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WATER STATUS ASSESSMENT IN MAIZE AND SUNFLOWER CROPS USING SENTINEL-2 MULTISPECTRAL DATA

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Резюме: *Productivity of sunflower (Helianthus annuus L.) and maize (Zea mays L.) is strongly regulated by the availability of water. Boosting the efficiency of using water resources in agriculture requires innovations in tracing crop water status in different growth stages. Early detection of water stress in plants is needed in order inevitable crop damage and yield loss to be prevented. Remote sensing methods provide low cost and quick techniques for monitoring of crop water status, assessment of water stress and irrigation scheduling. In this study, remotely sensed spectral indices (Normalized Difference Water index - NDWI, Moisture Stress Index - MSI, and Normalized Difference Wetness Index - NDWNI) and spectral transformation methods (Tasselled Cap Transform) are applied. The research evaluates dynamics of sunflower and maize water status in the environmental conditions of growth season 2019, using multispectral imagery, acquired by Sentinel-2 sensor of the European Space Agency Program for Earth Observation "Copernicus" and daily measured field climatic data (air temperature and precipitation).*

ОЦЕНКА НА ВОДНИЯ СТАТУС НА ЦАРЕВИЦА И СЛЪНЧОГЛЕД С ИЗПОЛЗВАНЕ НА МУЛТИСПЕКТРАЛНИ ДАННИ ОТ SENTINEL-2

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Abstract: *Продуктивността на агроекосистемите с царевица (Zea mays L.) и слънчоглед (Helianthus annuus L.) е силно зависима от наличието на вода. Повишаването на ефективността в използването на водните ресурси в земеделието изисква прилагането на иновативни подходи за проследяване на водния статус през различните фази на развитие на земеделските култури. За да бъдат предотвратени необратими физиологични поражения върху организма на растенията и загубата на земеделска продукция е необходимо ранно отчитане на водния стрес при насажденията. Методите на дистанционните изследвания предоставят икономични и бързи способи за мониторинг на водния статус на земеделските култури, оценка на водния стрес и определяне на поливния режим на посевите. В настоящето изследване са приложени спектрални индекси (NDWI, MSI, NDWNI) и методи за спектрална трансформация (Tasselled Cap Transform). Изследването прави оценка на динамиката на водния статус на насаждения с царевица и слънчоглед в условията на вегетационния сезон през 2019 г., с използване на мултиспектрални изображения от спътника Sentinel-2 на Европейската космическа агенция и ежедневно измервани полеви климатични данни (температура на въздуха и количество на валежите).*

Introduction

Water stress is one of the most important growth limiting factors in crop production. Vegetation phenology dynamics is strongly dependend on climate conditions.Each crop has a different response to drought and water stress, and the water requirements of each crop are different during different growth and development stages. Changes in environmental conditions, such as droughts and water scarcity, lead to changes in physiological features of plants. It is determined that the gradual reduction of soil moisture from field capacity to wilting point causes irreversible physiological processes with increasing intensity in the plant organism; the magnitude of irreversible physiological damage in the plant organism is different with the same decrease in humidity on the same soil at different stages of its development; the maximum physiological damages during the different stages of development limit irreversibly the quantity and quality of production, regardless of the subsequent increase of soil humidity induced by irrigation or rainfall [5,6]. Tracing the water status of agroecosystems in different growth stages in a specific weather pattern is crucial because it gives us valuable knowledge about the changes in agroecosystems functioning in various environmental conditions. In present study, the water status of sunflower (Helianthus annuus L.) and maize (Zea mays L.) crops, in different growth stages (based on BBCH scale), under the weather conditions in 2019 growing season, is assessed [3, 8].

Study sites

The study sites are located in Lom Municipality, North Central Bulgaria. The area is characterized by intensive agricultural management due to the production of cereal, technical, and forage crops (Fig. 1). Agriculture in the region is developing in the conditions of water deficit, insufficient and uneven annual rainfall distribution, high temperatures and low relative humidity, frequent droughts in the spring and longer in the summer. The average air temperature for the growth season of studied crops (March to September) for the period 1901–1980 is 17 °C, and the precipitation sum is 353.1 mm. Field measurements show that the average air temperature over the last years increases. The average air temperature for the period from 2015 to 2019 is 17.9 °C. The precipitation sum, on the contrary, notes a slight decrease - 349 mm.

The studied crops are developed on Calcic Chernozems. The Calcic Chernozems in the study area are characterized with weakened resistance and stability of topsoil. These processes contribute to increase of its density and hardness, limiting aeration, delaying filtration of water, and hence influencing the overall water status of the agroecosystems [13, 14].

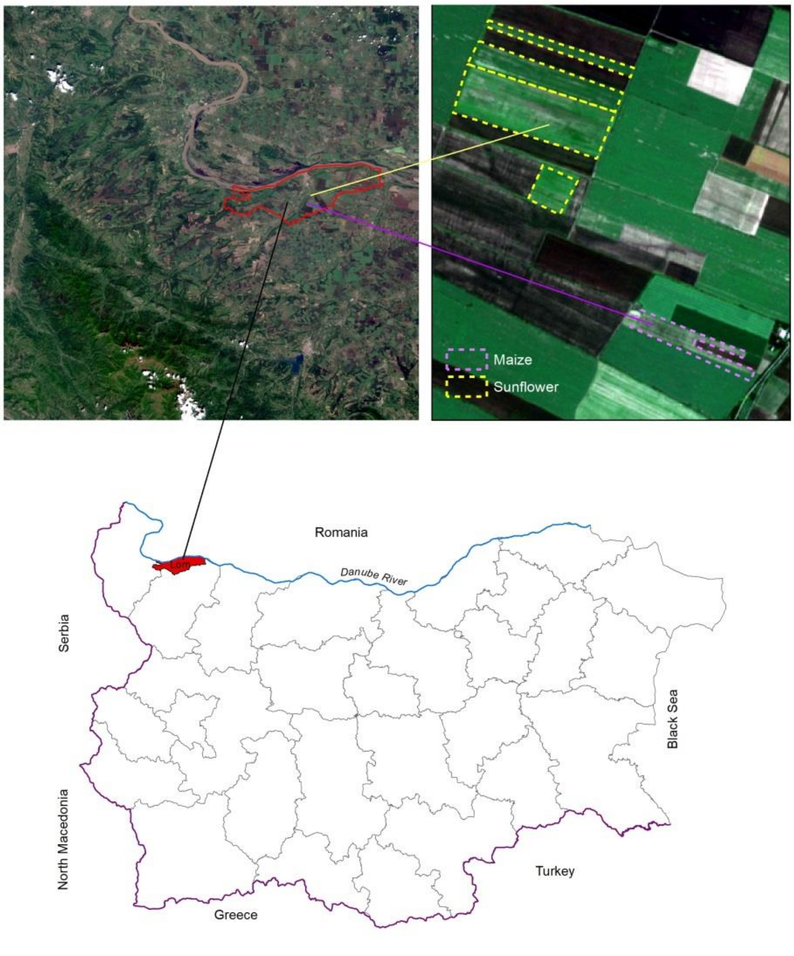

Fig. 1. Location of study sites

Materials / Data and methods

Satellite data acquisition

For the purpose of this study, multispectral data from the *Sentinel-2* sensor were used. The *Sentinel-2* images are acquired between 30 March 2019 and 01 September 2019 and encompass the period from the sowing till the full maturity of studied sunflower and maize crops. All available cloudless *Sentinel-2* images for that period are used. The image acquisition date and the relevant growth stage for the sunflower and maize crops are presented on Table 1.

Table 1. Satellite images acquisition dates and relevant crop growth stages (BBCH scale)

Image acquisition date (2019)	**Growth stage of sunflower (BBCH scale)**	**Growth stage of maize (BBCH scale)**
30 March	Germination	Germination
24 April	End of Leaf development /Beginning of Stem elongation	Leaf development
04 May	End of Stem elongation / Beginning of Inflorescence emergence, heading	Leaf development
08 June	Inflorescence emergence, heading	Stem elongation
13 June	Flowering, anthesis	Stem elongation
03 July	Flowering, anthesis	End of Inflorescence emergence, heading
08 July	Flowering, anthesis	Beginning of Flowering, anthesis
18 July	End of Flowering, anthesis / Beginning of Development of fruit	End of Flowering, anthesis / Beginning of Development of fruit
23 July	Development of fruit	Development of fruit
28 July	Development of fruit	Development of fruit
02 August	Ripening	Ripening
07 August	Ripening	Ripening
12 August	Ripening	Ripening
17 August	Ripening	Ripening
22 August	Senescence	Ripening
27 August		Ripening
01 September		Senescence

Climate data for the 2019 growth season

The field climatic data for 2019 growth season is presented on Fig. 2. The analysis show that there is a slight increase in the average air temperature (+0.7 °C) over the average for the period 1901–1980, but a significant decline of precipitation sum (–80.3 mm) from the average for the period 1901–1980, and (–76.2 mm) from the average for the period 2015–2019.

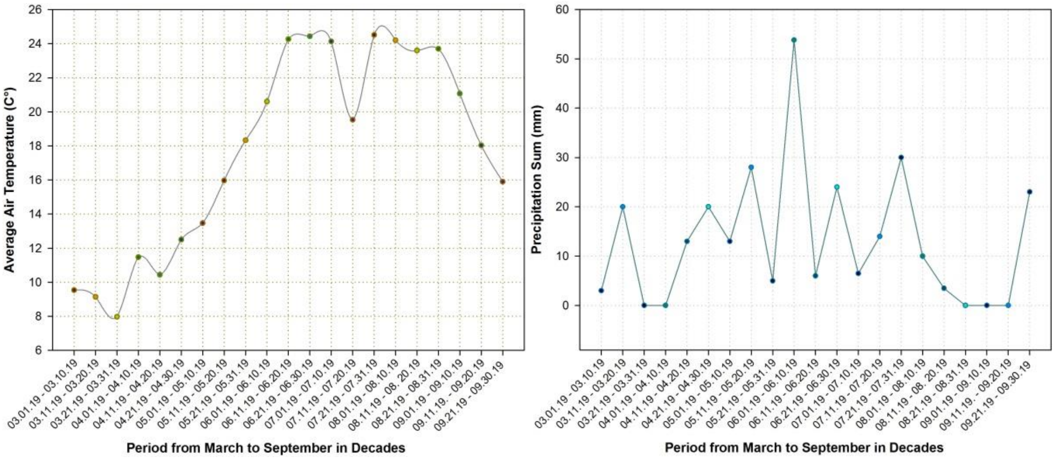

Fig. 2. Average air temperature and precipitation sum for the period from 01.03.2019 to 30.09.2019

Methodology

Spectral vegetation indices are mathematical expressions involving reflectance values from different parts of the electromagnetic spectrum, aimed to optimize information and normalize measurements made across varied environmental conditions (differences in plant species, solar angle, shadowing, illumination, canopy coverage, soil background, atmospheric condition, etc.) [9]. The increasing number of land-related spectral bands and expanding the spectral coverage into the shortwave-infrared region let to development of spectral vegetation indices, estimating the water status of ecosystems and detecting the water stress in vegetation [15]. The water absorption and reflection features in the red and NIR parts of the electromagnetic spectrum and the analysis of spectral reflectance has resulted in several useful water indices [12].

Normalized Difference Water Index (NDWI) [2], is a spectral vegetation index that capitalizes on the differential response of the NIR and the short-wave infrared (SWIR) reflectance in vegetation. The SWIR reflectance shows the changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content, but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content [1]. The NDWI is a very good proxy for plant water stress. The values of the index range from –1 to 1. The high NDWI values correspond to high plant water content and vice versa. The NDWI formula can be expressed as (1):

(1) $$NDWI = \frac{\rho NIR - \rho SWIR}{\rho NIR + \rho SWIR}$$

Moisture Stress Index (MSI) is used for canopy water stress analysis, productivity prediction and biophysical modeling. This index is developed to detect changes in leaf water content using the NIR and SWIR reflection ratio [4].When the leaf water content in vegetation canopies increases, the absorption in SWIR region of the electromagnetic spectrum increases with absorption in NIR remaining nearly unaffected by changing water content. MSI is also sensitive to soil moisture fluctuations, increasing in value with decreases in soil moisture with strongest correlation at 20 cm soil depth. Hence, in growing season MSI not only reflects the response of vegetation to soil moisture variation, but also can be used in the estimation of soil moisture variation [16]. Higher values of the index indicate greater plant water stress and consequently, less soil moisture content. The values of MSI range from 0 to more than 3 with the common range for green vegetation being 0.2 to 2.9. The MSI formula can be expressed as (2):

(2) $$MSI = \frac{\mathrm{SWIR1}}{\mathrm{NIR}}$$

Tasselled Cap model for orthogonalisation of satellite images is a very effective method of interpretation, classification, and analysis of phenomena and processes related to the dynamics of change of the main components of the Earth surface: soil, vegetation, and water [7]. In orthogonalization, three differentiable classes are obtained (soil brightness, greenness, and wetness axes), which are strongly sensitive to small increment processes of vegetation change. This enables more precise classification and tracking of changes of current condition of the soil and vegetation components of the land surface. Brightness component is based on the spectral reflectance characteristics (SRC) of non-vegetated areas, greenness component is defined by the signature of vegetation, and wetness - by the signature of moisture content. The Normalized Differential Wetness Index (NDWNI) is based on the wetness component of TCT and in the present study it is applied to identify the small changes that occur in sunflower and maize ecosystems in relation to moisture content. NDWNI values show the relative variation of moistures content in agroecosystems by periods and enables determination of its change in relative values. NDWNI ranges from +1 to −1 and indicates the positive and negative changes in moisture content for a given time period. The NDWNI formula can be expressed as (3) [10,11]:

(3) $$NDWNI = \frac{W_n(t_2) - W_n(t_1)}{|W_n(t_2)| + |W_n(t_1)|}$$

Results and conclusion

In the initial growth stages of crop development, high MSI values are observed. This is related to the lack or the smaller proportion of leaves area relative to those of bare soil. Nevertheless, the MSI values of sunflower are higher than those of maize, which on the one side could be related to earlier sowing of maize crops (5 days), and on the other, to morphological features of the crops leaves. After entering the inflorescence emergence stage (sunflower) and stem elongation stage (maize), a significant decrease of MSI values is observed. The MSI values of the sunflower are a bit lower than the MSI values of the maize. The beginning of fruit development stage records an increase of MSI values. After entering ripening stage, the MSI values of sunflower again exceed those of maize (Fig. 3). The sunflower is harvested on 23 August 2019, and the maize on 14 September 2019.

Expectedly, the lowest NDWI values are observed in the initial crops growth stages. The explanation is the same - smaller proportion of leaves area relative to those of bare soil. The highest NDWI values are observed in the beginning of July, when the studied crops are in flowering stage. After entering ripening stage, the NDWI values of sunflower become negative, whereas the NDWI values of maize fall under zero later, at advanced ripening stage (Fig. 4).

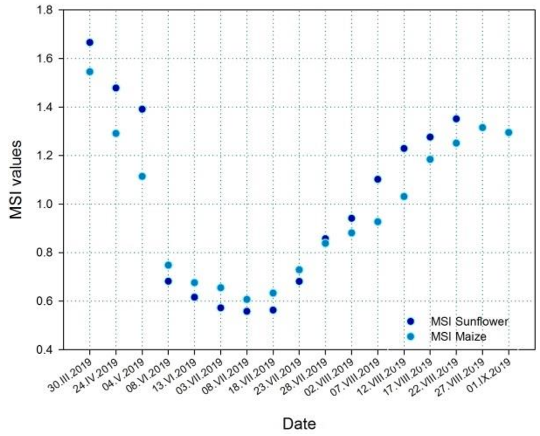

Fig. 3. Average values of MSI

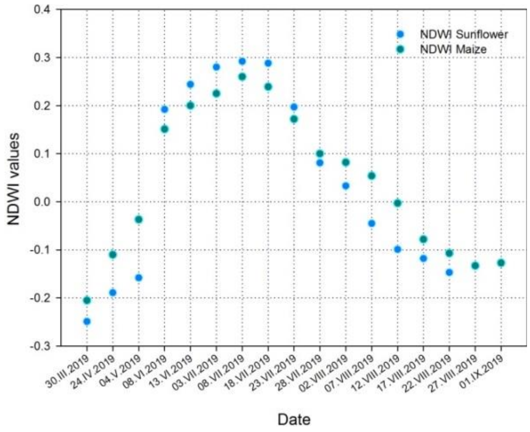

Fig. 4 Average values of NDWI

The results after calculation of NDWNI show the dynamics in moistures content in agroecosystems by periods. There is relative stability in moisture content during the studied periods. The largest deviations are reported for the sunflower crops in the period between 18 July and 23 July, when an increase of NDWNI values and a noticeable decrease in the next two periods (23 July – 28 July and 28 July – 02 August) are observed. In the period between 18 July and 23 July, the studied crops are in the end of flowering stage. After entering development of fruit stage, and during the whole stage, the decrease of NDWNI values and respectively of moisture content is observed. After the abovementioned periods, after starting of the ripening stage, an increase of NDWNI values and stabilization of moisture content is detected.

The dynamics of moisture content in maize ecosystems is similar, but less pronounced (Fig. 5).

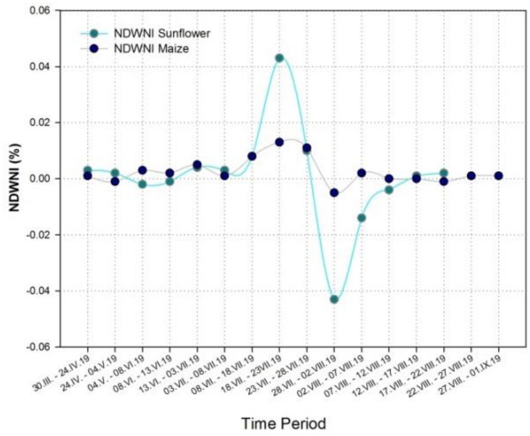

Fig. 5 Average values of NDWNI

As a conclusion, it could be said that the study confirms that the water status of agroecosystems and dynamics of moisture content is closely related to different growth stages. The suggested research approach is appropriate for an accurate examination of different crop types, developing under various environmental conditions, during growth season.

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