

A Length-of-Season Analysis for Maize Cultivation from the Land-Surface Phenology Metrics Using the Sentinel-2 Images

Analiza duljine vegetativnoga perioda za uzgoj kukuruza iz fenoloških metrika određenih korištenjem satelitskih snimaka sa sentinela-2

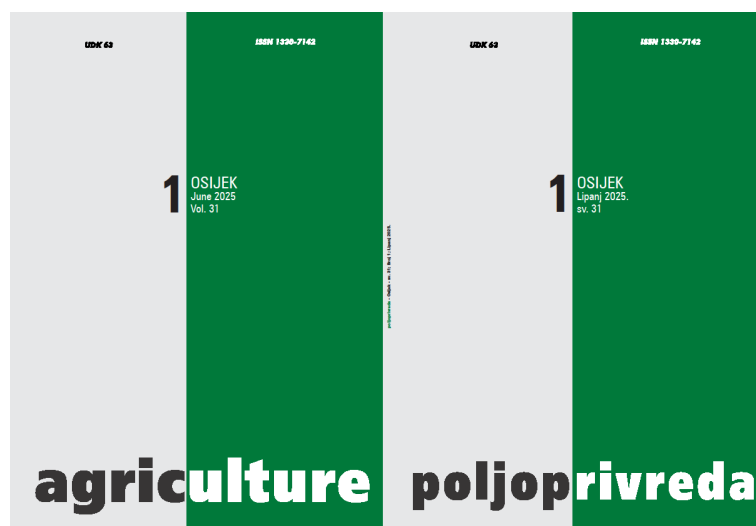
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A LENGTH-OF-SEASON ANALYSIS FOR MAIZE CULTIVATION FROM THE LAND-SURFACE PHENOLOGY METRICS USING THE SENTINEL-2 IMAGES

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SUMMARY

This study analyzes the length of a growing season for maize cultivation in Osijek-Baranja County utilizing a land-surface phenology metrics derived from the Sentinel-2 imagery according to a normalized-difference vegetation index (NDVI). The three key phenological indicators were calculated, including the start of a season (SOS), end of a season (EOS), and the length of a season (LOS) for the years 2017 and 2022. The mean monthly air temperatures during the maize-growing season were significantly higher than the 30-year average, while a total precipitation was notably lower, particularly in August, suggesting a direct impact on maize phenology, with the LOS values exhibiting a non-normal distribution and differing variances between the years studied. This research contributed the insights for the improvement of yield forecasting and the adaptive management strategies in response to a climate variability, ultimately supporting food security and sustainable land management practices in the region. A future work should be expanded on these methodologies to enhance their applicability across the diverse agricultural contexts.

Keywords: land-surface phenology, Sentinel-2 imagery, normalized-difference vegetation index (NDVI), climate variability growing-season analysis

INTRODUCTION

Climate change can result in the more frequent and intense extreme weather events, such as the droughts, floods, and storms, thus affecting the agricultural production (Dong and Chang, 2023). Climate variability is a significant factor influencing the maize yields, because an increased climate variability results in the largest decreases in the future maize yields (Southworth et al., 2000). Climate change can alter the precipitation patterns, including the amount, distribution, and seasonality. An insufficient or irregular distribution of precipitation can lead to an inadequate soil moisture, affecting the maize growth and yield. Conversely, an excessive precipitation can cause waterlogging and pest problems, negatively impacting the yield. Daničić et al. (2020) noted that the climate in Northern Serbia, as well as in the region of Southeastern Europe, has changed significantly in the last decades. The periods of extreme drought and precipitation are apparent and affect the agricultural production, which eventually impacts the production of most important crops in the Pannonian Basin (i.e., the parts of Serbia, Hungary, Croatia, Bulgaria, and Romania).

For the period until the middle of the 21st century, an increase in the air temperature between 4°C and 4.5°C is projected during the summer in continental Croatia (Branković, 2014). The same author concludes that the combined effects of increasing temperature and decreasing precipitation may, in the recent period, result in the more frequent and longer-lasting droughts, thus affecting the food production. Similarly, according to different climate change scenarios until 2050, Johnston et al. (2015) predicted an increase in the maximum, and even more significantly, in the minimum air temperatures and a decrease in precipitation. Both are predicted to lead to a reduction in the duration of the growing season of the rain-fed and irrigated maize in the USA. In the near-future climate in Croatia, the number of warm days is generally projected to increase (Branković et al., 2012), and, in Northern Hemisphere, on average, the temperature had a larger influence on the yields than precipitation did (Sakurai et al., 2011).

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The land-surface phenology metrics provides a basis for the understanding of seasonal dynamics of agricultural crops, as it delivers an insight into the growth patterns, productivity, and environmental responses. While in the previous studies the land-surface phenology was determined by various multispectral satellite-mission data, the Sentinel-2 mission of the European Space Agency (ESA) provides the superior, open, and multispectral imaging capabilities to its contemporary missions (Misra et al., 2020). Various phenology metrics allow for an indirect assessment of crop health (Kowalski et al., 2020), which improves the yield forecasting and a predictive mapping of soil parameters (Radočaj et al., 2022; Radočaj et al., 2023). Moreover, a land-surface phenology metrics derived from the Sentinel-2 imagery can contribute to the models predicting the impact of climate variability on the agricultural systems.

This study's hypothesis was that mean monthly air temperatures and monthly precipitation will affect the length of the maize-growing season in 2017 and 2022. Therefore, the aim of this study was to evaluate the length of a season based on a phenology analysis using the Sentinel-2 satellite images and determine the potential effects which could have caused its change during a five-year period.

MATERIALS AND METHODS

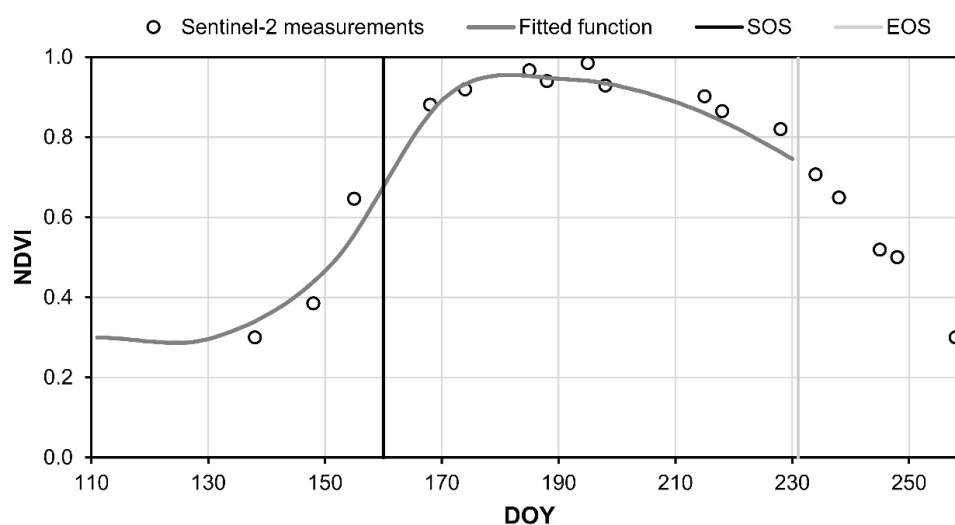
Study area and the data

The study area was selected in Osijek-Baranja County, a 4,155 km² region in eastern Croatia, due to its traditional importance for the arable crop production at the national level. For the sake of data availability, the ground-truth, maize-cultivated agricultural parcels for the years 2017 and 2022 were obtained from a database of the Agency for Payments in Agriculture, Fisheries, and Rural Development (APPRRR). The input parcels were filtered for the area with a parameter of minimally 1 ha. This resulted in a total of 2,583 and 7,878 maize-cultivated agricultural parcels for the years 2017 and 2022, respectively. The calculation of land-surface phenology

metrics was based on a normalized-difference vegetation index (NDVI) obtained from the Sentinel-2 imagery, which had been successfully used in previous studies due to a high spatial and temporal imaging resolution of the Sentinel-2 mission (Misra et al., 2020), as well as a high NDVI's correlation with several crop-productivity indicators (Kowalski et al., 2020). However, a potential NDVI's limitation for a phenological analysis is caused by a saturation effect, which prevents the NDVI from reliably discriminating the phenological properties in a high-biomass vegetation. The Sentinel-2 satellite images were filtered based on the criteria of a maximal 50% total cloud coverage per scene in the Google Earth Engine. The data on the parcel areas, production, and average maize-grain yield in 2017 and 2022 were obtained from the Osijek-Baranja County website, whereas the climatological data (average monthly air temperature and monthly precipitation) were obtained from the Croatian State Hydrometeorological Service.

Phenology analysis

The start of a season (SOS), end of a season (EOS), and the length of a season (LOS) were calculated applying a method proposed by Bolton et al. (2020), based on the satellite-image time series and a threshold-based approach (Fig. 1). These were generated by the Google Earth Engine, based on the parameters of a study by Orusa et al. (2023) during an April-to-October period in the years 2017 and 2022. The outlier removal was performed while applying an interquartile range (IQR) method, with a threshold multiple of 1.5. An amplitude percentage for the estimation of threshold was set to 0.5, while the minimum NDVI value for the reclassification of non-vegetated areas was 0.3. The example calculation of the SOS, EOS, and LOS was visually presented in Figure 1. A land-surface phenology analysis was conducted in a 100 m spatial resolution. A statistical analysis of the LOS values for the years 2017 and 2022 was conducted applying the descriptive statistics, Kolmogorov-Smirnov's test, the F-test, and Mann-Whitney's U test.



SOS: Start of season, EOS: End of season, NDVI: Normalized difference vegetation index, DOY: Day of year

Figure 1. An exemplary presentation of the calculation of land-surface phenology metrics for a representative maize-cultivated agricultural parcel during the year 2017.

Slika 1. Primjer izračuna fenoloških metrika zemljišta za reprezentativnu poljoprivrednu česticu kukuruza tijekom 2017. godine.

RESULTS AND DISCUSSION

In the years 2017 and 2022, a total maize-cultivation area was 52,380 and 57,100 ha, respectively, a total grain yield amounted to 419,040 and 456,800 t, respectively, and an average grain yield in both years was 8.0 t ha⁻¹. The beginning, duration, end of a growing season,

and a phenological phase of each crop, including maize, depended on a number of factors. Among the most important ones were the weather conditions, including an average air temperature and monthly precipitation. These two climatic indicators differed between the years studied, as well as from a multiannual average (Fig. 2).

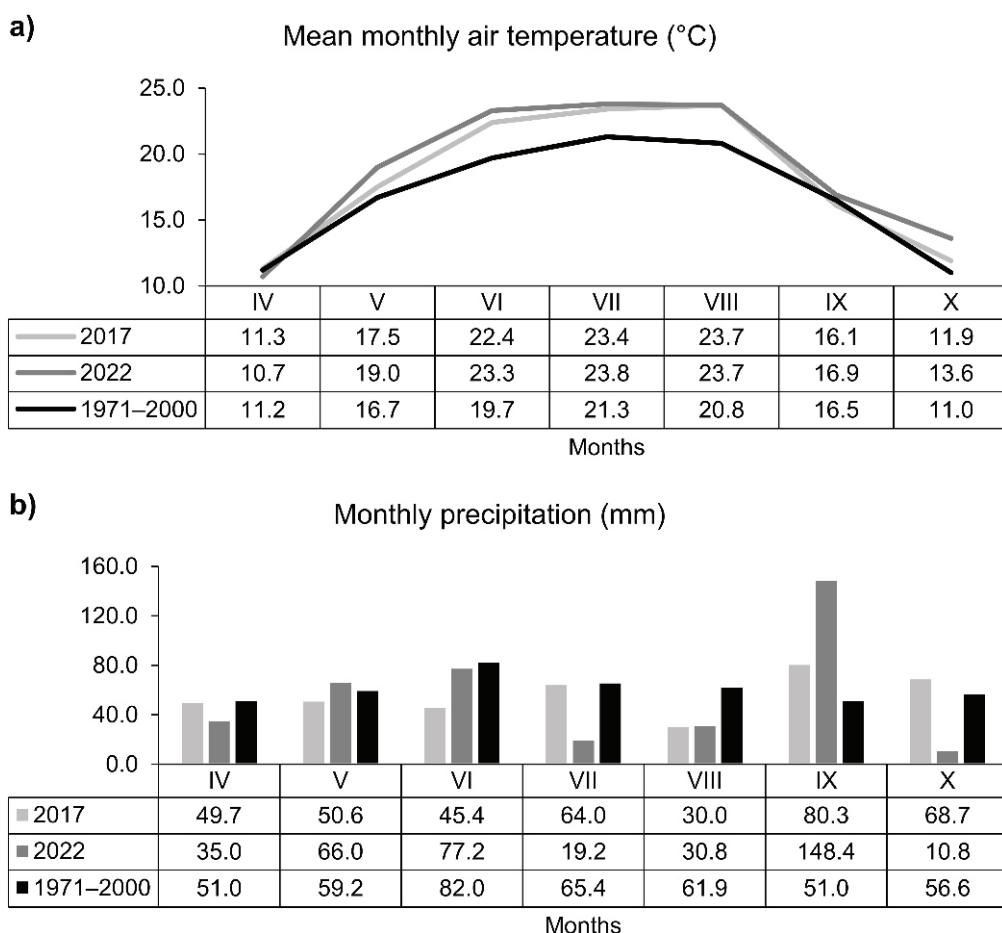


Figure 2. Climatic data for the months of the maize-growing season (April–October) for 2017 and 2022 and a multiannual average (1971–2000) for the following: a) a mean monthly air temperature, and b) monthly precipitation.

Slika 2. Klimatski podatci za mjesec vegetacije kukuruza (travanj – listopad) za 2017. i 2022. godinu te višegodišnji prosjek (1971. – 2000.) za sljedeće: a) srednju mjesečnu temperaturu zraka, i b) mjesečne oborine.

As depicted in Figure 2a, in both study years the mean monthly air temperatures were averagely higher in the months of the maize-growing season (18.04 and 18.69 °C, respectively) if compared with the 30-year average (15.31°C). Caubel et al. (2018) predicted a significant increase in the frequency of days with a temperature maximum over 35°C. Such an increase will affect a grain filling and therefore the yield. A comparison of the means for the two periods (1941–70 and 1971–2000) suggested greater differences in the vernal than in the autumnal variables. There was an overall reduction in the number of cold days by an average of about 10% in 1971–2000 when compared with the 1941–70 period. A consequence was an average increase in the growing season amounting to 6.5 days, as noted by Sparks et al. (2009). The same authors observe that the mean trend

across Europe was toward fewer cold days, more hot days, an earlier thermal spring, a slightly later thermal autumn, and hence a longer and warmer growing season during the 1941–2000 period. Temperature largely controls a crop's phenological stages, especially flowering and maturity, which determine the growth duration and thus the grain yield (Xiao et al., 2016). A total monthly precipitation for the maize-growing months was lower in both years (388.7 and 387.4 mm, respectively) than a multiannual average (427.1 mm). A significant precipitation deficit was observed over several months and was particularly severe in August in both years (Fig. 2b). The SOS, EOS, and LOS values in 2017 and 2022 encompassing the entire study area, which were used to assess the maize's vegetation period in these years, are represented in Figure 3.

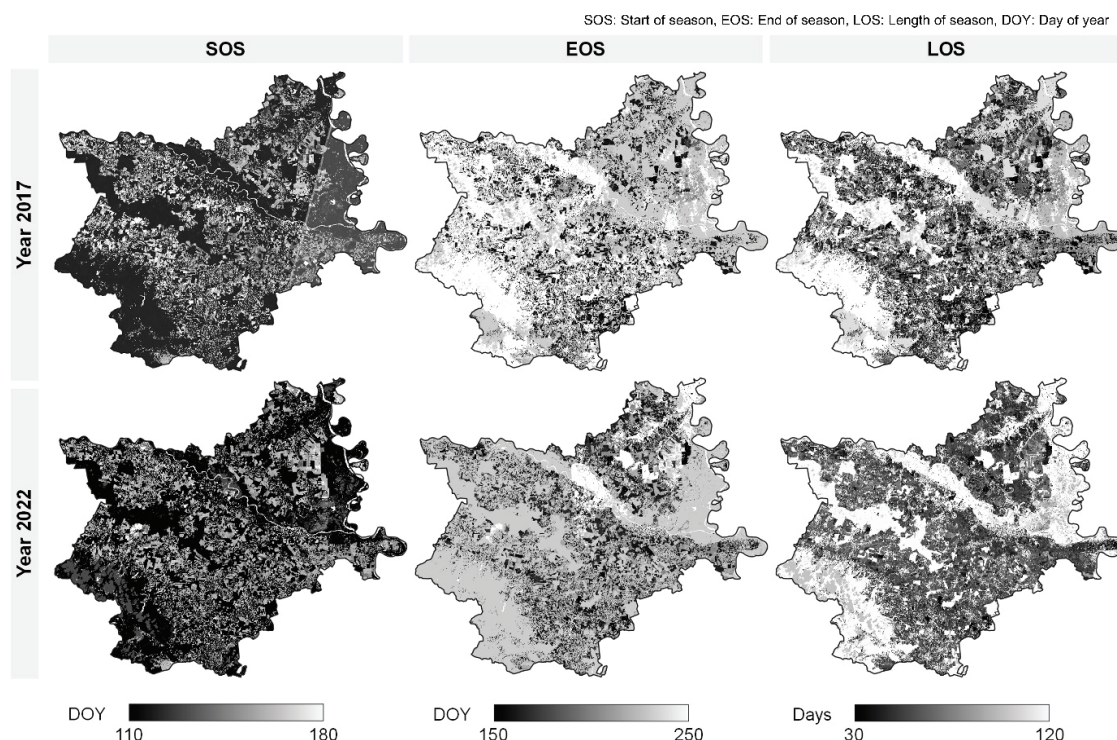


Figure 3. A presentation of the SOS, EOS, and LOS land-surface phenology metrics for Osijek-Baranja County for the years 2017 and 2022.

Slika 3. Prikaz SOS, EOS i LOS fenoloških metrika zemljišta za Osječko-baranjsku županiju u 2017. i 2022. godini.

A descriptive statistics of the LOS values for the maize-cultivated agricultural parcels for the years 2017 and 2022 is presented in Table 1. The LOS values for the maize-cultivated agricultural parcels for the years 2017 and 2022 indicated a non-normal distribution, with

significantly different variances according to the F-test and their values belonging to a different population (Table 2). Their value distribution was also visualized using the boxplots, as presented in Figure 4.

Table 1. A descriptive statistics of the length-of-season (LOS) values for the maize-cultivated agricultural parcels for the years 2017 and 2022

Tablica 1. Deskriptivna statistika LOS vrijednosti za poljoprivredne čestice kukuruza za godine 2017. i 2022.

Year / Godina	LOS (in days) / LOS (u danima)				
	Median / Medijan	Standard deviation / Standardno odstupanje	Coefficient of variation / Koeficijent varijacije	Interquartile range / Interkvartilni raspon	Median absolute deviation / Medijalno apsolutno odstupanje
2017	68.42	12.67	0.183	13.89	10.27
2022	62.55	7.94	0.127	10.30	7.64

Table 2. The results of statistical tests of the length of season (LOS) values for maize-cultivated agricultural parcels for the years 2017 and 2022

Tablica 2. Rezultati statističkih testova za LOS vrijednosti poljoprivrednih čestica kukuruza za godine 2017. i 2022.

Kolmogorov-Smirnov's test	
p (year 2017)	< 0.0001
p (year 2022)	< 0.0001
F-test	
F	2.549
p	< 0.0001
$Cf_{0.05}$	2.394–2.717
σ^2 ratio	2.549
Mann-Whitney's U Test	
W	13255737
p	< 0.0001

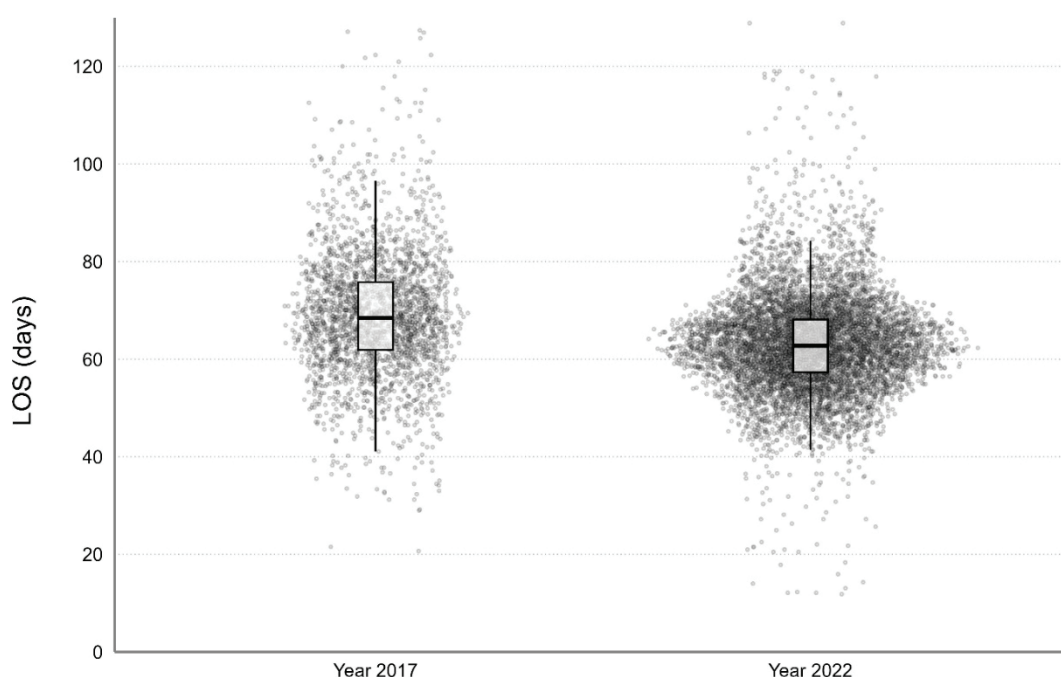


Figure 4. The boxplots of the length-of-season (LOS) values for the maize-cultivated agricultural parcels for the years 2017 and 2022

Slika 4. Kutijasti dijagrami LOS vrijednosti za poljoprivredne čestice kukuruza za godine 2017. i 2022.

Vegetation phenology is a sensitive indicator of changes in climatic conditions (Menzel and Fabian, 1999). The timing of the onset of greening in the spring (Piao et al., 2019) is among the most important phenological events, marking the growing-season length in the mid- and in the high latitudes (Kern et al., 2020). Apart from the ground observations of phenological stages, a satellite remote sensing has become an important data source for the derivation of information on the vegetation's phenological development (Tang et al., 2016). Global warming, particularly in the Northern Hemisphere, has led to an earlier onset of the vegetation cycle, as evidenced not only by the ground measurements (Schwartz et al., 2006) but also by a satellite-based monitoring of a land-surface greenness (Piao et al., 2015). An analysis, conducted by Rahmati et al. (2023), confirms the reports about an early greening in Europe. Bacsí and Hunkar (1994) have concluded that the maize's growth period in western Hungary in a changed climate would be 20–41 days shorter, which would result in a 7–14% smaller grain yield. As reported by Stričević et al. (2018), the maize's growth cycle in the referenced period (1961–90), lasted for 158 and 164 days under the rainfed and irrigated conditions, respectively. Under the future climate conditions, the maize's growth cycle will be reduced in all climate scenarios. Contrary to that, in a research conducted in Poland, Szyga-Pluta et al. (2023) pointed to an increase in the growing-season length by an average of 4.8 days/10 years. Lv et al. (2020) predicted the shortening of maize's vegetation duration, including the days to flowering and a grain-filling period. The same authors concluded that a future climate change would negatively affect the maize production in China. The maize's growing period would be shortened,

and the maize yield would be reduced significantly during the 2010–99 period, in relation to the 1976–2005 one.

Southworth et al. (2000) concluded that a lengthened growing season, dominated by a central period of high maximum daily temperatures, is a critical inhibitor of maize yields. A study by Chen and Pan (2002) suggested an integrated and surface-satellite approach involving statistical models, phenological and meteorological observations, and satellite remote sensing as an effective means to monitor the interannual vegetation dynamics and to estimate the growing-season parameters using the meteorological and satellite data at regional scales. Yang et al. (2021) concluded that the maize's growing-season lengths were markedly shortened (with the maize reaching flowering and maturity 3–14 days earlier) as an ambient temperature increased, if compared with the baseline data. In Serbia, Petrović et al. (2023) discovered a significant reduction in the maize yield in several years, including 2017. Vučetić (2011) stated that the maize-growing season would be a month shorter and the maize-grain yields would decrease by 9% if compared with that decade's climate. In the future, Croatia could belong to an area with the decreased maize yields. Vučetić (2012) provided predictions for the yield components and the maize-grain yield under different climate scenarios up to 2050. According to them, a maize-growing season will be shortened from 33 to 27 days, and the yield of the aboveground plant mass will decrease from 1,333 to 952 kg ha⁻¹. The weight of an individual grain will decrease from 15.4 to 9.4 g, and a total grain yield will decrease from 1.591 to 1.045 t ha⁻¹. According to the same predictions, these figures will be even more unfavorable by the year 2100. Some adaptation options, such as shifting to an earlier sowing date

and selecting the hybrids resistant to drought, could be an appropriate response to offset a negative effect of a temperature increase (Vučetić, 2011).

CONCLUSIONS

An analysis of maize's growing-season length in Osijek-Baranja County, Croatia, applying the land-surface phenology metrics derived from the Sentinel-2 imagery provided the insights into the agricultural dynamics in the region. This study used the NDVI to assess the phenological stages, including the SOS, EOS, and LOS, highlighting the advantages of the Sentinel-2's high spatial and temporal resolution. The results indicate that both the increasing air temperatures and a decreasing precipitation affect the length of a maize-growing season, with the notable trends observed in both years. The results indicated that the mean monthly air temperatures during a growing season exceeded the long-term averages, confirming the observations from the previous studies. The calculated LOS values exhibited a non-normal distribution with the different variances between the years, suggesting the potential impacts of a climate change on the maize production. From a remote-sensing perspective, this research highlighted a potential of using the advanced satellite imagery for agricultural monitoring and decision-making. The implications of these findings extend beyond the local agricultural practices, as they contribute to the broader discussions on food security and a sustainable land management in the face of an ongoing climate change. A future research should focus on refining these methods and exploring their applicability across the diverse agricultural systems to further support resilience in food production.

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ANALIZA DULJINE VEGETATIVNOGA PERIODA ZA UZGOJ KUKURUZA IZ FENOLOŠKIH METRIKA ODREĐENIH KORIŠTENJEM SATELITSKIH SNIMAKA SA SENTINELA-2

SAŽETAK

Ova studija analizira duljinu vegetativnoga perioda za uzgoj kukuruza u Osječko-baranjskoj županiji, koristeći fenološke metrike površine zemlje izvedene iz slika sa Sentinel-2. Primjenom indeksa normalizirane razlike (NDVI) izračunana su tri ključna fenološka pokazatelja, uključujući početak sezone (SOS), kraj sezone (EOS) i duljinu sezone (LOS) za 2017. i 2022. godinu. Analiza je otkrila da su srednje mjesečne temperature zraka tijekom vegetacije bile znatno više od tridesetogodišnjega prosjeka, dok je ukupna količina oborina bila osjetno manja, osobito u kolovozu. Ovaj klimatski kontekst sugerira izravan utjecaj na fenologiju kukuruza, s LOS vrijednostima koje pokazuju nenormalnu distribuciju i različite varijance između proučavanih godina. Rezultati naglašavaju učinkovitost podataka sa Sentinel-2 u praćenju poljoprivredne dinamike i naglašavaju važnost integriranja klimatskih varijabla kako bi se razumio njihov učinak na produktivnost usjeva. Ovo istraživanje doprinosi uvidima za poboljšanje predviđanja prinosa i prilagodljivih strategija upravljanja kao odgovor na klimatske varijabilnosti, u konačnici podupirući sigurnost hrane i prakse održivoga upravljanja zemljištem u regiji. Buduća istraživanja trebala bi proširiti ovu metodologiju kako bi se poboljšala njezina primjenjivost u različitim uvjetima poljoprivredne proizvodnje.

Ključne riječi: fenologija površine zemljišnog pokrova, snimke sa Sentinels-2, normalizirani vegetacijski indeks (NDVI), klimatska varijabilnost, analiza vegetacijske sezone

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