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MODEL FOR MONITORING AND PRODUCTION PREDICTING IN SUNFLOWER CROP BASED ON SATELLITE IMAGES

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Abstract

The study used imaging analysis to monitor and predict production in sunflower culture under farm specific crop technology. The studied plot was located in the area of Cornesti, Timis County, Romania. Satellite images (Landsat 8) with a resolution of 30 m were taken, at 6 moments (T) between April and September, 2020. NDVI and NBR indices were calculated from the image analysis. The variation of the values of the indices calculated in relation to the time (days) for the studied period was faithfully described by spline models, with the values of the errors calculated $\bar{\varepsilon} = 0.0069$ *in the case of NDVI and* $\bar{\varepsilon} = 0.18945$ *in the case of NBR. The interdependent relationship found between the NDVI and NBR indices was described by a polynomial equation of degree 3, under conditions of* $R^2=0.986$, $p=0.0015$. *Prediction of sunflower production (*Y_P*) based on the values of NDVI and NBR indices was possible under statistical safety conditions (*$R^2=0.998$, $p<0.001$*). The variation of the prediction error, resulted from calculus, was between -0.331 kg ha*$^{-1}$ *in the case of T4 indices (July 28) and 42.722 kg ha*$^{-1}$ *in the case of T6 indices (September 6). The Similarity and Distance Indices (SDI) was used to evaluate the similarity of the vegetation stages on sunflower crop in relation to the moment of the image captures, based on NDVI and NBR indices. The highest degree of similarity was identified between moments T2 and T3 (images from May), in which case SDI = 0.05285. The study provided useful information on the temporal variability of sunflower crop and production prediction in relation to agricultural technology and is the basis of agricultural crop management models.*

Key words: *crop monitoring, model, NDVI, NBR, production prediction, sunflower*

INTRODUCTION

Plant cultivation has undergone permanent improvements, in order to ensure food resources and increase the performance of agro ecosystems, through more adapted biological material [6], [3], [23], [52], more efficient agricultural machinery [17], [9], [25], optimized technologies [24], biotechnologies [10], [51], [30], nanomaterials and nanotechnologies [47], [27], [29], [60], sustainable management of soil resources [28], [50], water regime control [13], plant nutrition management [5], [2], [48], [41], [14], weed control [26], [39], disease and pest control [4], [56], [36].

Crop plants have a variable vegetation period, in relation to plant species (variety, hybrid), ecoclimatic conditions, cropping systems, harvest destination [31], [37].

Monitoring of agricultural crops during the vegetation period is necessary and important for various aspects regarding crop type and crop structure [11], [7], [61], crop variability [65], [45], the state of vegetation and plant nutrition [35], [1], the state of plant health [63], physiological indices and processes [62], [53], [64], productions estimation [16], [34], [22], [55], [57], and harvesting processes [19], [21], [40].

All these elements, previously presented, are necessary and useful for decision-making and different works in the field [8], [46], [33], [43].

Crop monitoring methods have evaluated over time, from simple field observations to the use of satellite, aerial or terrestrial imaging systems on agricultural crops, the use of sensors and dedicated software and applications, including for mobile devices, all while providing new facilities and functionality [18], [42], [59], [49].

The present study evaluated in dynamics a sunflower culture, based on two representative indices NDVI and NBR calculated from spectral information of satellite images, and made a prediction of sunflower production based on those indices.

MATERIALS AND METHODS

The aim of the study was to evaluate in dynamics a sunflower crop, under the conditions of a specific technology of cultivation at farm level, and to find models to describe the temporal variation of the crop and to predict the production based on indices calculated based on satellite images.

The agricultural land with the sunflower crop, with a surface of 59 ha, was in the area of Cornesti, Timis County, Romania, figure 1. During the vegetation, satellite scenes, with a spatial resolution of 30m, were taken, preprocessed and processed, from the Landsat 8 system using the platform http://earthexplorer.usgs.gov/ [54] and the software Erdas Imagine (2014) and ArcGIS v.10.5. Based on spectral information, the NDVI [44] and NBR [20], indices were calculated according to equations (1) and (2).

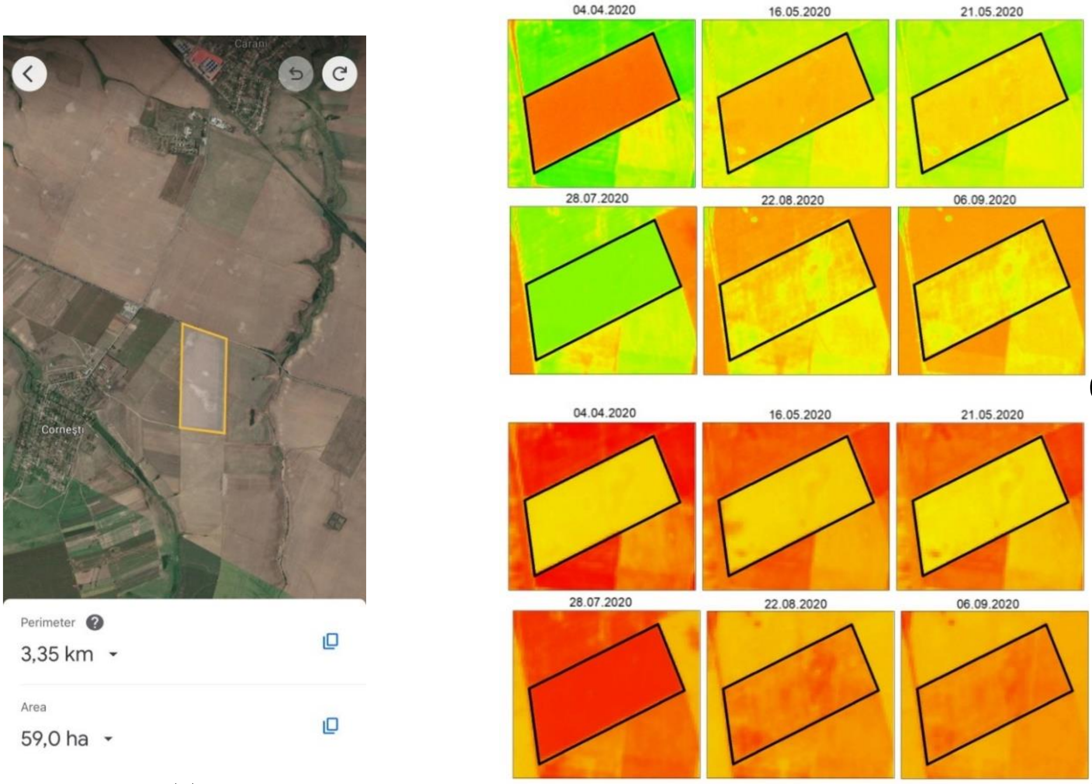
$$\text{NDVI} = \left(\frac{NIR - \text{Re}\,d}{NIR + \text{Re}\,d} \right) \tag{1}$$

$$\text{NBR} = \left(\frac{NIR - MIR}{NIR + MIR} \right) \tag{2}$$

For the dynamic characterization of the sunflower culture, the satellite images were taken at 6 time moments during the vegetation (April 4 - T1, May 16 - T2, May 21 - T3, July 28 - T4, August 22 - T5 and September 6 - T6).

The dynamics of NDVI and NBR indices is presented in Figure 1.

Generaly, light tones with values higher than 0.1 symbolize lands with high biomass (forests, dry bushes), and dark tones symbolize lands with low biomass (stone or concrete buildings, highways and roads, railways, etc.).



(a) (b) (c)

Fig. 1. Location of study area (a) and maps of NDVI (b) and NBR (c) indices for sunflower culture studied
Source: (a) original image captured from Google maps; (b), (c) original images generated on the basis of satellite images.

As a biological material, the sunflower hybrid P64LE25 was grown.
A suitable culture technology, for the studied area and sunflower culture, was applied; fertilization with complex fertilizers 16:16:16 and ammonium nitrate (200 + 200 kg ha^{-1}); foliar fertilization with macro- and micro-elements, including nitrogen (N) and boron (B) especially; weed control by herbicide; disease control through foliar treatments; use of adjuvant in order to increase the effect of foliar treatments. The harvest was carried out mechanized, and the average production obtained was 3,800 kg ha^{-1}.
The obtained data were analyzed and statistically processed with the mathematical module from EXCEL and the PAST software [12]. The 3D and isoquants graphics were generated with Wolfram Alpha (2020) [58].

RESULTS AND DISCUSSIONS

Consistent with the purpose of the study, the crop was monitored during the vegetation period based on satellite images, in the Landsat 8 system. Six sets of images were taken, based on which the values of NDVI and NBR indices were calculated. The values of the NDVI and NBR indices, the T moments of taking over the satellite images and the value of the obtained production are presented in Table 1.

Table 1. Technical data with reference to the study done on sunflower culture

Image capture date	Trial	t (days)	NDVI	NBR	Y (kg ha^{-1})
April 4	T1	0	0.191668	-0.040234	3,800
May 16	T2	42	0.217241	0.068693	
May 21	T3	47	0.249321	0.026692	
July 28	T4	105	0.748572	0.753765	
August 22	T5	130	0.360012	0.284486	
September 6	T6	145	0.302153	0.175900	

Source: Original data related to the studied sunflower culture.

In the conditions of the applied technology and of the pedoclimatic conditions of framing the farm and the plot of land, the sunflower culture had normal vegetation.
The ANOVA test confirmed the statistical safety of the data and the presence of the variance in the experimental data set (F>F crit, p <0.001, under Alpha = 0.001 conditions).
The variation of the values of NDVI and NBR indices in relation to the time (t, days) during the vegetation period of the sunflower crop was best described by a smoothing spline model, and the errors were calculated according to equation (3). The values associated with the spline model are presented in Table 2 for the NDVI index, and in table 3 for the NBR index. The graphical distribution of the model is shown in Figure 2 for NDVI and in Figure 3 for NBR.

$$\bar{\varepsilon} = \left(\sum_{i=1}^{n} \varepsilon_i \right) / n = \left(\sum_{i=1}^{n} \left| \frac{ys_i - y_i}{y_i} \right| \right) / n \quad (3)$$

Table 2. Statistical values regarding the NDVI variation in relation to time (t) in sunflower culture, in the study conditions and agricultural technology, resulting from the spline model

Trial image capture		NDVI			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	0	0.19167	0.18848	-0.0166	1.000
2	42	0.21724	0.21907	0.0084	1.162
3	47	0.24932	0.25856	0.0371	1.372
4	105	0.74857	0.71896	-0.0396	3.815
5	130	0.36001	0.39692	0.1025	2.106
6	145	0.30215	0.28699	-0.0502	1.523

$\bar{\varepsilon} = 0.0069$

Source: Original data, obtained from the calculation.

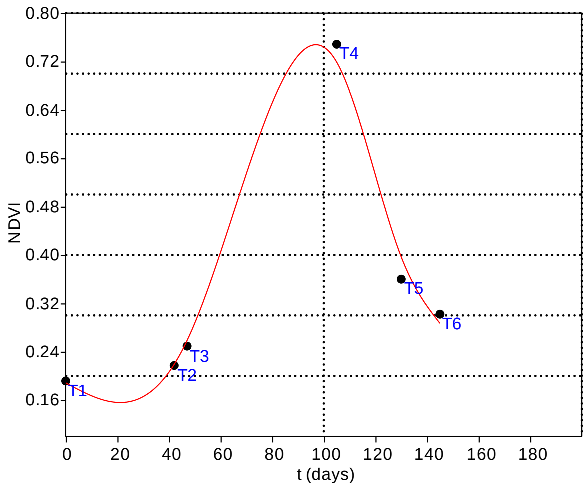


Fig. 2. NDVI in relation to t (days) in sunflower culture, according to the spline model
Source: original graphic obtained from data processing.

Table 3. Statistical values regarding the NBR variation in relation to time (t) in sunflower culture, in the study conditions and agricultural technology, resulting from the spline model

Trial image capture		NBR			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	0	-0.04023	-0.04143	0.02975	1.000
2	42	0.06869	0.03791	-0.44812	-0.915
3	47	0.02669	0.06806	1.54987	-1.643
4	105	0.75376	0.72287	-0.04098	-17.448
5	130	0.28449	0.31953	0.12317	-7.712
6	145	0.17590	0.16236	-0.07698	-3.919

$\bar{\varepsilon} = 0.1894$

Source: Original data, obtained from the calculation.

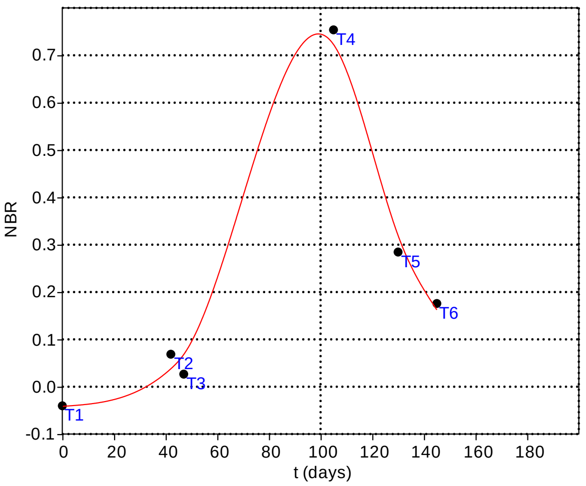


Fig. 3. NBR in relation to t (days) in sunflower culture, according to the spline model
Source: original graphic obtained from data processing.

In both the NDVI and the NBR index, a maximum was found around July 27 (T4), associated with the vegetation stage of the flowering plants.
An interdependence relationship, described by equation (4), was found between NDVI and NBR, in conditions of statistical safety (R^2 = 0.986, p=0.0015, F=112.7). The graphical distribution of NBR values in relation to NDVI is shown in Figure 4.

$$NBR = -7.573x^3 + 9.768x^2 - 1.248x - 0.04876 \quad (4)$$

where: x - NDVI values;

Regression analysis was used to estimate flower production based on the values of NDVI and NBR indices resulting from spectral information of satellite images, taken during the vegetation period of the sunflower crop.

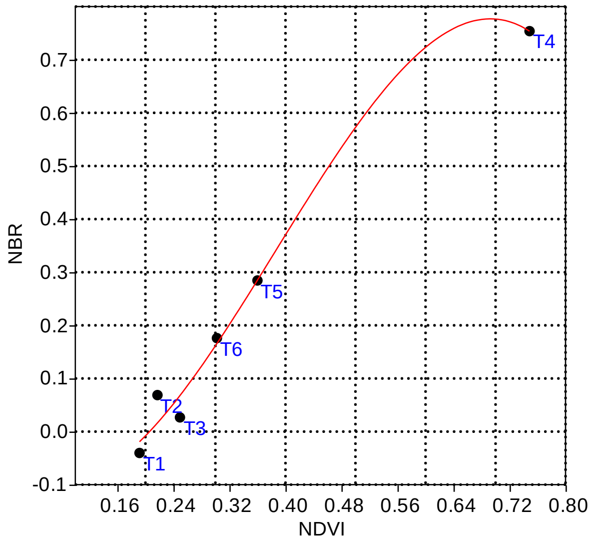


Fig. 4. Graphic distribution of NBR values according to NDVI in sunflower culture
Source: original graphic obtained from data processing.

The prediction of flower production (Y_P) based on the values of NDVI and NBR indices, was possible in statistical safety conditions (R^2=0.998, p <0.001), equation (5). The graphical distribution of the production in relation to the indices NDVI (x-axes) and NBR (y-axes) is shown in Figure 5 as a 3D model, and in Figure 6 as isoquants.

$$Y_P = ax^2 + by^2 + cx + dy + exy + f \quad (5)$$

where: Y_P - sunflower production (kg ha^{-1});
x – NDVI index; y – NBR index;
a, b, c, d, e, f – coefficients of the equation (5);
a= -94262.4890711; b= -42049.8493233;
c= 38115.8634605; d= -25389.4108121;
e= 126038.5049952; f= 0

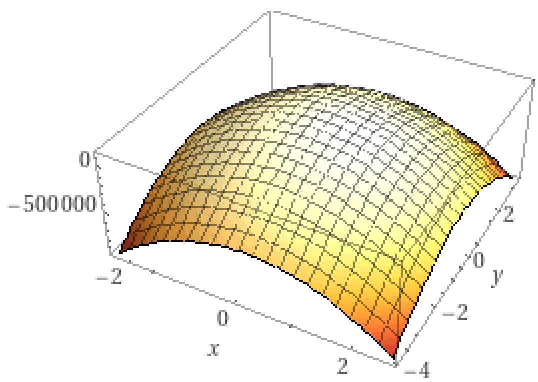


Fig. 5. 3D model distribution of Y_P in sunflower culture based on NDVI (x-axis) and NBR (y-axis) values
Source: Original graph based on data analysis.

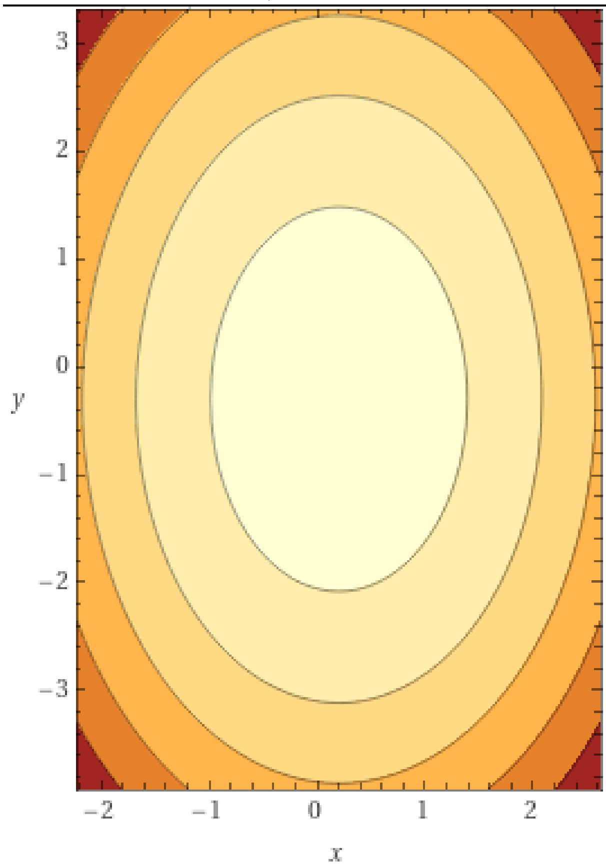


Fig. 6. Isoquants model distribution of Y_P in sunflower culture based on NDVI (x-axis) and NBR (y-axis) values
Source: Original graph based on data analysis.

Starting from equation (5), the production was calculated based on each pair of values of the NDVI and NBR indices in the 6 moments of capturing the satellite images. The predicted yields (Y_P) were compared with the actual yield obtained (Y), and the prediction error is represented graphically in Figure 7. The variation of the prediction error was found between -0.331 kg ha^{-1} in the case of T4 indices (July 28) and 42,722 kg ha^{-1} in the case of T6 indices (September 6).

The evaluation of the similarity of the stages in the case of sunflower culture, quantified through the prism of the two indices (NDVI and NBR), was made by Similarity and Distance Indices (SDI. The T4 moment was positioned on an independent position, with the highest values of the NDVI and NBR indices. It is also the T moment of the images sampling, for which the values of the NDVI and NBR indices provided the most reliable predicted production (Y_P) of sunflower crop, appreciation made based on the predictive error (Figure 7). The highest level of similarity was recorded between T2 and T3 (SDI = 0.05285) (Table 4).

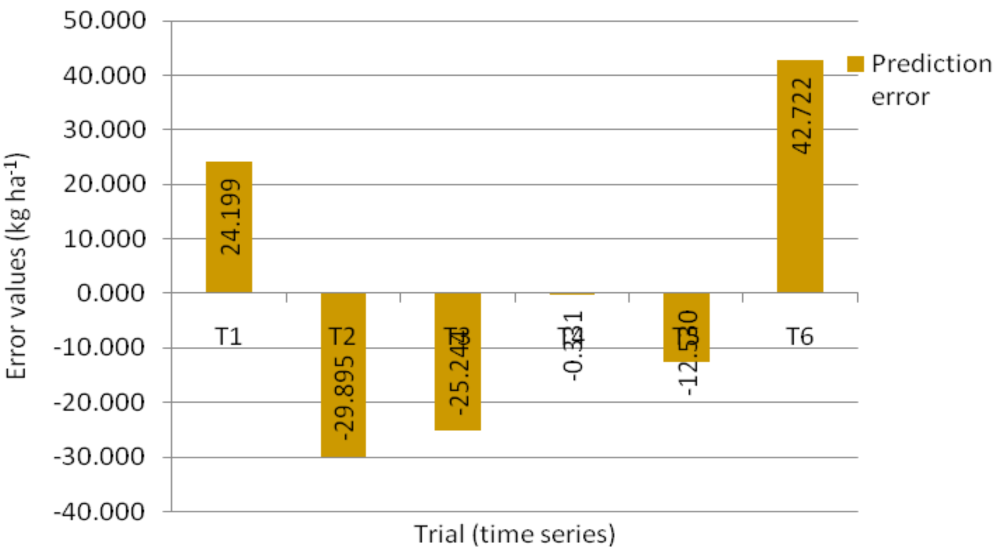


Fig. 7. Graphical representation of the prediction error of sunflower production based on NDVI and NBR indices
Source: Original graph based on data analysis

The description of sunflower vegetation stages based on Landsat 8 satellite images and calculated indices was communicated by Herbei and Sala (2015) [15] in conditions of high statistical safety. The authors of the study found the variation of the values of the indices in relation to the maintenance works and the vegetation stages (BBCH code) of the sunflower culture.

Table 4. SDI values in the case of sunflower culture studied

	T1	T2	T3	T4	T5	T6
T1		0.11189	0.08833	0.96983	0.36576	0.24274
T2	0.11189		0.05285	0.86697	0.25875	0.13676
T3	0.08833	0.05285		0.88198	0.28055	0.15829
T4	0.96983	0.86697	0.88198		0.60926	0.73022
T5	0.36576	0.25875	0.28055	0.60926		0.12304
T6	0.24274	0.13676	0.15829	0.73022	0.12304	

Source: Original data, obtained from the calculation.

Similar studies have recently been reported by Narin et al. (2021) [32], based on satellite images in Sentinel-2.

Variable levels of correlation were found in relation to the BBCH stages in which the images were taken.

Based on remote sensing, Peña-Barragán et al. (2007) [38] monitored some weeds in sunflower culture in relation to vegetation stages.

The variation of the NDVI and NBR indices considered in the present study to characterize the sunflower culture, presented maximum values around July 27, after which a descending distribution of values was registered, associated with the evolution of the culture. Minimum values were recorded in the primary stages of vegetation, when in the captured satellite images a high share was represented by the soil. Also, lower values compared to the maximum were recorded towards the end of the vegetation period, as a result of the biological maturation of the plants. The obtained results can be the basis of some models of temporal variation of the sunflower culture, in the study conditions, deviations from the normal evolution model being associated with different possible deficiencies in the culture (weeds, uneven density, diseases or pests).

CONCLUSIONS

The values of the NDVI and NBR indices resulting from the satellite images, Landsat 8, facilitated the description of the temporal variation of the sunflower culture, in the conditions of a specific culture technology, at farm level.

Spline-type models were found to be the most appropriate to describe the temporal variation of NDVI and NBR index values relative to time (t) during the vegetation period in sunflower culture under study conditions.

The production (Y_P) was predicted based on the values of the NDVI and NBR indices in high conditions of statistical safety and 3D and isoquants models of production expression were obtained.

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