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RESEARCH ON THE USE OF NDVI IN MONITORING THE WHEAT CROP VEGETATION, THE CARBON STORAGE AND THE YIELD LEVEL, ON THE CHERNOZEMIC SOILS FROM SOUTH ROMANIA

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Abstract

In the southern part of the Romanian Plain, a research was carried out over a period of 5 agricultural years (2016-2021) regarding the evaluation of wheat crops, consisting of 7 premium varieties, on a surface of 110 ha. The NDVI index was used to assess the quality of management, the influence of climate change, which are in constant variation, on wheat crops and their ability to fix atmospheric carbon in the form of CO_2. For analyzing the data obtained from the Sentinel-2 satellite, in order to make the NDVI periodically summing and, then, to establish the daily average during the vegetation period from spring to summer, the calculation of the correlations and of the complex functions in 2D were used. In the integrated amount, NDVI ranged between 110.06 in 2020, the driest year, and 124.79 in 2018, the most favorable year for wheat cultivation. Yields also fluctuated in direct proportion to NDVI values, from 2,100 to 6,700 kg of wheat/ha. The obtained results place the area in conditions of high risk to water and other climatic factors, risks that can be partially reduced by optimizing crop management.

Key words: *wheat, NDVI, Sentinel-2, yield, crop management*

INTRODUCTION

The Normalized Difference Vegetation Index (NDVI) is the most widely used indicator, the one that best describes the level of vigour, the metabolic activity of the crop, the consumption of CO_2 by photosynthesis, of water and nutrients, in order to achieve production and its quality. At the same time, NDVI serves to detect the phytosanitary status of the crop and it provides information on the necessity for interventions. Indirectly, it provides information on the quality of technological works and on the need for nutrition, especially with nitrogen [5].
NDVI is a dimensionless parameter, which describes the visible reflective difference of crops and the one in near infrared, as well as the measurement of the crop's green color intensity that it transforms and transmits in numbers, which can then be calculated and interpreted [2]. Together with NDMI (The Normalized Difference Moisture Index), which deals specifically with measuring the state of water stress of the crop, it provides us with valuable information on the effect of climate change on the evolution and productivity of crops.
The measurement of reflectance, i.e. of the light intensity reflected by the crop on certain specific bands (wavelengths), can be easily done today, using specialized sensors, mounted on drones or satellites.
For NDVI search and calculation, the following are used in light spectrum [9]:

- the red band (RED) is visible in the spectral range (600-700 nm or 0.6-0.7 μm) and is in the visible spectrum of the human eye;
- the NIR band is in infrared on the spectral width 750-1,300 nm (0.75-1.3 μm) and is not retained by the eyes, but only by sensors.

The sensors mounted on the satellites are very varied and can also record slightly wider widths, that don't affect the index calculation. With a very good working algorithm, the Sentinel-2 and Landsat 8 satellites [6, 8] accumulate data over a longer interval, usually 5 years. According to several authors

[1, 3, 7], the calculation formula of NDVI is (1):

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

The values of the index vary between -1 and +1, each value in this range corresponding to a different vegetative state and agronomic situation, regardless of the crop [12]. If two wheat crops of the same variety are in the same phenological phase, the lower NDVI values found in one of them indicates one of the following situations [4]:

- food stress (bad nutrition);
- phytosanitary stress, attack of weeds, diseases or pests;
- damage caused by frost or other calamities – hail, fire or major technological errors.

The greener the plants are, the closer the index is to +1, without being able to reach it because they aren't perfect colors. The more degraded, yellowed the crop is, the farther it goes from +1 to 0. Under 0 there are no crops, the ground is empty and black. The value of NIR (near infrared) increases the greener the culture is, while the opposite happens with RED [10]. The NDVI index correlates with many other parameters, which are extremely useful for agricultural specialists, in order to optimize their crop management [11].

Here are just a few:

(1)The correlation between NDVI and chlorophyll assimilation – is usually significant and very significant and serves to:

- determination of carbon absorbed in the form of CO_2 from the atmosphere and its fixation in crop and soil;
- establishing plant health, but also the climatic environment;

(2)The correlation between NDVI and LAI (leaf area index) – extremely important for determining the size of foliar surface and the efficiency of photosynthesis;

(3)The correlation between NDVI and crop level – a decisive factor in crop planning and in their management;

(4)The correlation between NDVI and NDMI – it provides special information about the state of water stress of crops, requesting interventions in the genetics of varieties.

Knowing the possible losses is also useful for sizing costs in case crop management optimizations aren't possible. These correlation vectors make NDVI one of the most important and useful index, able to describe many aspects of the relationship between crops and the natural and social environment. Otherwise, it comes in several variants, allowing to a lot of researchers and practitioners to use it extremely differently.

MATERIALS AND METHODS

Work was carried out in the research and production field of Probstdorfer Saatzucht Romania from Modelu – Calarasi county (south Romania), on a slightly leached chernozemic soil, with 26% clay and 3.1% humus. Texturally, the soil is predominantly loamy.

The field under test measured an area of 110 ha, on which 7 premium wheat varieties, with over 14.5% protein, were grown. Researches took place from the autumn of 2016, until the summer of 2021 (5 agricultural years).

The climatic conditions of the research area are presented in Table 1.

Table 1. Precipitation and temperatures in Modelu (Calarasi), September 2016 – August 2021

Month	Precipitation (mm/month)					Temperatures (°C, mean)				
	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021
Sept.	52	0	10	9	57	19.4	20.1	19.3	19.5	21.0
Oct.	20	0	26	39	43	11.3	12.4	13.7	14.0	15.5
Nov.	74	154	64	27	8	6.2	7.6	5.4	11.7	5.9
Dec.	0	37	47	19	114	0.0	4.8	0.5	4.9	5.4
Jan.	0	45	9	2	106	-4.3	1.8	0.5	1.9	3.3
Febr.	17	44	11	31	42	1.7	1.8	3.8	5.8	3.3
March	65	38	16	16	102	9.0	4.1	9.7	8.9	5.3
Apr.	57	0	34	11	35	11.0	15.7	11.1	12.1	10.2
May	49	20	45	75	70	16.6	19.2	18.0	17.4	17.7
June	50	121	38	105	171	22.7	22.8	23.8	22.0	20.9
July	132	109	15	18	32	23.9	23.6	24.0	24.9	24.8
Aug.	20	64	43	3	19	24.1	24.5	24.6	25.1	24.2
Total/ Mean	536	632	358	355	799	11.8	13.2	12.9	14.0	13.1

Source: Own determination.

For the measurements the Sentinel-2 satellite was used, which has the sensors and the algorithm for measuring the radiation reflected in the specific bands – NIR and RED.

The patterns reflected by plants and captured by satellite sensors vary depending on the phenological phase of the crop, and at the level of the same phenological phase differ depending on the state of the crop (drought, nutrition, plant health, crop rotations and other climatic conditions, etc.). The sensors capture the intensity, the clarity of the light reflected by the plants in the present bands and, depending on the degree of intensity, turn the moment of capture into numbers.

This system was used, by purchasing NDVI values during the research period, but only for the spring-summer vegetation period of wheat. Specifically, it was found that this period lasts 186 days, starting with February 1, when the soil is usually cleared of snow and wheat plants resume their vegetative activity, and until the harvest of the crop.

The raw data received from Sentinel-2 came in both graphical and tabular form. Because the sky was often covered at the time of reading, there were many points of sudden decline. These figures had to be replaced by ground observations or drone recordings.

After making the corrections, the data were subjected to a correlation analysis calculation, in order to compute the annual specific curve of NDVI for wheat crop by year and its average. The correlation represented a pattern of evolution over time (during the vegetation period), transiting all wheat phenophases, from early spring to the harvest. It resulted a number of 5 annual models (curves accompanied by function and statistical assurance by the correlation coefficient) and 5-year average model, which is intended to be a zonal average characterization of the index and of the benefits resulting from its use.

RESULTS AND DISCUSSIONS

For the acquired annual data, the evolution in time of NDVI to wheat crop in each spring of the analyzed agricultural years is calculated and presented in Figures 1-5, of which we note a few aspects.

In the first agricultural year of study (2017) the NDVI curve starts with negative values, suggesting that this year the soil didn't show measurable crops by Sentinel-2. In about 50 days, due to the rains and to the right temperatures for the early phenophases, it is expected that in the last decade of March NDVI values will exceed the figure of 0.7 (70%) covered crop, to increase to 0.8 by the end of April, then 0.9 in May, i.e. during the flowering and grain filling period, and will decrease, once maturity begins, in yellow (June), returning to values of 0.2 → 0.1 at the time of wheat crops harvesting.

Throughout the vegetation period, values were registered according to the phenological phases (Fig. 1), the year being considered positive, favorable for wheat cultivation, obtaining average yields between 5,000-6,000 kg/ha.

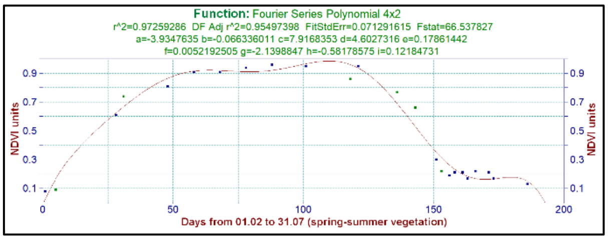

Fig. 1. NDVI values for the wheat crop, in the spring of 2017

Source: Own determination.

By performing the function integral we'll find summed the daily NDVI values from the summer vegetation period of the wheat, i.e.:

$$\sum_{x=1}^{186} NDVI = \int_{1}^{186} fx(dx) = 120.46$$

$$\text{Average NDVI} = \frac{120.46}{186} = 0.64$$

The average also shows a quality crop, but without allowing the maximum potential of the varieties to be obtained in the area.

In the second year (2018), the curve was very different (Fig. 2). First of all, the beginning is different – February has a NDVI = 0.85, i.e. 85% of the surface was covered. The climatic conditions allowed, throughout the vegetation period, up to 120 days (end of May), going through all the phenophases, the NDVI remaining at 0.85 → 0.90 (85-90%) coverage, taking us into highlights the most suitable year for wheat cultivation. Yields ranged from 6,000-7,000 kg/ha. The amount and average value of the index were:

$$\int_{1}^{186} fx(dx) = 124.79$$

$$\text{Average NDVI} = \frac{124.79}{186} = 0.67$$

Only 0.03 NDVI average points brought an additional production of about 1,000 kg/ha.

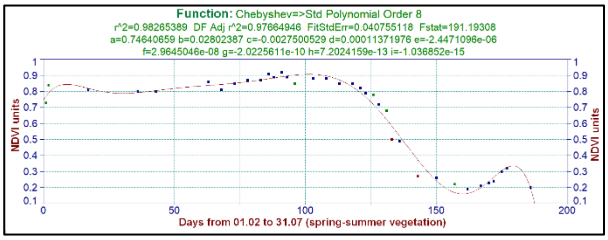

Fig. 2. NDVI values for the wheat crop, in the spring of 2018
Source: Own determination.

The third year (2019) started with quite high values of the index, but with 0.3 points below those of the previous year. As a result of the rainfall at the end of March and in April, the crop recovered, and in March - May the index increased to over 0.85, after which it suddenly decreased (Fig. 3), both due to the reduction in the amount of precipitation, as well as to an attack of diseases. The varieties reacted differently, and the yield varied in a wide range, from 4,200 to 6,500 kg/ha.

$$\int_{1}^{186} fx(dx) = 113.12$$

$$\text{Average NDVI} = \frac{113.12}{186} = 0.61$$

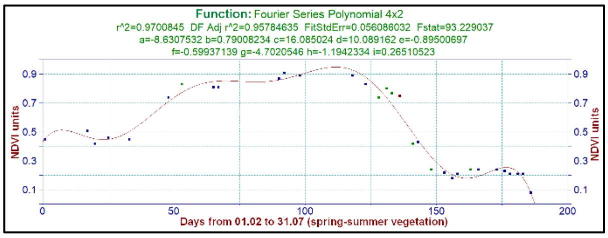

Fig. 3. NDVI values for the wheat crop, in the spring of 2019
Source: Own determination.

In the fourth year (2020), the data showed an extreme situation. Spring, although dry, finds the crop with an NDVI of almost 0.8, increases slightly to almost 0.85, then decreases continuously along the phenophases, to values of 0.2 → 0.3 during the grains filling period. Although the indicator describes the presence of the crop, the decrease of NIR values and the increase of RED values lead us to think of a yellowed culture, exhausted by drought. The determinations of the NDMI index (to be published) pointed out a high degree of dehydration, water stress of the crop, which ended with yields between 900 and 3,000 kg/ha (Fig. 4), totally unsatisfactory to cover costs.

$$\int_{1}^{186} fx(dx) = 110.06$$

$$\text{Media NDVI} = \frac{110.06}{186} = 0.59$$

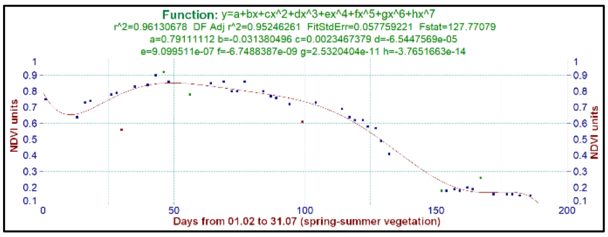

Fig. 4. NDVI values for the wheat crop, in the spring of 2020
Source: Own determination.

In the last year of research (2021), good values of NDVI in spring and high values of the index (0.85) during most phases of vegetation were founded, but there is a sudden decrease in its maturation period (Fig. 5), generated by a high disease attack, generated by heavy rains. The rains also made the harvesting more difficult. Wheat yield was between 4,800-5,500 kg/ha, with an average of 5,000 kg/ha.

$$\int_{1}^{186} fx(dx) = 116.70$$

$$\text{Average NDVI} = \frac{116.70}{186} = 0.63$$

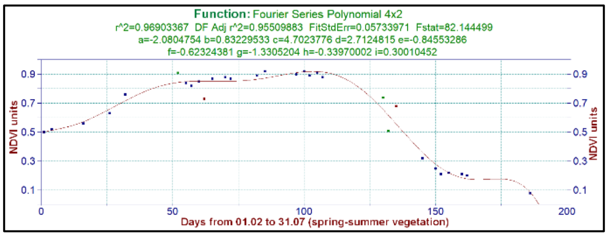

Fig. 5. NDVI values for the wheat crop, in the spring of 2021
Source: Own determination.

Due to the variability of the climatic conditions, the models of the functions and those of the curves don't resemble each other at all in the five years of study (2017-2021). As a result, it was impossible to extract a single interval along the phenophases, representing all years in the calculation of a correlation with production or biomass.

Consequently, it was calculated an average function of the NDVI evolution (Fig. 6), which characterizes quite well the area as a whole, but also mitigates the role of climate change and especially doesn't take into account the water supply of the soil. It shows, on average, crops that start growing in early spring, form good vegetation (85% coverage) in most periods of vegetation, but fall sharply during the ripening period, not giving the necessary climatic space to fill the grains, obtaining high components of production and especially the weight of 1,000 grains (MMB) and the hectoliter weight.

$$\int_{1}^{186} fx(dx) = 115.88$$

Average NDVI = $\frac{115.88}{186} = 0.623$ – for an average yield of 5,000 kg/ha, with variations from 2,000 to 8,000 kg/ha

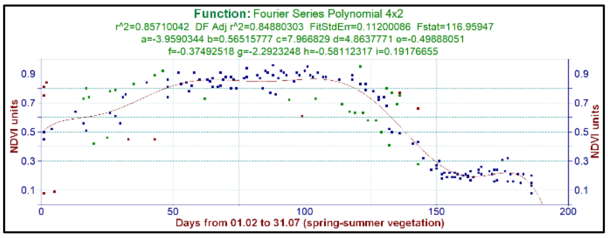

Fig. 6. NDVI values for the wheat crop, in spring, average for 2017-2021
Source: Own determination.

If the average index would increase to 0.75, then the production would be very close to the potential of the varieties, respectively 7,500-9,000 kg/ha.

It is to be mentioned that using these complex functions, were obtained very high correlation ratios ($r^2 > 0.96$). The 5-year average function, taking over the negative influence of the years, reduced the correlation ratio ($r^2 > 0.85$ - 85%).

The correlation between NDVI and wheat production is shown in Fig. 7, in which it is observed that during the experimentation period (5 years) the NDVI sum index oscillated between 110 (in 2020) and almost 125 (in 2018), i.e. the average daily NDVI = 0.59 → 0.67. During this period, the average level of wheat production ranged between 2,000 and 6,500 kg/ha.

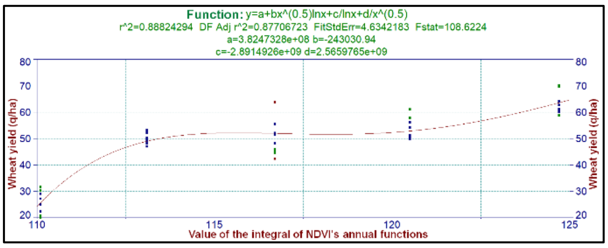

Fig. 7. Correlation between NDVI, as an integral of annual functions and wheat yield, average for 2017-2021
Source: Own determination.

The function is an exponential one, naturally logarithmic, ensured statistically by a very significant correlation ratio $r^2 = 0.89$, a determination of 89% and a correlation coefficient $r = \sqrt{r^2} = \sqrt{0.89} = 0.94$, also very significant. The function shows that, on the NDVI range = 0.59 → 0.62, the production values increase from 2,500 to 4,900 kg/ha, after which on the NDVI range = 0.62 → 0.65 they increase slightly to 5,100-5,300 kg/ha, so that from NDVI = 0.65 → 0.67 to reach 6,500 kg/ha. The average yield increase was $\frac{6.5-2.5}{0.67-0.59} = \frac{4.0}{0.08} = 50$ – the transformation coefficient for a NDVI unit.

If NDVI would had been equal to 0.75, then a yield of about 8,000 kg/ha could have been obtained, which would have brought the area close to about 10-15% below the potential of these valuable varieties. This isn't the case in the south of the Romanian Plain, where due to the unfavorable climatic conditions, on average for 5 years, yields of about 5,200 kg/ha can be obtained $\Rightarrow$ 5,200/115.88 = 44.8. Can't be yet estimated whether the average long-term production is more than 10 years. The formula for calculating the harvest, starting from the function data and NDVI is:

$$NDVI \times 44.8 \times 186 = 0.623 \times 44.8 \times 186 = 5{,}191$$

CONCLUSIONS

NDVI is one of the most important indices that is used, along with other parameters, in the process of agricultural crops monitoring and control, in this case of wheat cultivation. It is obtained by acquiring the primary data from the Sentinel-2 satellite, correcting them with drone and ground observations in the crop, and then processing them using time functions of the length of the vegetation period of wheat crops in spring-summer, around 186 days, from February 1 to July 30.

The calculation and interpretation of NDVI showed that the agricultural area is in an extremely variable region from one year to the next in terms of climate, with NDVI ranging between 110.06 in 2020, a disastrous year for wheat cultivation, and 124.79 in 2018, which was the year with the highest yields (an average of 6,500 kg of wheat/ha). In average daily values, NDVI ranged from 0.59 to 0.67, with an amplitude of 0.08 NDVI units. Functions and graphs were statistically provided by correlation ratios $r^2 > 0.96$, i.e. determinations of over 96%.

The large variation from one year to another doesn't allow the selection of a phenological area to link it with the obtained production. Correlated with the yields obtained on the ground, the NDVI indicates an average 5-year production of about 5,200 kg of wheat/ha, i.e. more than 45% below the potential level of the tested varieties, but with large variations, from 2,100 to 6,700 kg/ha. Each hundredth of NDVI brings us a harvest of 44.8 kg/ha.

Therefore, a crop close to the varieties' potential could have been obtained with an NDVI of 0.75, which would have translated into a production of 8,000 kg of wheat/ha.

The obtained NDVI values, correlated with the yields, place the area in conditions of high risk to climatic factors, which can be partially reduced by agricultural technologies, by a better tolerance of varieties to water stress and by optimizing crop management.

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