Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Technical Paper
Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v44e20220212/2024

MONITORING THE VEGETATIVE STATE OF COFFEE USING VEGETATION INDICES

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KEYWORDS

Coffea arabica, precision agriculture, satellite image, planet labs.

ABSTRACT

Vegetation indices are a quick and practical alternative for monitoring crops due to the availability of satellite images on various platforms for free, allowing a quick analysis of the vegetative state of the crop and interventions in the field in case of signs of diseases and pests. In this context, this study aimed to evaluate the vegetative state of the coffee crop using vegetation indices (NDVI, SAVI, ARVI, EVI, and VDVI) in an agricultural year. The study was carried out on a commercial farm using satellite images from the Planet platform, during an agricultural coffee growing season (2021/2022). The indices selected for the study were the Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), Atmospherically Resistant Vegetation Index (ARVI), Enhanced Vegetation Index (EVI), and Visible Difference Vegetation Index (VDVI). The index data were analyzed using descriptive statistics, Pearson correlation, classification/interpretation proposal, and the Kappa index. NDVI and SAVI are efficient in monitoring coffee cultivation in an agricultural year, as the Kappa index was higher than 90%. ARVI and EVI had Kappa index values close to 90% and can be used to monitor the crop. VDVI was inefficient, with a low Kappa index value when compared to the others. The proposed classification for vegetation indices based on NDVI classes and values consisted of an important tool for classifying and interpreting the values of these indices, assisting monitoring and management of coffee cultivation.

INTRODUCTION

Brazil holds the title of the world's foremost producer and exporter of coffee, encompassing both Arabic and Robusta species across 15 Brazilian states (CECAFÉ, 2022). Total production in the 2021 growing season reached 47.71 million bags and is expected to reach 50.38 million bags in the 2022 growing season (CONAB, 2022). Therefore, the crop has a significant impact on the Brazilian economy.

Agricultural producers need quick and reliable information to make assertive decisions to minimize production costs and optimize processes in the field. In this context, the use of technologies and tools that use remote sensing principles are increasingly present to obtain such information, which can be acquired through different platforms such as satellites, drones, and aircraft. Images provided by the sensors have spatial, spectral, temporal, and radiometric resolution, which together with computer programs has a great value for obtaining a range of space-time information from any location on the planet (Queiroz et al., 2020).

Remote sensing, according to Monteiro et al. (2013), has become an important tool for identifying the areas occupied by crops, discriminating agricultural varieties, and estimating biophysical parameters used in agricultural productivity models, such as leaf area index (LAI). In addition to these applications, the estimation of crop biomass and productivity, monitoring of plant vigor, and assessment of the crop's phenological stage through vegetation indices also stand out. However, each index must be properly applied to provide as much correct information as possible. According to Nogueira et al. (2018), vegetation indices are sensitive to phenological changes and have been used in correlation with agricultural productivity.

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Area Editor: Job Teixeira de Oliveira
Received in: 11-26-2022
Accepted in: 11-3-2023

According to Fabri et al. (2023), NDVI presents the highest correlation with coffee biophysical variables, such as height and diameter, among the tested vegetation indices (NDRE, GLI, and NDVI). In contrast, Costa (2019) found no correlation between agronomic components (nodes, foliage, growth, and leaf area) and NDVI and NDRE. Luna et al. (2020) emphasized the challenge of selecting a vegetation index, highlighting that SAVI can estimate leaf area, EVI can assess water content, and NDVI is suitable for biomass estimation. Nogueira et al. (2018) assessed coffee productivity and NDVI and SAVI values based on the phenological stages during the 2013/2014 (low productivity) and 2014/2015 (high productivity) agricultural years. Their findings revealed that NDVI emerged as the most effective index for estimating coffee productivity during the high-production year, as opposed to the year characterized by low production.

In this sense, it is imperative to conduct further studies focused on identifying vegetation indices that effectively capture the characteristics of the coffee crop. Therefore, this study aimed to evaluate the vegetative state of the coffee crop using vegetation indices (NDVI, SAVI, ARVI, EVI, and VDVI) in an agricultural year using images from Planet Team (2017).

MATERIAL AND METHODS

The study was conducted in a 63.34 ha property located in the municipality of Romaria – MG, Triângulo Mineiro region, Brazil, and present in the Cerrado biome (Figure 1). The property is located in UTM zone 23 S at central coordinates 226425.7 m and 7915861.5 m, with an average altitude of 991 m with an average slope of 4.49%.

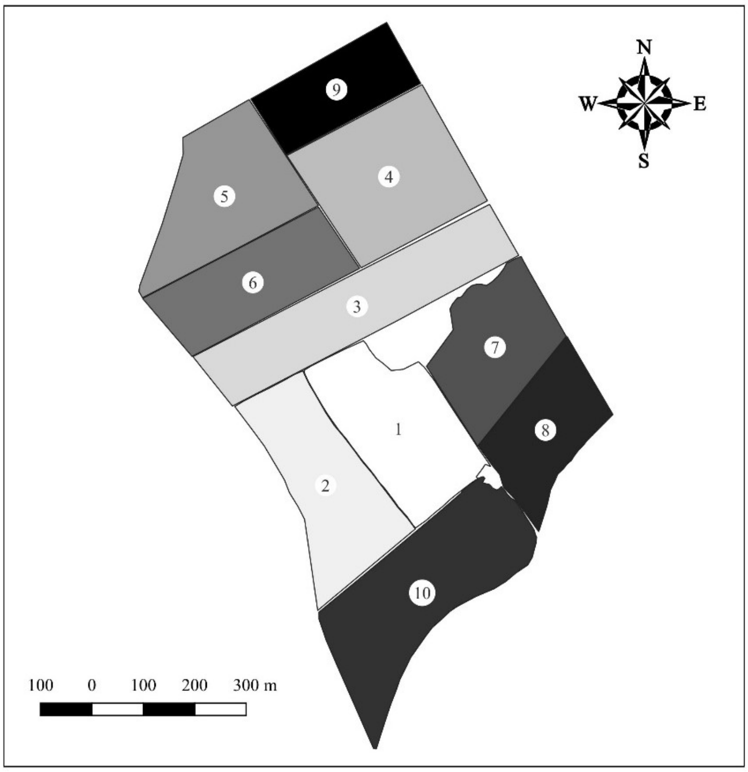

FIGURE 1. Plots used in the experiment.

The property had the Cerrado vegetation until 1985 when coffee transplanting commenced in plots 3 and 5. Subsequently, other plots underwent transplanting at later dates; however, the exact records for these transplanting practices are not available. The average crop spacing is 4.0 m between rows and 1 meter between plants. The Arabic coffee is planted in the area, with plots 1, 2, 3, 4, 6, 7, and 8 consisting of the Mundo Novo variety, plots 5 and 9 the Catuaí variety, and plot 10 could not be identified, but it is more associated with Catuaí varieties.

The meteorological data for the period during which the experiment was conducted come from rain gauge point 13,240 of the Sismet Cooxupé monitoring system (Figure 2), which records rainfall data in the property. Temperature and humidity came from the weather station of the Cooperativa Regional de Cafeicultores em Guaxupé Ltda (Cooxupé), retrieved from the Web platform SISMET.

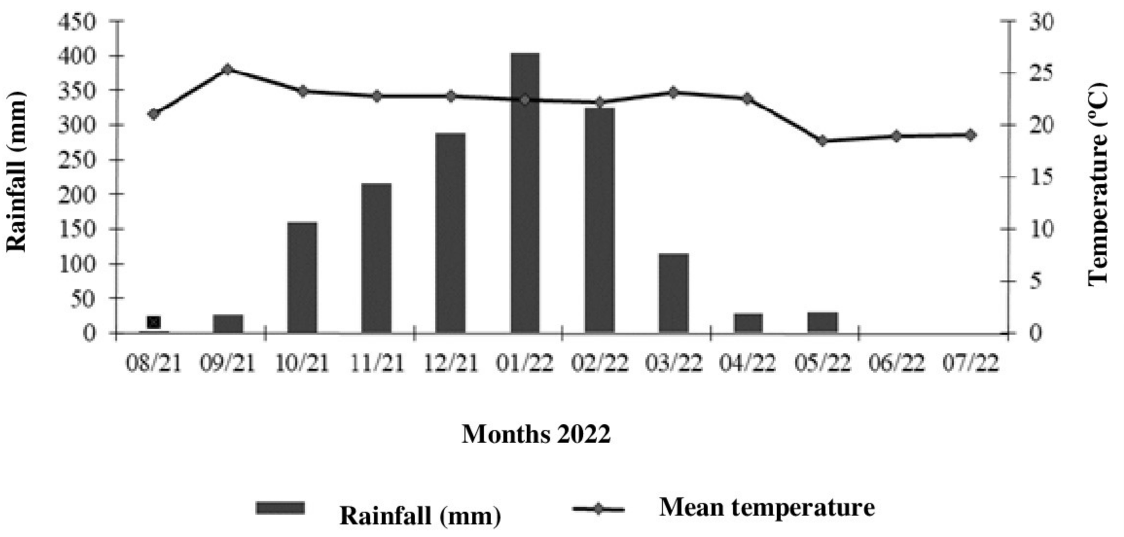

FIGURE 2. Rainfall (point 13240) and average air temperature in 2021/2022. Source: Sismet Cooxupé (2022).

Orbital images from August 2021 to July 2022 of the selected property, used to determine vegetation indices (VIs), were obtained from the PlanetScope platform (Planet Team, 2022a). The images were obtained from the Super Dove sensor (PSB.SD), which has an orbit of 475–525 km, 98° inclination, daily revisit, and images with 12 bits of radiometric resolution in the WGS84 Web Mercator projection (EPSG:3857) (Planet Team, 2022a).

The last image available for each month without cloud cover in the area of interest was downloaded from the Planet catalog. The images were acquired from the Super Dove sensor (PSB.SD), with correction level 3B, which has four bands (red, green, blue, and NIR – near infrared), being orthorectified, with surface reflectance (SR) and spatial resolution of 3 m, according to Planet Team (2022b). The image dates were 7/26/2022, 6/24/2022, 5/29/2022, 4/26/2022, 3/10/2022, 2/25/2022, 1/23/2022, 12/10/2021, 11/25/2021, 10/9/2021, and 9/27/2021, 8/31/2021.

The following bands were used to obtain the vegetation indices (VIs): B1, referring to the blue wavelength; B2, green; B3, red; and B4, near-infrared. The Planet images were processed using the free software QGIS Desktop 3.24.2. (QGIS.org, 2022) to obtain the vegetation indices.

The most commonly used vegetation index is the Normalized Difference Vegetation Index (NDVI). The Soil-Adjusted Vegetation Index (SAVI) is similar to NDVI, but with the application of the L constant to mitigate the influence of soil reflectance. The Atmospherically Resistant Vegetation Index (ARVI) is used to interpret planting stresses and analyze vegetation in environments with low sensitivity to atmospheric effects. The Enhanced Vegetation Index (EVI) originated from the combination of ARVI and SAVI, presenting correction for soil, atmosphere, and dense biomass. The Visible Difference Vegetation Index (VDVI) uses all bands of the visible spectrum (green, red, and blue), with results ranging from −1 to 1. The VIs were calculated following the mathematical expressions by Rouse et al. (1973) for the Normalized Difference Vegetation Index (NDVI), Huete (1988) for the Soil-Adjusted Vegetation Index (SAVI), Kaufman & Tanré (1992) for the Atmospheric Resistant Vegetation Index (ARVI), Huete et al. (2002) for the Enhanced Vegetation Index (EVI), and Wang et al. (2015) for the Visible Difference Vegetation Index (VDVI).

Five interpretation classes were established for the other indices, based on the NDVI interpretation classes of 0–0.20, 0.20–0.40, 0.40–0.60, 0.60–0.80, and 0.80–1.0 (Aquino & Oliveira, 2012), allowing their comparison because the indices vary out of the NDVI limits of −1 to +1.

The interpretation classes of the other indices were obtained by matching the minimum and maximum values of each index within the range stipulated in NDVI. This procedure was carried out in the QGIS software by extracting the raster data (indices) into a single matrix, in which each pixel (grid) contained all the index values in the evaluated twelve months. Thus, it enabled to filtering of the minimum and maximum values of each index in the NDVI interpretation range. Subsequently, the minimum and maximum data were organized in an electronic spreadsheet, with the mean of the twelve months being calculated per interpretation class. An analysis was conducted on the minimum and maximum values of each index using the mean data spreadsheet for each class, as the minimum and maximum values in several classes did not allow sequential class formation because they exceeded the values between one class and another. In this case, the mean between the minimum and maximum intervals was once again calculated to establish the limits of interpretation.

The VI data were initially subjected to descriptive analysis to obtain measures of central tendency and dispersion for the entire area. The Kappa index (Cohen, 1960) was calculated to compare the VI maps considering the NDVI as a control, as it is the most used and consists of a reference for the other indices.

RESULTS AND DISCUSSION

The mean values of the vegetation indices for 2021 were discrepant on all dates, allowing differentiation between those with higher (EVI and SAVI) and lower values (VDVI and ARVI) and the NDVI presenting mean values (Table 1).

TABLE 1. Summary of vegetation index data for the year 08/2021-01/2022.

Total	Parameter						
	Index	Mean	Minimum	Maximum	Range	SD	CV (%)
8/31/2021	NDVI	0.72	0.27	0.92	0.65	0.09	12.50
	SAVI	1.09	0.41	1.38	0.98	0.13	11.93
	ARVI	0.67	-0.01	0.96	0.96	0.12	17.91
	EVI	1.43	0.31	2.52	2.21	0.31	21.68
	VDVI	0.08	-0.16	0.43	0.59	0.08	100.00
9/27/2021	NDVI	0.68	0.23	0.83	0.59	0.07	10.29
	SAVI	1.02	0.35	1.25	0.89	0.11	10.78
	ARVI	0.53	-0.02	0.76	0.78	0.10	18.87
	EVI	1.26	0.29	1.93	1.64	0.22	17.46
	VDVI	-0.02	-0.21	0.18	0.40	0.05	250.00
10/9/2021	NDVI	0.61	0.14	0.75	0.61	0.07	11.48
	SAVI	0.91	0.21	1.13	0.91	0.10	10.99
	ARVI	0.54	-0.17	0.74	0.91	0.10	18.52
	EVI	1.15	0.16	1.70	1.53	0.21	18.26
	VDVI	-0.01	-0.24	0.28	0.52	0.04	400.00
11/25/2021	NDVI	0.74	0.16	0.86	0.70	0.08	10.81
	SAVI	1.10	0.24	1.29	1.05	0.11	10.00
	ARVI	0.62	-0.06	0.80	0.87	0.10	16.13
	EVI	1.54	0.22	2.07	1.85	0.24	15.58
	VDVI	0.07	-0.14	0.25	0.40	0.05	71.43
12/10/2021	NDVI	0.76	0.17	0.87	0.70	0.08	10.53
	SAVI	1.15	0.26	1.31	1.06	0.12	10.43
	ARVI	0.67	-0.05	0.84	0.89	0.11	16.42
	EVI	1.71	0.25	2.23	1.99	0.27	15.79
	VDVI	0.12	-0.11	0.25	0.37	0.05	41.67
1/23/2022	NDVI	0.80	0.36	0.87	0.51	0.06	7.50
	SAVI	1.19	0.54	1.30	0.76	0.09	7.56
	ARVI	0.77	0.15	0.88	0.73	0.08	10.39
	EVI	2.31	0.56	3.49	2.93	0.28	12.12
	VDVI	0.12	-0.09	0.23	0.32	0.04	33.33

SD = standard deviation; CV = coefficient of variation.

The lowest coefficients of variation were observed for SAVI and NDVI, while the highest values were observed for EVI and VDVI (Table 1). This high CV value for EVI can be explained by the higher range and standard deviation observed on all dates, indicating a higher degree of dispersion of observations associated with this vegetation index. In contrast, although VDVI had a trend towards lower values for range and standard deviation compared to the other indices, the dispersion resulting from the higher number of observations with low values and, consequently, the occurrence of a low number of possible outliers (high values), was significantly reflected in the high CV values on all dates.

The lowest degrees of dispersion were observed for NDVI and SAVI (Table 1), which may be an indication of possible stability and better adjustment of these indices in coffee cultivation. These indices demonstrate a correlation with leaf area indices in eucalyptus plantations based on TM – Landsat 5 images. However, future studies would require correcting the soil effects constant for the studied area when considering SAVI. This correction is crucial for enhancing the accuracy of biophysical parameter estimation (Almeida et al., 2015).

Similarly, discrepant mean values for the vegetation indices on all dates could be observed in the other months (Table 2), with a higher degree of dispersion for EVI and VDVI and lower for NDVI and SAVI. It indicates the stability of these indices regardless of the variability of environmental conditions and, mainly, the phenological stage of coffee plants when the images were obtained. Leite et al. (2017) conducted a temporal analysis of the dynamics of land use at the Itatinga Experimental Station – SP in 2013 and 2015 using NDVI and SAVI through the Operational Land Imager (OLI) sensor in the Landsat 8 satellite and observed that both indices presented approximate results. However, the use of NDVI was more appropriate due to the high vegetation density of the study site.

TABLE 2. Summary of the vegetation index data from February to July 2022.

Total	Parameter						
	Index	Mean	Minimum	Maximum	Range	SD	CV (%)
2/25/2022	NDVI	0.84	0.12	0.97	0.85	0.08	9.52
	SAVI	1.26	0.18	1.45	1.28	0.12	9.52
	ARVI	0.80	-0.20	1.04	1.25	0.12	15.00
	EVI	2.14	0.10	3.50	3.40	0.38	17.76
	VDVI	0.16	-0.67	0.40	1.07	0.07	43.75
3/10/2022	NDVI	0.86	0.29	0.96	0.67	0.07	8.14
	SAVI	1.28	0.44	1.45	1.00	0.11	8.59
	ARVI	0.81	0.04	0.99	0.95	0.11	13.58
	EVI	2.08	0.38	2.82	2.43	0.33	15.87
	VDVI	0.20	-0.13	0.47	0.60	0.08	40.00
4/26/2022	NDVI	0.78	0.05	0.92	0.87	0.09	11.54
	SAVI	1.16	0.08	1.38	1.31	0.14	12.07
	ARVI	0.69	-0.16	0.94	1.10	0.14	20.29
	EVI	1.82	0.07	2.78	2.71	0.43	23.63
	VDVI	0.09	-0.34	0.58	0.92	0.06	66.67
5/29/2022	NDVI	0.76	0.14	0.94	0.85	0.09	11.84
	SAVI	1.14	0.21	1.42	1.21	0.14	12.28
	ARVI	0.67	-0.07	0.97	1.04	0.14	20.90
	EVI	1.73	0.23	2.82	2.60	0.38	21.97
	VDVI	0.12	-0.33	0.40	0.73	0.08	66.67
6/24/2022	NDVI	0.76	0.19	0.93	0.74	0.10	13.16
	SAVI	1.14	0.28	1.39	1.11	0.15	13.16
	ARVI	0.67	-0.70	0.94	1.02	0.15	22.39
	EVI	1.74	0.22	2.98	2.76	0.44	25.29
	VDVI	0.10	-0.18	0.35	0.52	0.08	80.00
7/26/2022	NDVI	0.73	0.15	0.92	0.77	0.10	13.70
	SAVI	1.09	0.23	1.38	1.16	0.15	13.76
	ARVI	0.61	-0.12	0.94	1.06	0.15	24.59
	EVI	1.53	0.17	3.52	3.35	0.40	26.14
	VDVI	0.09	-0.15	0.40	0.54	0.08	88.89

SD = standard deviation; CV = coefficient of variation.

NDVI, SAVI, ARVI, and EVI (Figure 3) had a predominance of the light green class until the fifth month (12/21), a predominance of the dark green class sixth for the seventh and eighth months (01/22, 02/22, and 03/22), and a predominance of light and dark green classes in April (04/22), with balanced proportions in the area. Importantly, a slight increase in the index was observed in the rainy season (11/21 to 03/22) when it reached the dark green class, indicating higher vegetation cover.

Leite et al. (2017) evaluated eucalyptus plantations and observed that reduced values obtained for NDVI were related to areas with lower vegetation cover, such as exposed soil, roads, post-harvest areas, and plantations at initial growth stages.

The obtained NDVI values (Figure 3) ranged from 0.2 to values higher than 0.8, with the lowest values for exposed soils and roads. The spatialization obtained for SAVI was similar to that for NDVI, but the range had higher values, varying from 0.32 to values higher than 1.18. In contrast to these results, Leite et al. (2017) found NDVI values of 0.45 to 0.89 in eucalyptus plantations in 2013 and 0.41 to 0.91 in 2015, while SAVI values ranged from 0.28 to 0.65 in 2013 and 0.27 to 0.71 in 2015. According to the authors, advances in values in these indices could be justified by the development of eucalyptus plants in the period studied, with a higher planting density and vegetative vigor identified in 2015.

VDVI (Figure 3) showed a higher discrepancy in the spatial representation of the vigor of coffee cultivation compared to the other indices, but the spatialization in March 2022 was similar to that observed in the other maps. This result is related to the scale used for the index and the high dispersion of spatial observations on all dates, indicating that this is not an index or that it requires a larger time series to be used in monitoring coffee cultivation under the studied conditions.

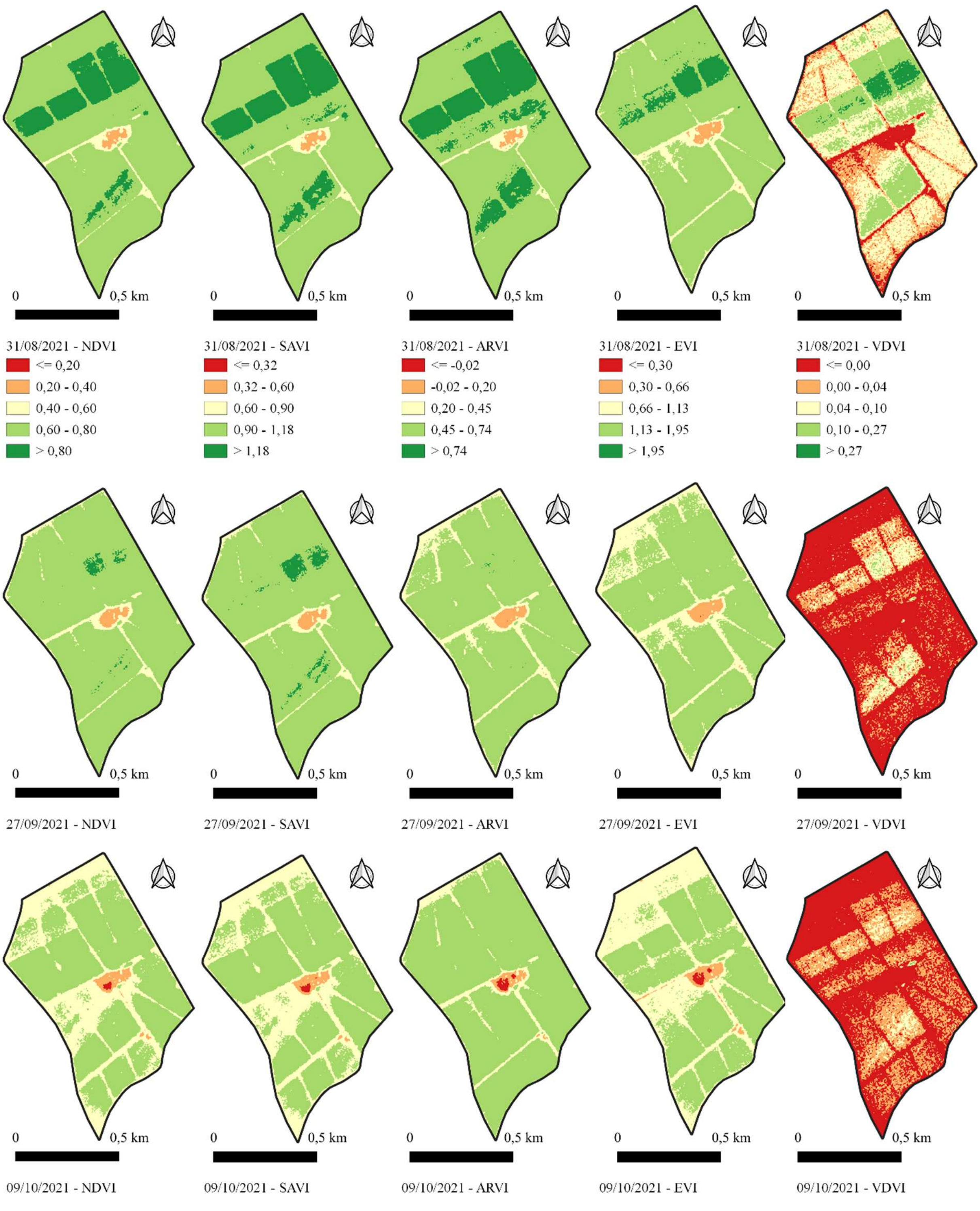

FIGURE 3. Vegetation indices classified according to the proposed interpretation.

FIGURE 3. (continued).

FIGURE 3. (continued).

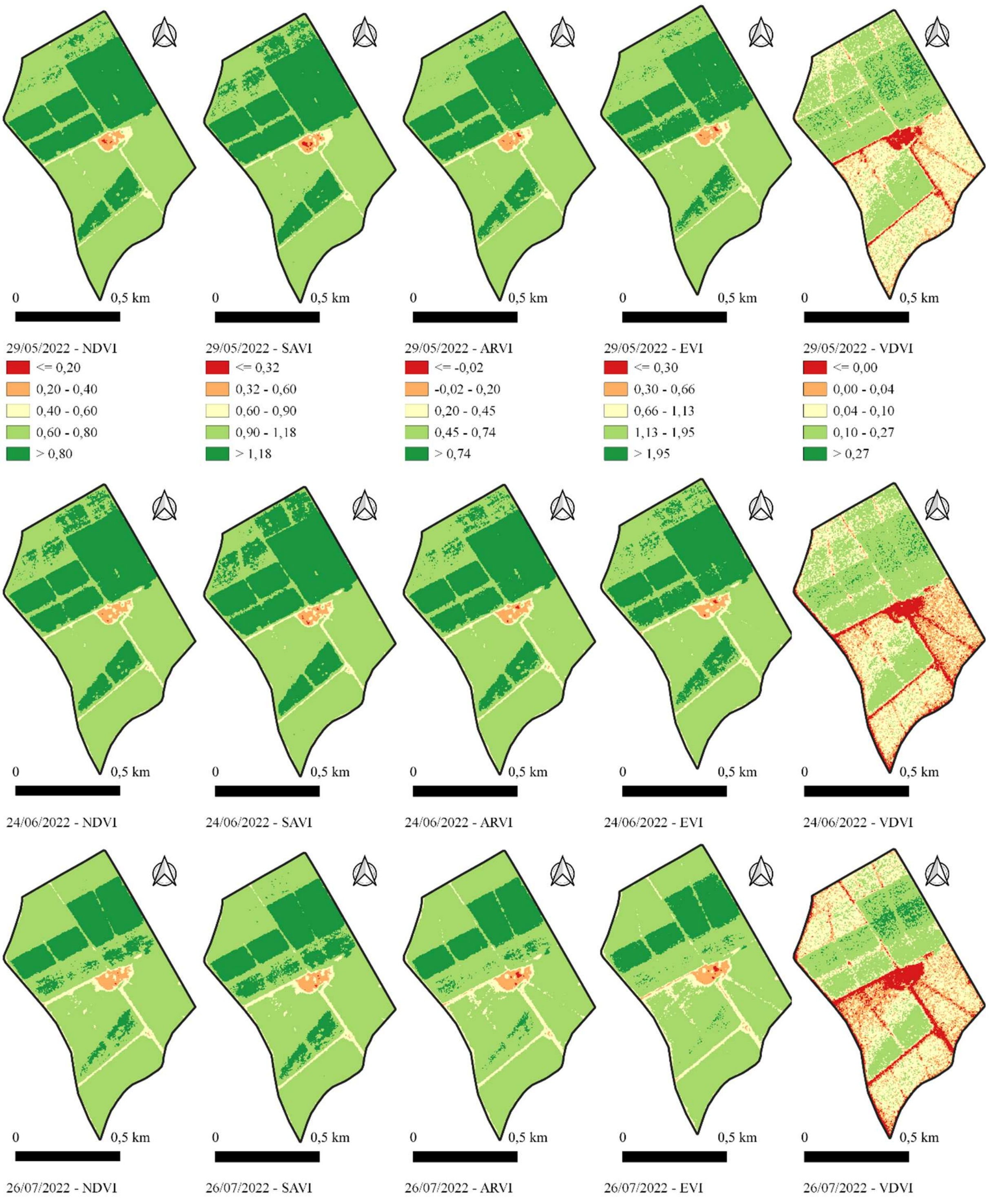

FIGURE 3 (continued).

The variation in the indices (minimum and maximum) as a function of NDVI was determined based on the interpretation of the vegetation indices for coffee by the NDVI observed in the maps in Figure 3 and the proposed interpretation of NDVI for coffee, based on Table 3. It allowed the establishment of a proposal for classes and intervals for interpreting vegetation indices in coffee cultivation (Table 3).

TABLE 3. Interpretation and proposed analysis of NDVI for coffee using the maps in Figure 3 as a reference.

Class	NDVI	Proposal – Interpretation – Coffee
1	0.0–0.2	No vegetation or non-vegetation targets
2	0.2–0.4	Soil/non-vegetation targets
3	0.4–0.6	Soil/non-vegetation targets/Coffee plants under unfavorable climate conditions
4	0.6–0.8	Coffee plants in vegetation activity
5	0.8–1.0	Coffee plants at maximum vegetation activity

Class	NDVI	SAVI	ARVI	EVI	VDVI
1	0.00–0.20	0.00–0.32	-1.00–0.02	0.00–0.30	-1.00–0.00
2	0.20–0.40	0.32–0.60	-0.02–0.20	0.30–0.66	0.00–0.04
3	0.40–0.60	0.60–0.90	0.20–0.45	0.66–1.13	0.04–0.10
4	0.60–0.80	0.90–1.18	0.45–0.74	1.13–1.95	0.10–0.27
5	0.80–0.92	1.18–1.50	0.74–1.00	1.95–4.00	0.27–0.50

Leite et al. (2017) compared the range of variation between NDVI and SAVI and observed that the higher range presented by SAVI could indicate preference in choosing it over NDVI. In fact, the higher range of the index reflects a higher detail of vegetated areas in contrast to exposed and/or impermeable soils (Xu, 2007). Moreover, the study area is more densely vegetated, though not as much as the eucalyptus plantation. Consequently, the soil's impact on the final spectral results must be taken into consideration. This emphasizes the suitability of using both SAVI and NDVI for accurate vegetation representation, supporting their application in monitoring the coffee area under investigation.

These results indicate that vegetation indices may be sensitive to coffee vegetation cover. In this sense, Nogueira et al. (2018) stated that the indices could express the relationships between leaf phytomass and coffee productivity. The authors observed that NDVI presented the best correlations with productivity at dormancy and flowering stages in two years of study. This index explained the productivity variation between 62% and 89% of the data observed at the dormancy stage and 58% to 73% at flowering. However, they observed that SAVI presented a lower relationship with productivity than NDVI and NDWI in the 2013/2014 and 2014/2015 growing seasons.

The Kappa index showed an excellent quality of the NDVI thematic map with the SAVI index (Landis & Koch, 1977) on all dates, with overall accuracy exceeding 91%. On the other hand, the Kappa index showed fair (0.2 to 0.4), good (0.4 to 0.6), very good (0.6 to 0.8), and excellent (0.8 to 1.0) map qualities for ARVI and EVI compared to NDVI, according to Landis & Koch (1977). However, ARVI was superior to EVI both in map quality, ranging from very good to excellent, and in overall accuracy on all dates, except 10/9/21. Finally, the maps presented poor or poor quality when compared to VDVI.

NDVI and SAVI were promising in this study as tools for monitoring coffee cultivation. However, longer-lasting studies are necessary, as this is a perennial crop, associated with the use of other analysis methods to validate the indices and establish a relationship between them and crop productivity. Therefore, SAVI proved to be efficient under the conditions in which this research was carried out and could be an alternative to NDVI.

CONCLUSIONS

NDVI and SAVI are efficient in monitoring coffee cultivation in an agricultural year since the Kappa index was higher than 90%. ARVI and EVI had Kappa index values close to 90% and can be used to monitor the crop. VDVI was inefficient, with a low Kappa index value when compared to the others.

The proposed classification for the other vegetation indices based on NDVI classes and values constitutes an important tool for classifying and interpreting their values, assisting monitoring and management of coffee cultivation. The proposed classes and intervals for interpretation for VDVI were not adequate, requiring further studies.

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