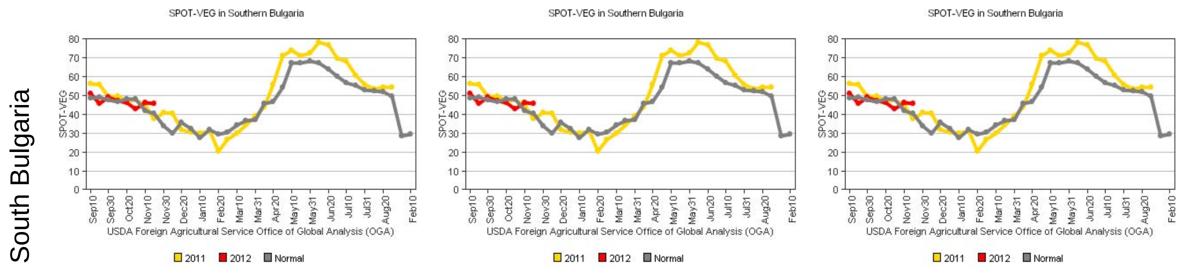


Fig. 10. Time-series curves derived from SPOT VEGETATION NDVI S10 products. (data courtesy to USDA-FAS)

It can be inferred from the figure that 2011 is comparatively better that the multiannual average of NDVI. The beginning of 2011/2012 agricultural year is even better (from November 2012 onwards) compared to the multi-annual average and the 2011 record. In Table 1 is presented the area, yield, and production of the main agricultural crops in Bulgaria.

Table 1. Area, yield, and production of main agricultural crops for Bulgaria (with modifications) (data courtesy to USDA-FAS)

	Harvested area (million ha)		Yield (t/ha)		Production (million metric tons)		Change in production
Commodity	2010/11	2011/12	2010/11	2011/12	2010/11	2011/12	Percent (%)
Barley	0.245	0.180	3.400	3.928	0.833	0.707	-8.77
Corn	0.327	0.399	6.260	5.536	2.047	2.209	-29.83
Oilseed, Rapeseed	0.212	0.220	2.571	2.364	0.545	0.520	-55.77
Oilseed, Sunflower seed	0.730	0.740	2.104	1.946	1.536	1.440	-9.72
Wheat	1.131	1.137	3.620	3.921	4.094	4.458	-4.67

The final figures in the change of production show that the wheat, barley and sunflower seed demise in production as of ~5 to 9 %, whereas the corn, oilseed and rapeseed are lowering their values by 30 to 56%. This come to support the discussions already made using the NIMH-BAS monthly bulletin data and MODIS Terra NDVI satellite products.

Conclusions

Although during the spring period of 2011/2012 a low amount of rainfall was observed, the FC was optimal for development of winter crops. This conditions hold until the beginning of the summer season, i.e. end of June 2012 and beginning of July 2012, when drought conditions settled in. The continuous drought did not have significant effect on the yield from winter crops (5-9% less). Moreover, the harvested crop was rich in gluten. Nevertheless, the severe drought has had an impact mainly on spring crops by shortening of their between-phase periods. Consequently, this highly affected their yield figures: (30% less) for maize and (56% less) for sunflower compared to the yield of the previous agricultural year 2010/2011. The significantly better agro-meteorological conditions observed in the first decade of October 2012 were improving the development of winter crops, which is also confirmed by the mean annual values of NDVI products from SPOT VGT satellite data.

Acknowledgments

The data and analysis is based on freely available materials provided by the United States Department of Agriculture (USDA) Foreign Agriculture Service's Crop Explorer and the monthly bulletins of NIMH-BAS.

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