MODEL FOR ESTIMATING RAPESEED PRODUCTION BASED ON REMOTE SENSING

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Abstract. The study analyzed in dynamics a rapeseed culture based on remote sensing. Satellite images from the Landsat 8 system were used. The images were taken at 8 different time points, t1 (March), t2, t3 (April), t4, t5 (May), t6, t7 (June), t17 (July). Based on spectral information, NDVI and MSAVI indices were calculated. The variation of the values of NDVI and MSAVI indices in relation to time was described by polynomial models of 2nd degree, in conditions of statistical accuracy (R²=0.798, p=0.0182, F=9.9134 for NDVI, respectively R²=0.851, p=0.00856, F=14.286 for MSAVI). In the case of both indices, a deviation of the values of the moment t4 (flowering period) was found in relation to the theoretical model obtained. The regression analysis facilitated the obtaining of a production prediction equation (YP) based on the values of the NDVI and MSAVI indices, in statistical accuracy conditions, R²=0.994, p=0.0105, F=94.1279. The prediction error (PE) was calculated compared to the actual production obtained, and the moments t1, t2 and t3 facilitated the estimation of the production under the most accurate conditions (PE values were minimal). 3D and isosurfaces models were obtained and they have described the variation in estimated YP output in relation to NDVI and MSAVI. A high level of similarity regarding PE was recorded in the case of t1, t2 and t3 (SDI=17.098), respectively t2 and t4 (SDI=18.098). According to the PCA, PC1 explained 67.745% of the variance, and PC2 explained 32.037% of the variance.

Keywords: NDVI, MSAVI, prediction model, rapeseed crop, remote sensing, yield

INTRODUCTION

For various ecological, economic and social reasons, the study of natural or anthropogenic land surfaces, vegetation and agricultural crops is of permanent interest (Martin et al., 2016; Cebrián-Piqueras et al., 2020). Agricultural ecosystems occupy an important place and are intensively studied from different perspectives, such as ensuring food resources, sustainability, biodiversity, rural development, etc. (Karampela et al., 2021; Newton et al., 2019).

Agricultural production has been studied in relation to different influencing factors and their interactions, such as cultivated genotypes (Beres et al., 2020; Henry, 2020), climatic conditions (Arora, 2019; Bellouin et al., 2020), soil conditions (Rosatto et al., 2017; Kopittke et al., 2019), crop irrigation (Borsato et al., 2020; Tamburino et al., 2020), fertilization (Rawashdeh and Sala, 2014, 2015; Cen et al., 2020; Liu et al., 2021), stress factors (Fahad et al., 2017; Balla et al., 2019), quality elements (Jivan and Sala, 2014; Kameswara Rao et al., 2017), economic aspects (Walters et al., 2016; Porfirio et al., 2018; Cen et al., 2020) and the agri-food system (Beeby et al., 2020; Fankor et al., 2021).

Within agricultural ecosystems, the need to estimate agricultural production is an important aspect, in relation to cultivated plants and genotypes (Constantinescu et al., 2018; Shook et al., 2021), culture technologies (Chlingaryan et al., 2018; Najafi et al., 2018), fertilization (Sala and Boldea, 2011; Sala et al., 2016; Szulc et al., 2021), category of agricultural products (Kuehne et al., 2017; Kurumatani, 2020), storage and capitalization of production (Taşkıncı and Bilgen, 2021), product market (Jiang et al., 2020; Kamath et al., 2021), the profitability of farmers (Sangeeta, 2020; Kamath et al., 2021).

Different methods and models of production prediction have been proposed and developed to estimate agricultural production and yields in relation to crops, production factors, environmental factors and their interaction (Beres et al., 2020; Meng et al., 2021). Methods and models based on remote sensing are very useful and used for the analysis and characterization of natural areas of agroecosystems, with a high level of estimation of agricultural production (Govedarica et al., 2015; Awad, 2019; Popescu et al., 2020; Khaki et al., 2021).

The present study used remote sensing in order to analyze a rapeseed culture and estimate production based on spectral information and calculated specific indices.

MATERIAL AND METHODS

The study aimed to evaluate the rapeseed culture during the vegetation based on satellite images and to formulate models for estimating the production based on the calculated specific indices.

The rapeseed crop was located within the SDE of BUASVM Timisoara, agricultural year 2019-2020. The plot cultivated with rapeseed had an area of 53.36 ha, figure 1.

In order to achieve the proposed goal, a satellite scene was taken from the portal www.planet.com (48).
Figure 1. The area for framing the agricultural land and the plot of studied culture, rapeseed culture

Satellite images were acquired at 8 moments in time, during the vegetation period of the rapeseed crop. The images were analyzed in terms of spectral information, and NDVI indices were calculated (Rouse et al., 1974), equation (1), and MSAVI (Qi et al., 1994), equation (2).

\[
NDVI = \frac{NIR - R}{NIR + R} = \frac{(B5 - B4)}{(B5 + B4)}
\]

(1)

\[
MSAVI = \frac{2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - Re d)}}{2}
\]

(2)

For the analysis and processing of the data obtained in the study, the statistical module from EXCEL was used, as well as the PAST software (Hammer et al., 2001), respectively Wolfram Alpha (2020). In order to interpret the data and the results obtained by statistical processing, different tests were used such as ANOVA, regression analysis, cluster analysis, PCA, and various statistical safety parameters \(R^2\), \(p\), Coph. corr.

RESULTS AND DISCUSSIONS

The data obtained by processing satellite images, according to NDVI and MSAVI indices, image acquisition moments, as well as the value of production in rapeseed culture, are presented in table 1. From the analysis of the variation of the two indices, a higher variation was found in case NDVI (Coeff. var. = 62.87583, compared to MSAVI, where the coefficient of variation had the value Coeff. var. = 57.69644.

The variation of the values of NDVI and MSAVI indices was analyzed, as an expression of the rapeseed culture, in relation to time, during the study period.

The NDVI variation with respect to time (T) was described by equation (3), in statistical accuracy conditions \(R^2=0.798\), \(p=0.0182\), \(F=9.9134\). The graphical distribution of NDVI values in relation to T is presented in figure 2.
Table 1. Data of the study regarding the moment of taking the images, calculated indices and the production to the rapeseed culture

<table>
<thead>
<tr>
<th>Calendar Time</th>
<th>Moment of satellite image acquisition</th>
<th>Images acquisition interval (days)</th>
<th>Indices</th>
<th>Production Y, kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 27</td>
<td>t1</td>
<td>1</td>
<td>0.45638642</td>
<td>0.624742139</td>
</tr>
<tr>
<td>April 09</td>
<td>t2</td>
<td>14</td>
<td>0.449991108</td>
<td>0.618825415</td>
</tr>
<tr>
<td>April 28</td>
<td>t3</td>
<td>33</td>
<td>0.453279583</td>
<td>0.623035419</td>
</tr>
<tr>
<td>May 08</td>
<td>t4</td>
<td>43</td>
<td>0.603818216</td>
<td>0.752312203</td>
</tr>
<tr>
<td>May 21</td>
<td>t5</td>
<td>56</td>
<td>0.363312597</td>
<td>0.531526301</td>
</tr>
<tr>
<td>June 02</td>
<td>t6</td>
<td>68</td>
<td>0.261012427</td>
<td>0.41128143</td>
</tr>
<tr>
<td>June 27</td>
<td>t7</td>
<td>93</td>
<td>0.037402956</td>
<td>0.068900026</td>
</tr>
<tr>
<td>July 24</td>
<td>t8</td>
<td>120</td>
<td>0.026594767</td>
<td>0.049724841</td>
</tr>
</tbody>
</table>

\[ \text{NDVI} = -3.779 \times 10^{-5} x^2 + 5.65 \times 10^{-5} x + 0.4888 \]  

Figure 2. NDVI variation in relation to time, rapeseed crop, agricultural year 2019 - 2020

The variation of MSAVI in relation to time (T) was described by equation (4), in statistical accuracy conditions \( R^2 = 0.851, p = 0.00856, F = 14.286 \). The graphical distribution of MSAVI values in relation to T is shown in figure 3.

\[ \text{MSAVI} = -5.263 \times 10^{-5} x^2 + 0.000463 x + 0.6586 \]  

Both in the case of NDVI and in the case of MSAVI, a significant deviation of the values of the indices related to the t4 moment of acquiring the images was found (May, 8), in relation to the vegetation stage of the rapeseed culture (flowering period).

In order to obtain a model for predicting rapeseed production, regression analysis was used to analyze the experimental data obtained. Based on the regression analysis, equation (5) was obtained, as a mathematical model for predicting rapeseed production, based on NDVI and MSAVI, in statistical accuracy conditions \( R^2=0.994, p=0.0105, F=94.1279 \).
Based on equation (7), 3D models were generated in the form of isoquants for the variation of rapeseed production in relation to NDVI (x-axis) and MSAVI (y-axis), figures 4 and 5. For high calculation accuracy, in equation (7), the values of the coefficients of the equation had up to 16 decimals.

\[ Y_P = ax^2 + by^2 + cx + dy + exy + f \]  

where:  
\[ Y_P \] - predicted rape production (kg ha\(^{-1}\));  
\[ x \] - NDVI index;  
\[ y \] - MSAVI index;  
\[ a, b, c, d, e, f \] – coefficients of the equation (5);  
\[ a = -2424394.13288 \];  
\[ b = -1837592.05929 \];  
\[ c = -922670.18264 \];  
\[ d = 574356.66921 \];  
\[ e = 4519962.89487 \];  
\[ f = 0 \]
In order to evaluate the prediction accuracy of rapeseed production ($Y_r$), in relation to the time of satellite imagery, the prediction error (PE) was calculated as the difference between the real value of production ($Y$) and the value of the estimated production ($Y_P$), from equation (5). The distribution diagram of the PE values is shown in figure 6.

![Diagram showing prediction error (PE) in relation to the moment of acquisition of satellite images, rapeseed crop, agricultural year 2019-2020.]

According to the PCA, the distribution diagram of the $t$-moments of satellite imagery was generated, in relation to the PE for production estimation, figure 7. PC1 explained 67.745% of variance, and PC2 explained 32.037% of variance. From the analysis of the PCA diagram it was found the independent positioning of moments $t_6$, $t_7$ and $t_8$ and the association of $t_5$ with PE, respectively of moments $t_1$, $t_2$, $t_3$ (partial) and $t_4$ with NDVI and MSAVI indices.

Cluster analysis led to the grouping of $t$-moments of satellite imagery, in relation to PE resulting from the prediction of production based on NDVI, MSAVI indices, in statistical accuracy conditions (Coph. Corr = 0.916), figure 8. From the analysis of the cluster diagram, the grouping of $t$ moments in two distinct clusters was found.

A C1 cluster comprises moments $t_5$ and $t_8$, where the largest prediction errors of rapeseed production were recorded. Within cluster C2, there are two subclusters, C2-1 and C2-2. Subcluster C2-1 comprises moments...
t3, t6 and t7 where moderate errors were recorded for the prediction of rapeseed production. Subcluster C2-2 comprises the time moments t1, t2 and t4, where the smallest prediction errors of rapeseed production were recorded.

Figure 7. PCA diagram on the distribution of t-moments of satellite imagery, in relation to PE, NDVI and MSAVI (as biplot) to rapeseed culture

Figure 8. Dendrogram for grouping t-moments of satellite imagery, in relation to the prediction error (PE)
The highest degree of similarity in relation to PE was recorded in the case of moments t1 and t2 (SDI=17.098). The moments t2 and t4 (SDI=18.098) and the moments t1 and t4 (SI=35.195) followed, and the set of SDI values recorded in the case of all the moments t of taking the images, in relation to the PE values is presented in table 2.

<table>
<thead>
<tr>
<th></th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
<th>t5</th>
<th>t6</th>
<th>t7</th>
<th>t8</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>17.098</td>
<td></td>
<td>381.59</td>
<td>35.195</td>
<td>537.41</td>
<td>319.87</td>
<td>306.70</td>
<td>548.41</td>
</tr>
<tr>
<td>t2</td>
<td></td>
<td>17.098</td>
<td>398.69</td>
<td>18.098</td>
<td>520.32</td>
<td>336.97</td>
<td>323.80</td>
<td>531.31</td>
</tr>
<tr>
<td>t3</td>
<td>381.59</td>
<td>398.69</td>
<td></td>
<td>416.79</td>
<td>919.00</td>
<td>61.717</td>
<td>74.891</td>
<td>930.00</td>
</tr>
<tr>
<td>t4</td>
<td>35.195</td>
<td>18.098</td>
<td>416.79</td>
<td></td>
<td>502.22</td>
<td>355.07</td>
<td>341.90</td>
<td>513.21</td>
</tr>
<tr>
<td>t5</td>
<td>537.41</td>
<td>520.32</td>
<td>919.00</td>
<td>502.22</td>
<td></td>
<td>857.29</td>
<td>844.12</td>
<td>11.007</td>
</tr>
<tr>
<td>t6</td>
<td>319.87</td>
<td>336.97</td>
<td>61.717</td>
<td>355.07</td>
<td>857.29</td>
<td></td>
<td>13.178</td>
<td>868.28</td>
</tr>
<tr>
<td>t7</td>
<td>306.70</td>
<td>323.80</td>
<td>74.891</td>
<td>341.90</td>
<td>844.12</td>
<td>13.178</td>
<td></td>
<td>855.11</td>
</tr>
<tr>
<td>t8</td>
<td>548.41</td>
<td>531.31</td>
<td>930.00</td>
<td>513.21</td>
<td>11.007</td>
<td>868.28</td>
<td>855.11</td>
<td></td>
</tr>
</tbody>
</table>

The statistical analysis regarding the distribution of prediction error (PE) values in relation to the median, resulting from the production prediction based on the values of the NDVI and MSAVI indices, is presented in figure 9, as a normal probability plot, in conditions of PPCC: 0.939.

The comparative analysis of the values of the prediction errors (PE) of the production in relation to the real value of the rapeseed production (Y = 4300 kg ha\(^{-1}\)), with graphical representation in figure 10, shows that the most reliable prediction when using satellite images from t1, t2 and t4 moments. The highest errors resulted from the prediction of the production based on the images from t5 and t8 moments, and intermediate values were recorded for PE in the case of the other t moments of images acquisition.

Production estimation way used in this study is easy for farmers, due to the use of satellite images, image processing and analysis techniques, and the usual and accessible mathematical and statistical tools. The analysis facilitates the prediction of production from early vegetation stations. If it is estimated that it will not be at the appropriate level of profitability, it is possible to intervene in rapeseed crop management, sequentially, through measures that lead to a profitable production (eg fertilization, irrigation, plant protection etc.).

![Figure 9. Normal probability plot, for prediction error (PE), rapeseed culture, under study conditions](https://www.lssd-journal.com)
**CONCLUSIONS**

Based on the NDVI and MSAVI indices calculated from the spectral information related to some satellite scenes, Landsat 8, taken in 8 calendaristic moments, it was possible to describe the dynamics of vegetation in rapeseed culture and estimate the production, in statistical accuracy conditions.

Indices calculated based on satellite images taken at times t1 (March), t2 and t4 (April) facilitated the prediction of production with the smallest errors, so with the highest level of accuracy, in conditions of statistical safety. This has a practical advantage in the sense that it facilitates technological interventions in the early stages of vegetation (especially fertilization), in order to correct the vegetation condition of the rapeseed crop, with positive effects on production.

The approach model can be adapted for other agricultural crops and can provide data and information on the basis of which to improve the management of agricultural crops.

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