MEDI@ÇÕES
Revista OnLine

EDUCAÇÃO
ESCOLA SUPERIOR
POLITÉCNICO SETÚBAL

Temporal analysis of the maize crop using the Copernicus and Granular link platforms

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Abstract

Precision agriculture is associated with digital transformation and technological innovation. The data provided by remote sensing sensors, combined with data from other sources of information, offers the agricultural entrepreneur a more efficient view than direct observation in the field, enabling more informed and sustainable decision-making. This study used data from two platforms Copernicus and Granular Link to assess the behavior of the NDVI, NDMI and NDRE vegetation indices throughout the maize crop cycle of a plot located in Vale Figueira, Santarém, during the year 2021. Two months after sowing differences were found at saturation level between NDVI and NDRE. The correlation of these indices with the NDMI was greater between the NDMI and the NDRE. The spatial variability found in the right part of the plot agrees with the strong relationship between yield and values. Processing and analyzing images from the Granular Link platform were faster and easier than those obtained from the Copernicus platform. In this way, the Granular Link platform enables almost real-time monitoring. However, it is not possible to carry out analyses that are not part of the contracted service.

Key concepts:

Monitoring, NDMI, NDRE, NDVI, Yield.

Resumo

A agricultura de precisão está associada à transformação digital e à inovação tecnológica. Os dados fornecidos pelos sensores de deteção remota, combinados com dados de outras fontes de informação, oferecem ao empresário agrícola uma visão mais eficiente do que a observação direta no campo, possibilitando uma tomada de decisão mais consciente e sustentável. Neste estudo foram utilizados dados provenientes das plataformas Copernicus e Granular Link com o objetivo de avaliar o comportamento dos índices de vegetação NDVI, NDMI e NDRE, ao longo do ciclo cultural do milho (2021) de uma parcela localizada em Vale Figueira, Santarém. Dois meses após a sementeira foram encontradas diferenças ao nível da saturação, entre o NDVI e NDRE. A correlação destes índices com o NDMI mostrou ser superior para o NDRE. A variabilidade espacial, encontrada na parte direita da parcela, está de acordo com a forte relação da produtividade com os valores obtidos de NDVI e NDRE. O processamento e análise de imagens provenientes da plataforma Granular Link mostrou uma maior rapidez e facilidade na obtenção das imagens relativamente àquelas que foram obtidas pela plataforma Copernicus. Desta forma a plataforma Granular Link permite uma monitorização quase em tempo real. No entanto, não é possível realizar análises que não façam parte do serviço contratado.

Palavras-chave:

Monotorização, NDMI, NDRE, NDVI, Produtividade.

Introduction

Vegetation indices are a fundamental tool in agricultural and environmental monitoring and consequent characterization of the spatial and temporal variability of crops and soil (Immitzer et al., 2016; Mezera et al., 2021). The NDVI (Normalized Difference Vegetation Index) is one of the most widely used indices for assessing plant health and vigor. This index was developed by Rouse et al. (1974) and is based on the difference be-tween the maximum absorption values of radiation in the red spectral region, as a result of chlorophyll pigments, and the maximum reflectance in the near-infrared spectral region, because of leaf cellular structure (Tucker, 1979). The NDRE (Normalized Difference Red Edge Index) is a variation of the NDVI that uses the Red Edge band instead of the near-infrared band, a spectral region located between the red and near-infrared wavelengths (Gitelson & Merzlyak, 1994). The NDRE has been shown to be more sensitive to changes in chlorophyll and more effective for denser vegetation or crops in advanced growth stages, potentially providing a more accurate representation of crop variability (Naguib & Daliman, 2022). The NDMI (Normalized Difference Moisture Index) is a vegetation index that is related to the water content present in the vegetation and is obtained through reflectance in the near-infrared and shortwave infrared spectral regions (Gao, 1996). Some studies (Herbei et al. 2023; Machado et al., 2014; Karamihalaki et al. 2016; Strashok et al., 2022) have shown a significant relationship between NDVI and NDMI in several crops.

Currently, vegetation indices can be obtained directly from commercial platforms or through the processing of satellite images, such as those provided by the Sentinel-2 mission, Copernicus program, of the European Space Agency (ESA). Commercial platforms provide users with ready-to-use vegetation indices, usually derived from satellite images with different resolutions. These platforms are very practical and can integrate agronomic data. Direct processing of Sentinel-2 images offers greater flexibility and control over the data but requires advanced knowledge in remote sensing or image processing.

The aim of this work was to study the NDVI, NDMI and NDRE vegetation indices throughout the maize crop cycle, obtained directly from a commercial platform, Granular link (Corteva agriscience), and calculated from images made available by the ESA, Sentinel-2 (ESA, 2020).

1. Materials and methods

The study was carried out on an agricultural plot called "Pivot Grande", with approximately 43 hectares, belonging to the "Sociedade Agro-Florestal CampoDobrado", located in Vale Figueira (39.309620°, -8.585591°), Santarém. The soils of the plot under study are classified as eutric fluvisols according to World Soil Map of FAO (FAO-UNESCO, 1974) and the FAO World Reference Ba-sis for Soil Resources (FAO, 1998). The climate of this region, according to the Koppen classification, is defined as a temperate climate with rainy winters and dry, hot summers (Csa). Irrigated maize hybrid "P0937" (FAO 500) was sown on 1st April 2021, with 85 790 plants / ha. Yield data was obtained from a combine harvester with a cutting width of 4.5 meters, a yield monitoring system (t/ha) and grain moisture and working speed sensors. The data obtained were filtered to remove errors according to Blackmore (1999), Menegatti & Molin (2003) and Simbahan et al. (2004).

The vegetation indices NDVI (Normalized Difference Vegetation Index) (Rouse et al., 1973; Rouse et al., 1974; Tucker, 1979), NDMI (Normalized Difference Moisture Index) (Gao, 2015) and NDRE (Normalized Difference of Red Edge) (Gitelson & Merzlyak, 1994) were obtained using Copernicus (Sentinel-2) and Granular Link platforms.

Granular Link platform offers three user plans: Basic, Advanced and Premium. The Basic and Advanced plans use Sentinel-2 imagery. The Premium plan uses PlanetScope imagery. The Basic plan is available to all farmers. On the other hand, the Advanced and Premium plans are available to farmers associated with the "Corteva" company. The main differences between these three plans can be seen in Table 1.

Table 1

Description of Granular Link plans

Type of use	Spatial resolution	Temporal resolution	Vegetation indices
Basic	10 m x 10 m	5 days	NDVI
Advanced (Sentinel+)	3 m x 3 m	3 – 5 days	13 indices
Premium (Planet HD)	3 m x 3 m	Every day	13 indices

Note. Adapted from Corteva agriscience (n.d).

The software used to develop this work was ArcGIS™ (ESRI, 2019). We highlight the tools for data editing, geoprocessing, coordinate projection and transformation, and spatial analysis tools.

2. Results

2.1. Copernicus Platform (Sentinel-2)

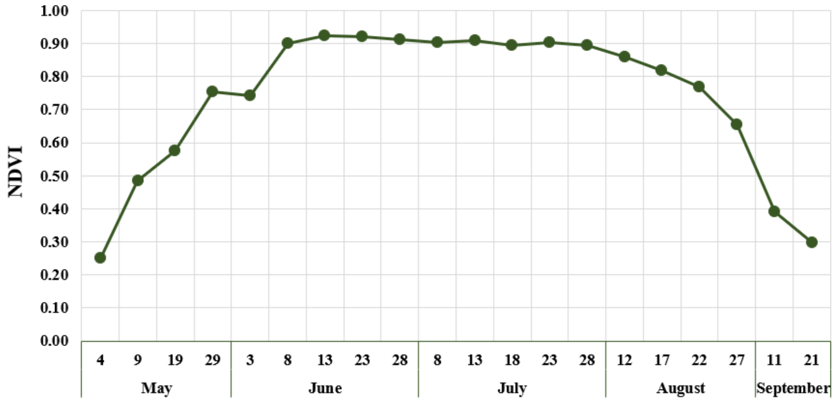
The vegetation indices obtained in this chapter resulted from processing the bands provided by the Sentinel-2A and Sentinel-2B satellites.

2.1.1. NDVI

Figure 1 shows the average NDVI values throughout the maize crop cycle. In the first phase (April 4 to June 13) of vegetative development, from emergence to flag leaf appearance, a gradual increase in NDVI was observed, with average values between 0.25 and 0.92. This increase was due to a gradual rise in soil cover and biomass, up to the stage at which the plant shifted resource allocation toward grain production. A slight decrease in the NDVI value was recorded on June 3, possibly due to the presence of cloudiness in the area. The second phase (June 13 to August 27) corresponds to the reproductive phase, from silking to harvest, with NDVI stabilizing at values close to the maximum. From August 27 onwards there is a tendency for a decrease due to the beginning of flowering and consequent grain formation.

Figure 1

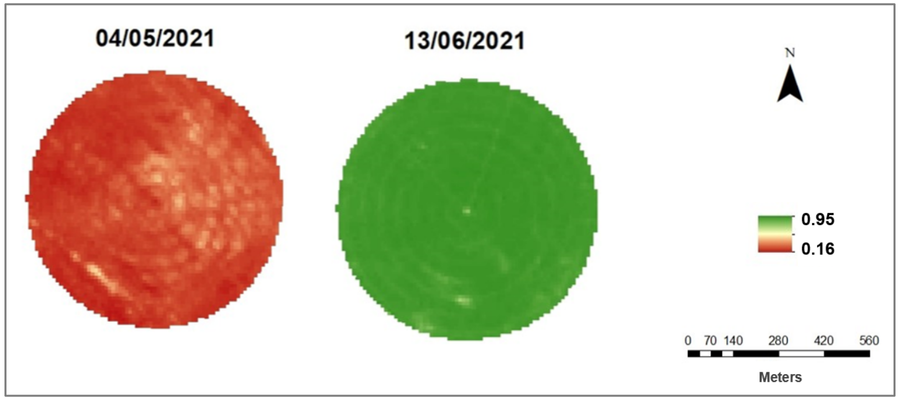
Evolution of average NDVI values during the crop cycle



NDVI maps were calculated throughout the crop cycle. NDVI values recorded a minimum of 0.16 on May 4 and a maximum of 0.95 on June 13, as shown in figure 2.

Figure 2

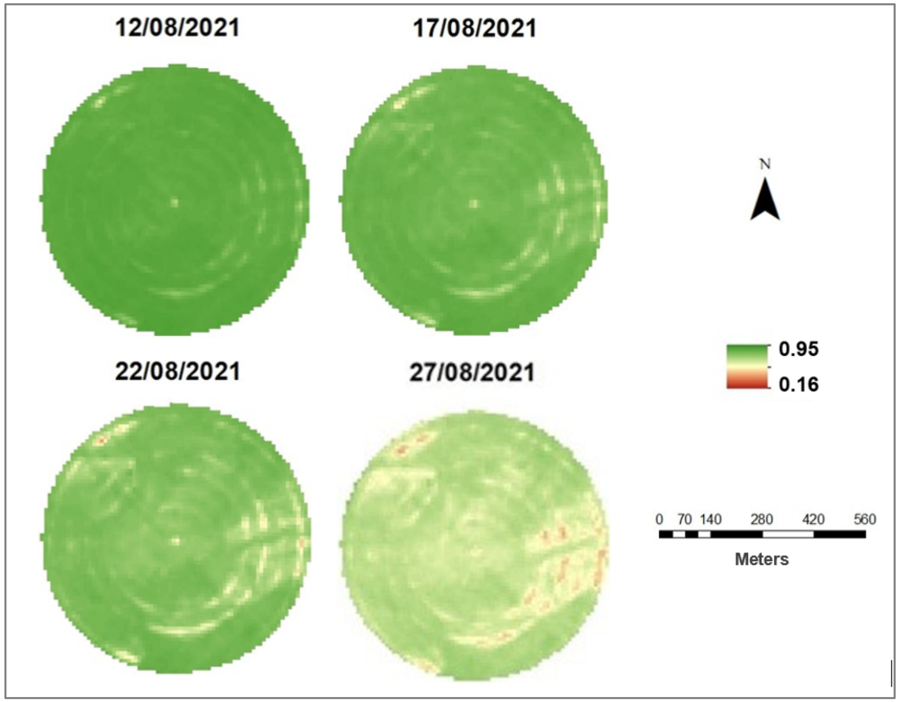
NDVI: Lowest (left) and highest (right) records during the crop cycle



In May, a higher NDVI value was seen in the right half of the pivot, which could be explained by faster plant development. At the beginning of June, a trend towards uniformity of the plot was observed, distinguishing some spots with lower NDVI values in the lower part of the pivot. From 28 June to 28 July, the average NDVI values stabilized. From August 12 until harvest, in the lower right part of the pivot, a more pronounced decrease in NDVI was noted in relation to the other parts, possibly due to an advance in the crop cycle in the initial phase (Figure 3).

Figure 3

NDVI: Evolution between August 12 until harvest



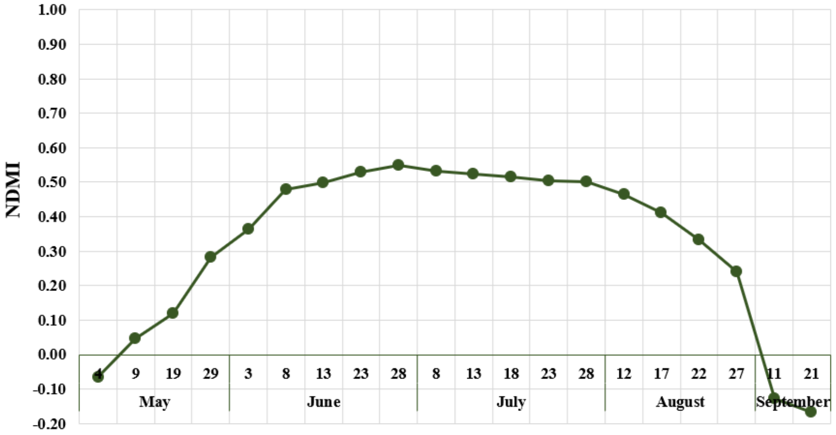
2.1.2. NDMI

The evolution of NDMI (Figure 4) shows lower average values in the initial phase due to low vegetation density. Throughout vegetative development, these values gradually increased until June 8. From this day onwards, a slight increase was observed, reaching a peak of 0.55

average NDMI on June 28. The values remained close to 0.5 until July 28. These values can be explained by the critical reproduction phase in which the plants need to avoid water stress. Between August 12 and 27, there was a decrease in NDMI, meaning a decrease in water content in the plants, that is, the period of physiological maturation was reached.

Figure 4

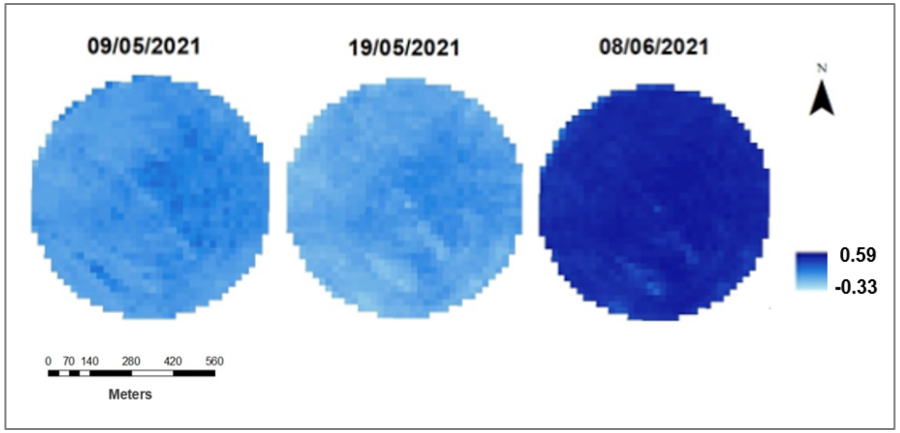
Evolution of average NDMI values during the crop cycle



Throughout the crop cycle, the NDMI showed a minimum value of 0.33 and a maximum of 0.59, on September 21 and July 28, respectively. During the month of May, the right half of the pivot showed higher NDMI values, which is in line with the NDVI. From June 3 onwards, a uniformity of water content in the vegetation was noted except for some spots in the lower part of the pivot where the NDMI showed higher values (Figure 5). After August 12 until harvest, the lower right part distinguished itself from the others with lower NDMI.

Figure 5

NDMI: Evolution during the month of May and uniformity from June 3 onwards

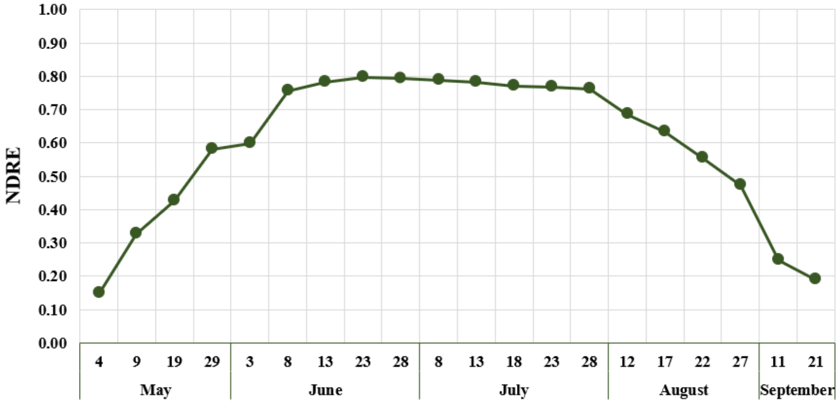


2.1.3. NDRE

The mean NDRE (Figure 6) increased during vegetative development, stabilized briefly between May 29 and June 3, and reached a maximum of 0.8 on June 23. The index remained stable until July 8, followed by a slight decline until July 28 and a marked decrease thereafter, up to Harvest.

Figure 6

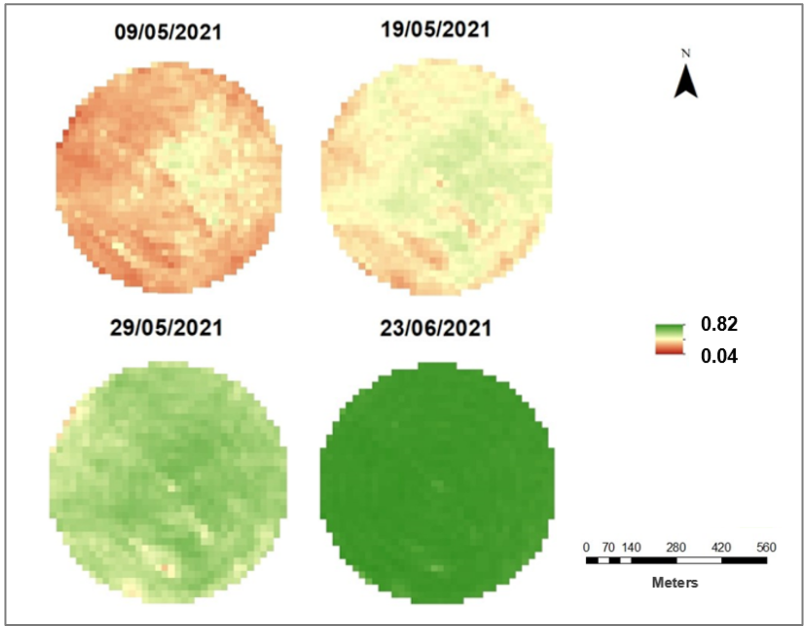
Evolution of average NDRE values during the crop cycle



Throughout the crop cycle, NDRE ranged from 0.04 to 0.82. Like NDVI and NDMI, higher values were observed on the right side of the pivot during May, with a trend toward uniformity by June 23, although some lower values persisted in the lower section (Figure 7).

Figure 7

NDRE: Evolution during the month of May until June 23



In August and September, a sharp decrease in NDRE values was observed, coinciding with the decrease in green mass, that is, with crop senescence.

2.2. Granular Link Platform

2.2.1. Advanced Plan

The average NDVI values obtained in the Advanced plan gradually increased from 0.36 to values close to 0.83 on July 13, with a slight decrease on June 13. From this date onwards, there was a downward trend, which was accentuated from August 17 onwards.

Following seeding, the images from the Advanced plan showed greater initial development on the right side of the pivot until reaching a certain uniformity, but with some spots of lesser development on the lower side (Figure 8). After reaching the maximum NDVI value (Figure 9), an area with lower vegetative vigor was noted on the right side of the pivot. As the vegetative cycle progressed, the difference between the right and left parts of the pivot became more pronounced (Figure 10).

Figure 8

Granular Link - Advanced Plan: NDVI on June 3

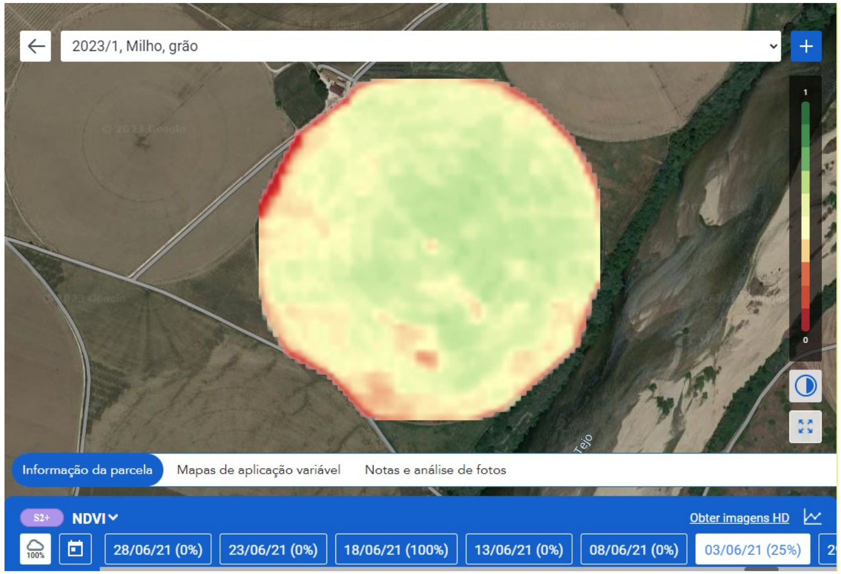


Figure 9

Granular Link – Advanced Plan: NDVI on July 13

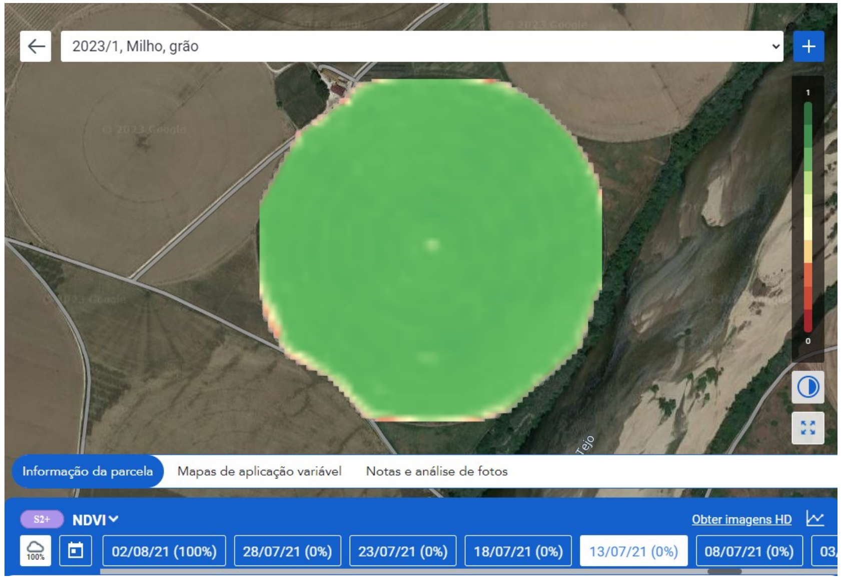


Figure 10

Granular Link - Advanced Plan: NDVI on August 22

2.2.2. Premium Plan

After crop emergence, an average NDVI value close to 0.26 was recorded, followed by a gradual increase, but with some decreases, reaching a maximum of 0.91 on June 24. Some of the decreases seem to be due to the presence of clouds. From June 24 until July 13, the average NDVI stabilized, with values close to 0.91. From July 13 until the harvest, there was a gradual decrease in the average values. The right part of the pivot, in the early stages of crop development, recorded higher NDVI values (Figure 11). This trend continued until June 24, when the values reached a maximum and there was uniformity throughout the pivot (Figure 12). From July 28th until harvest, this right half of the pivot started to stand out with lower values (Figure 13).

Figure 11

Granular Link –Premium Plan: NDVI on May 8

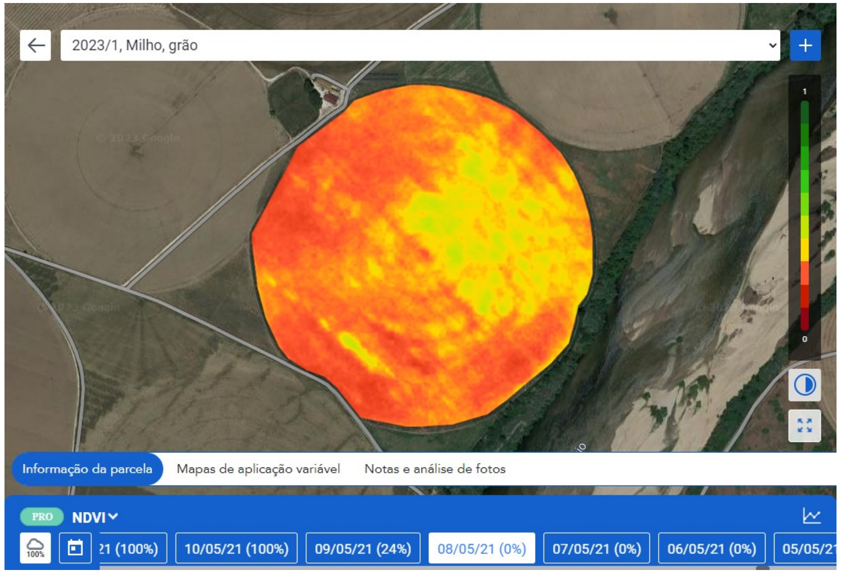


Figure 12

Granular Link –Premium Plan: NDVI on June 24

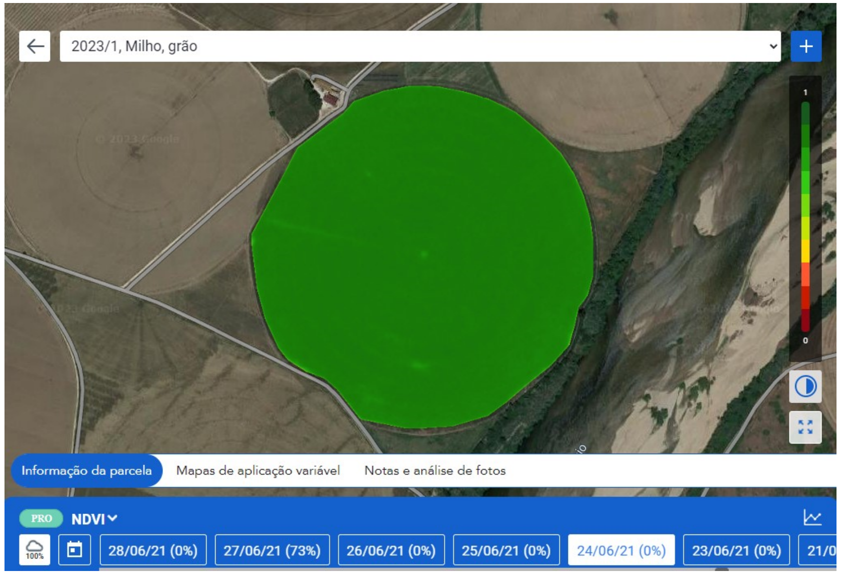
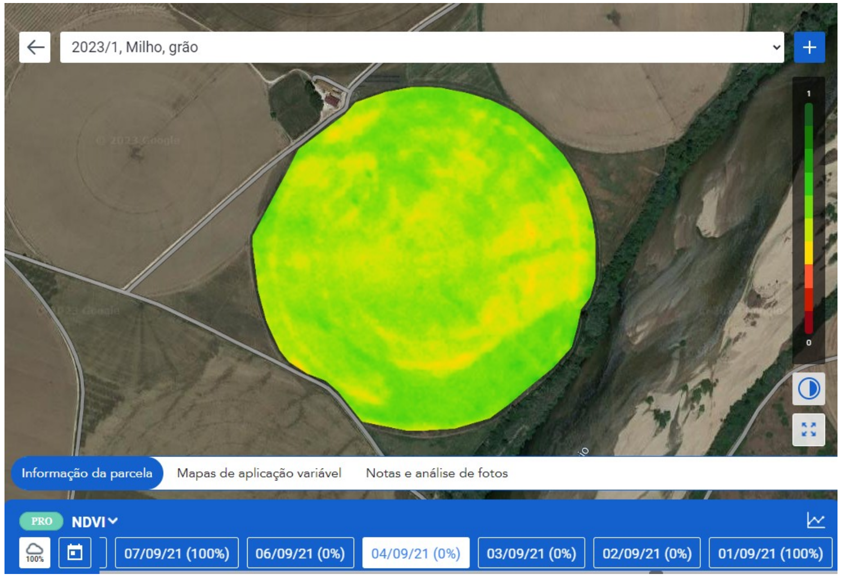


Figure 13

Granular Link –Premium Plan: NDVI on September 4

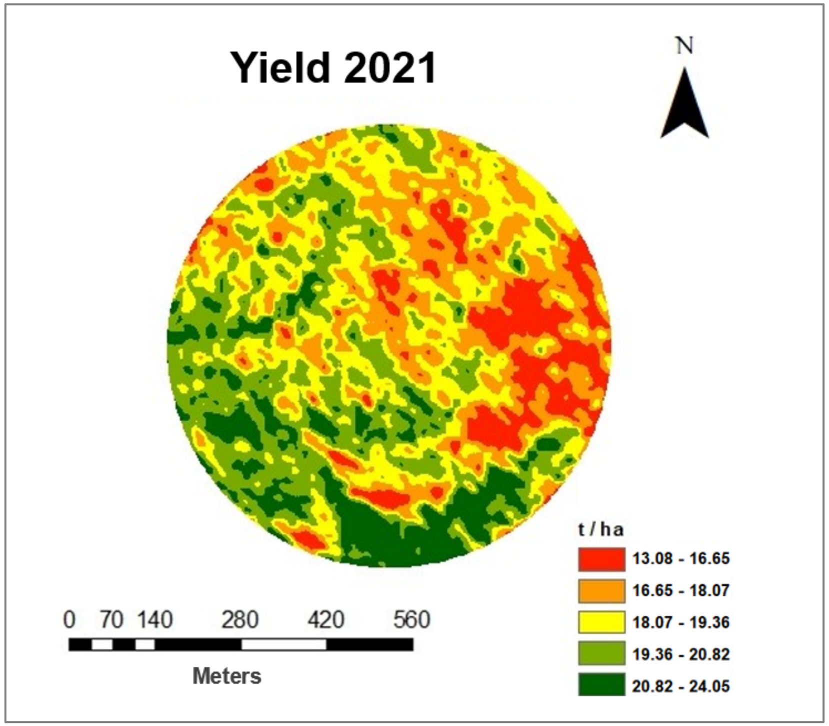


2.3. Yield

The data obtained from the combine harvester made it possible to analyze the spatial variability of yield in the plot (Figure 14). The exploratory data analysis showed an average yield of 18.78 t/ha, with a standard deviation of 1.72 t/ha, with a minimum and maximum of 13.08 t/ha and 24.05 t/ha, respectively. Although the yield values are high, some spatial variability can be observed. The right side of the pivot stood out with lower yields, while the lower part showed higher values.

Figure 14

Yield map of the Great Pivot



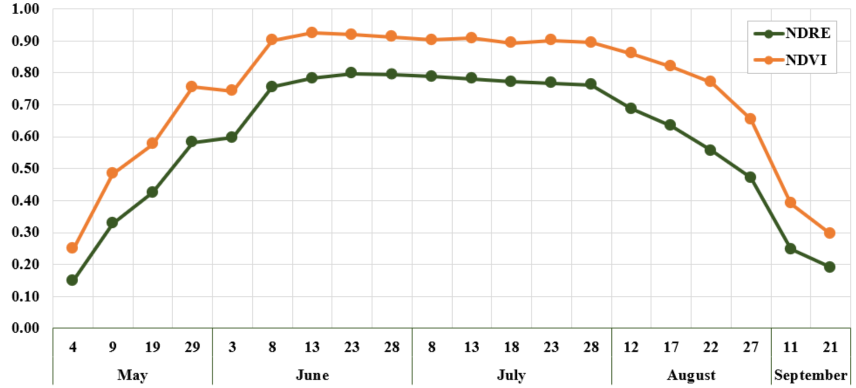
3. Discussion

3.1. Comparison between NDVI, NDMI and NDRE

The comparative evolution of the NDVI and NDRE indices (Figure 15), throughout the crop cycle, showed that the average NDVI values were always higher than the average NDRE values. These results agree with those of Li et al. (2014), showing that the NDRE was better at detecting nitrogen and chlorophyll concentrations. On June 3rd there was a deflection in the evolutionary line of these indices, probably due to the presence of clouds.

Figure 15

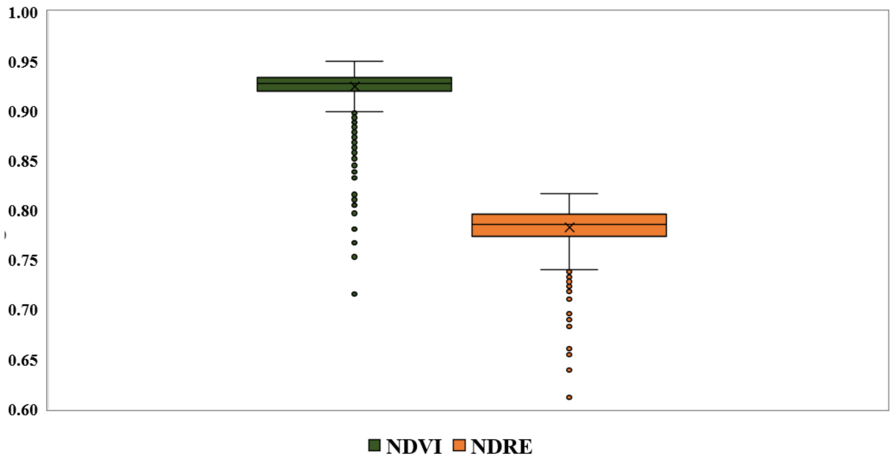
Comparative evolution of average NDVI values with average NDRE values throughout the crop cycle



After the beginning of the crop's reproductive phase (June 13), the NDVI begins to saturate, with values close to 1, making differentiation difficult (Gao et al., 2015; Jensen, 2009). The range of NDVI values is between 0.9 and 0.95, unlike the NDRE where the values vary between 0.75 and 0.83, with a slightly wider range (Figure 16). In this analysis, the outliers shown in the figure were not considered. These values resulted from the presence of irregularities, such as the wheelset and the central part of the rotating ramp.

Figure 16

Comparison of NDVI and NDRE values as of June 13, 2021



After the beginning of the physiological maturation of the crop, the range of the index values decreased, with values very close to the average values. However, the NDRE continued to show slightly greater differentiation. The same was true at the end of the crop cycle, but with a decrease in average values and an increase in their respective ranges.

The NDMI, an index used to assess vegetation water stress, makes it possible to anticipate the detection of moisture problems in the crop and take timely action. The relationship between NDVI and NDMI (Figure 17) was highly significant (p-value <0.001) showing a positive and very strong correlation (R = 0.983) between these two variables. The relationship between NDRE and NDMI was also shown to be highly significant (p-value <0.001) but with a positive and slightly stronger correlation (R = 0.986). These results show that high NDVI and NDRE values were associated with high moisture contents.

Figure 17
Correlation between NDVI and NDMI

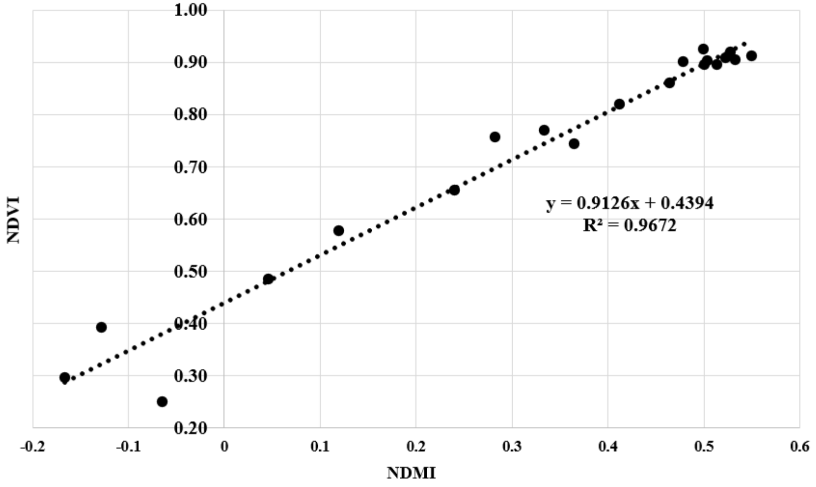
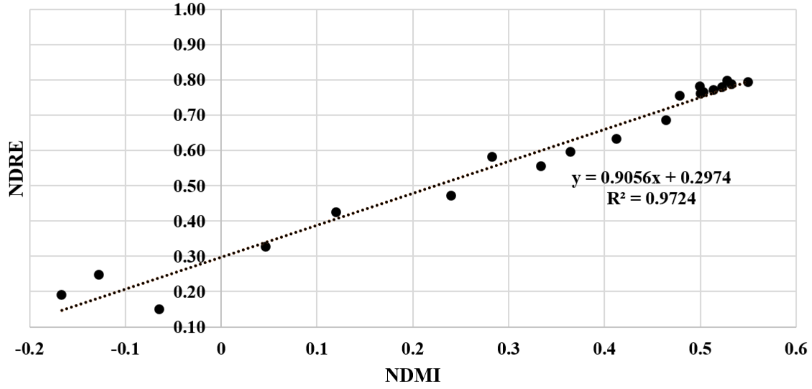


Figure 18
Correlation between NDRE and NDMI



3.2 Comparison of processing and analysis of images obtained by the two methods

The Granular Link platform allows you to obtain images of various vegetation indices, in a simple and expeditious way. Consequently, it is possible to view their evolution throughout the crop cycle, with a frequency that, in the premium plan, is daily. However, this platform was not always able to identify shadows resulting from the presence of clouds.

The vegetation indices obtained from Sentinel 2 platform images are the result of laborious and time-consuming processing, the best temporal resolution of which is every 5 days. These images have the advantage of being available at no cost to users.

The delineation of the study plots is quite fast on the Granular Link platform, whereas on the Sentinel-2 platform it requires knowledge of geoprocessing tools. However, it allows for pixel-by-pixel data retrieval and statistical analysis.

The Granular Link platform enabled visualization of index images and trend graphs but did not allow manipulation of image data. Despite this limitation, it facilitated rapid access to multiple indices, effective crop monitoring, and more timely decision-making.

3.3 Comparison of Vegetation Indices with Yield

At the beginning of crop development, the NDVI and NDRE indices recorded higher values on the right side of the pivot. Greater vegetative development on the right side led to earlier entry into physiological maturity and senescence compared to the rest of the pivot, causing some spatial variability in the yield map.

The average yield of the pivot was quite high (18.78 t/ha). This average could have been even higher if the right side of the plot had been uniformed with the rest of the area.

Conclusions

The introduction of new Precision Agriculture tools enables the development of alternative cropping practices. These tools require testing and calibration within the agricultural system to ensure accurate and appropriate performance.

NDVI is one of the most widely used vegetation indices in the agricultural sector, however, it has certain limitations that can be resolved with the help of other indices. In this study, it was found that the NDRE can be a solution in the later stages of development of the maize crop (mainly in the reproductive phase), when NDVI tends to saturate. In these phases, the NDRE was able to better differentiate vegetation classes. The NDMI showed a strong relationship with these two indices and made it possible to highlight some of the variations in vegetation. Yield reflected the differences found in the index values throughout the crop cycle.

Comparing the methods used for image processing and analysis, it was concluded that there are benefits for the farmer in using the Granular Link application in relation to the use of images obtained by the Copernicus platform. The Premium plan recorded average NDVI values very similar to those obtained by Sentinel-2. However, the Premium plan offers farmers the possibility to monitor their crops almost daily, allowing for a much faster response time compared to images obtained through Sentinel-2, which are available every five days and still require processing. The Advanced and Premium plans are only available to farmers affiliated with the "CORTEVA Agriscience" group. If such affiliation does not exist, the alternative is the Basic plan, which is free for any user. In this plan, the observations that can be made are like those obtained from Sentinel-2 images.

The results obtained on both platforms led to similar conclusions, with the differences found being due to the different spatial and temporal resolutions. When greater data manipulation is required, the Granular Link platform does not yet offer this possibility, making it necessary to use, for example, the Copernicus platform.

To mitigate the spatial variability of yield, it is proposed in future studies to analyze the apparent electrical conductivity of the soil, to better understand the spatial variability of soil texture. It will also be important to integrate additional vegetation indices that can strengthen the results obtained, with the aim of building a yield prediction model for the maize crop.

Acknowledgments

The authors are very grateful to Sociedade Agro-Florestal Campo Dobrado and Corteva Agriscience™ for all support.

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Curriculum note

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