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NDMI USE IN RECOGNITION OF WATER STRESS ISSUES, RELATED TO WINTER WHEAT YIELDS IN SOUTHERN ROMANIA

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Abstract

In the south part of Romania, during 2016-2021, research was conducted on the water stress of wheat crop, represented by 7 varieties of premium genetics wheat, i.e. high in protein and gluten. The analysis of NDMI (Normalized Difference Moisture Index) showed that, during the research period, the plants benefited from an average index of 0.21 units, placing the area in the category of those that offer a moderate size of vegetation and a medium stress for water. Under these conditions, the average wheat yield was 4,413 kg/ha, i.e. less than 50% of the varieties potential. The annual wheat variation of NDMI (170 days, spring-summer) ranged from -0.015 units in 2020, when yield was below 2,000 kg/ha, to 0.356 units in 2021, when due to phytosanitary stress, the average yield was of 5,512 kg/ha. Rest of the years had intermediate values, in each of them the water stress being present either in spring or in summer. The correlation between the water stress and the obtained yields was represented as a polynomial function, statistically assured. Average yields of 50% of the variety potential can be obtained at stresses of not less than 0.1-0.2 NDMI units. In this regard, it is necessary to rethink technologies, especially on recalculating the level of some inputs, which in conditions of pronounced water stress are only partially used by plants.

Key words: *NDMI, wheat, water stress, yield*

INTRODUCTION

The Southern part of Romanian Plain, an area of about 50-80 km along the Danube River, has been noted in the last 10 years by the modified parameters of climatic conditions, with an emphasis on increasing temperatures (especially in summer time), on reducing quantities of precipitation and on the appearance of an aggressive alternation between day and night temperatures, especially in April and early May [2]. Declared by the meteorological institutions of NASA as the hottest decade of the last 80 years [12], the period 2011-2020 also left its negative mark in the study area, 2015 being the warmest year, and the agricultural year 2019- 2020 being extremely dry.

Climate stress factors, and especially drought, due to the lack of water in the soil reserve, correlated with the precipitation volume reduction, require new studies, highlighting the risks of reducing wheat yield, the main agricultural crop of the area and the development of new agricultural techniques, to capitalize more efficiently the reduced water resource and deal with hot summers, especially during the flowering – filling the grain – maturity periods, when the wheat is very sensitive to temperatures above 30°C.

New technologies, offered by specific satellites, positioned outside the atmosphere and intended to monitor the state of vegetation [3, 6, 7], but also the agricultural crops [5, 13], are becoming more and more used for accurate and predictive knowledge of crop water stress [4, 8, 16], in order to resize the volume of inputs needed for crops to obtain the maximum possible yields, but with minimum costs [11] in the new conditions.

From the many techniques offered by satellites, we first approached the use of two monitoring indicators, that can be used for assessing the condition of agricultural soils, being non-invasive methods, without environmental impact [9], namely:

(1)NDVI (Normalized Difference Vegetation Index) – described in another paper [1];

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(2)NDMI (Normalized Difference Moisture Index).

NDMI shows the water stress of crops and has values between –1 and +1, each obtained value corresponding to a certain agronomic situation [14], depending on the mapping of the studied area. The calculation formula for NDMI, when performing readings using Sentinel-2 satellite is:

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR} = \frac{B8A - B11}{B8A + B12} \quad (1)$$

where:

NIR = near infrared;

SWIR = shortwave infrared.

NDMI has been used successfully in various aspects of vegetation assessment, as soil brightness is canceled [10]. Research has shown that a 30-40% land cover results in more accurate NDMI readings [15].

Based on what is already known, we will present the results obtained with NDMI in wheat crop, this being the index that provides us with information on the water content of plants (stems + leaves). The proposed objective is to demonstrate that NDMI can be used for measuring the water stress in which wheat plants have entered very frequently in recent years.

MATERIALS AND METHODS

The research area is located in the south of Romania and includes an area of 110 ha, cultivated with 7 premium wheat varieties, with different vegetation periods. According to our own hypothesis, in very different climatic conditions from one year to another, it is necessary to combine the varieties, so that they can substitute each other in the capitalization of vegetation factors, depending on their appearance in the system. From pedological point of view, the study was carried out on chernozemic soils, slightly carbonated, with about 25-26% clay and 3.1-3.2% humus, with good permeability and contact with groundwater only at rainfalls over 100 mm (up to a depth of 6-8 m).

The thermal regime, on average in the years 1961-1990, indicates a temperature of 11.68°C, as well as precipitations of 473.9 mm, i.e. 4,739 m^3/ha.

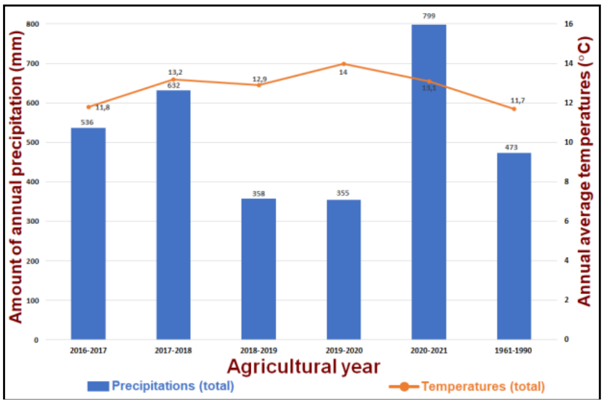

Fig. 1. Temperatures and precipitations from 2016-2021, compared to the average of 1961-1990
Source: Own determination.

Figure 1 shows the temperature and precipitation regime, which influenced the climate in the agricultural years of experimentation.

The average annual temperature during the experiment period was 13°C, with more than 1.3°C higher than the multiannual average (1961-1990). It is a high value, which speaks for itself about the stress suffered by plants in recent years. Also, the annual temperature variation is large, from 11.8°C in the agricultural year 2016-2017, to 14.0°C in the very warm and dry year 2019-2020. An amplitude of 2.2°C is observed only within the 5 analyzed years.

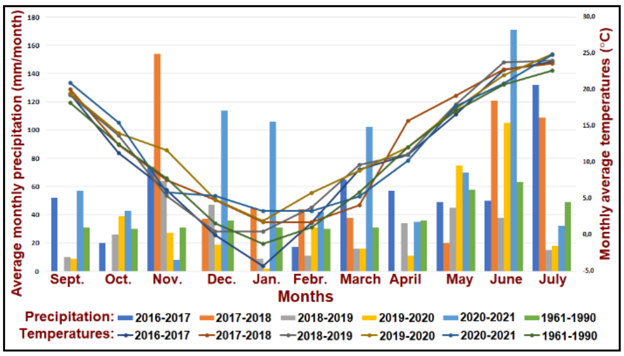

Fig. 2. Average monthly temperatures and precipitations from 2016-2021, compared to the average of 1961-1990
Source: Own determination.

The variation of precipitation in the studied period was also very large, from 355 mm in

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the agricultural year 2019-2020 (with high water stress), to 799 mm in 2020-2021, i.e. over 2.25 times more. It should be noted that the most abundant rainfall fell outside the optimal range for plants, namely in June and July, during the harvest period (Figure 2).

On the other hand, in April and May, decisive for the formation of the wheat production elements, precipitations were reduced and often unsustainable by the water supply of the soil, so that the plants did not have the necessary water to achieve optimal yields, although the used technologies required yields of over 6 t/ha.

The role of the NDMI is to indicate exactly the water content in the plants, which correlates with the mapping of the phenological development of the varieties and, finally, with the level of harvests.

The NDMI calculation was performed in the following successive steps:

(1) Data for the 5 agricultural years (2016-2021) were collected from the satellite monitoring system (Sentinel-2).

(2) Data were analysed and the readings from the days with overcast skies were removed, since they gave non-compliant figures due to the lack of radiation reception by the evaluation bands.

The remaining data, confirmed with several observations made on the ground and/or with the personal drone (DJI Mavic 2 Pro) are then sorted in tables and subjected to calculations of correlative evolution over time.

For the five agricultural years (2016-2021), bifactorial (2D) functions were calculated between NDMI and time (170 days, on average, from February 1 to harvest time). We don't have similar data for the phenological evolution in autumn, so we excluded that period. The calculated functions are presented in five annual graphs. By summing up the data, the average NDMI for the period 2016-2021 was calculated, a parameter that shows us to what extent the studied area provides the water necessary for the phenological development and the achievement of the average wheat yield for the 7 varieties. The aim of this paper is to develop a model on the influence of climatic conditions on the water supply of plants, a model of water stress and to find out to what extent there is a correlation between the winter wheat yield and the NDMI results, thus verifying its correctness and usefulness for agriculture.

RESULTS AND DISCUSSIONS

To begin with, there is presented the scalar interpretation of NDMI. Assuming that NDMI varies between –1 and +1, the scale of interpretation in Table 1 is used.

Table 1. Interpretation of NDMI values – estimation

Crt. no.	NDMI value	Interpretation
1.	–1.0 → –0.8	Uncovered soil, without vegetation
2.	–0.8 → –0.6	Almost absent vegetation
3.	–0.6 → –0.4	Very reduced vegetation
4.	–0.4 → –0.2	Low and dry vegetation
5.	–0.2 → 0	Medium-low vegetation cover, high water stress
6.	0 → 0.2	Medium-low vegetation cover, low water stress
7.	0.2 → 0.4	Medium vegetation cover, low water stress
8.	0.4 → 0.6	High vegetation cover, no water stress
9.	0.6 → 0.8	Very high vegetation cover, no water stress
10.	0.8 → 1.0	Total vegetation cover, no water stress – optimized yields.

Source: Own determination.

Models of NDMI functions for the five agricultural years are shown in Figures 3-7.

The year 2017 starts on February 1 with a low to medium coverage of the plant sector (Figure 3). Plants come out of the winter already under water stress.

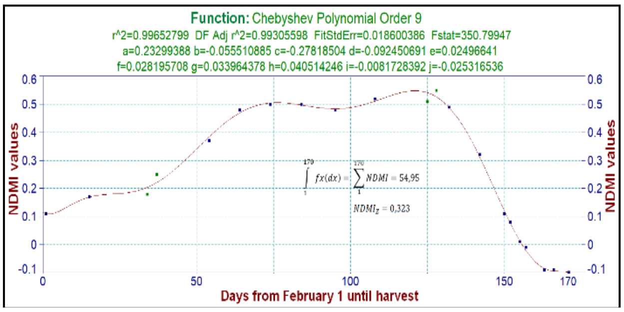

Fig. 3. The time dynamics of NDMI in wheat crop, spring-summer 2017
Source: Own determination.

The rains of April, May and June (first part) reduced the stress, the crop formed a high cover, in which the water stress was no longer felt until it entered in the maturation-harvest

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phase, at the end of June and beginning of July. The varieties had enough water during the formation of the reproductive organs. Overall, however, the integral under the curve, which gives us the sum of the daily values of NDMI during the vegetation period is relatively small (54.95) and leads us to a daily NDMI of 0.323 units, which can justify the yields of 5,139 kg/ha.

The year 2018 begins with high NDMI values (Figure 4), which remain high until the end of March due to high water reserves in the soil, as a result of the 160 mm of rainfall in November 2017, then supported by the 40 mm fallen in December 2017 – March 2018. The lack of precipitation in April and May led to the entry of vegetation under high water stress, with negative consequences on the formation of production. The tolerance to water stress of most varieties made the heavy rains that fell in early June led to improved production elements and helped them obtaining satisfactory yields.

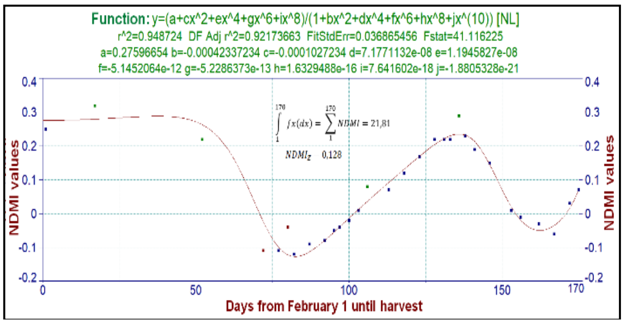

Fig. 4. The time dynamics of NDMI in wheat crop, spring-summer 2018
Source: Own determination.

This agricultural year (2017-2018) has shown that, if the crop has no hydric stress until the formation of fruiting, it better withstands the lack of rainfall in April, as long as the rains return in May-June to complete yields by improving its components. With the described parameters an average wheat yield of 5,512 kg/ha was obtained, even though the NDMI values were small (amount of 21,81 units, with a daily NDMI of 0,128 units).

The year 2019 falls between the first two years, without major stress in February and beginning of March and with a significant return of plant turgidity throughout the period from the beginning of stem formation to grain filling, but with stress before maturation. The amount of the daily NDMI values during the vegetation period is 41.69, which leads to a daily NDMI of 0.245 units (Figure 5), i.e. the stress exists, is low, but not sustainable. The yield obtained under these conditions was 5,915 kg/ha. We emphasize that although the precipitation in the vegetation was reduced, their distribution was very good.

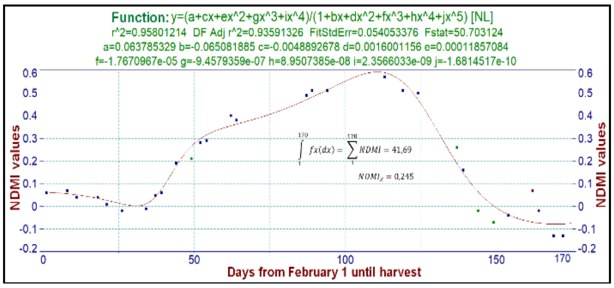

Fig. 5. The time dynamics of NDMI in wheat crop, spring-summer 2019
Source: Own determination.

The year 2020 was completely dry, the NDMI parameters being close to 0 at the beginning of the vegetation period and below 0, pronounced negatively for the entire vegetation period (the sum of the daily values was –2.62, and the daily NDMI was –0.015). The few rains that fell in May (towards the end of the month) couldn't get the plants out of the permanent stress they were in, and those in June made it difficult to harvest and reduced the yields. The integral under the curve is negative (Figure 6), indicating the depth of stress in which the plants hardly withstood, manifested by low plant cover, low density and small ears. Average yield was 1,998 kg/ha, with low quality. An extreme year, so that only the late varieties reacted to the delayed humidity.

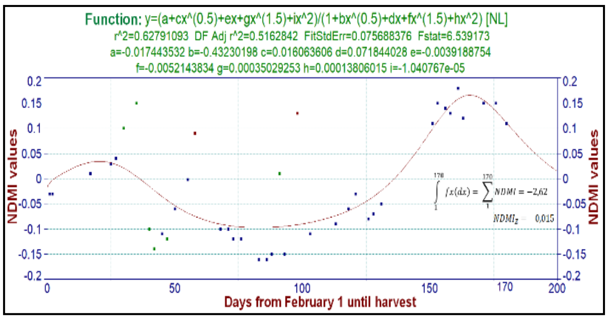

Fig. 6. The time dynamics of NDMI in wheat crop, spring-summer 2020
Source: Own determination.

The agricultural year 2020-2021 had a lot of rainfall, started in September 2020, continued in the spring of 2021, with excess even at harvest time, when they became restrictive on the final yield. Under these conditions, the dynamics of NDMI was extremely favorable to the wheat crop in spring, at the beginning of summer, in all the phenophases of its growth and development, with a smaller vegetal cover at the beginning and a well-developed one later, not being at all in water stress. However, there was a stress towards the end of the vegetation period, but it was caused by the degradation of the foliage due to the attack of diseases. Without water shortage, but with phytopathological stress, the crop suffers in the grain filling – maturation phase, reducing its yield and quality below the potential of the varieties. The amount of the daily values of NDMI during the vegetation period is 60.63, which leads to a daily NDMI of 0.356 units (Figure 7), the highest of the whole experimentation period, but the final result was influenced by the phytosanitary stress.

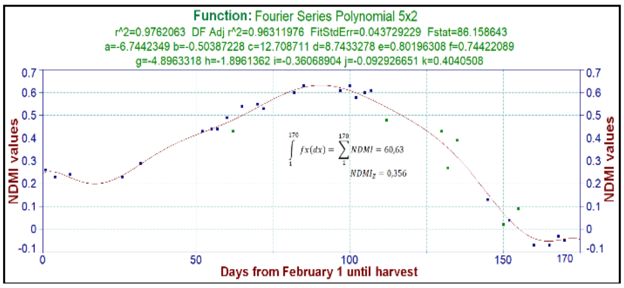

Fig. 7. The time dynamics of NDMI in wheat crop, spring-summer 2021
Source: Own determination.

From the NDMI evolution during the vegetation periods of the agricultural years 2016-2021 it can be seen a very large variability of the water stress intensity from one year to another. Only 2020-2021 wasn't under hydric stress, but the presence of water couldn't compensate for pest issues. Under these conditions, the yield reached only 5,512 kg/ha, less than in the years with lower NDMI values, but with a very good plant health, especially during the crop development stages. Having such a climate variability from one year to another, we tried to find a mathematical pattern for the entire period (2016-2021), which would describe the multiannual evolution of climate stress on wheat yield (Figure 8). A very complex function is observed and ensured by a correlation ratio r^2 = 0.255 and a determination of 25%. As the correlation coefficient for this very large number of determinations is $r = \sqrt{r^2} = \sqrt{0.255} =$ 0.505, we find that the model is statistically assured. It also shows us that the amount integral of NDMI over the period of wheat vegetation, which is 35.29 units, and the daily value of 0.207 places the southern part of Romania in a state of high stress for water in the case of a high cover (well-developed plants in spring) or in a lower state of water stress if the spring was drier and the crop had a low vegetative mass. In both cases, the yield will suffer, being greatly diminished below the potential of the varieties.

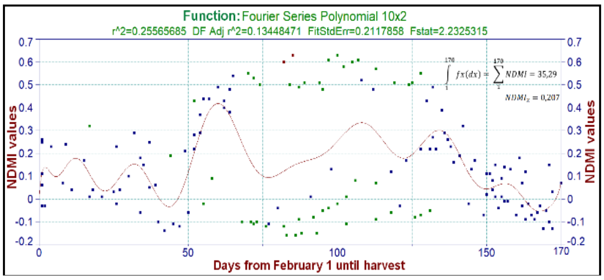

Fig. 8. The time dynamics of NDMI in wheat crop, spring-summer 2017-2021
Source: Own determination.

The mathematical pattern of the correlation between NDMI and the average wheat yield for the 7 varieties is presented in Figure 9, in the form of a polynomial function which is statistically ensured by a correlation ratio r^2 = 0.775 and a determination of 77.5%. It turns out that in 77.5% of cases the situation is the same as in this model.

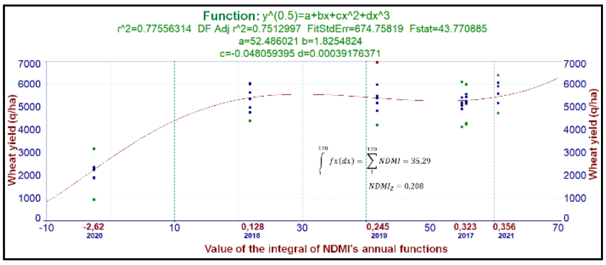

Fig. 9. Correlation between the total value of NDMI units and the wheat yields obtained, average for 7 varieties, in the agricultural years 2016-2021
Source: Own determination.

There are years when the average NDMI during the vegetation period was negative (–0.015), in which case the water stress of the crop is permanent, and the crop level is around 1,000 kg/ha for some varieties or around 2,000 kg/ha for the more tolerant ones. Once the indicator becomes positive (0.128) the stress continues to exist, but it’s reduced, and the yield increases to 4,000-5,000 kg/ha and is maintained up to NDMI = 0.323. Reducing the stress by increasing the average daily indicator above this value makes the yield exceeding 6,000 kg/ha. Unfortunately, in the only year in which this situation was favorable for obtaining high yields (2020-2021), the phytosanitary stress appeared, preventing the studied varieties of reaching their maximum potential of, which is 9,000 kg/ha.

CONCLUSIONS

For the south of Romania, in the analyzed period (2016-2021) the climatic conditions were extremely variable, as a whole characterized by high temperatures and a precipitation regime that wasn’t favorable for agricultural crops. Using the data obtained from the Sentinel-2 satellite, it was possible to calculate the moisture index (NDMI), which highlighted the fact that there is a correlation between the hydric stress, presented as NDMI units, and the wheat yields, as long as these measurements are correlated with the situation found in the field (direct visits or using drones), to identify the occurrence of other limiting factors (e.g., weeds, diseases or pests).

Average yields varied between 1,998 kg/ha (in the agricultural year 2019-2020, with an average daily NDMI of –0.015 units) and 5,915 kg/ha (in the agricultural year 2018-2019, with an average daily NDMI of 0.245 units).

Yields aren’t significantly correlated with the level of rainfall in the area due to their random fall and often during harvesting time, causing damages instead of helping the crop. The efficiency of spring precipitation also depends a lot on the water supply of the soil. If it's missing, the rains are retained by the soil and enter into the hydration process of the plants only after the restoration of moisture above the wilting coefficient.

In these conditions, it is necessary to rethink the technologies, with emphasis on the tolerance of varieties to climatic stresses, but also on the recalculation of some inputs and on the way in which they are made available to plants.

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