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MODEL FOR MONITORING AND ESTIMATING THE PRODUCTION OF ALFALFA CROP BASED ON REMOTE SENSING

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Abstract

The study used the technique based on remote sensing to analyze and study the dynamics of an alfalfa crop and to estimate the production of fresh biomass in the climatic conditions of the agricultural year 2021-2022. Alfalfa culture in year III, was under non-irrigated cultivated conditions, in the perimeter of DER, University of Life Sciences "King Michael I" from Timisoara, Romania. A period between March 22 and July 23, 2022 was considered, the period during which 14 sets of images from the Sentinel 2 system were acquired. Based on the spectral information contained in the images, the MSAVI, NDMI, NDVI and NBR indices were calculated to characterize the dynamics of the alfalfa crop and estimate the production of fresh biomass. Three harvests (mowing) were made, on May 25 with a production of 10 t ha^{-1} fresh biomass, on July 1 with a production of 7.5 t ha^{-1} fresh biomass and on July 26 with a production of 7.5 t ha^{-1} fresh biomass. Spline models have described most accurately and under statistical safety conditions ($\bar{\varepsilon} = 0.000493$ for MSAVI; $\bar{\varepsilon} = 0.391963$ for NDMI; $\bar{\varepsilon} = 0.002972$ for NDVI; $\bar{\varepsilon} = 0.006759$ for NBR) the dynamics of the indices calculated in relation to the time during the study period, also associated with the moments of fresh biomass harvested. The regression analysis facilitated obtaining predictive models of fresh biomass production, under statistical safety conditions (RMSEP=0.019289 for the combination of MSAVI and NDMI). 3D and isoquants graphic models described the variation of biomass production in relation to the pairs of indices used in the analysis.

Key words: *alfalfa, fresh biomass production, indices, prediction model, regression analysis, remote sensing*

INTRODUCTION

The management of the farm and agricultural crops is based on correct information, in real time for appropriate decisions in relation to the purpose and objectives proposed as well as the identified problem [16, 24, 25]. The methods of obtaining information are diverse, in relation to the category of elements taken into account (ecological, economic, and social) [36, 38].

For the management of agricultural crops, real-time information on the status of plants, the evolution of crops, influencing factors, maintenance or harvesting works, techniques based on remote sensing offer a series of real-time information [5, 8, 33].

Remote sensing has been used in numerous studies for the classification of crops, the evaluation of the vegetation structure, the establishment of certain moments and intervention works, for the monitoring of crops, for the prediction of biomass production or the evaluation of land quality [1, 13, 26].

Fodder crops occupy an important place in order to produce fodder resources for raising animals, and the periodic evaluation of these crops is important in order to establish some maintenance, harvesting, or variation works in relation to different influencing factors [9, 12]. Remote sensing has been used in various studies for mapping and inventorying grassland surfaces [17], grassland management [3, 30], monitoring of fodder resources [11, 15], the influence of fertilizing resources on the improvement of meadow lands [6].

Alfalfa is a crop plant of high importance for the production and quality of fodder, for food security, being cultivated in different regions of the world, with various conditions [37, 39].

At the same time, alfalfa is important for sustainable agriculture systems, in the structure of crops, crop rotations, as a soil-improving plant [10, 35]. Alfalfa is also important for fixing nitrogen through

symbiotic means [32], in the context in which the price of fertilizers and fertilizing resources causes their use to be re-evaluated [7, 20].
In the context of the presented aspects, the present study used techniques based on remote sensing to study the dynamics of an alfalfa crop, and to find models for estimating the production of fresh biomass based on specific indices.

MATERIALS AND METHODS

Through techniques based on remote sensing, the study evaluated the dynamics of an alfalfa crop within DER, University of Life Sciences "King Michael I" from Timisoara, Romania.
The alfalfa crop was in the third year of exploitation, in a non-irrigated culture system.
In order to evaluate the dynamics of the alfalfa crop, satellite images were taken from the Sentinel 2 system [23], between March 22, 2022 and July 23, 2022, at different time intervals, correlated with the harvesting of fresh food production. 14 sets of satellite images were retrieved, and specific indices were calculated based on the spectral information, MSAVI [27], relation (1), NDMI [34, 40], relation (2), NDVI [31], relation (3) and NBR [19] in order to characterize the alfalfa crop and to predict the production of fresh biomass.

$$MSAVI = \frac{2\,NIR + 1 - \sqrt{(2\,NIR+1)^2 - 8(NIR - Red)}}{2} \quad (1)$$

$$NDMI = \frac{NIR - SWIR1}{NIR + SWIR1} \quad (2)$$

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (3)$$

$$NBR = \frac{NIR - SWIR2}{NIR + SWIR2} \quad (4)$$

To describe the dynamics of the alfalfa crop over time, over the study interval, the variation of the index values in relation to time (T, days) was evaluated. There were three harvests (mowing) of fresh biomass for the alfalfa crop, on May 25 (H1), on July 1 (H2) and on July 26 (H3).
The regression analysis was used to obtain production estimation models based on the calculated index values. For the safety of the obtained results, appropriate statistical parameters were used ($\bar{\varepsilon}$, R^2, RMSEP). The software PAST [14] and Wolfram Alpha (2020) [41] were used, and also the EXCEL calculation module for data analysis and the generation of different graphic models.

RESULTS AND DISCUSSIONS

From the analysis of satellite images, taken from the Sentinel 2 system, between March 22 - July 23, 2022, the spectral information was obtained, and based on the relationships (1) - (4), specific indices were calculated for the characterization, dynamic analysis of alfalfa culture and production estimation, (Table 1, Figure 1).

Table 1. Index values in relation to the date of taking the images, in the study of alfalfa culture

Data	T (days)	MSAVI	NDMI	NDVI	NBR
22.03.2022	1	0.54943480	-0.01900972	0.27756590	0.16938811
06.04.2022	16	0.66740014	0.10968359	0.39805683	0.32540163
14.04.2022	24	0.71217897	0.23053786	0.47145179	0.41288917
26.04.2022	36	0.75626211	0.27941614	0.51916824	0.48118806
04.05.2022	44	0.73452243	0.26465471	0.49366455	0.46029426
19.05.2022	59	0.63278337	0.08275454	0.36595634	0.31211769
03.06.2022	74	0.66394500	0.07994425	0.38156028	0.32348280
13.06.2022	84	0.57854357	-0.03939745	0.28642021	0.19547576
20.06.2022	91	0.57419200	-0.03811468	0.27804945	0.21104460
28.06.2022	99	0.61339991	-0.00050141	0.31019303	0.26416654
03.07.2022	104	0.59037569	0.00328488	0.28227862	0.27068291
10.07.2022	111	0.60878031	0.00371384	0.31261114	0.24185937
18.07.2022	119	0.48549074	-0.10483241	0.18480114	0.12739878
23.07.2022	124	0.48758671	-0.09829534	0.18700221	0.13647699

Source: Original data, obtained by calculation.

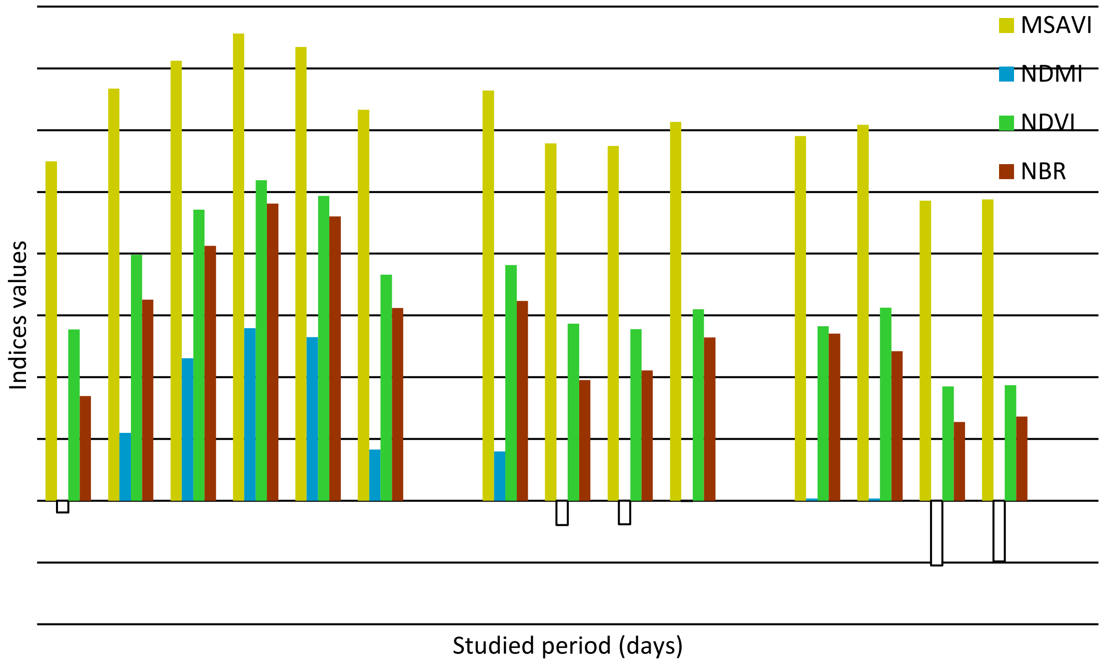

Fig. 1. The graphic distribution of the index values calculated for the dynamic characterization of the alfalfa crop
Source: Original graph.

During the studied period, three harvests were made to harvest the production of green mass in the studied alfalfa culture.

The first harvest was made on May 25 with a production of 10 t of green mass/ha, the second harvest was made on July 1 with a production of 7.5 t of green mass/ha, and the third harvest of was done on July 26 with a production of 7.5 t green mass/ha.

The variation of indices calculated on the basis of satellite images, in relation to the vegetation period of the alfalfa crop and the harvest times, was evaluated by appropriate mathematical and statistical methods and it was found that spline models most accurately described the variation of the index values in study conditions.

In the case of approaching each index through spline models, the average error ($\bar{\varepsilon}$) was calculated with a general equation of the type (5).

$$\bar{\varepsilon} = \left(\sum_{i=1}^{n} \varepsilon_i\right) / n = \left(\sum_{i=1}^{n} \left| \frac{ys_i - y_i}{y_i} \right| \right) / n \qquad (5)$$

In the case of the MSAVI index, the variation of the values recorded during the study period and associated with the harvesting moments were described by a spline model, under statistical safety conditions ($\bar{\varepsilon} = 0.000493$) with the presentation of the associated values in Table 2 and the graphic distribution in Figure 2.

Table 2. Values related to the spline model in relation to the MSAVI index

Trial		MSAVI			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	1	0.54943	0.54967	0.00044	1.00000
2	16	0.66740	0.66683	-0.00085	1.21315
3	24	0.71218	0.71337	0.00167	1.29782
4	36	0.75626	0.75537	-0.00118	1.37422
5	44	0.73452	0.73251	-0.00274	1.33264
6	59	0.63278	0.63779	0.00792	1.16031
7	74	0.66395	0.65649	-0.01124	1.19433
8	84	0.57854	0.58414	0.00968	1.06271
9	91	0.57419	0.57689	0.00470	1.04952
10	99	0.61340	0.60400	-0.01532	1.09884
11	104	0.59038	0.60313	0.02160	1.09726
12	111	0.60878	0.59222	-0.02720	1.07741
13	119	0.48549	0.50197	0.03395	0.91322
14	124	0.48759	0.48051	-0.01452	0.87418

$\bar{\varepsilon} = 0.000493$

Source: Original data, obtained by calculation.

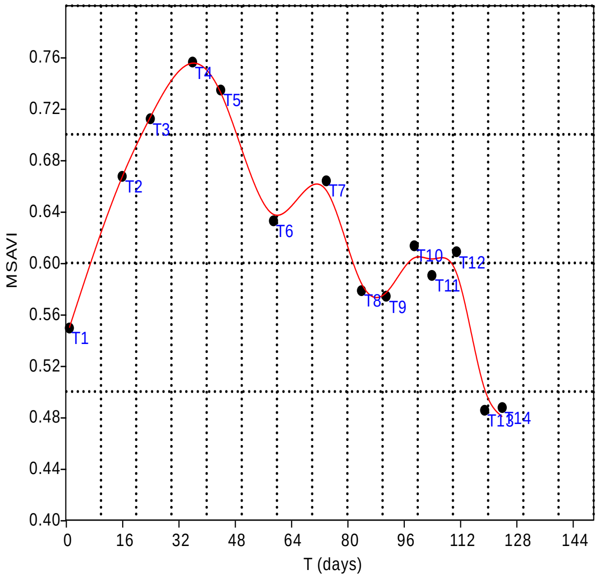

Fig. 2. Spline model for MSAVI variation during the study period
Source: Original graph.

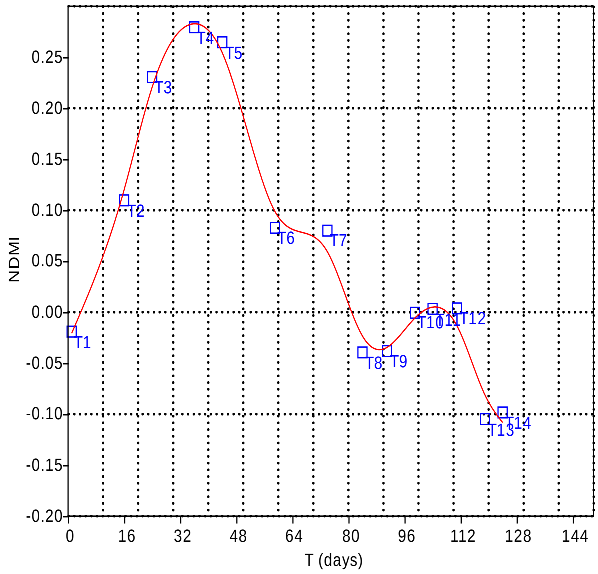

Fig. 3. Spline model for the NDMI variation during the study period
Source: Original graph.

In the case of the NDMI index, the variation of the values recorded during the study period, associated with the harvesting moments of the biomass production, were described by a spline model, under statistical safety conditions ($\bar{\varepsilon} = 0.391963$) with the presentation of the associated values in Table 3 and the graphic distribution in Figure 3.

Table 3. Values related to the spline model in relation to the NDMI index

Trial		NDMI			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	1	-0.01901	-0.02075	0.09169	1.00000
2	16	0.10968	0.12026	0.09646	-5.79482
3	24	0.23054	0.22084	-0.04208	-10.64135
4	36	0.27942	0.28280	0.01210	-13.62695
5	44	0.26465	0.25431	-0.03907	-12.25413
6	59	0.08276	0.09890	0.19507	-4.76548
7	74	0.07994	0.05921	-0.25937	-2.85303
8	84	-0.03940	-0.02334	-0.40765	1.12451
9	91	-0.03812	-0.03450	-0.09492	1.66227
10	99	-0.00050	-0.00562	10.20400	0.27070
11	104	0.00328	0.00492	0.49761	-0.23705
12	111	0.00371	-0.01353	-4.64425	0.65215
13	119	-0.10483	-0.08140	-0.22350	3.92237
14	124	-0.09830	-0.10826	0.10138	5.21660

$\bar{\varepsilon} = 0.391963$

Source: Original data, obtained by calculation.

In the case of the NDVI index, the variation of the values of this index recorded during the study period, associated with the harvesting moments of the biomass production, were described by a spline model, under statistical safety conditions ($\bar{\varepsilon} = 0.002972$) with the presentation of the associated values in Table 4 and the distribution graphics in Figure 4.

Table 4. Values related to the spline model in relation to the NDVI index

Trial		NDVI			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	1	0.27757	0.27734	-0.00083	1.00000
2	16	0.39806	0.39993	0.00470	1.44202
3	24	0.47145	0.47030	-0.00244	1.69575
4	36	0.51917	0.51882	-0.00067	1.87070
5	44	0.49366	0.49052	-0.00636	1.76866
6	59	0.36596	0.37290	0.01896	1.34456
7	74	0.38156	0.37175	-0.02571	1.34041
8	84	0.28642	0.29390	0.02612	1.05971
9	91	0.27805	0.28068	0.00946	1.01204
10	99	0.31019	0.29926	-0.03524	1.07904
11	104	0.28228	0.29861	0.05785	1.07669
12	111	0.31261	0.29118	-0.06855	1.04990
13	119	0.18480	0.20488	0.10866	0.73873
14	124	0.18700	0.17871	-0.04433	0.64437

$\bar{\varepsilon} = 0.002972$

Source: Original data, obtained by calculation.

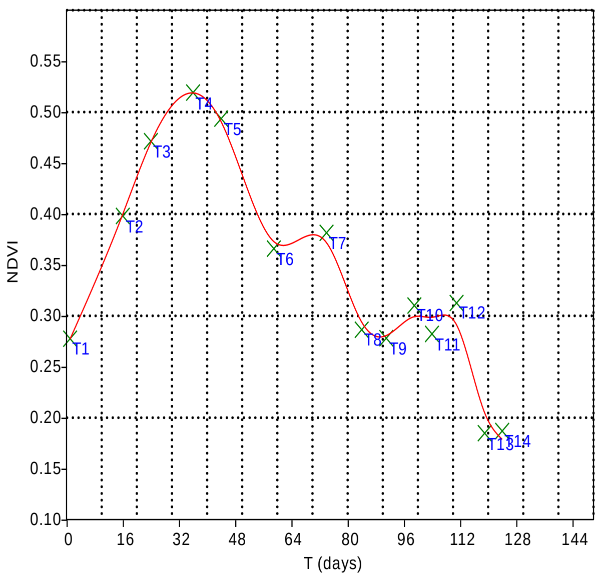

Fig. 4. Spline model for NDVI variation during the study period
Source: Original graph.

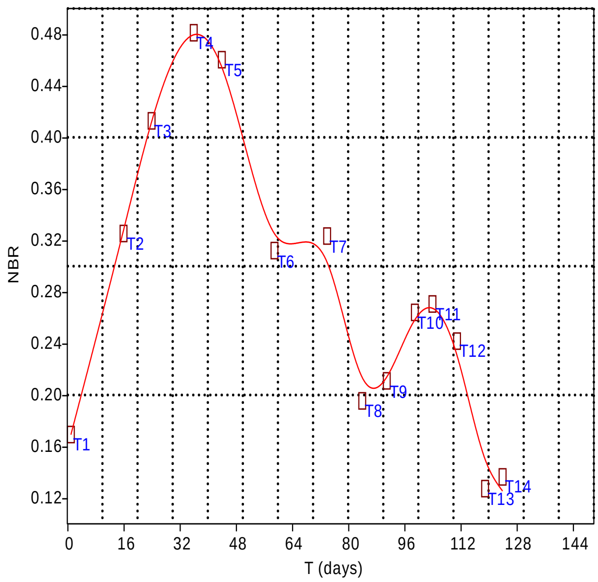

Fig. 5. Spline model for NBR variation during the study period
Source: Original graph.

In the case of the NBR index, the variation of the values of this index recorded during the study period, associated with the harvesting moments of the biomass production, were described by a spline model, under statistical safety conditions ($\bar{\varepsilon} = 0.006759$) with the presentation of the associated values in Table 5 and the distribution graphic in Figure 5.

Table 5. Values related to the spline model in relation to the NBR index

Trial		NBR			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
1	1	0.16939	0.16922	-0.00100	1.00000
2	16	0.32540	0.32795	0.00784	1.93801
3	24	0.41289	0.41211	-0.00189	2.43535
4	36	0.48119	0.47965	-0.00320	2.83448
5	44	0.46029	0.45449	-0.01260	2.68579
6	59	0.31212	0.32530	0.04223	1.92235
7	74	0.32348	0.30303	-0.06322	1.79075
8	84	0.19548	0.21367	0.09305	1.26268
9	91	0.21104	0.21404	0.01422	1.26486
10	99	0.26417	0.25845	-0.02165	1.52730
11	104	0.27068	0.26739	-0.01215	1.58013
12	111	0.24186	0.23087	-0.04544	1.36432
13	119	0.12740	0.15023	0.17920	0.88778
14	124	0.13648	0.12546	-0.08074	0.74140

$\bar{\varepsilon} = 0.006759$

Source: Original data, obtained by calculation.

To estimate the production of alfalfa, fresh mass, the regression analysis was used, which led to equation (6), under statistical safety conditions ($p<0.001$). The values of the equation coefficients are presented in Table 6. For high calculation accuracy, up to 16 decimal places were used for the coefficient values of equation (6). The RMSEP parameter was calculated for each production estimate. Based on the values obtained, it was possible to appreciate that based on the MSAVI and NDMI indices, the most accurate estimate of the production of fresh alfalfa mass was obtained, under the study conditions (RMSEP=0.01928). A 3D model of the variation of fresh alfalfa production was generated, in relation to the values of the MSAVI and NDMI indices (x – MSAVI; y – NDMI), Figure 6 and a graphic model in the form of isoquants, Figure 7.

$$Y_{FB} = ax^2 + by^2 + cx + dy + exy + f \qquad (6)$$

where: Y_{FB} – alfalfa production, fresh biomass;
x, y, - indices considered in equation, table 6
a, b, c, d, e, f – coefficients of the equation (6), table 6

Concerns for the study and estimation of the production of fodder crops through techniques based on remote sensing, or adaptable, have been used for several decades [29] and have been developed and perfected over time, associated with the progress of satellite systems, of specific indices calculations, algorithms and computer systems with high data processing capacity [15, 30].

Table 6. The values of the equation (6) coefficients and RMSEP parameter, in alfalfa fresh biomass estimating

Equation (6) coefficients	Indexes used					
	x=MSAVI *y*=NDMI	*x*=MSAVI *y*=NDVI	*x*=MSAVI *y*=NBR	*x*=NDMI *y*=NDVI	*x*=NDMI *y*=NBR	*x*=NDVI *y*=NBR
a	-73.12800584	-196.13783570	-148.36772866	-194.16199235	-375.23431017	-1588.67638576
b	-32.01305530	-115.99642416	-79.64529887	-286.19401227	-479.32088854	-700.64570179
c	85.56554538	140.10351110	122.06475125	-141.22553874	-192.29621357	423.87774559
d	-57.64276011	-107.36109033	-90.01916256	169.41053502	220.18985159	-313.38234413
e	98.18799891	301.10284959	217.93284513	474.80405985	840.45038844	2185.71093096
f	0	0	0	0	0	0
RMSEP	0.019289	0.022434	0.021844	0.045899	0.266102	0.940291

Source: Original data, obtained by calculation.

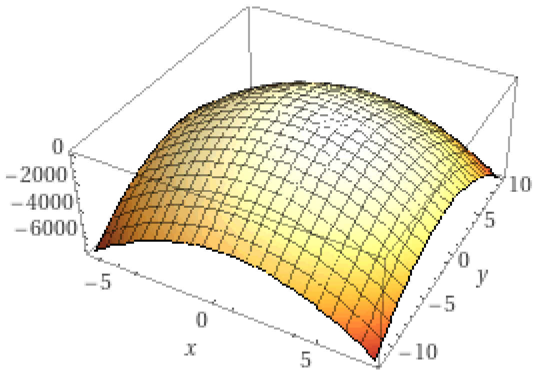

Fig. 6. 3D model of the variation of green mass production in alfalfa in report with MSAVI (x-axis) and NDMI (y-axis)
Source: Original graph.

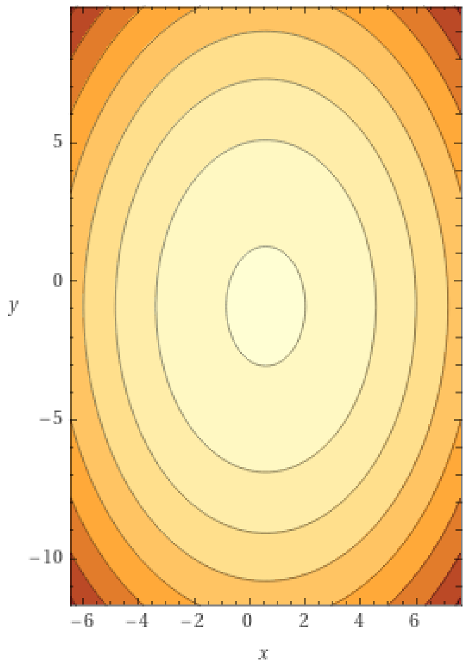

Fig. 7. Model in the form of isoquants regarding the variation of green mass production in alfalfa in relation to MSAVI (x-axis) and NDMI (y-axis)
Source: Original graph.

Good results regarding the prediction of production and quality of forage plants (estimated based on R^2, RMSE), based on remote sensing and associated techniques, were communicated for different fodder plants [2, 21, 28]. Spatial variability and alfalfa production were estimated by techniques based on remote sensing, based on specific indices (NDVI, SAVI, NIR reflectance) in safe statistical conditions based on the correlation coefficient (r=0.63 to r=0.69) [18]. The estimation of alfalfa production based on remote sensing techniques was of interest, and good values of production prediction reliability were communicated, assessed based on RMSE (RMSE=1114.0 to RMSE=1237.4 kg/ha) or other statistical safety indices [4, 22].

In the present study, the negative values recorded in the case of the NDMI index (Table 1, Figure 1) highlighted moisture deficits associated with the excessive drought of 2022, with values particularly accentuated in the June-July period. Associated with the respective periods, there was also a decrease in the NDVI values as well as the NBR index, which expresses the vegetation state of the alfalfa crop, respectively the biomass production. Positive correlations were recorded between the respective indices (NDVI, NBR) and NDMI (r=0.996 between NDVI and NDMI, respectively r=0.976 between NBR and NDMI for the period of June; r=0.982 between NDVI and NDMI, respectively r=0.986 between NBR and NDMI for the period of July).

Regarding the estimation of the production based on the indices calculated from the satellite images, and through the regression analysis method, this was possible in conditions of statistical safety, and also, 3D models were obtained in the form of isoquants that described the variation of the production of fresh alfalfa mass in relation to the indicators taken into account.

The authors of the study appreciate that the method can be adapted to other fodder plants in order to monitor crops and estimate production through techniques based on remote sensing.

CONCLUSIONS

The analysis based on remote sensing, 14 sets of images taken between March 22 - July 23, 2022, agricultural year 2021 - 2022, for an alfalfa crop in the third year of exploitation, non-irrigated system, facilitated the dynamic description of the culture evolution based on the indices specific calculated (MSAVI, NDMI, NDVI, NBR). The NDMI index, through the negative values recorded, highlighted periods of water deficit, in the months of June and July, associated with the actual climatic conditions of the year 2022.
The variation of the indices taken into account in relation to time, during the study period, was most accurately described by spline models. Several combinations of indices were found which, through regression analysis, facilitated the estimation of alfalfa production under statistical safety conditions, and the combination of MSVI and NDMI ensured the most reliable prediction (RMSEP=0.019289).

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