REVISTA DO DEPARTAMENTO DE GEOGRAFIA
Universidade de São Paulo
www.revistas.usp.br/rdg - ISSN 2236-2878
Volume 45 (2025), e224356
DOI: 10.11606/eISSN.2236-2878.rdg.2025.224356

Use of drones in agricultural monitoring: generation of vegetation index with RGB camera in sorghum crops

Uso de drones no monitoramento agrícola: geração de índice de vegetação com câmera RGB em cultivos de sorgo

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Recebido (*Received*): 25/04/2024
Aceito (*Accepted*): 14/04/2025

Resumo: Esta pesquisa traz resultados de projeto com financiamento CNPq que objetiva adaptar um drone de uso civil e asas rotativas da linha DJI/Phantom 4 para o monitoramento de plantios comerciais de sorgo na Universidade Federal de Jataí por meio dos índices de vegetação VARI (Índice Resistente à Atmosfera na região do visível) e NDVI (Índice de Vegetação por Diferença Normalizada). Como metodologia, foram realizados 06 sobrevoos entre abril e julho de 2021 e 07 sobrevoos entre março e julho de 2022, em duas parcelas de 3ha em áreas cultivadas com sorgo, com geração de índice VARI a partir das ortofotos da câmera RGB e comparação com índices gerados a partir de imagem Sentinel-2. As fotografias aéreas foram georreferenciadas com pontos coletados por GNSS Trimble R4 e mosaicadas no *software* Metashape®. Os demais processamentos foram realizados no ArcGIS PRO®, com definição 32 amostras de 20mx20m (04 pixels da imagem Sentinel-2) para validação estatística. Entre os resultados, obteve-se coeficiente de determinação de 0,94 e índice de desempenho D de 0,90 ao comparar valores de VARI mensurados pela câmera RGB e os obtidos a partir de imagem Sentinel-2, e coeficiente de determinação de 0,87 e índice D de 0,98 entre VARI/drone e NDVI/Sentinel-2, indicando ótimo desempenho para monitoramento de índices de vegetação sem suporte de câmera infravermelha. O Erro Médio entre os valores de VARI/drone e VARI/Sentinel-2 foi de 0,0037, indicando alta concordância entre as variáveis com leve superestimativa dos valores pela câmera RGB do DJI/Phantom 4.

Palavras-chave: Aeronaves remotamente pilotadas; Índice de vegetação; Agricultura de precisão; Sustentabilidade agrícola.

Abstract: *This study brings the results of a project funded by CNPq that aims to adapt a drone for civil use and rotary wings of the DJI/Phantom 4 line for the monitoring of commercial sorghum plantations at the Federal University of Jataí through the vegetation index VARI (Visible Atmospherically Resistant Index) and NDVI (Normalized Difference Vegetation Index). As methodology, 06 overflights were carried out between April and July 2021 and 07 overflights were carried out between March and July 2022 in two plots of 3ha in areas cultivated with sorghum, with generation of VARI from the orthophotos of the RGB camera and comparison with indices generated from the Sentinel-2 image. The aerial photographs were georeferenced with points collected by Trimble R4 GNSS and mosaicked in Metashape® software. The other processing steps were performed in ArcGIS PRO® software, with 32 samples of 20mx20m (04 pixels from the Sentinel-2 image) for statistical validation. Among the results, it was possible to obtain a coefficient of determination of 0.94 and a performance index D of 0.90 when comparing VARI values measured by the RGB camera and those obtained from Sentinel-2 images, and a coefficient of determination of 0.87 and a D index of 0.98 between VARI/drone and NDVI/Sentinel-2, indicating excellent performance for monitoring vegetation index without infrared camera support. The mean error between VARI/drone and VARI/Sentinel-2 values was 0.0037, indicating high agreement between the variables with slight overestimation of the values by the DJI/Phantom 4 RGB camera.*

Keywords: *Remotely piloted aircraft; Vegetation index; Precision agriculture; Agricultural sustainability*

1. Introduction

Among the main global challenges related to agriculture are population growth along with the growing demand for food and environmental degradation, as well as climate change, driven by the current production model. For this reason, the advent of precision agriculture has established paradigms to increase crop yield and quality, in addition to seeking to improve management conditions (DAPONTE *et al.*, 2019). Such factors play an important role in making agriculture more sustainable through the rational use of natural resources.

Many farmers have been applying high-tech solutions, such as Remotely Piloted Aircraft (RPA), for crop forecasting and monitoring, given that these tools can collaborate in the optimization of agricultural production. These drones can be equipped with RGB cameras (which capture spectral signatures in the red, green, and blue ranges), which make up the visible range of the electromagnetic spectrum, as well as multispectral cameras, which already have the advantage of capturing images including the near-infrared portion, in addition to specific cameras for the infrared portion over crops (ALZAHRANI *et al.*, 2020).

In areas where agriculture predominates as an economic activity, as is the case of the municipality of Jataí, state of Goiás, Brazil, where the experimental study areas are located, performing aerial surveys and measuring indices such as the Normalized Difference Vegetation Index (NDVI) allow, for example, to carry out agrochemical applications in a more rational way, optimizing the use of products and reducing damage to the environment.

NDVI, as well as its variations such as the SAVI (Soil Adjusted Vegetation Index), EVI (Enhanced Vegetation Index) and VARI (Visible Atmospherically Resistant Index), is the most used index for analyses of vegetation cover at different scales, being generated by the difference between the reflectance in the near-infrared channel and the reflectance in the red channel. The use of vegetation index as a biophysical parameter of agricultural crops has two major advantages: reducing the size of multispectral information, hence minimizing the impact of lighting and target conditions; and providing a number that is highly correlated with agronomic parameters. Changes in the vegetation index in agricultural crops may indicate, for example, water stress, pest attack, inadequate distribution of solar radiation on leaves, need to correct soil fertility, nutritional deficiencies, among others (MOREIRA *et al.*, 2010; SCHWALBERT *et al.*, 2020; ANDRADE JÚNIOR *et al.*, 2022).

When obtained by means of drones, the images can have pixels with spatial resolution between 1 and 5 cm, depending on the height of the flight, allowing the generation of extremely accurate indices. The process of photosynthesis depends on the interception of light and its conversion into energy, making vegetation indices indicative of yield (FAVARIN *et al.*, 2002), being useful for studies on plant growth and for the evaluation of cultural practices such as planting density, fertilization, irrigation, pruning, application of agrochemicals etc.

Therefore, the general objective of this study was to adapt drones from DJI Phantom line for the monitoring of sorghum plantations in commercial areas of the Federal University of Jataí – Jatobá Campus (**Figure 1**), Brazil. The specific objectives were: a) to monitor vegetative growth and soil cover by means of vegetation indices; b) to integrate GNSS technologies for georeferencing and orthorectification of images obtained by drones; and c) to evaluate the performance of an RGB camera for generating VARI index from the comparison with indices generated from images of the MSI sensor of the Sentinel-2 platform.

To date, there are few studies in the field of Human Sciences, especially in Geography, aimed at adapting devices of civil use for aerial photogrammetric surveys, since most studies use more specific equipment, such as fixed-wing RPA, with market prices higher than R$80,000.00. In parametric searches with the keywords presented in this article (Remotely piloted aircraft; Vegetation Index; Precision agriculture; Agricultural sustainability) on the CAPES journal portal and on Google Scholar, it was possible to observe that the vast majority of research on the subject was developed in undergraduate and graduate courses in Agronomy, Cartographic Engineering, Remote Sensing, Bioenergy/Agroenergy, among others. This indicates a vast field of studies to be explored by Geography, especially with regard to the sustainability of agrosystems, considering that the techniques can be used on small and medium-sized properties to optimize the use of agrochemicals, diversify production and improve the income of families that supply local markets with food.

Postgraduate studies such as those conducted by Nascimento (2018), Abrantes (2019), Oliveira Neto (2020) and articles such as the one published by Silva Júnior *et al.* (2018) and Andrade Júnior *et al.* (2022) present potentials of use of these indices associated with Geotechnologies (especially remotely piloted aircraft) to monitor plantations of soybean, as this is the main commodity produced in Brazil, justifying a greater volume of studies. Resende *et al.* (2020) presented research on the use of images taken by RPA to detect caterpillar infestation, indicating potential for use in pest control and controlled use of pesticides. Linhares (2016) presented the potential use of RPA to monitor vegetation index in pastures.

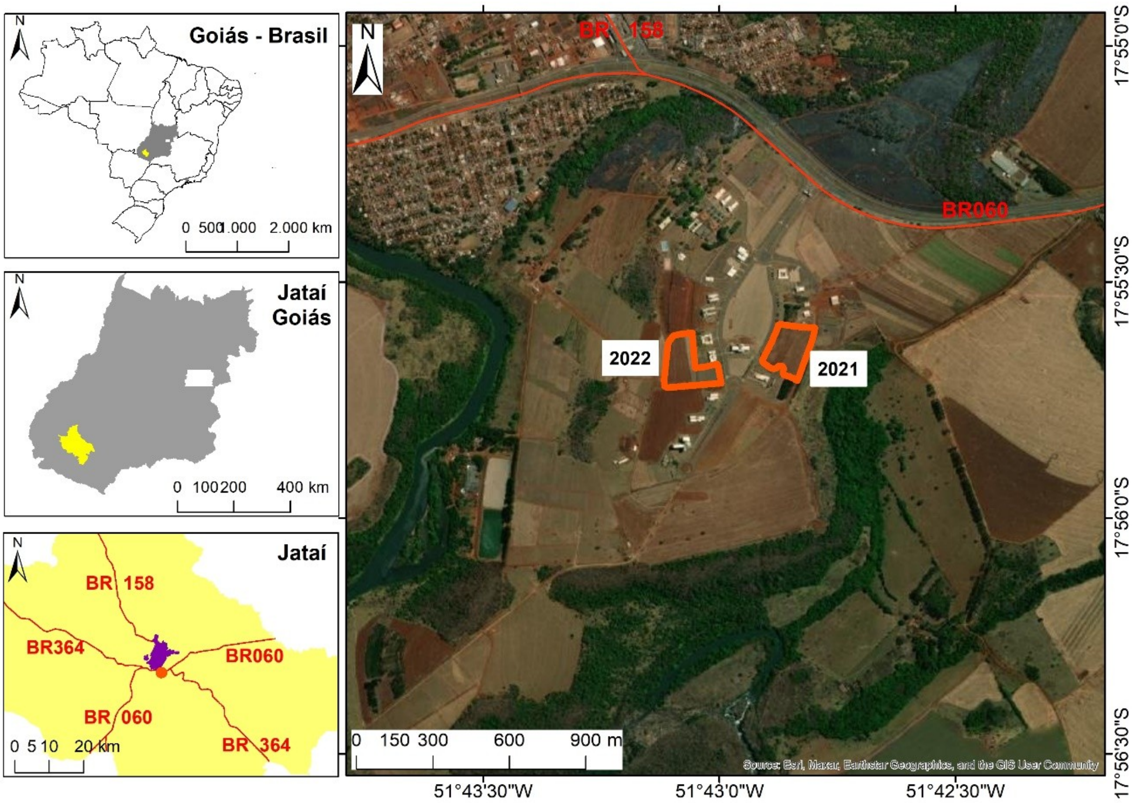

Figure 1: Monitoring areas of sorghum crops (2021/2022) at the Jatobá Campus – Federal University of Jataí. **Source:** IBGE, 2014; SIEG, 2020; Basemap/ArcGIS PRO® image. **Organization:** Authors, 2022.

In this study, as it is a methodological test for index validation, it was decided to work with sorghum given the greater resistance of the crop to pests, in addition to the cultivation in the beginning of the dry season, reducing the possibilities of atmospheric effect on the indices. The volume of rainfall recorded between April and July is lower in the region, which makes it possible to carry out weekly overflights and obtain satellite images with low cloud cover.

This article presents the results of two scientific initiation studies conducted in the 2020/2021 and 2021/2022 cycles and integrated into the project "FEASIBILITY STUDY OF THE USE OF DRONES FOR AERIAL PHOTOGRAMMETRIC SURVEYS: Applications in urban planning, land regularization and environmental monitoring", with CNPq funding, and more recently into the project "Aerial photogrammetry applied to the mapping and monitoring of agricultural experiments" linked to the productivity grant (PQ2) of the first author. Also within the scope of these projects, studies with monitoring of soybean, maize, sugarcane and pasture crops are being conducted.

2. Methodological procedures

2.1. Aerial photogrammetric and topographic surveys and temporal monitoring of sorghum areas

The RPA used were DJI Phantom 4 Advanced and Phantom 4 Plus, available at the Geoinformation Laboratory of the Institute of Geography of the Federal University of Jataí, which allowed the acquisition of high-resolution aerial photographs for the monitoring of commercial sorghum areas. These aircraft have a GPS module with altitude control, although the positioning can generate errors from 01 to 30 meters, making it necessary to subject the photos to georeferencing and orthorectification processes. For controlling the aircraft on the ground, open source Android applications were tested, such as Pix4Dcapture and DroneDeploy, which allow the establishment of automatic flight plans for the acquisition of aerial photographs, and DroneDeploy was selected for use, which has a more user-friendly and interactive interface, being more suitable for users with different levels of training.

The flights were conducted at an altitude of 100 m, with 75% lateral and frontal overlap, always between 9:00 AM and 11:00 AM to avoid significant variation in solar angle, and with the camera positioned at 90°. RGB images were generated in natural color, without contrast adjustment. Overflights should also be avoided on days when precipitation has occurred in the last 36 hours to minimize the effect of humidity on the images. The time chosen also coincides with the Sentinel-2 imaging interval in the region. The drone was adjusted to a flight height of 100m above ground level, a value defined after a series of tests carried out in the field.

Two different monitoring procedures were carried out, according to the characteristics of the crop described by Rodrigues *et al*. (2012) in a bulletin published by EMBRAPA Maize and Sorghum:

a) The first, in an area planted with sorghum seeds of the Agromen 70G70 variety, with planting on 03/15/2021 and overflights on 04/07/2021 (after EC1 stage, plants with average height of 10 to 15 cm), 04/21/2021, 05/06/2021, 05/21/2021 (EC2 stage, from growth to flowering), 06/18/2021 (EC3 stage, of maturation and grain filling), being interrupted with the occurrence of heavy frost on 07/01/2021, with the last overflight carried out on 07/08/2021, with the plants already completely dry.

b) The second monitoring was carried out in an area planted with sorghum seeds of the Dekalb 530 variety, with planting on 03/10/2022 and overflights on 03/31/2022 (transition from EC1 to EC2 stages), 04/09/2022 (data removed from this article considering the high interference of cloudiness and humidity), 05/03/2022, 05/14/2022 (EC2 stage), 05/25/2022, 06/07/2022 (EC3 stage), 06/24/2022 and 07/07/2022 (end of EC3 stage, from developmental stage 8, more than 85 days after emergence).

To record the aerial photographs and generate georeferenced orthomosaics with planialtimetric correction, the experimental areas were georeferenced using Trimble R4® geodetic equipment with RTK and post-processed millimetric precision. In the field, signaling was made on the ground with hydrated lime, constituting control points for the georeferencing and orthorectification of the photos, facilitating the identification of these points in the images, constituting control points for the georeferencing and orthorectification of the photos. The number of control points depends on the area to be mapped and should not be less than 05, giving a better accuracy to the survey. For the two monitored areas, 10 control points were defined, with a distance of 100m between each one on the edges of the crop and in the center of the monitored area, with a horizontal post-processing error of 3 mm and a vertical post-processing error of 8 mm. The correction of subsequent orthomosaics was performed using the georeferencing tool in ArcGIS PRO®, using fixed points such as poles and sewer networks to ensure image positioning accuracy

2.2. Processing of information

The data obtained on the surface with the use of GNSS receiver were downloaded and processed using the accompanying software, especially the Trimble Business Center®, in which they underwent differential correction and export in KMZ and SHP formats. For post-processing, data from the Brazilian Network of Continuous Monitoring (*Rede Brasileira de Monitoramento Contínuo* – RBMC-IBGE) of the Jataí station were used as reference.

The aerial photos were processed (digital aerial photogrammetry) using Agisoft® Metashape software. Mosaicking of the aerial photographs was carried out by following the methodological procedure that corresponds to the processing steps of Metashape, namely: alignment of the images, considering the overlapping areas for photogrammetry; adjustment of coordinates of the control points collected in the field, with new alignment; generation of the dense point cloud, which allows the determination of depth information; creation of the polygonal terrain model (three-dimensional polygonal mesh); and generation of georeferenced orthomosaics, later classified and processed using ArcGIS PRO® software.

Satellite images were acquired using the Copernicus Open Access Hub portal, with selection of images on dates close to those of the overflights, in order to compare the indices obtained. Sentinel-2 was chosen due to its greater periodicity, since this sensor makes its complete orbit around the Earth in an interval of 05 days. Images from the T22KDF scene on 04/10/2021, 04/20/2021, 05/10/2021, 05/20/2021, 06/19/2021, 07/09/2021, 04/05/2022, 04/10/2022, 05/05/2022, 05/15/2022, 05/25/2022, 06/06/2022, 06/24/2022 and 07/09/2022 were obtained.

Bands 02 (blue), 03 (green), 04 (red) and 08 (near-infrared) of the MSI sensor (Sentinel-2) with resolution of 10 meters were used, as they are the most suitable for the generation of vegetation index. Thus, the bands were imported into ArcGIS PRO® and their indices were generated from the raster calculator, available in the Spatial Analyst Tools extension of the ArcToolbox menu. In the post-processing, also performed with

ArcGIS PRO®, 32 polygons of 20 m x 20 m, coinciding with 4 pixels of the Sentinel-2 image, were created for the calculation of vegetation indices in samples of the monitored areas, as shown in **Figure 2**.

Figure 2: Orthophotos with representation of the sampling polygons of sorghum area 2 from 03/31/2022, 05/14/2022 and 07/07/2022. **Source:** Authors, 2022.

Among vegetation index, NDVI is one of the most suitable for monitoring crop development dynamics, as it measures photosynthetically active biomass in plants. However, these indices are very sensitive to soil lightness and atmospheric effects, attenuated in other indices such as EVI, SAVI, ARVI, GCL or SIPI (EARTH OBSERVING SYSTEM, 2022). In remote sensing, they are the most common indices and can be used throughout the agricultural production season, except when the vegetation cover is very scarce, as its spectral reflectance is very low, so more accurate values are obtained in the middle of the season, in the active growth stage of the crop. It is calculated using Equation 1, according to Deering *et al.* (1975):

$$NDVI = \frac{NIR - R}{NIR + R} \qquad \text{(Eq.1)}$$

Where NIR corresponds to the near-infrared and V corresponds to the red channel (obtained from the infrared camera). VARI, on the other hand, is ideal for RGB images obtained by drones, as it works with the entire visible segment of the electromagnetic spectrum and is used to assess the state of the crop when minimal sensitivity to atmospheric effects is required. Its specific task is to improve the visualization of vegetation under strong atmospheric impact while smoothing out lighting variations. According to the Earth Observing System, due to the low sensitivity to atmospheric impact, the error of the VARI index for monitoring vegetation under conditions of different atmospheric thicknesses is less than 10%. Its calculation is defined by Equation 2 (GITELSON *et al.*, 2003):

$$VARI = \frac{\rho g - \rho r}{\rho g + \rho r - \rho b} \qquad \text{(Eq.2)}$$

Where ρg, ρr and ρb correspond respectively to the reflectances in the green, red and blue bands. Both bands 1 (red), 2 (green) and 3 (Blue) of the RGB image obtained by the drone and bands 2 (blue), 3 (green), 4 (red) and 8 (near-infrared) of MSI/Sentinel-2 had their radiometric resolution converted to 8 bits (256 levels of gray) to allow for comparison, since Sentinel-2 originally has 12-bit resolution. Regarding the spatial resolution, obtaining images at 100 m height relative to ground level generated an orthomosaic with resolution of 3.5 cm, while that of Sentinel-2 is 10 m, thus allowing a greater refinement of the index obtained from the drone-generated images. In the statistical validation, this difference was minimized with the definition of plots of 400 m².

The variables were subjected to descriptive statistical analysis, with generation of means and identification of maximum, minimum, standard deviation and variance using the Zonal Statistics as a Table tool of ArcGIS PRO®. In a second moment, the correlation (r) between the variables (Pearson's correlation), the regression equations and coefficients of determination (r^2), the mean error (ME), and the root mean squared error (RMSE) were identified and performance tests based on the coefficients D of Willmott *et al.* (1985) and C of Camargo; Sentelhas (1997) were carried out. Both have a performance scale that ranges from very poor to excellent, according to Oliveira (2016): Very poor, < 0.40; Poor, 0.40 to 0.50; Sufferable, 0.50 to 0.60; Median, 0.60 to 0.65; Good, 0.65 to 0.70; Very good, 0.75 to 0.85; and Excellent, > 0.85.

3. Results and discussion

After the stages of processing and calculating the indices, both from the aerial images obtained by drone and from the Sentinel-2 satellite, Pearson's correlation was calculated to check the statistical relationship between the vegetation indices. As shown in **Table 1**, in the areas cultivated with sorghum, the correlation (r) between VARI/Sentinel and NDVI Sentinel ranged from -0.4872 (end of season, in area affected by frost) to 0.9865 (peak of vegetative growth), indicating that the values tend to be lower in the final stages of cultivation when vegetative vigor decreases considerably and the image begins to show greater influence from the reflectance of the soil and dry material.

Table 1: Correlation between the indices obtained in the area cultivated with sorghum.

Data	VARI/Drone X VARI/Sentinel-2	VARI/Drone X NDVI/Sentinel-2	VARI/Sentinel-2 X NDVI/Sentinel-2
04/07/2021	0.8217	0.8022	0.9721
04/21/2021	0.6064	0.6307	0.9865
05/06/2021	0.6473	0.6995	0.9855
05/21/2021	0.8384	0.6584	0.9229
06/28/2021	0.6187	0.6716	0.7094
07/08/2021*	-0.5266	0.2081	-0.4872
03/31/2022	0.4764	0.7718	0.7814
05/03/2022	0.4793	0.5159	0.9392
05/14/2022	0.6289	0.6549	0.7683
05/25/2022	0.7036	0.8567	0.8744
06/07/2022	0.6700	0.8180	0.8695
06/24/2022	0.4491	0.7500	0.4430
07/07/2022	0.3906	0.3758	0.3610

*Occurrence of heavy frost on 07/01/2021. **Source:** Authors, 2022.

The VARI values obtained from orthomosaics generated by aerial survey were compared to the VARI and NDVI values obtained from Sentinel-2 images. There was variation in the VARI/drone X VARI/Sentinel correlation from -0.5266 (end of season, in area affected by frost) to 0.8384 (peak of vegetative growth) and in the VARI/drone and NDVI/Sentinel correlation from 0.2081 to 0.8567 due to the same factors mentioned above.

To proceed with the statistical analysis, the values calculated for the samples on 07/08/2021 and 07/07/2022 were discarded, considering that the plants were totally dry and, therefore, with low NDVI. As a way of validating the indices, all the indices calculated for the 64 samples (two monitored plots) were arranged in a table for all the dates indicated in the methodological procedures, organized considering the EC1, EC2 and EC3 stages of the crops.

When analyzing the overall data set, $r = 0.9144$ and $r^2 = 0.8363$ were found between the NDVI and VARI values calculated from the Sentinel-2 images, demonstrating that VARI has a high statistical relationship with NDVI and can be reliably used in images obtained without infrared sensors (**Figure 3**). When comparing the VARI values obtained by drone and Sentinel images, $r = 0.9486$ and $r^2 = 0.9$, indicating that drone images can be used to generate vegetation index, even without the infrared channel (**Figure 4**), which is confirmed by the $r = 0.8718$ and $r^2 = 0.6667$ obtained between VARI/drone and NDVI/Sentinel (**Figure 5**).

In the three graphs, especially in **Figures 4** and **5**, there is a large volume of negative VARI values recorded both in the drone image and in the Sentinel image, referring to the initial and final stages of cultivation, when the reflectance of the bare soil and/or the low volume of biomass interfere in the calculation of the index. In **Figure 5**, the dispersion between the VARI/Drone and NDVI values is more evident, as a result of the absence of an infrared camera on the drone. Even with dispersion, the values reinforce the feasibility of using a drone with an RGB camera for vegetation studies.

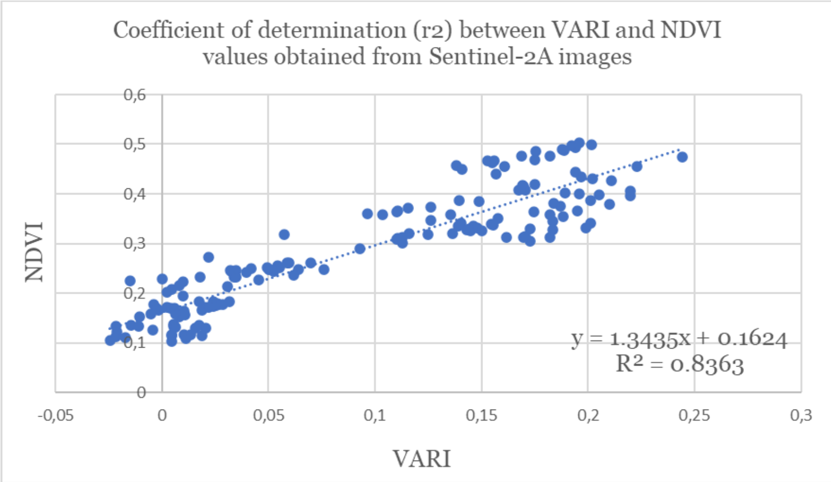

Figure 3: Coefficient of determination between VARI and NDVI values calculated for sorghum areas from Sentinel-2 images (2021 and 2022). **Source:** Authors, 2022.

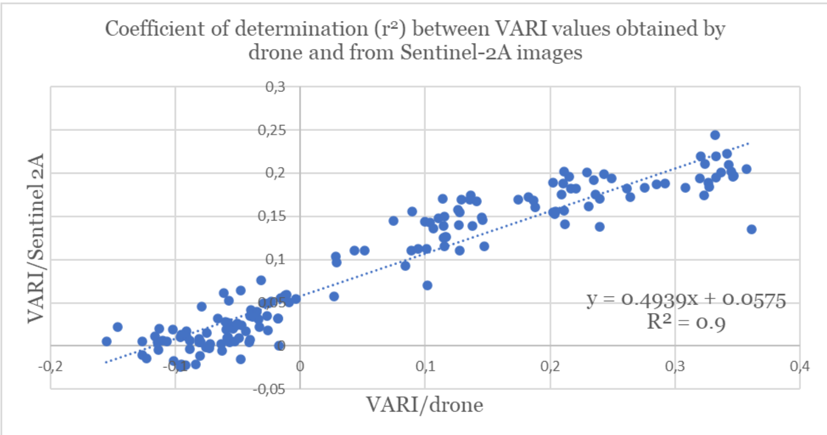

Figure 4: Coefficient of determination between VARI values obtained by drone and VARI calculated for sorghum areas from Sentinel-2 images (2021 and 2022). **Source:** Authors, 2022.

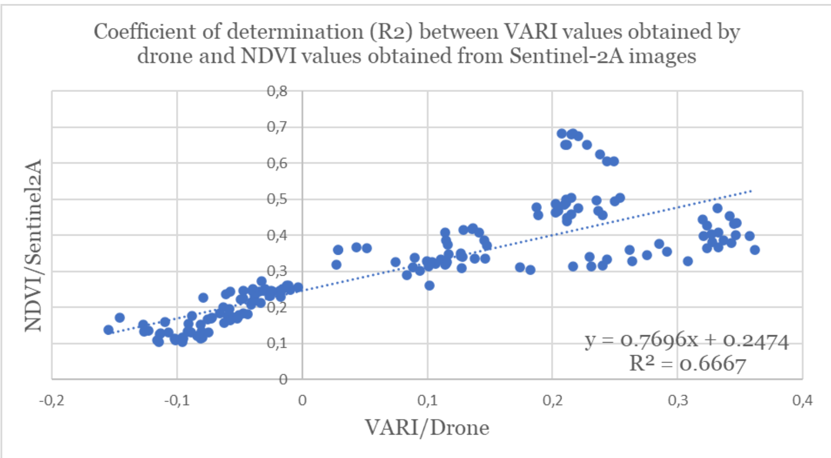

Figure 5: Coefficient of determination between VARI values obtained by drone and NDVI calculated for sorghum areas from Sentinel-2 images (2021 and 2022). **Source:** Authors, 2022.

Andrade Junior *et al*. (2022), in a study that used drones to predict soybean productivity, found r values greater than 0.8 for indices that use the red, NIR and red-edge bands such as EVI, EVI-2, NDRE and RECI, and also for indices that correct the effect of the soil on the vegetation signal, such as SAVI and OSAVI. Silva Junior *et al*. (2018) also found a high correlation between indexes that apply adjustments for ground effect, which cannot be measured using only an RGB camera.

When comparing the MRPI index (Modified Photochemical Reflectance Index) obtained by TIRIBA UAV and the NDVI obtained from OLI/Landsat 8 images in pasture area, Linhares (2016) obtained r values higher than 0.96. The author indicates that, despite the limitations of autonomy and imaged area, UAVs and satellites can be used as complementary technologies with high performance.

In the graph presented in **Figure 6** it is possible to visualize the variation of the vegetation index (VARI/drone and VARI and NDVI/Sentinel-2) in sorghum areas from the ordering of the samples between the initial and final stages of cultivation, as the highest values are recorded between the end of April and the end of May, period of considerable development and production of the plant (EC2 stage).

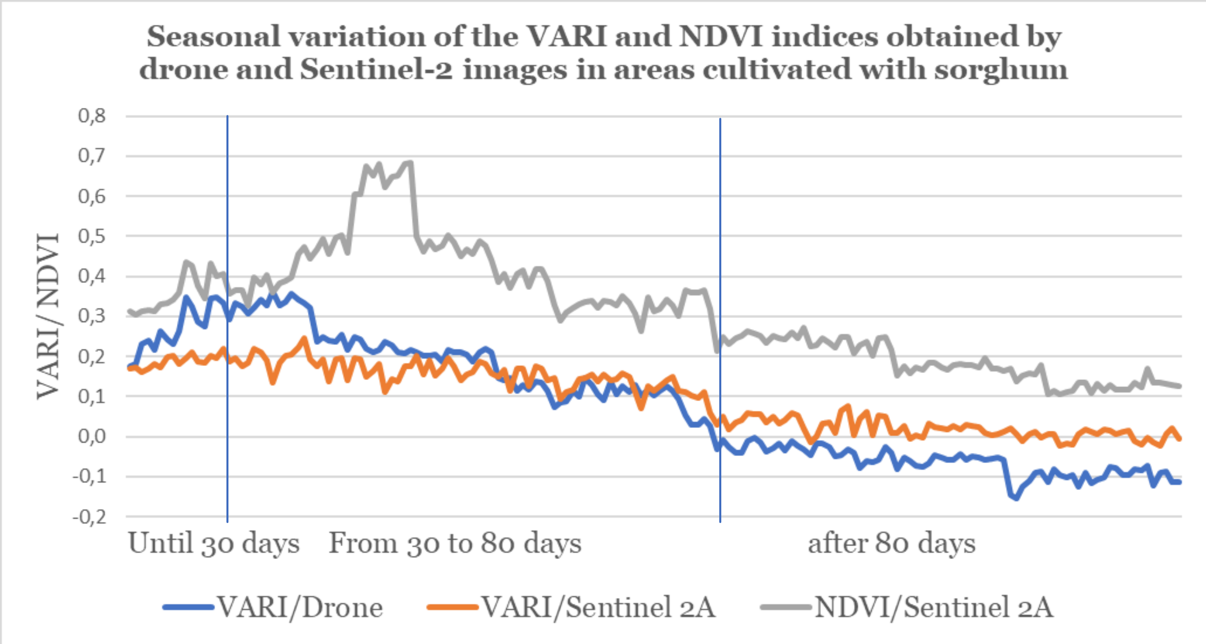

Figure 6: Seasonal variation of the VARI and NDVI indices obtained by drone and Sentinel-2 images in areas cultivated with sorghum (2021 and 2022). **Source:** Authors, 2022.

From the 90th day onwards, the indices decrease considering the period of senescence of the vegetation and maturation of the grains, which acquire a reddish tone (**Figure 7**). Unlike crops such as soybean and maize, which have NDVI values higher than 0.8, the maximum NDVI values recorded in sorghum areas range from 0.5 to 0.7 in the period of greater vegetative vigor, resembling areas with improved pasture. **Figure 7** presents a sequence of photos to illustrate the development cycles of sorghum in the monitored period.

After analyzing the correlation and coefficient of determination between the variables, four statistical techniques were used to check the agreement between the variables and the performance of the calculations: 1) the mean squared error and its root (OLIVEIRA, 2016); 2) the performance index D of Willmott *et al.* (1985); 3) the performance index C of Camargo; Sentelhas (1997).

The mean error (ME) and its root (RMSE) indicate that the lower the result, the greater the agreement between the variables, and should be close to 0. For the samples from the monitored sorghum areas, the ME between the VARI values obtained by drone and the values obtained from the Sentinel-2 images was 0.0037, indicating high agreement between the variables with slight overestimation of the values by the VARI/drone. In turn, the RMSE was 0.0056.

When evaluating the monitoring performance, a D index of 0.9047 was obtained between the VARI/drone and VARI/Sentinel-2 values, confirming the premise that the calculation of VARI for images obtained by drone has high performance (the maximum performance would be 1.0). On the other hand, the D index between VARI/drone and NDVI/Sentinel-2 was 0.9875, reinforcing the assertion that the VARI values obtained by drone can be used to monitor crops with high performance.

Finally, the C index that reflects the reliability and/or performance of the method, calculated by multiplying the D index by Pearson's correlation, was 0.8582 (very good) for the comparison between VARI values obtained by drone and those obtained from Sentinel-2 images. The C index between VARI/drone and

NDVI/Sentinel was 0.8609, indicating high correspondence and excellent performance for vegetation index analysis from RGB orthomosaics generated by aerial surveys.

This performance of vegetation index generated from images obtained by drone opens up the possibility of new discussions, such as the use of these images to estimate yield, monitor phytosanitary problems, and optimize the use of pesticides and fertilizers in areas cultivated with grains. Zhao *et al*. (2020), when addressing wheat yield prediction in northeastern Australia, found RMSE ranging from 0.54 t/ha to 0.64 t/ha, combining chlorophyll indices to soil-adjusted vegetation index, with potential for building prediction models suitable for various climatic conditions. Maimaitijiang *et al*. (2020), when evaluating soybean yield prediction from RPA in the US using Deep Neural Network (DNN), indicated high precision of the model with r^2 of 0.720 and RMSE of 15.9%, pointing out that the fusion of multimodal data using low-cost RPA can provide a relatively accurate estimate of crop yield.

Figure 7: Final season of sorghum cultivation on 06/24/2022. **Source:** Authors, 2022.

After experimental monitoring in sorghum areas with an RGB camera, other research developed at the UFJ Geoinformation Laboratory incorporated the use of a MAPIR/Survey camera that captures responses in the OCN bands (orange, cyan and NIR), which can be purchased and attached to a common drone with a relatively low financial investment. The preliminary results showed that it is an excellent alternative to generate more accurate indexes with the incorporation of the NIR band, allowing the analysis of the effects of the soil on reflectance in the initial and final periods of cultivation, in addition to identifying damage to plants caused by fungi, insects or water deficiency (DAMASCENO, 2024).

4. Conclusions

From this study it was possible to structure a methodological procedure for carrying out aerial surveys in agricultural areas, establishing control points, calculating vegetation index, establishing sampling areas and performing statistical validation, fundamental to guide other studies that are under development in the undergraduate and graduate courses in Geography of the Federal University of Jataí. Areas cultivated with soybeans, maize, sugarcane and pastures are currently being monitored, which will allow a greater advance and deepening of the use of drones to generate vegetation index and agricultural monitoring aiming at a more sustainable use of natural resources.

To date, the performance of RGB cameras attached to drones for civilian use has shown promise for generating indices such as VARI, with a very strong correlation with VARI and NDVI values measured by satellite images. The VARI results obtained from the monitoring of sorghum cultivated areas in two seasons (2021 and 2022) by drone showed a D performance index of 0.9047 and a C index of 0.8582 when compared to the indices obtained from Sentinel-2 images, being classified as very good.

However, the use of RGB cameras limits analyses by not allowing, for example, the evaluation of the effect of soil on reflectance in the initial and final stages of cultivation. They also do not allow for a more precise assessment of insect or fungal infestations, in addition to problems related to water deficit or surplus, considering that only infrared channels can offer these responses. In this case, the best option is to purchase and attach cameras such as MAPIR/Survey to the drones, which record responses in the orange, cyan and NIR bands, and work simultaneously with the RGB camera, allowing the generation of indexes such as NDVI, SAVI, EVI, etc. Other limitations are represented by atmospheric effects, since rotary wing drones have low resistance to humidity or strong winds, in addition to the ground shading effects that high cloud cover can cause on images.

Among prospects, considering the popularization of the use of drones and the diversity of equipment on the market, it is estimated that the costs of acquiring aircraft and multispectral cameras should reduce, in addition to expanding the possibilities of using artificial intelligence to improve flight autonomy, image processing and real-time data transmission. It is of utmost importance that small and medium-sized rural producers have access to these technologies, which allow economic and environmental gains by optimizing the use of agrochemicals, allowing crop diversification and monitoring, and increasing family income.

Acknowledgments

The first author would like to thank the National Council for Scientific and Technological Development (CNPq - Brazil) for the Research Productivity Grant (PQ2) through process 307438/2021-0. The second and fourth authors would like to thank the CNPq - Brazil for the Scientific Initiation scholarships. The third author thanks the Funding from the Coordination for the Improvement of Higher Education Personnel in Brazil (CAPES), Financing Code 001 - master's scholarship.

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