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INVESTIGATION OF THE NDVI CORRELATION IN A *VITIS VINIFERA* CV. MERLOT VINEYARD GROWN WITH DIFFERENT NUTRIENT REGIMES UNDER NON-IRRIGATED CONDITIONS

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Abstract

The production of high-quality wine grapes represents a significant challenge for winemakers, both in the short term and on an annual basis. In the context of modern viticulture, the means to achieve this goal include the application of vegetation indices derived from remote sensing.
The objective of this study was to establish a correlation between NDVI and the growth stages of Vitis vinifera cv Merlot vines grown in the village of Brestnik. The study period was the 2023-2024 growing season.
The NDVI values were calculated from time series of Sentinel-2 images for the main phenological stages. The results indicated the vegetative and reproductive potential of the vines and relation with NDVI. The resulting mathematical model and correlations can be used as predictive models.

Key words*: NDVI, grapevine, remote sensing, vineyards, vegetation indices.*

INTRODUCTION

In modern agriculture, optimal vineyard management is particularly important given the impacts of climate change and limited water resources.
Satellite imagery provides a wide range of opportunities for rapid monitoring of agricultural fields (Szabó et al., 2016; van Dessel et al., 2008; Lóki-Szabó, 2011; Burai et al., 2014; Varga et al., 2015). Precision agriculture has received considerable attention in the agricultural community over the last two decades (Sun et al., 2019; Palalottino et al., 2018; Comba et al., 2016). Modern agriculture is characterised by the need for precision vineyard management, especially in the context of global warming and changing climatic conditions. These factors are altering traditional growth phases, with serious implications for grape yield and quality, with traditional vineyard regions adapting to new conditions or even moving to more northern regions (Nistor et al., 2020; Sun et al., 2011; White R., 2009; Popova, 2022).
In viticulture, the precision agriculture approach aims to ultimately improve grape yield and quality in vineyards while reducing the impact of climate change by addressing difficulties in the production cycle through appropriate crop management decisions (Arnó, et al., 2009; Silvestroni et al., 2019).
NDVI is widely used in remote sensing because it provides a quick and efficient method of assessing plant vigour and health, which is particularly important in viticulture. Under non-irrigated conditions, where water resources are limited, effective nutrient management becomes even more critical to achieve optimum grape yield and quality. In this context, the present study aims to analyse the relationship between NDVI and grapevine growth performance, taking into account the influence of different nutrient regimes (Sun, 2017).
Remote sensing using satellite imagery has become an indispensable tool for monitoring crop conditions. Among the many vegetation indices available, the Normalised Difference Vegetation Index (NDVI) stands out for its ability to reflect plant vigour and provide a quick and efficient assessment of plant health. The use of NDVI in viticulture is of particular importance as it allows the tracking of spatial variability in vineyard areas, which is key for the assessment of yield and production quality (Szabó et al., 2016; Burai et al., 2014).
A number of studies have attempted to analyse the relationship between NDVI and agrobiological performance in vineyards grown with different nutrient regimes under non-

irrigated conditions. Under such conditions, limited water availability and variation in nutrient regimes provide additional challenges to vine growth.

Remote sensing using satellite imagery provides a synoptic, timely and broad-spectrum view of actual viticultural conditions, allowing assessment not only of plant vigour but also of key biophysical parameters such as leaf area index (LAI), which are important for yield prediction (Szabó et al., 2016; Lóki-Szabó, 2011).

The results of this study can provide valuable information for the development of agronomic strategies aimed at improving the productivity and sustainability of vineyards in a changing climatic environment.

The aim of this study was to establish a correlation between NDVI and growth stages of *Vitis vinifera* cv Merlot vines grown under different nutrient regimes in non-irrigated conditions in the village of Brestnik.

MATERIALS AND METHODS

The experiment was conducted in the training experimental field of the Agricultural University in the town of Kuklen, which is situated in the Plovdiv district in Central-South Bulgaria (Figure 1).

Figure 1. Location of study area
(Google Earth 23.05.2021)
L42° 3'22.80"N B 24°47'1.19"E

Experimental design and treatments

Satellite imagery

NDVI was obtained from Copernicus Browser. https://browser.dataspace.copernicus.eu/

The data were available for the Area of Interest (AOI) from Sentinel 2 L2A with HR multispectral satellite imagery. The images were obtained for the main growth stages during the investigated period 2023-2024.

Vegetation health assessment is a crucial part of environmental monitoring, precision agriculture, and land cover classification. One of the most widely used vegetation indices in remote sensing and GIS applications is the Normalized Difference Vegetation Index (NDVI). NDVI is a remote sensing-derived index that measures vegetation health and biomass by analyzing the difference between near-infrared (NIR) and red (RED) reflectance values from satellite or drone imagery. Since healthy vegetation strongly reflects NIR light and absorbs RED light, NDVI helps in distinguishing between healthy and stressed vegetation (https://geoinfotech.ng/).

The formula of the NDVI is

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where:
NIR is near-infrared light;
RED is red light.
For Sentinel-2, the index looks like this:

$$NDVI = \frac{B8 - B4}{B8 + B4},$$

where:
B8 = 842 nm;
B4 = 665 nm.

Using the NDVI data in the study regions, the changes in vegetation cover present in the area and the trend in occurrence of agricultural drought can be studied (Sruthi et al., 2015).

The vegetation index was calculated from Sentinel-2 bands images and sample raster values were processed by GRASS in QGIS 3.34. The growth stages are calculated in the Days Of the Year (DOY). The correlations between the studied variables were obtained by regression analysis in Excel Microsoft 365 and were valid within the time range studied.

In situ measurements

The experiment focused on a Merlot variety grafted onto the rootstock Berlandieri x Riparia SO4. The vines were planted in 2011 in the training experimental base of the Department of

Viticulture and Fruit Growing at the Agricultural University, Plovdiv.
The variety is cultivated under non-irrigated conditions.
The planting distance is 3.0 m between the rows and 1.0 m between the vines in each row.
In the experimental plan, the following 7 variants are defined for the foliar treated, the feeding phases are: First inflorescence appearance, start flowering, after mass flowering, “Pea” size and Veraison.
V0 - control (no treatment);
V1 - treatment at a dose of 200 ml/ha;
V2 - Treatment at 300 ml/ha;
V3 - 400 ml/ha treatment;
V4 - 500 ml/ha treatment
In both variants with incorporation into the soil of "Humate Rost" as (solid residue) is applied in two doses at the beginning of the growing season.
V5 - root treatment at the beginning of vegetation with a dose of 15 kg/ha;
V6 - Root treatment at the beginning of the vegetation period at a rate of 25 kg/ha.
10 plants are included in each variant.
The climate data for temperature and precipitation has been recorded by the climate station in the plantation during the period April-September.

RESULTS AND DISCUSSIONS

The Merlot grape variety is characterized by its medium-ripening tendency, which typically manifests around mid-September. When cultivated with optimal agrotechnical practices and sufficient loading, the vegetative strength of the vines is notably pronounced.
The experiment was conducted in seven variants, with different levels of foliar and root nutrition with liquid fertiliser "Humat Rost". "Humat Rost” is a fully organic nutrient derived from peat. The liquid concentrate is characterised by a deep, dark brown colour and a relatively high viscosity.
This product is a recent innovation developed in Bulgaria (Agroprom LTD) and is part of the organic family.
The primary source of energy in the soil is plant residues and animal excreta. The water-soluble organic compounds of the soils from which "Humate Rost" is mineralized (degraded) by soil microorganisms.
This organic product eventually releases energy that is used by the vines to stimulate the growth of the vegetative and reproductive organs of the grape variety. (https://humatrost.com/)

Climate data

The start and duration of phenological stages are genotype specific and depend not only on hereditary characteristics but also on agro-ecological conditions. Day length and temperature have a direct impact on the growth stages in general and on the vegetative growth and flowering, which is why the vine crop responds differently to climatic conditions.
To conduct a thorough and scientifically sound study, it is necessary to monitor both quantitative and abiotic factors to analyse the changes in the microclimate of the vineyard under study.
From a practical standpoint, it is imperative to emphasise that in 2024, the precipitation levels during the spring season were markedly below average. This resulted in impediments to sap movement and the development of winter buds. Concurrently, the combination of elevated temperatures with the opening of the roof scales of the buds led to a cessation in further growth. This observation underscores the pivotal role of temperature as a restrictive factor, while underscoring the indispensability of water for sustaining growth. The application of “Humat Rost” at doses of 300 and 400 g at 0.1 h in 2023 had a positive influence on the interphase transition in 2024 due to enhanced plasticity of the canes. To optimise the outcomes, it is recommended that this practice be accompanied by the implementation of early spring irrigation or the deepening of inter-rows in vineyards during the autumn season to a depth of 20 cm. This approach will facilitate enhanced aeration and facilitate effective water movement around the root zone.
Temperatures are systematically organized by the decade and signify the increase in temperature. The year 2024 is evidently distinguished by elevated temperatures during the initial ten days of April, which corresponds to the onset of the growing season (Figure 2).

Table 1. Phenological development of the Merlo cultivar

Year	Budding	First inflorescence appearance	Flowering	Veraison	Maturity	Fall leaf	Vegetation period
2023	8.04	21.04	12.06	10.08	14.09	27.11	233
2024	3.04	7.04	29.05	29.07	19.08	17.10	197

The growth and development of vine plants is influenced by a number of factors, including temperature, but also the availability of soil moisture, which is formed by precipitation during the autumn-winter and winter-spring periods of the year.

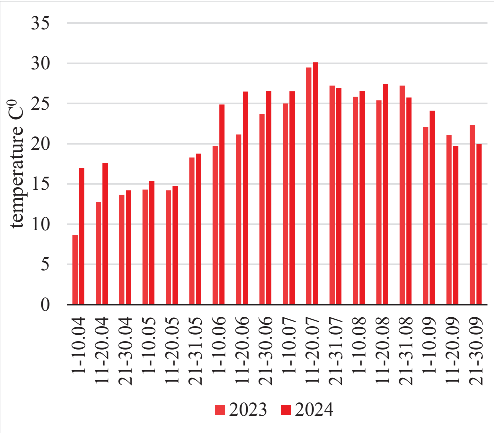

Figure 2. Average temperatures by ten-day periods from April to September

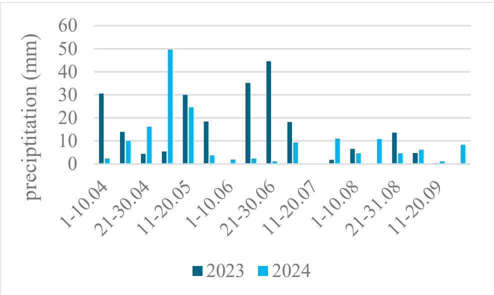

Figure 3. Precipitation totals in mm by ten-day periods from April to September

The spring of 2023 was marked by anomalous seasonal mean temperatures and substantial deviations in precipitation levels.

In particular, April, May and June experienced approximately one-third of the annual mean precipitation typically observed in the Southern wine region.

In 2023, growth processes in the root zone started significantly earlier due to higher temperatures in spring, resulting in a shorter period for mature grapevine pruning.

In the second year of our study, this trend is maintained, with a change in temperature anomalies throughout the 2024 period.

The total precipitation recorded during the entire year of 2023 was 350.4 mm.

The highest recorded precipitation was in June, with 79.8 mm.

The variability in precipitation amounts was significant, with considerable variation observed across the region during the study period (Figure 3).

The combination of elevated summer temperatures and deficient precipitation resulted in the premature termination of growth processes, despite the presence of greater vegetative mass in certain variants.

The utilization of satellite imagery in the initial stages of grapevine development, along with the significance of the vegetation index (NDVI) from the onset of active vegetation (first inflorescence appearance), can provide grape farmers with valuable information to facilitate the implementation of measures that stimulate growth processes and facilitate the transition to subsequent growth stages. The selected cultivar and vineyard are in a transitional-continental zone, where there are periods of irregular precipitation and significant temperature variation. The experimental years had a growing season length of 233 (2023) and 197 (2024) days (see Table 1).

Relationship between NDVI and experimental variants

In the present study, the efficacy of "Humat Rost" growth fertilizer in enhancing foliar and root nutrition was assessed. To this end, regression equations were derived from NDVI values for each of the treatments during the main growth stages and 10 days following the fertilizer application. The temporal progression of the experiment is delineated by DOY, which denotes days of the year. The results for the 2023 growing season are illustrated in Figures 4(a), 4(b), 4(c), 4(d), while those for the 2024 season are presented in Figures 5(a), 5(b), 5(c), 5(d).

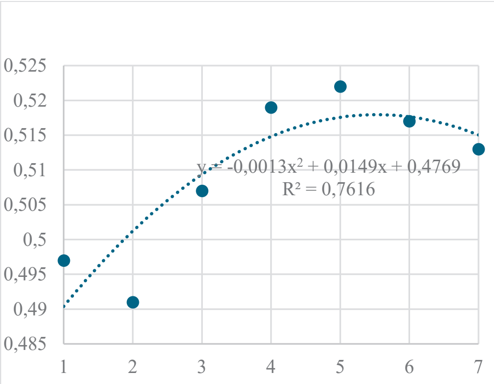

Figure 4(a). Relationship between NDVI and First inflorescence appearance (DOY 110)

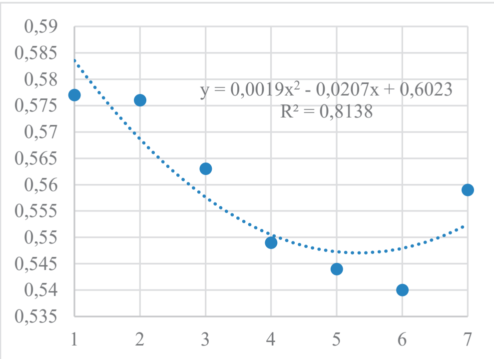

Figure 4 (b). Relationship between NDVI and Flowering (DOY 163)

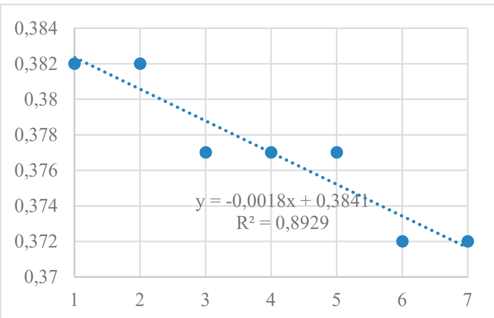

Figure 4(c). Relationship between NDVI and Veraison (DOY 223)

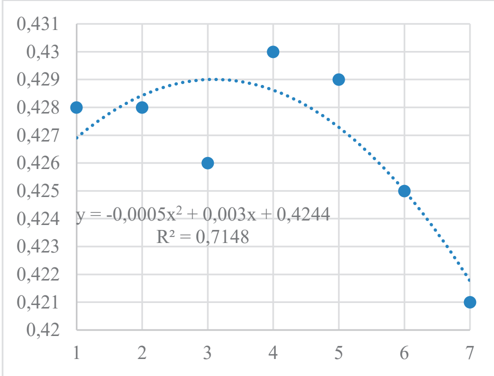

Figure 4(d). Relationship between NDVI and Maturity (DOY 257)

As demonstrated in Figures 4(a), 4(b), 4(c), 4(d) the regression equations derived from the initial research year demonstrate a high multiple correlation coefficient R^2, ranging from 0.71 during Maturity to 0.81 in the Flowering growth phase. These equations are expressed as second-degree curves. With values undergoing a smooth transition during the Version growth stage and are represented by a linear equation.

It is observed that the flowering phase yields high values of NDVI (0.53-0.59), which, at this early stage of plant development, is a very good indicator of plant vigour.

However, as the plants progress through the various stages of development, they are subjected to conditions of drought and elevated temperatures, which results in a decline in NDVI values to 0.37-0.38.

Variants V2 and V3, supplied with the highest concentration of "Humat Rost", exhibited optimal development. Anomalies were observed in the Flowering growth stage, where these two variants demonstrated the lowest values, likely attributable to inadequate nutrient uptake due to elevated temperatures and scarcity of precipitation.

The data for the second year of the study are presented in Figures 5(a), 5(b), 5(c), 5(d), and the resulting regression equations have a high, and very high, multiple correlation coefficient R^2= 0.66-0.97.

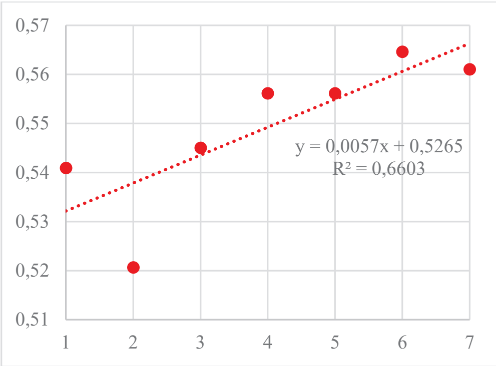

Figure 5(a). Relationship between NDVI and First inflorescence appearance (DOY 100)

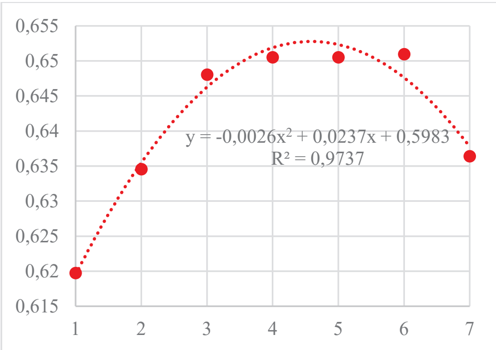

Figure 5(b). Relationship between NDVI and Flowering (DOY 150)

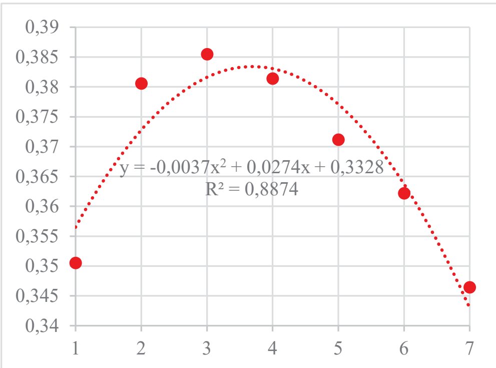

Figure 5(c). Relationship between NDVI and Veraison (DOY 210)

When compared to the results from the previous year (2023), the equations demonstrate a very good representation of the results. The year was distinguished by elevated temperatures and deficient precipitation, particularly during the Veraison and Maturity phenological phases, with NDVI values ranging from 0.3 to 0.39. The optimal development and NDVI values were once again observed for variants V2 and V3, with no aberrations in plant development.
Technical maturity was attained 36 days earlier than the previous year.

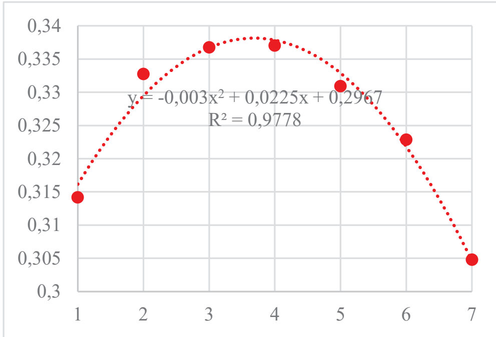

Figure 5(d). Relationship between NDVI and Maturity (DOY 230)

CONCLUSIONS

The present study investigates the efficacy of "Humat Rost" as an organic fertiliser to influence growth, with a focus on its impact. The analysis of the results indicates that the vine crop adapts expeditiously to environmental changes, and depending on the thermal dynamics of spring and the irregular distribution of precipitation in winter and spring, it can concomitantly progress with some of the growth stages.The findings of the research indicate a shortening of the growing season by 233 (2023) and 197 (2024) days, respectively. This finding indicates that, with a discrepancy of approximately 36 days, the vine can effectively compensate for phenological development. on foliar and root nutrition. The experimental setup provides a compelling rationale for recommending the utilisation of the tested organic product as a foliar fertiliser, with doses of 300 and 400 g per 0.1 ha. The regression equations between NDVI and the variants with different nutrient regimes obtained in this study exhibit a remarkably high coefficient of multiple correlation between the individual variations in the studied phenophases, thereby substantiating the in-situ measurements.
The utilisation of satellite imagery and vegetation indices could have facilitated reliable monitoring of vine crops.

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