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ANALYZING THE INFLUENCE OF TEMPERATURE ON NDVI FOR A POTATO CROP IN BRAŞOV AREA

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Abstract

It is known that meteorological parameters, among others, are highly determinant for the growth of the agricultural crops. On the other hand, vegetation indices computed on remote sensing data are widely-used for crop monitoring. In this paper we focus on temperature, one of the determinant meteorological parameters, and the Normalized Difference Vegetation Index (NDVI), the most used vegetation index. We use temperature and NDVI time series, the latter one computed based on Copernicus data. Based on the hypothesis that effect accumulations of temperature in time determine the plant age and growth and, implicitly, its vegetation status, we study the influence of temperature on NDVI and attempt to model it. We present a use case for the monitoring of two potato crops during the 2023 and 2024 seasons in Braşov area, Romania and formulate the conclusions.

Key words: *temperature, NDVI, time series, Copernicus data, potato crop.*

INTRODUCTION

It is currently estimated that the world population will increase from 7.5 to 9.7 billion by 2050 (Gu et al., 2021), resulting in a high demand of agricultural products and a high pressure on natural resources. Despite the fact that agriculture is still the major activity in many countries, we face a global decrease in both production and employment in agriculture. The solutions to boost productivity are agricultural investments and technological innovations (Godfray et al., 2010).

In the context of Agriculture 5.0 (Ivanovici et al., 2024), Earth Observation (EO) data is widely used for the monitoring of agricultural crops. Nowadays remote sensing technologies provide support for precise agricultural operations at the scale of farmers' fields, as well as to the management and strategic planning of agricultural production both at regional and national levels (Guo et al., 2017). EU Copernicus programme provides free EO data which can be used for various applications in smart agriculture (EU, 2014).

We focused our research in an area situated in Brasov County, in the central part of Romania. The area is part of the region used to be called *Potato Country* in Romania, being renowned for its large areas cultivated with potatoes. However, in the last decade, due to climate change, the area cultivated with potatoes has dropped to approx. 25%. The potato (*Solanum tuberosum* L.) thrives in moderate temperatures, typically between 14°C and 22°C, and is sensitive to environmental changes during storage (Teper-Bamnolker, 2010). The suitable relative soil moisture content for potato growth and development is 55% to 85%, and the suitable temperature is 15°C to 25°C. The growth and development of potato plants under drought and high-temperature stress conditions are inhibited, and plant morphology is altered, which affects the process of potato stolon formation, tuberization and expansion, ultimately leading to a significant reduction in potato tuber yields and a remarkable degradation of the market grade of tubers, the specific gravity of tubers, and the processing quality of tubers (Fang et al., 2024). According to (Sánchez-Correa, 2024), optimal potato development occurs at temperatures between 15°C and 20°C, with yields ranging from 12 to 60 tons of tubers per hectare. However, observations show a decline in yield when the ambient temperature exceeds 24°C. This is due to a combination of independent morphological, physiological and developmental issues. According to (Timlin, 2006), the optimum temperature for canopy photosynthesis is 24°C (but this decreases with the plant age) and the total biomass was highest at 20°C. However, the ideal temperature for potato crop may vary with plant growth stages (Singh, 2019).

In this paper we use temperature and NDVI time series for the analysis of their relationship for two potato crops in Brasov area, Romania, in 2023 and 2024. We build our model based on the hypothesis that the accumulations in time of temperature effects determines the plant age and growth and has impact on vegetation status, as observed through vegetation indices such as NDVI. The temperature impacts the entire potato plant (Lazarević et al., 2022). Based on the proposed model, we study the influence of temperature to the vegetation status indicated by NDVI computed on Copernicus data. We present the materials and methods, then we show experimental results, as well as a discussion, and conclude the paper.

MATERIALS AND METHODS

For the current study, we used Sentinel-2 data, more specifically, the satellite images were freely downloaded from the Copernicus browser (https://browser.dataspace.copernicus.eu/). In particular, we were interested in monitoring the evolution of potato crops belonging to the National Institute of Research and Development for Potato and Sugar Beet (NIRDPSB), Braşov, Romania (see Figure 1).

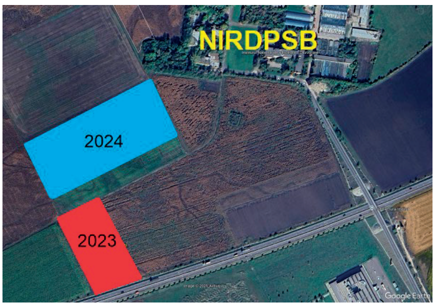
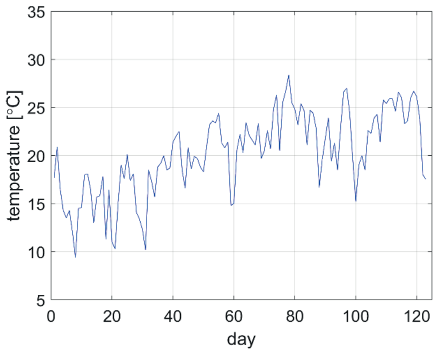


Figure 1. NIRDPSB and the two potato crops of interest, Braşov area, Romania (source: Google Earth)

With more than 60 years of experience, NIRDPSB plays an important role in the preservation of the potato heritage at the national level (Chiru et al, 2017). Through its activities, NIRDPSB promotes both fundamental and applicative research in the domain of potato and sugar beet cultivation. In Figure 1 we show a satellite view with the under-study potato crops for 2023 and 2024 highlighted with red and blue, respectively, with respect to the location of NIRDPSB, for easy identification. For the two potato crops of interest, the time period of interest was from 1st May to 31st of August (122 days), both for 2023 and 2024.

In Figure 2 one can see the evolution of average daily temperature for 2023 and 2024, with a minimum of approximately 10ºC (both in 2023 and 2024) and a maximum of 28ºC in 2023 and 30ºC in 2024. The temperature readings were provided by the NMA Braşov-Ghimbav Station, located at approx. 3 km from the potato crops.



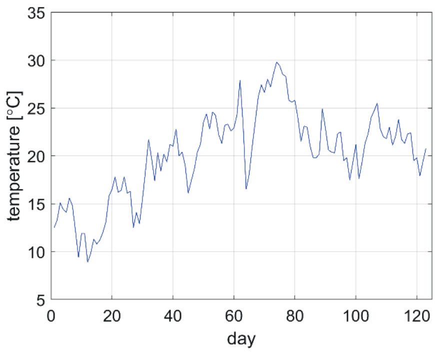


Figure 2. The average daily temperature for 2023 (top) and 2024 (bottom) for the potato crops of interest

From the Copernicus data we downloaded the NDVI product for the two corresponding potato crops, for 2023 and 2024, respectively. The two original NDVI time series are depicted with black in Figure 3. One can notice that for some dates the NDVI values are erroneous, i.e. they exhibit very low values. These erroneous values were filtered out by using a morphological filter in order to produce a smoother variation of the NDVI – depicted with green. The filtering was applied both for the 2023 and 2024 time series.

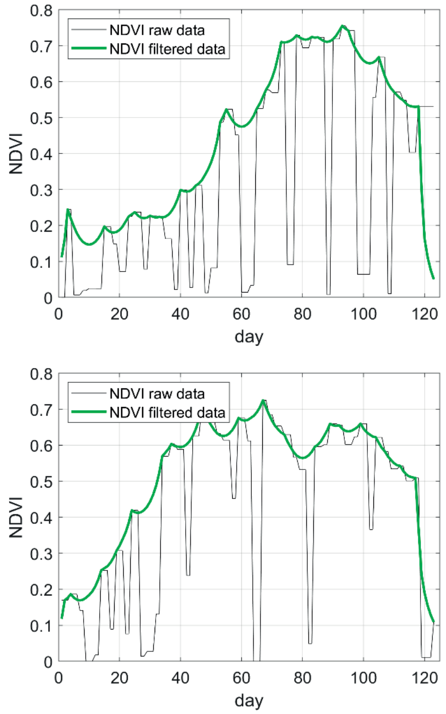


Figure 3. The NDVI time series for 2023 (top) and 2024 (bottom) for the potato crops of interest

In order to build our model, we considered the following observations. Potato develops best at approximately 20°C (Rykaczewska, 2015). An increase with 5°C above this optimum temperature causes a reduction in the photosynthetic rate with 25%, which ultimately affects biomass accumulation and, later, the sink activity (Obiero et al., 2019). Transitory or constant high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield (Wahid et al. 2007; Lal et al., 2022). These inhibitory effects occurred at all developmental stages (Van Harsselaar et al., 2021), including growth inhibition at the seedling stage (Daim and Zhangzz, 2018), decreased number of stolons and hindered tuber expansion, which resulted in lower yields, abnormal tuber morphology and fewer salable tubers (Liu et al., 2025).

Based on these observations, we propose the following approach to perform the analysis of temperature influence on NDVI (see the block diagrams in Figure 4). The first block maps the daily temperature to the degree of influence of temperature to the overall vegetation status and, implicitly, NDVI, assuming a purely Gaussian model (in blue), similar to the ones seen in the literature. Alternatively, we propose the usage a piecewise linear model (in red), better matching the observations made above. The second block cumulates the degrees of influence over a specified period of time, significant for the process of plant growth. The resulting cumulated degree of influence is then correlated with the NDVI time series, resulting in the Pearson correlation coefficient ρ.

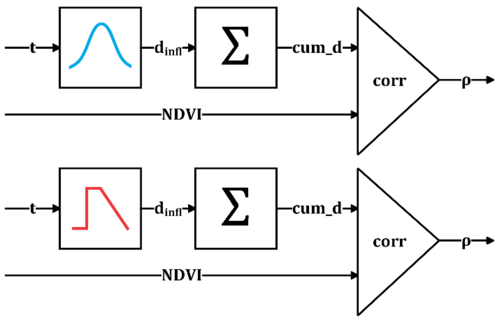


Figure 4. The block diagram of the proposed approach – based on the Gaussian (top) and piecewise linear (bottom) model for the temperature degree of influence

There exist several attempts to model the influence of the temperature for the development of the roots of plants. We make the assumption that such a model can be designed for the degree of influence of temperature to the overall vegetation status of the plants. Consequently, we assume a direct relationship between the degree of influence of temperature and the measured NDVI (as it is measured by means of remote sensing). For the degree of influence of temperature to NDVI, we considered a generic, symmetric Gaussian model, as the one depicted in Figure 5. This choice was inspired by the existing models for other crops (Walne, 2022). We assume a symmetrical mapping of the range of temperatures from 0ºC to 40ºC to the [0,1] interval. The maximum degree of influence corresponds to a temperature of 20ºC. This particular choice was merely to have a starting base for experiments, the shape can be later on determined by experiments or by inverting the model. In red, we propose a piecewise linear model that better suits the observations made in the literature.

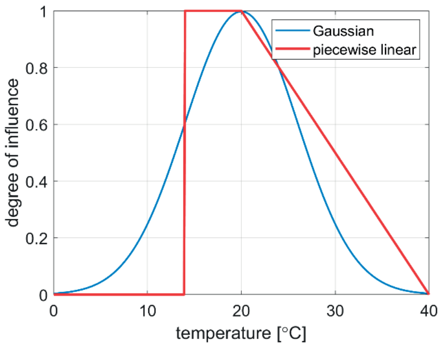


Figure 5. The chosen Gaussian model for mapping the temperature to the degree of influence

After mapping the daily temperature to the degree of influence, we further cumulate the degrees of influence over a time period significant to the plant development process. Basically, we compute a moving sum over *N* samples, as described in eq. (1):

$$cum\_d_{infl}(i) = \sum_{k=0}^{N-1} d_{infl}(i-k) \qquad (1)$$

The summation corresponds to the accumulation effects (e.g. of biomass) in the plant, as a direct consequence of the temperature to the plant's growth processes.

RESULTS AND DISCUSSIONS

In Figure 6 we present the daily degree of influence of temperature d_{infl} computed for 2023, with thin blue line, which shows values from 0.2 to 1 (for the Gaussian model) and from 0 to 1 (for the piecewise linear model). The thick blue line corresponds to the averaged degree of influence over a period of 13 days, which roughly corresponds to two weeks. The noticeable difference is for the beginning of the season, when lower temperatures are impacting in different ways the plant's growth. In Figure 7 we show the same comparison for the year 2024.

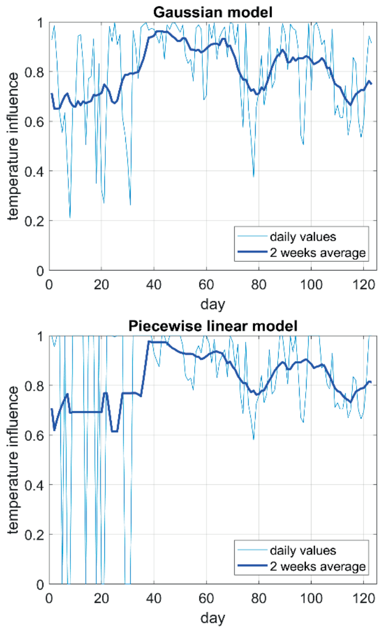


Figure 6. The degree of influence of temperature d_{infl} and for 2023. Gaussian (top) vs. linear (bottom)

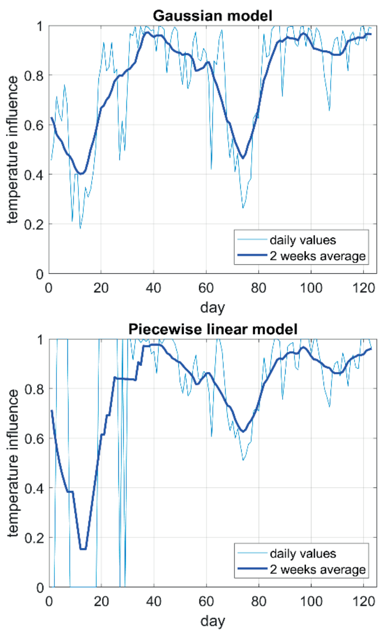


Figure 7. The degree of influence of temperature d_{infl} and for 2024. Gaussian (top) vs. linear (bottom)

In Figure 8 we show, for a qualitative comparison, the normalized filtered NDVI time series (in blue) and the normalized cumulated degree of influence of temperature cum_d_{infl} (in green), when the Gaussian model is applied, the latter one being computed over three summation intervals corresponding to 1, 2 and 3 weeks. One can notice a good resemblance between the NDVI time series and the cumulated degree of influence. However, differences may be due to the fact that influence of other parameters (such as solar radiation, precipitations, or soil-related parameters, as well as the occurrence of diseases that may affect the plants) was disregarded in this study.

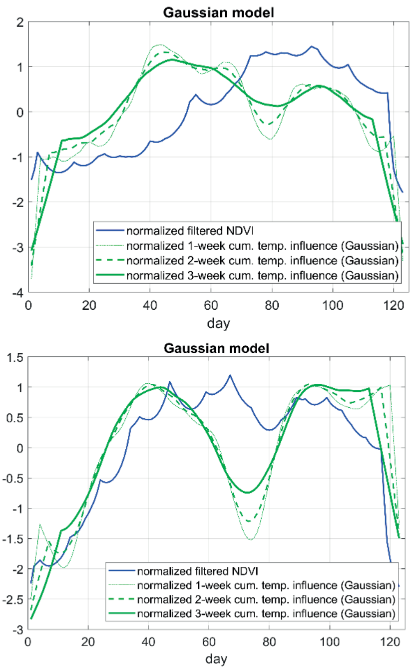


Figure 8. The normalized filtered NDVI time series (in blue) and the normalized cumulated degree of influence of temperature cum_d_{infl} (in green), Gaussian case, for 3 summation intervals, for 2023 (top) and 2024 (bottom)

One may notice that the choice of the size of the summation interval has some considerable impact on the shape of the curve. The analysis results for both 2023 and 2024 are shown. The resemblance of the curves is higher for 2024.

The same comparison is presented in Figure 9 for the case when the linear model is used, for both 2023 and 2024. Again, the choice of the size of the summation interval has a relatively small impact on the shape of the curve and the similarity of the curves is, again, higher for 2024.

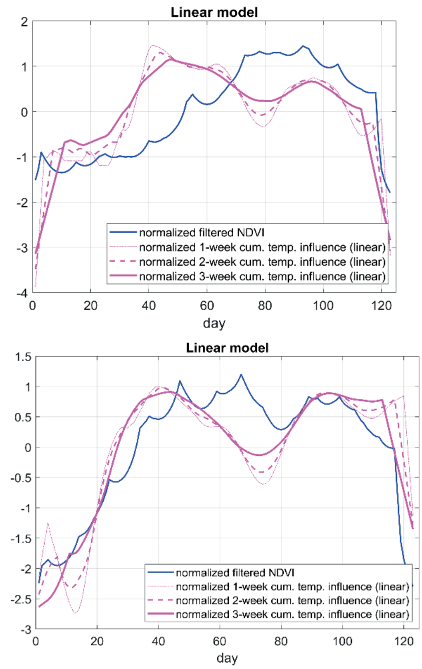


Figure 9. The normalized filtered NDVI time series (in blue) and the normalized cumulated degree of influence of temperature cum_d_{infl} (in green), linear case, for 3 summation intervals, for 2023 (top) and 2024 (bottom)

Furthermore, we performed a comparison between the two models for the degree of influence of temperature (Gaussian versus piecewise linear). From a quantitative perspective, in Table 1 we show the values of the Pearson correlation coefficient ρ as a function of the choice of the length of the summation interval (N = 5, 7, 13 and 21 days) for the analysis performed for the 2023 crop, for the two cases – the Gaussian and the linear model. One can notice that the correlation coefficient increases with the increase of the summation interval, however the length of the interval should be chosen or determined to be pertinent to the plants' growth processes. The values, however, indicate a relatively weak correlation for the Gaussian model and slightly larger for the linear model. In Table 2 we show the same comparison for the analysis performed on the 2024 potato crop. We see higher values of the correlation coefficient for the analysis of the 2024 potato crop, indicating a stronger correlation between NDVI and the temperature influence. Both for 2023 and 2024, the proposed piecewise linear model led to higher correlation. Figure 10 compares normalized NDVI (blue) with normalized cumulative temperature influence over three weeks, showing both the Gaussian (green) and linear (magenta) cases for 2023 and 2024.

Table 1. The Pearson correlation coefficient ρ as a function of the number of samples N (the length of the summation interval) for the crop in 2023

Cumulative sum over N =	5 days	7 days	13 days	21 days
Pearson correlation coeff. (Gaussian model)	0.3669	0.3907	0.4384	0.4573
Pearson correlation coeff. (Piecewise Linear model)	0.4770	0.4994	0.5416	0.5529

Table 2. The Pearson correlation coefficient ρ as a function of the number of samples N (the length of the summation interval) for the crop in 2024

Cumulative sum over N =	5 days	7 days	13 days	21 days
Pearson correlation coeff. (Gaussian model)	0.5613	0.5977	0.6934	0.7701
Pearson correlation coeff. (Piecewise Linear model)	0.7022	0.7357	0.8204	0.8745

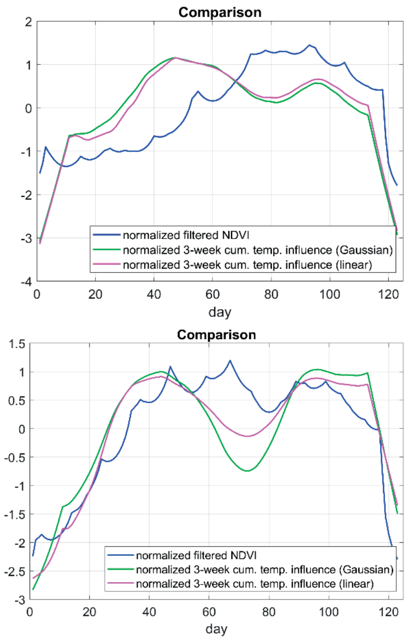


Figure 10. Normalized NDVI (in blue) and cumulated temperature influence over 3 weeks, for the Gaussian case (in green) and the linear case (in magenta), for 2023 (top) and 2024 (bottom)

One may notice that the difference between the Gaussian and the proposed piecewise linear models is better emphasized for the analysis performed on the 2024 data.

CONCLUSIONS

In this study we propose a model for the influence of temperature to the measured NDVI, as temperature is one determinant parameter for the plant growth processes. The proposed model is based on the hypothesis that the temperature has a certain degree of influence to the plant growth and that degree has, eventually, a cumulative effect on NDVI. We model the degree of influence of the temperature both as a Gaussian and a piecewise linear model. The proposed piecewise linear model better matches the observations made in the literature about the influence of temperature on the potato plant growth and vegetation status.

We show experimental results for a potato crop in Brasov area, Romania, in 2023 and 2024. The cumulated degree of influence curve showed good resemblance to the NDVI curve and the computed Pearson correlation coefficient between the two showed that there is significant correlation between the two times series. Differences, however, may be due to the fact that we did not consider in our study the influence of other parameters which have also an important role in the development of plants. The proposed piecewise linear model showed better performance compared with the Gaussian. As future work, we consider including in our study other parameters such as soil moisture, solar radiation, precipitations etc. In addition, given the correlation between NDVI and the proposed cumulative degree of influence, we consider assessing the causality between temperature and NDVI time series.

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