Scientific Papers. Series B, Horticulture. Vol. LXVIII, No. 1, 2024
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

RELATIONSHIP BETWEEN NDVI AND IN SITU DATA IN PEPPER PLANTATIONS ON OPEN FIELD CONDITIONS

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Abstract

Of the spectral vegetation indices, NDVI is one of the most suitable for tracking the dynamics of vegetable crop development. Its values are most accurate in the active phases of pepper growth. Due to the individual nature for the determination of vegetation indices, it is necessary to look for correlation with the analytical measurements of plants. The aim of this paper is to determine the relationship between NDVI and in situ data in pepper plantations, field production in the phases of active plant growth. In situ data collection was carried out in a production pepper plantation, cv. Slonsko uho, grown under field conditions in the village of Katunitsa, Plovdiv region, Bulgaria. Measurements were carried out in two phases - mass flowering (BBCH 59610) and technological maturity (BBCH 73703). Vegetative plants parameters were determined. NDVI was obtained from Sentinel-2 HR multispectral satellite imagery. The relationships between NDVI and in situ data were determined.

Key words*: pepper, productivity, vegetation indices.*

INTRODUCTION

Traditional monitoring of plant development is carried out through field observations and laboratory analyses. These investigate the main characteristics of growth in relation to phenological development, intensity of crop grow and fresh biomass accumulation. These methods are periodical, very intensive and time consuming. Compared to traditional methods, remote sensing is rapid and provides a wide view of the status of the overall production crop (Li et al., 2019). According to Tunca & Köksal (2022), in the last two decades remote sensing has become an important monitoring tool and a main non-instrumental method for diagnostics and forecasting of crop development and productivity.

Many researchers have worked to clarify the practical application issues of vegetation indices, such as Crippen (1990); Friedl et al. (1994); Penuelas et al. (1997); Blackburn (1998); Gobron et al. (2000); Gitelson et al. (2003); Ceccato et al. (2002); Ferencz et al. (2004); Maire et al. (2008); Ahamed et al. (2011); Dang et al. (2011), Omia et al. (2022);

Ji-Hua & Bing-Fang (2008) pointed that the basis of direct observations is the determination of vegetation indices such as NDVI and LAI. The same authors found that the higher the values of these indices, the better the overall condition of the crop. They concluded that satellite data with high frequency and low spatial resolution provide information for quantitative monitoring with vegetation indices playing a key role. To achieve more accurate information, they recommend combining the obtained data with those from GPS and GIS (Arnaudova et al., 2020). NDVI was designed to estimate vegetative mass from reflectance spectral bands from satellite data. According to Sahebjalal & Dashtekian (2013), the generated images and vegetation indices can be used to determine the vegetation changes occurring between two different stages of development. Ozyavuz et al. (2015) determined changes in plants growth and development by tracking changes in NDVI.

Vegetable crops have increasingly been the subject of scientific research in recent years (Na et al., 2017a; 2017b). Pepper takes the fifth place in terms of production compared to all vegetable crops and is a traditional crop for Bulgaria (Shaban, 2014). According to FAO (2010), average yields, worldwide, are relatively low compared to the biological potential of the species. Therefore, there is a clear need to use innovative approaches to monitoring vegetable plants in order to design and conduct agronomic practices. Na et al.

(2018) estimated the growth of red pepper by determining the vegetation index NDVI at different stages of plant development. Tunca & Köksal (2022) estimated the yield of pepper by time series of several vegetation indices, incl. NDVI. Karaca et al. (2023) compared traditional chlorophyll and fluorescence measurement methods and NDVI in predicting productivity and yield in pepper and melon. The available scientific information is limited for the development of practical methods for remote sensing of vegetable crops using vegetation indices.

The main aim of this paper is to determine the relationship between NDVI and *in situ* data in pepper plantations, field production in the stages of plant growth.

MATERIALS AND METHODS

Study area

The open field located in the South-central region of Bulgaria in the village of Katunitsa, municipality Sadovo, Plovdiv district (Figure 1 a, b).

a) L 42° 6'49.69"N B 24°52'38.77"E (2022)

b) 42° 8'16.77"N 24°52'17.84"E (2023)

Figure 1. Location of study area and target fields

Experimental design and treatments

Satellite imagery

NDVI was obtained from Copernicus Land Monitoring Service as a daily update of Normalised Difference Vegetation Index provided at pan-European level and in near real time. The data were available at 10 m x 10 m spatial resolution from Sentinel-2 HR multispectral satellite imagery (according to Data viewer - Copernicus Land Monitoring Service).

The images and sample raster values from NDVI were processed by QGIS 3.10.

Time series imageries were downloaded for the same period of experimental in situ data collection and are calculated in days after transplanting the pepper in open field.

Dependencies between the studied indicators were obtained by regression analysis in Excel Microsoft 365 and are valid within the limits of the studied time interval.

In situ data collection was carried out in the period 2022-2023 on a production pepper plantation. The randomized block design was used. Five target fields were determined. These elementary sites are 50 m^2 having 400 plants each (Figure 2).

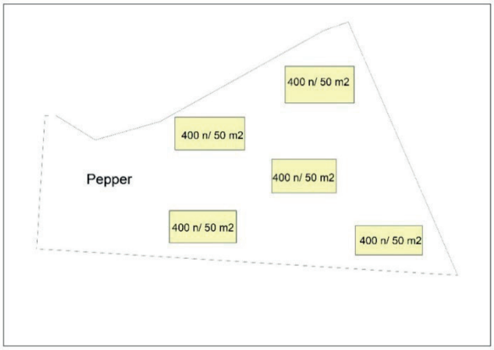


Figure 2. Scheme of target fields

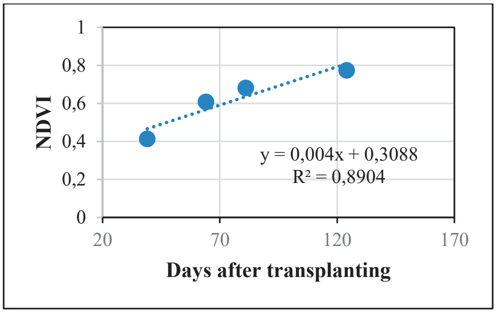
In situ measurements were carried out in four main stages of pepper development - flower buds, flowering, before maturity, maturity. The parameters of growth height of stem (cm) and total fresh biomass (kg/dka) were determined. Height of stem was determined by analyzing 5 plants from each target site. Total fresh biomass was determined as the sum of the weight of leaves and stems for the stages flower buds and flowering and as the sum of the weight of stems, leaves and fruits for the stages before maturity and maturity (Arnaudova et al., 2022).

Pepper agronomy

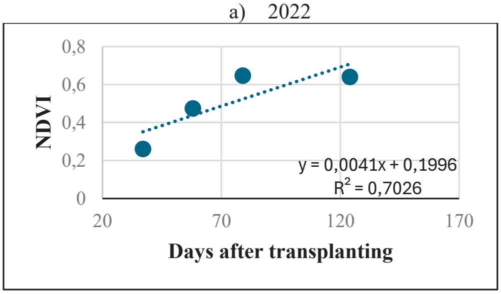
The pepper was grown according to the conventional technology for middle-early field production in open fields (Cholakov, 2009). The scheme used is 90+70/15 with a population of 8333 plants/da and drip irrigation.

RESULTS AND DISCUSSIONS

Among the typical spectral vegetation indices, NDVI is one of the most suitable for tracking crop development dynamics as it measures the photosynthetically active biomass of plants. It can be used throughout the crop production season, except when plant cover is too sparse and therefore its spectral reflectance is too low. NDVI values are most accurate in mid-season, at the stage of active crop growth (https://eos.com/make-an-analysis/). The variation of NDVI was analysed during the growing season of pepper in 2022 and 2023. The relationship between the NDVI values and the condition of the plants in the different stages of their development was established (Figure 3 a, b).



a) 2022



b) 2023

Figure 3. Correlation between NDVI value and pepper development

The determined NDVI values from the satellite images change from 0.41-0.77 for 2022 and 0.26-0.64 for 2023 After the regression analysis, a high degree of multiple correlation $R^2 = 0.89$ for 2022 and $R^2 = 0.70$ for 2023 was found.

The results obtained from the *in situ* plant height data were similar for both experimental years. Intense growth of the stem is established in the initial stages of plant development (Figure 4). After the onset of intensive fruiting, vegetative growth slows down.

The dependence of the height of the stems in the different growth stages and the NDVI values for the two years is described by linear equations of the type $y = ax + b$ for both experimental years.

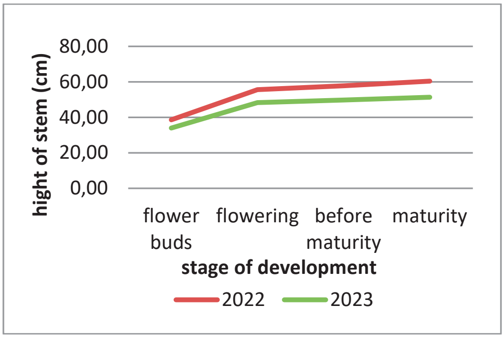
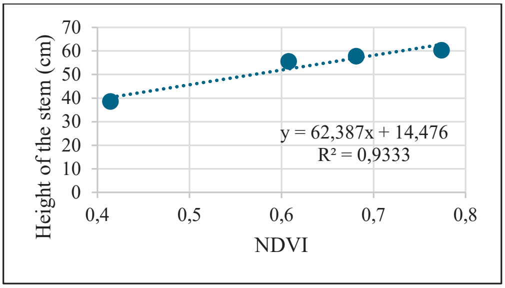


Figure 4. Stem growth dynamics during the different stages of pepper development

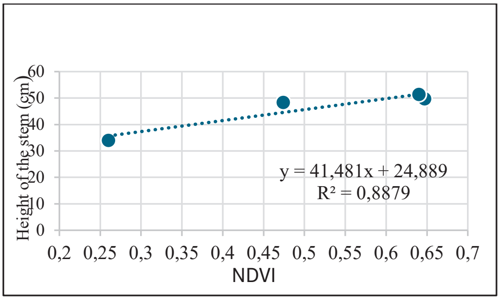
High multiple correlation coefficients $R^2 = 0.93$ for 2022 $R^2 = 0.89$ for 2023 was established (Figure 5 a, b).

The high coefficients of determination suggest that in approximately 90% of the cases, with the established values of NDVI, the height of the plants will be in the indicated trends.

The accumulation of the total fresh biomass follows the trend described in the growth of the stem (Figure 6). More pronounced differences are noted at the beginning of fruit formation. Due to the polycarpic nature of the fruiting of this vegetable species, it maintains constant values in the stages before maturity and maturity. The results obtained by us directly correspond to the specified features of growth and development by a number of researchers (Saban et al., 2014; Panayotov & Jadchak, 2020).



a) 2022



b) 2023

Figure 5. Scatter plot between NDVI value and height of the plant stem (cm)

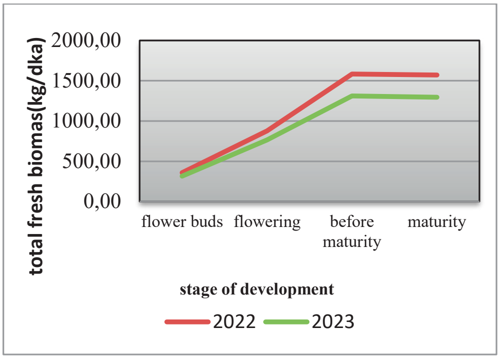
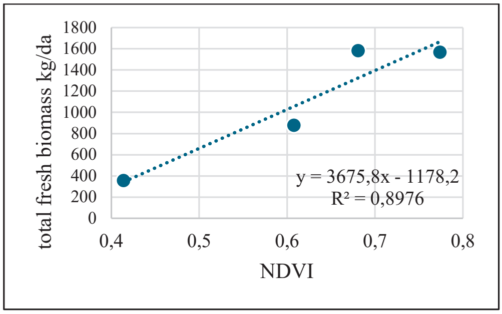


Figure 6. Dynamics of total fresh biomass accumulation during the different stages of pepper development

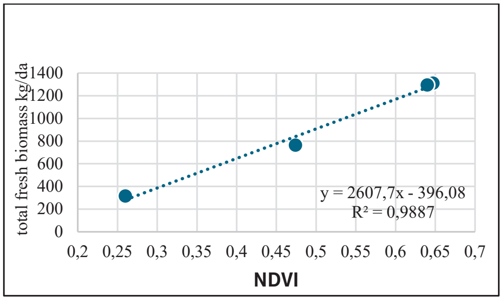
For 2022 and 2023, regression relationships between total fresh biomass, as a complex indicator of productivity, and NDVI were derived (Figure 7 a, b).

The processes are described by a linear regression equation of the *type* $y = 3675.8\,x - 1178.2$ and $R^2 = 0.90$ (2022). For 2023, the equation describing the relationship between in situ data and NDVI is $y = 2607.7x + 396.8$ and a high degree of multiple correlation $R^2 = 0.99$.

The high coefficients of determination suggest that in approximately 90% of the cases, with the established values of NDVI the accumulated total biomass will be in the indicated trends.



a) 2022



b) 2023

Figure 7. Relationship between total fresh biomass and NDVI

Shisodia et al. (2020) evaluate the available vegetation indices and find the relevance to plant diagnostics and their use in precision agriculture. They point out that due to the individual nature of their determination (crop-specific vegetation index values) it is necessary to look for a link with analytical measurements that can be performed in situ to validate the data and to prove the relationship between them. The research we have conducted is in the context of their arguments.

CONCLUSIONS

The mathematical description of the established NDVI shows a very good relationship with high degrees of multiple correlations during all development stages of the studied process in pepper.

The established dependencies are in line with increasing stem height and the accumulation of total fresh mass.

The obtained relationship between the *in situ* data and the value of NDVI by time series imagery from Copernicus Land Monitoring Service is the prerequisite for using NDVI as a source of data for pepper growth behaviour.

The guidelines for future research work are: development and testing of regression models based on the developed algorithms for quantification of certain parameters of the studied vegetable crops; development of a comprehensive methodology for monitoring vegetable crops through remote sensing methods.

ACKNOWLEDGEMENTS

This work is supported by the Bulgarian Ministry of Education and Science under the National Research Program “Smart Crop Production”, Grant Д01-65/19.03.2021, approved by Decision of the Ministry Council No 866/ 26.11.2020

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