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MONITORING THE VEGETATION STATE IN OLTENIA PLAIN, USING COPERNICUS LAND PRODUCTS

Denis MIHAILESCU[1, 2], Sorin Mihai CIMPEANU[2]

[1]National Meteorological Administration, 97 Bucharest-Ploiesti Street, District 1, Bucharest, Romania
[2]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: denis.mihailescu@meteoromania.ro

Abstract

The development of Earth Observation Systems in Europe began since the 1970s. France, through the National Center for Space Studies (CNES) together with partners from Belgium and Sweden and later through the establishment of Spot Image, laid the foundations of the SPOT space program. The year 1998 brings the first steps of a new common space program of the EU countries by the appearance of the GMES (Global Monitoring for Environment and Security) initiative. In 2014 GMES changed its name to Copernicus and is coordinated and managed by the European Commission, in collaboration with European Space Agency for the space component, European Environment Agency and Member States for the in-situ component. An important step in the study of vegetation was made with the emergence of the SPOT-VEGETATION program based on SPOT 4 and 5 from 1998 to 2013, followed by Proba-V from 2013 until 2020 and continued today by Sentinel-3. Vegetation indices are widely used for assessment of green biomass, crop production, plant health and stress to water scarcity, extreme weather conditions, and diseases.

***Key words**: Copernicus, CGLS, Proba-V, Vegetation state.*

INTRODUCTION

The Copernicus program is the European Earth observation system, using both satellite and in-situ data. It is coordinated and managed by the European Commission and implemented in partnership with Member States, ESA, EUMETSAT, ECMWF (European Center for Medium-Range Weather Forecasts), EU Agencies and Mercator Océan (copernicus.eu).
To meet all user’s needs and requirements in all areas of interest, Copernicus has been divided into 6 services: atmosphere, marine, land, climate change, security and emergency. Copernicus Global Land Service (CGLS) is the global component of the land monitoring service, which produces a series of medium and low-resolution bio-physical indices. In the initial phase of operation (2013-2016), CGLS developed 13 products (variables), based on observations made by VEGETATION instruments on board SPOT (Arnaud et al., 1991; Pulitini et al., 1994; Kurtis et al., 1998; Maisongrande et al., 2003), MetOp-ASCAT (Eumetsat, 2014) and other geostationary meteorological satellites. In 2016, new products were made available from PROBA-V (Dierckx et al., 2013), with improved spatial resolution of 300 m. From January 2017, other products with the same spatial resolution of 300 m were added. In the last phase of development (2016-2019), the number of bio-physical variables with global coverage was increased. Products from the cryosphere area have been added, as well as new products in existing areas. After the retirement of PROBA-V in 2020, the coverage is provided by OLCI instrument on board of Sentinel-3. The products are used for vegetation monitoring, water circuit, solar energy and cryosphere, being complemented by the existence of multi-temporal data series (land.copernicus.eu). All datasets can be accessed through several services: interactive notebooks, web, virtual machine desktop, manifest files, regular FTP, legacy portal and GEONETCast. For visualization there are 4 services: Global Land Cover Viewer, Africa demo Land Cover Viewer, Hot Spot Land Cover Change Explorer and Tiled map viewing service. There is also a multi-temporal analysis

service, for several variables. Analyzes can be made starting with 1998 at the level of administrative region (predefined) but also on customized points and polygons.

MATERIALS AND METHODS

Due to the position in southwestern Romania, the generally smooth landscape with average altitudes of approx. 100 m, the aspect of steppe and forest-steppe, the climatic influences and particularities, the Oltenia Plain has mainly an agricultural feature. It represents the plain area of Mehedinți and Dolj counties and almost 2/3 of the plain area of Olt County. The main cultivated crops are wheat, rye, barley, oats, corn, sunflower and rapeseed. In addition to these, potatoes, melons, vegetables and various types of fodder plants are also grown. Cumulated in the 3 counties, between 1990 and 2018, areas cultivated with wheat and rye increased by 110.000 ha, sunflower by 77.000 ha and rapeseed crops from 2000 ha to 63.000 ha. Instead, the areas occupied by corn decreased by 88,000 ha and those with barley and oats by almost 30,000 ha (Figure 1).

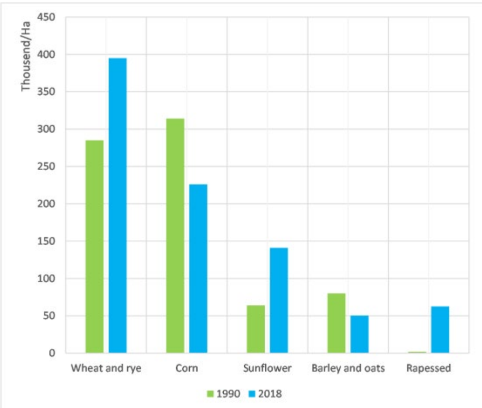

Figure 1. Cumulated areas occupied by the main crops in Mehedinți, Dolj and Olt counties for 1990 and 2018 (Source INS)

From the area of the Oltenia Plain, approximately 800.000 ha, 82% is used as agricultural land, and the arable land represents 70% (560.000 ha) of the total unit area. Between 1990 and 2018, the largest changes in land cover were recorded by arable land, which gains 50.000 ha taking over vineyards and pastures (Mihailescu & Cimpeanu, 2019). The most cultivated plant type is wheat, which together with barley, oats and rye can cover almost 60% of the total arable land. Next are corn, sunflower, rapeseed that have gained ground in recent years, and watermelon, especially in the Dabuleni-Sadova area.

Figure 2 show the density of the main crops in 2010, for the plots with an area of at least 10 ha and 10 km x 10 km grid. The data are acquired in the Farm Structure Survey (FSS), carried out by all Member States, following a common methodology to have comparative and representative results and statistics in time and space. The study is performed with a complete set of observations at an interval of 10 years (the last agricultural census and at 3-4 years on certain test areas - Eurostat).

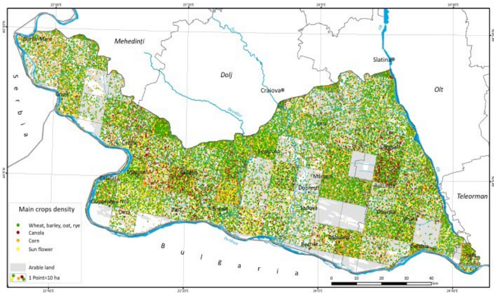

Figure 2. Main crops density in Oltenia Plain (Source: EC/Eurostat)

Wheat crops are covering areas of approx. 280.000 ha and together with barley, oats and rye exceed 320.000 ha. Maize exceeds 100.000 ha, sunflower 80.000 ha and rapeseed over 50.000 ha. Considering the data from 2018, it is foreseen that for the next FSS study, the values will remain constant for the crops over Oltenia Plain. The map above clearly shows three distinct areas: north of Dabuleni, Desa and east of Gruia in Blahniței Plain, where the crop density is low or almost non-existent. This is due to the presence of sandy soil and the phenomena of aridization and desertification associated with pedological drought.

With the launch of the NOAA AVHRR satellites and continuing with the NASA ERTS-Landsat program, the Earth's surface was also scanned into the red and infrared bands of the electromagnetic spectrum. The notion of "vegetation index" was first used by American researchers Donald Deering and Dr.

Robert Hass. Together with mathematician Dr. John Schell, they studied the biophysical characteristics of vegetation in the Great Plains region, using spectral signals from satellites. The first study to use NDVI, "Monitoring Vegetation Systems in the Great Plains with ERTS" was published in 1974 by Dr. J. W. Rouse. In the following period it was introduced in more studies on vegetation, remaining even today the most known and used vegetation index. NDVI is an indicator of presence, density and greenness state of biomass, thus having a close link with other vegetation proprieties indicator Fraction of Absorbed Photosynthetically Active Radiation (FAPAR). Even if it is not a physical property of vegetation, the use in the calculation algorithm of spectral bands in red and near infrared, makes NDVI to be widely used in ecosystem monitoring.

$$\text{NDVI}=\frac{(NIR-Red)}{(NIR+Red)} \tag{1}$$

The normalized values of the pixels are between -1 and 1. The spectral signature of the vegetation shows a reflection increase around 0.7 µm, while the land without vegetation, depending on the type of surface, has a more linear spectral signature. The negative values (-1; 0) of NDVI can be associated with water, snow, clouds, land without vegetation (or dead vegetation). The positive values increase the more active the chlorophyll is, which makes the level of infrared reflection (0.78-1 µm) very high. Between 0 and 0.33, sparse vegetation and unhealthy plants occur, up to 0.66, moderately healthy and denser vegetation. The high values of NDVI, over 0.6, show healthy and high-density vegetation, as in the case of forests (0.7-1).

The Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is defined as the fraction of active radiation absorbed by the process of photosynthesis (PAR) by the canopy. PAR is the solar radiation that reaches the leaves with a wavelength between 0.4-0.7µm. FAPAR quantifies the fraction of solar radiation absorbed by healthy leaves, necessary for the process of photosynthesis and depends on the structure of the canopy, the optical properties of vegetation, atmospheric conditions and angular configuration. FAPAR plays a crucial role in the energy balance of ecosystems and in estimating the carbon balance. It is one of the surface parameters that can be used to quantify CO_2 assimilated by plants and water released by evapotranspiration. The continuous observation of FAPAR is indicated for the monitoring of the seasonal and inter-annual cycle of the variability of the photosynthesis activity of the terrestrial vegetation. FAPAR is used as an input parameter in primary productivity models, based on considerations of light use efficiency. There is a relationship between FAPAR and NDVI. The increase in values depends on land cover and leaf area, with a similar response to leaf orientation, zenithal solar angle, and the coefficient of attenuation of solar radiation by the atmosphere (Myneni et al., 1994). FAPAR is recognized by the Global Climate Observing System (GCOS) as an Essential Climate Variable (ECV) and is a good indicator of drought.

The Leaf Area Index (LAI) is defined as half of the total area of the green elements of the vegetation canopy per horizontal ground surface (Chen & Black, 1992). The values derived from the satellite correspond to the total green leaf area in all layers of the canopy, including the first layer at ground level, which can be a significant contribution, in particular, for forests. LAI varies depending on several factors including seasonal climate change, the presence of water and nitrogen, the distribution of carbon dioxide vertically (Cowling et al., 2003). LAI can be estimated by in-situ measurements but also by remote sensing with the specification that this includes all green vegetation, such as in the case of forests, the lower layer of vegetation on the ground. With the exception of directional observations (Chen et al., 2005), LAI is not directly accessible through remote sensing observations due to the possible existence of heterogeneity in leaf distribution relative to canopy volume (Baret et al., 2016). Therefore, remote sensing observations are rather sensitive to the "effective" leaf surface index, thus the value that provides the same diffuse difference fraction, assuming a random distribution of leaves (Baret et al., 2016). The difference between the current and the actual leaf surface index can be quantified by the vegetation agglomeration index (Chen et al., 2005) which varies approximately between 0.5 (dense canopy) and 1 (randomly distributed leaves). The measured LAI actually corresponds to the green elements, being rather a greenness indicator.

Soil moisture (SM) dynamics is important in understanding environmental but also socio-economic processes, such as its impact on vegetation vitality, crop yields, droughts or flood risk exposure. SM is a key factor in the exchange of water and heat between soil and atmosphere, regulating air temperature and humidity (Bauer-Marschallinger et al., 2018). Soil Water Index (SWI) quantifies the state of humidity starting from the soil surface to a depth of 1m. It is mainly conditioned by precipitation through the infiltration process. Soil moisture is a very heterogeneous variable and varies on small scales depending on soil properties and drainage patterns. Satellite determinations are integrated over relatively large areas, with the presence of vegetation which adds complexity to the interpretation (land.copernicus.eu). SWI is produce in 2 forms: at European level, with 1 km spatial resolution, based on daily measurements from Sentinel-1 (C band SAR) and Metop ASCAT and at global level, with 12.5 km spatial resolution, from Metop ASCAT, daily and 10 days synthesis (SWI10). The quality of the SWI 1 km product was evaluated in the period 2015-2019 by comparing with the in-situ measurements provided by International Soil Moisture Network (ISMN), to which Romania also contributes with its own measurement network (RSMN) composed of 20 automatic stations. The analysis includes an examination of the temporary dynamics of SWI and how it correlates with field reference data. The SWI retrieval method does not consider the soil texture, which determines the relationship between T-value (time length) and soil depth (de Lange et al., 2008), and evapotranspiration. Eight T-values are provided to give more possibility to the user for selecting the best matching data (CGLS Product user manual, 2018). Currently is not possible to associate a T-value to a certain soil depth since this depends strongly on the application and the soil composition of the area of interest (Paulik et al., 2014). The quality of the SWI and SWI10 was evaluated by comparing different T-values to different layers of the global GLADS Noah model (higher T-values represent deeper soil layer) and in situ data from ISMN (GIO-GL Quality assessment report, 2015).

For validation, Pearson correlation coefficient (R) with a *p value < 0.01* and root mean square difference (RMSD) were used. The accuracy assessment is performed every year using the latest *in situ* measured reference data.

RESULTS AND DISCUSSIONS

Knowing the soil moisture values is very important as the occurrence of drought and associated phenomena of aridization and desertification are increasingly frequent in Oltenia Plain given that the agricultural area occupies 82% of the total unit. Soil moisture is graphically represented in Figure 3, through the Soil Water Index (SWI), over entire plain at various soil depths (T-values = 5.40 and 100) for 2019 and 2020. The temporal resolution is 10 days.

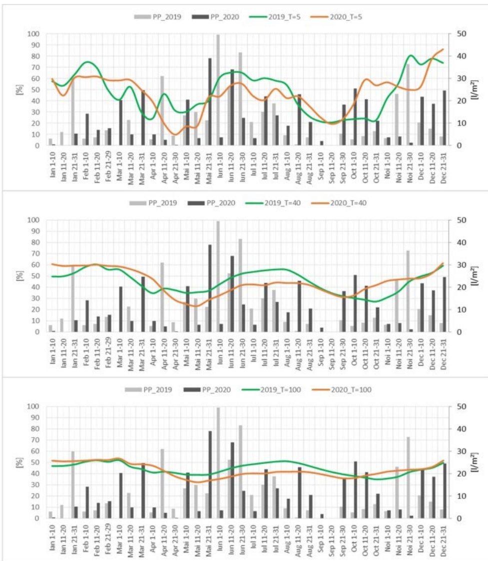

Figure 3. Soil Water Index and rainfalls for 2019 and 2020

An accentuated dynamics can be observed for T = 5 where the humidity is strongly correlated with rainfalls. SWI reacts immediately, naturally, to the appearance of water but also to small and insufficient amounts for plant development. In spring 2019, due to low amounts of rainfall, the relative value of humidity reaches a minimum of 24% in the first decade of April. There is a period of growth until mid-July, after which the values fall sharply in August, September and October, following an increase and a maximum of 80% in the last decade of November. In 2020, starting with the second decade of March, soil humidity is decreasing from 59% to under 10% in the last decade of April and stay under 2019 values until late August. For T = 40 and T = 100, the humidity is more linear and similar, a lower dynamic due to the ability of water to infiltrate into the soil depending on its texture. The SWI 2019-2020, March to September average is presented in Table 1.

Table 1. SWI average 2019 vs. 2020

Year	SWI T = 5	SWI T = 40	SWI T = 100
2019	48%	45%	45%
2020	46%	45%	43%
1.03-30.09.2019	42%	44%	45%
1.03-30.09.2020	38%	40%	41%

In spring, when moisture intake is necessary for plant development, soil moisture for T = 40 and T = 100 is 50-60% in the first decade of March, then rapidly dropping to a minimum of 23-35% in the second decade of May. In August and September (droughty months), even if the SWI values at depth are on average 40%, they remain higher than the surface values of 30%, thus ensuring a certain degree of humidity in the soil. The occurrence of drought in May 2020 is observed by comparing the values recorded in the second decade of the month in 2019 and 2020 (Figure 4). During May 11-20, 2019, on the largest surface of the Oltenia Plain, the average value of relative humidity is approx. 40%, except for two areas. In the center of Bailestilor Plain, for T = 5 and T = 40, the values were lower, between 20% and 30%, and east of Jiu River (Romanatilor Plane), the SWI values were higher, between 40% and 50%. Between 11 and 20 May 2020, the relative humidity for T = 5 was 10-20% on most of the unit, even below 10% in the south, in the Lake Bistret are and maximum 30% in the center and north of the Romanatilor Plain.

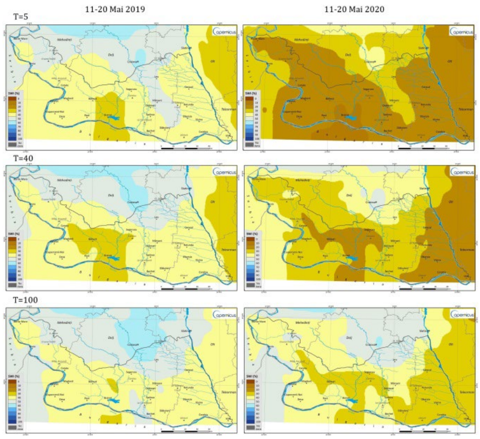

Figure 4. SWI10 in the second decade of May 2019 and 2020 (T = 5, 40 and 100), highlights the occurrence of drought in late spring 2020

For T = 40 the average is 30%, but on two areas, in the center and east, the values are lower, from 10% to 20%. For T = 100, the situation is slightly better, with values of 20-40% and over 40% in the north of the Romanatilor Plain.

The amounts of rainfalls measured at 5 meteorological stations, Bailesti, Bechet, Calafat, Caracal and Craiova (Figure 5), confirm the lack of soil moisture recorded by satellite sensors. From May 7, 2020 until May 19 (13 consecutive days) three of the five stations do not record rainfall values (Bechet, Calafat and Caracal) and the other two, only at the end of period, registered low quantities.

On May 18, 2020, at Craiova station there are very low amounts of rainfalls, of only 0.5 mm, and on May 19 in Bailesti 8.4 mm.

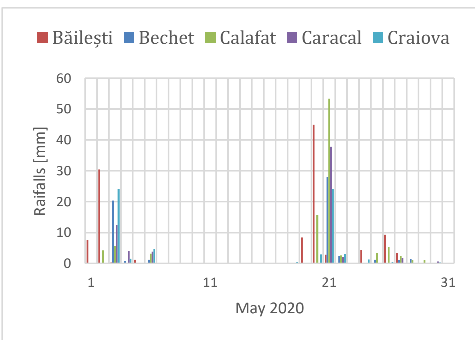

Figure 5. Rainfall amount in May 2020 at five meteorological stations

After two days of rain, with quantities that even exceeded 50 mm in Calafat, follows a period with very low or even non-existent quantities at some stations. These quantities may not be enough for the affected plants to return, moreover, a new period with moisture deficit can occur.

What is important to emphasize is that May is one of the months with the richest rainfall recorded at the 5 weather stations, compared to the climatic average. In addition, even if they all approach the value of the climatological average or even exceed it, the drought occurs. This is possible because rainfalls were recorded practically only in 2 periods of the month: at the beginning of the first and third decade. The uneven distribution of rainfalls and the deficit of humidity in winter due to an almost non-existent layer of snow, led to the appearance of drought.

The evolution of vegetation and in particular of crops depends to a very large extent on the amount of water (from rainfall or irrigation) that provides the necessary soil moisture. The temporary extension of rainfalls during the most important phenological phases of crops is also important. Even if the norm is met at an average/month level, it is important to be evenly divided during the entire period. The response of the vegetation to the presence or scarcity of water is reflected in the NDVI values with a delay of several days. The beginning of 2019 came with a higher amount of water from rainfalls but with NDVI values smaller than 2020. This happened because of an extensive layer of snow that persisted until the end of February. In the first 10 days of May 2020, NDVI drops suddenly as consequence of an April almost without rain. Following this period, the values remain lower than same period of 2019, highlighting a drought phenomenon in May 2020 (Figure 6).

The graph pointed out the agricultural characteristics of the plain and the type of crops. Winter crops, especially wheat, give higher NDVI values in the first half of the year, so that in the second half, spring crops, which occupy smaller areas, together with the moisture deficit, give lower NDVI values.

The first 3 months of the year are part of the last phase of the rooting stage of wheat (beginning in September-October), when the twining of the shoots and the elongation of the stem takes place.

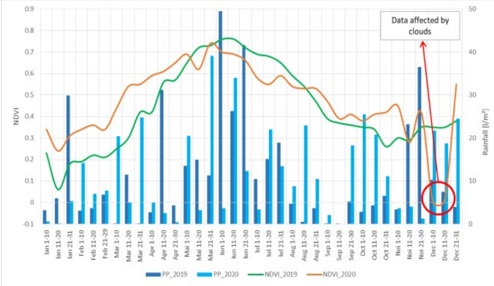

Figure 6. NDVI evolution in 2019 and 2020

The growth depends during this period on temperature, the number of sunny days, and the presence of a protective snow layer. In April and May follows the establishment stage, a critical period in the plant's development, as the elongation of the stem continues, the roots deepen, the first detectable node appears, the inflorescences and spike formation appear. This is a period in which the presence of water plays an important role, on which the productivity of the plant depends. The production stage begins in June, after flowering, when the number of grains/m^2 and their weight can be determined.

With the maturation and gradual loss of greenness, starting in mid-June, the NDVI values begin to decrease. This cycle can be observed annually, with slight differences depending on environmental conditions and possible image errors (Figure 7).

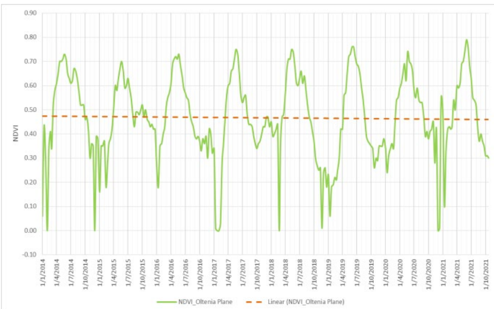

Figure 7. NDVI multitemporal cycle and trend from 2014 until 2021

The NDVI trend shows a slight decrease of values from 2014 until 2021, which can be caused by a low amount of water from rainfalls

at the times when the plant needs it the most, the lack of irrigation especially in the months when the phenomenon of drought occurs and possible diseases that affect the plant condition.
Given that NDVI is considered a vegetation index and FAPAR represents vegetation properties, the response to soil reflectance and vegetation optical properties are different. Depending on the type of vegetation, the canopy can cover ground. Higher soil reflectance negatively influences NDVI but increases FAPAR values. The canopy of summer crops like corn and sunflower decrease soil reflectance. The diminishing of photosynthesis process occurs when the plants are mature and close to harvest. When canopy is losing his greenness becoming browned, FAPAR begins to decrease. This can be observed starting May when NDVI continues to increase until June and FAPAR reaches its maximum in the last decade of May. From June, the differences increase due to the harvesting of winter crops and the appearance of the panicle and corn silk, when part of the leaves at the base may turn yellow and dry. With the ripening of the grain and the reaching of physiological maturity in the months of July and August, adding a lack of rainfalls, FAPAR registers a steep drop on arable land, reaching values of 0.2 at the end of September, which means low health or no vegetation. If in the first decades of May 2019, the average value of FAPAR for arable land was 0.64, in the similar period of 2020, the value is 0.57. In Figure 8, orange-red areas from 2019 highlight a greater absorption of solar radiation, therefore, more active photosynthesis process compared to 2020.

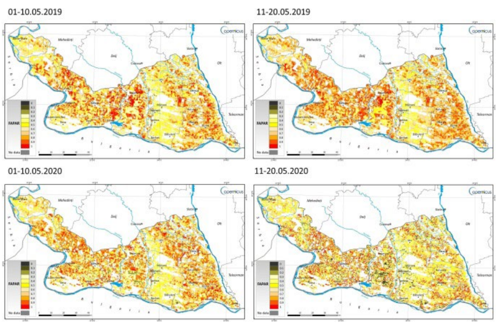

Figure 8. FAPAR evolution in the first two decades on May 2019-2020

In the decade 10-20 May 2020, with the intensification of the drought, dark areas appear in the central part of the plain, which indicate a decrease of the crop's health and withering.
A large variety of models used in agriculture, ecology, carbon cycle, climate or other studies use LAI to quantify the number of leaves present in each environment to correctly represent radiation, heat, water and various gas exchanges with the atmosphere and soil.
The main uses are in the soil-vegetation-atmosphere transfer scheme, in models of biogeochemical cycles, in agrometeorology for crop evaluation, which usually require long time series at a certain spatial scale. Together with the variation of FAPAR and soil moisture, LAI can highlight the increase or decrease of green mass in agricultural area. For arable land in the plain area, the maximum annual value of LAI is usually reached at the end of May or the beginning of June. In the Oltenia Plain, during this period, the values are around 3, in the years favorable for the development of crops reaching the value of 3.4-3.5 and in the deficit years around the value of 2.2-2.4. Moreover, the multi-temporal average over a period of 20 years is slightly above the value of 2.2 in the last decade of May. If in the first decade of May 2020, the LAI had a slightly higher value compared to the same period in 2019, in the second decade, the LAI value is lower and continues to decrease in the last decade as well (Table 2).

Table 2. LAI values in May 2019-2020

Decade	2019	2020
01-10 May	2.65	2.67
11-20 May	2.94	2.69
21-31 May	3.15	2.52

Figure 9 shows the differences that appear in the second decade, more pronounced in the center, south of Segarcea, between Desnațui and Jiu rivers, continuing in the last decade of May. Due to the 2 weeks without rainfall, the soil moisture decreased on the surface, while at depth (root zone), the water reserve managed to ensure a small amount, however, insufficient for further development of the crops. The LAI values started to decrease in the second and third decade of the month, compared to 2019 when the development continues and the LAI reaches the maximum value of 3.15. These decreases are equivalent to the reduction of the percentage of green mass, which can lead to a lower agricultural production. Since, in general, the maximum LAI values are at the end of May, even with the contribution of rainfall that fell in the last decade of the month, it is impossible to return to values close to 3, resulting in a period affected by drought.

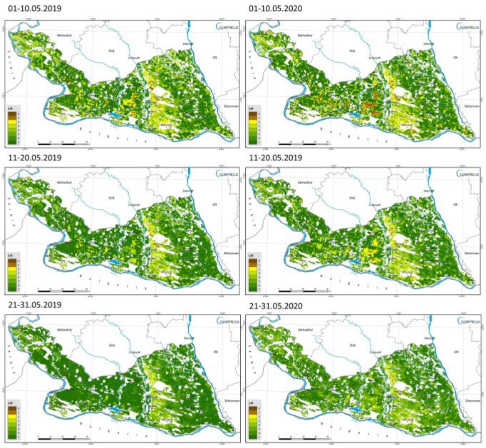

Figure 9. Leaf Area Index in May 2019-2020

What stands out is the lack of vegetation on the eastern side of the Jiu River, from south of Craiova to the contact with the Danube valley. This strip, which can reach a width of 30 km in the southern part, is known as an area dominated by sandy soils on which sand dunes have developed. Land fragmentation, active processes of desertification and aridization, lack of land reclamation especially irrigation and sand-stabilizing plants, will lead to an increase of affected areas by climate change.

CONCLUSIONS

The satellite products for land monitoring are increasingly used because they are non-invasive means of measurement, ensure the observation of any area with global coverage, daily temporal resolutions and 10-day synthesis, delivery of products in less than 24 hours and consolidated after 3 days. In this case, only a small part of what is called vegetation thematic area was described and used (products with medium spatial resolution of 300m, 1km and coarser at 12.5km), useful for monitoring larger areas, such as plains. For detailed analysis, vegetation indices derived from higher spatial resolution satellite images such as Sentinel-2 can be produced. With the archiving of older products, time series of data can be created that help to develop new indices such as VCI (Vegetation Condition Index) or VPI (Vegetation Productivity Index), which evaluate the current state of vegetation with the help of long-term statistics. Together with the data acquired in-situ, with the help of specific devices, from meteorological stations in the national system or from mini-stations located right in the cultivated land, the satellite data provide a picture of what happened in the recent past, for at least 24 hours, thus being able to make forecasts or act punctually in the field, for the best possible management of material and human resources. In the evolution of the vegetation indices (NDVI, FAPAR, LAI) can be observed the effects of climate change that affect the evolution of the phenological phases. This effects together with poor land reclamation actions will lead to a decrease in crop productivity.

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