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FROST ON SUGARCANE CROP IN RIO BRILHANTE – MS

GEADA NA CULTURA DA CANA-DE-AÇÚCAR EM RIO BRILHANTE - MS

HELADA EN CULTIVO DE CAÑA DE AZÚCAR EN RIO BRILHANTE – MS

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ABSTRACT

The municipality of Rio Brilhante, in the state of Mato Grosso do Sul, is the second largest sugarcane planted area in Brazil. The 2021/22 harvest showed a drop of 10.60%, mainly due to frost and drought. This work consisted of procedures to monitor the damage caused by frost in the months of June and July of 2021 in sugarcane crops. High-resolution satellite images were used, providing accurate spectral data for monitoring and estimating the sugarcane cultivation area affected by frost. To obtain this result, we used Normalized Difference Vegetation Index (NDVI) technology, which indicates vegetation growth activity and has a strong correlation with dry matter. The experiment was conducted on ten farms in the aforementioned municipality, before and after the frost. The variables evaluated were: bud mortality; lateral sprouting; insulation of internodes; and NDVI. The effect of the occurrence of frost on the crop that could be observed most frequently was the death of the apical bud. No significant damage was observed when isolating. The NDVI images were extremely important for carrying out this analysis.

RESUMO

O município de Rio Brilhante, no estado de Mato Grosso do Sul é o segundo em área plantada de cana-de-açúcar do Brasil. A safra de 2021/22 apresentou queda de 10,60%, devido, principalmente, à geada e estiagem. Este trabalho constituiu-se em procedimentos para monitorar os danos causados pela geada nos meses de junho e julho de 2021, em lavouras de cana-de-açúcar. Foram utilizadas imagens de satélites de alta resolução fornecendo dados espectrais precisos para o monitoramento e estimativa da área de cultivo da cana-de-açúcar afetada por consequência da geada. Para obter tal resultado, utilizamos a tecnologia de NDVI (Índice de Vegetação por Diferença Normalizada), que indica a atividade de crescimento da vegetação e tem uma forte correlação com a matéria seca. O experimento foi conduzido em dez fazendas no município, antes e depois da ocorrência da geada. As variáveis avaliadas foram: mortalidade de gemas; brotação lateral; isoporização de entrenós; e NDVI. Os efeitos da ocorrência da geada na cultura que puderam ser observados com mais frequência, foi a morte da gema apical. Na isoporização não foi observado nenhum dano significativo. As imagens de NDVI foram de suma importância para realização desta análise.

RESUMEN

El municipio de Rio Brilhante, en el estado de Mato Grosso do Sul, es la segunda mayor área plantada de caña de azúcar en Brasil. La cosecha 2021/22 cayó un 10,60%, principalmente por las heladas y la sequía. Este trabajo consistió en procedimientos para monitorear los daños ocasionados por heladas en los meses de junio y julio de 2021, en cultivos de caña de azúcar. Se utilizaron imágenes satelitales de alta resolución, que proporcionaron datos espectrales precisos para monitorear y estimar el área de cultivo de caña de azúcar afectada por las heladas. Para obtener este resultado, utilizamos la tecnología NDVI (Normalized Difference Vegetation Index), que indica la actividad de crecimiento de la vegetación y tiene una fuerte correlación con la materia seca. El experimento se realizó en diez fincas del municipio, antes y después de la ocurrencia de las heladas. Las variables evaluadas fueron: mortalidad de yemas; brotación lateral; isoporización de entrenudos; y NDVI. El efecto de la ocurrencia de heladas en el cultivo que se pudo observar con mayor frecuencia fue la muerte de la yema apical. En la isoporización no se observaron daños significativos. Las imágenes NDVI fueron de suma importancia para este análisis.

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1. INTRODUCTION

In 2001, the state of Mato Grosso do Sul became a major financier of the sugarcane growth process and intervened directly in the price of land, thus providing good situations for the installation of industries in the field, as well as the expansion of the country through the sugar sector and alcohol industry (Domingues, 2010).

From 2003 onwards, there was a great expansion of sugarcane cultivation in Brazil, driven by the increase in demand for ethanol and alternative energy sources (Gilio and Morales, 2016). From the year mentioned until mid-2016, the area planted with sugarcane practically doubled in the country, incorporating around a new 4.9 million hectares (IBGE, 2021).

The Central-West region assumed a position of growth in sugarcane production, becoming the second largest producer in the country (Meurer et al., 2015; Demattê et al., 2014). The state of Mato Grosso do Sul has favorable climatic conditions for such cultivation, with larger and flatter areas, which facilitate operations through mechanization; also, it´s a region that is located close to the main consumer markets (Granco et al., 2015).

With two sugar-energy units in operation, Rio Brilhante allocates 97 thousand hectares of area for the cultivation of sugarcane, being the second largest sugarcane planted area in the country. In 2018, the crushing of raw material in the municipality totaled 7. 8 million tons (Duarte, 2011).

Sugarcane (*Saccharum officinarum*) is a perennial crop that produces for 4 to 6 years. There is a certain ease in its implementation and management, reaching green mass yields above 120 t/ha/year, with maturation during the dry period. Productivity and longevity are regulated by several factors, among which the following stand out: chosen variety, soil fertility, climatic conditions, cultural practices, pest and disease control, and harvesting method. The adequacy of these production factors is important for maximizing the production and longevity of the sugarcane field (Townsend, 2015).

Among the climatic factors, frost is one that directly influences the development of sugarcane plants. According to CONAB (2021), in Mato Grosso do Sul, adverse climatic factors such as the drought that occurred between May and June 2021, as well as the intense frost recorded in the first week of July of the same yearend the dry period that followed, harmed the yield of crops. Brazilian sugarcane production in the 2021/22 harvest recorded a total of 585.2 million tons, a volume that represents a drop of 10.60% compared to the previous 2020/21 harvest.

Meteorology refers to the occurrence of frost, when there is deposition and formation of ice on plants and objects exposed to the open air. This occurs when the air temperature reaches 0 °C and there is humidity in the atmosphere (Rossi et al., 2016). The authors also state that it is an atmospheric phenomenon that causes the death of plants or their parts (leaves, stems, fruits, branches) causing freezing of plant tissues and there may be ice on the plant.

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Currently, tools are used with the technological function of productivity control, system sustainability and optimization of resources and profits. One of these tools is known as the Normalized Difference Vegetation Index (NDVI), and it is used for remote sensing, assisting in management practices and recognition of cultivated areas, in addition to enabling the determination of the vegetation index, through the reading of the reflectance in the near-infrared and red bands, related to photosynthetic activity. With this, it is possible to monitor and determine the accumulation of crop biomass. In short, the amount of reflectance of the leaves is measured, in which the greener the leaf, the greater its reflectance, making it possible to analyze the plant's nutrition, health, water deficit and others (Fontana et al., 2019).

Thus, the objective of this work was to evaluate the effects of frost on sugarcane cultivation, on ten farms in the region of Rio Brilhante, Mato Grosso do Sul, analyzing interference factors and the NDVI.

2. MATERIAL AND METHODS

The experiment was conducted on ten farms located in the municipality of Rio Brilhante - MS as shown in the table below:

Table 1. Farms sampled followed and coordinates of sampling points.

Farm	Latitude	Longitude
Esteio Farm	21°27’27,0”S	56°36’54,0”W
São Carlos Farm	21°38’08,3”S	54°46’13,7”W
Duas Marias Farm	21°40’20,2”S	54°33’29,7”W
Proteção Farm	21°43’33,6”S	54°44’04,1”W
Pitanga Farm	21°44’52,3”S	54°30’45,9”W
Celeiro II Farm	21°33’45,7”S	54°38’50,5”W
Passa Tempo Farm	21°29’25,9”S	54°44’14,8”W
Sossego Farm	21°25’32,7”S	54°44’57,4”W
Dallas Farm	21°19’48,9”S	54°39’11,1”W
Estreito P11 Farm	21°31’24,1”S	54°38’50,5”W

According to Fietz et al. (2017), the Köppen climate classification type characteristic of the study region is Cwa (humid mesothermal climate, hot summers and dry winters). Rainfall in summer is practically daily and average monthly totals vary from 145 mm in February to 180 mm in December.

To evaluate the NDVI, sampling points were analyzed in two stages, the first before the occurrence of frost on July 10, 2021, and the second after the occurrence, on August 18, 2021. For each farm, samples were taken from four to 5 five points per plot, distributed to represent the entire plot.

At each sampling point, five sugarcane plants were taken, cutting the pointer in the longitudinal direction. The quality of the lateral buds was evaluated from top to bottom on the culm by removing them and observing the occurrence of darkening at this point. If the color observed was brown or black, we considered that the lateral bud was dead. If there is no death of the first five lateral buds, we consider that there was no death of lateral buds on the culm.

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The apical buds were analyzed through longitudinal section. After observing the color of the growth region, if the color observed is brown or black, we consider the apical buds dead. The evaluation criteria were as follows: 0 (blue) – unaffected, 1 (green) with burning of leaves and no death of buds, 2 (yellow) with death of apical buds, 3 (red) with death of apical and lateral buds.

Looking at the maps, we present a construction using NDVI time series, based on the red and infrared bands from the Landsat-8 and Sentinel satellites. We used the spectral bands according to the calculation by Rouse et al. (1974), in which the NDVI vegetation indices were the red (RED) and near infrared (NIR) bands whose formula used was:

$$NDVI = (NIR - RED) \div (NIR + RED)$$

According to the United States Geological Survey (USGS,2020), for each satellite there is a color band. In the case of the Landsat 8 satellite, bands 4 and 5 are used to calculate the NDVI vegetation index, with band 4 being RED and band 5 NIR. For the Sentinel satellite, it´s used the bands 3 (RED) and 8 (NIR).

To perform image processing and extract precise information from occurrences, QGIS software was used. It is an Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official Open Source Geospatial Foundation (OSGeo) project.

A multivariate redundancy analysis (RDA) was conducted in order to explore linear relationships between bud mortality; lateral sprouting; insulation of internodes; NDVI (matrix of response variables); and the points and varieties (matrix of explanatory variables), with the significance of the linear relationship being tested using 1000 permutations. For this purpose, the XLSTAT (2019) software (AddinSoft, 2019) was used.

3. RESULTS AND DISCUSSION

Table 2 shows the climate data for the city of Rio Brilhante - MS in 2021, in which region frosts occurred, with a minimum temperature of -2.20 °C being recorded on July 20th, and on the 29th it reached -2.60 °C. In the month of June, on the 29th, a temperature of 1.60 °C was recorded, and on the 30th, it reached -3 °C (CEMTEC, 2021).

It is worth mentioning that temperatures up to 30 °C increase the photosynthetic rate of sugarcane; however, temperatures below 15 °C cause inhibition of photosynthesis and vegetative growth. Therefore, plants with C4 metabolism are rare in places where temperatures are below 16 °C (Sales et al., 2013).

However, sugarcane varieties may present different sensitivity to cold up to certain temperatures. The temperature at the bud sprouting stage affects the number of stalks, the growth and the final production of industrializable stalks. It is reported that all these variables present higher values when the temperature is around 30 °C, while temperatures lower than 20 °C and higher than 35 °C result in lower values. The minimum temperature for sugarcane emergence is 12 °C (Tatoo et al., 2017).

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Table 1. Climate Data for the year 2022 in Rio Brilhante - MS

Climate Data						
Moths	Max. Temp.	Mín. Temp.	Max. Humidity	Mín. Humidity	Precipitation mm	Frost Occurrence
January	14,50	19,50	97,6	38	505	No
February	37,5	12,9	97,4	22	71	No
March	36,90	15,40	96,13	22	53	No
April	35,60	6,70	93,9	22	31	No
May	34,70	2,60	94,7	21	0	No
June	34,20	-3	95,4	22	76	Yes
July	35,20	-2,60	89,3	12	0	Yes
August	38,60	5	80,7	11	38	No
September	41,6	12,6	85,4	12	30	No
October	40	13	93,8	24	148	No
November	37,5	15,5	93,6	25	153	No
December	3,40	14,60	93,1	19	46	No

Source: CEMTEC/MS, 2021.

In mapping using NDVI technology, it was possible to verify the difference in the vegetative vigor of sugarcane plants, when before the occurrence of frost, the sugarcane field presented higher reflectance values, in all bands, indicating plants that were more vigorous than 30 days after the frost, when the values were lower Figure 1 and 2 show the NDVI results before and after the frost.

Figure 1. Normalized Difference Vegetation Index (NDVI) before frost.

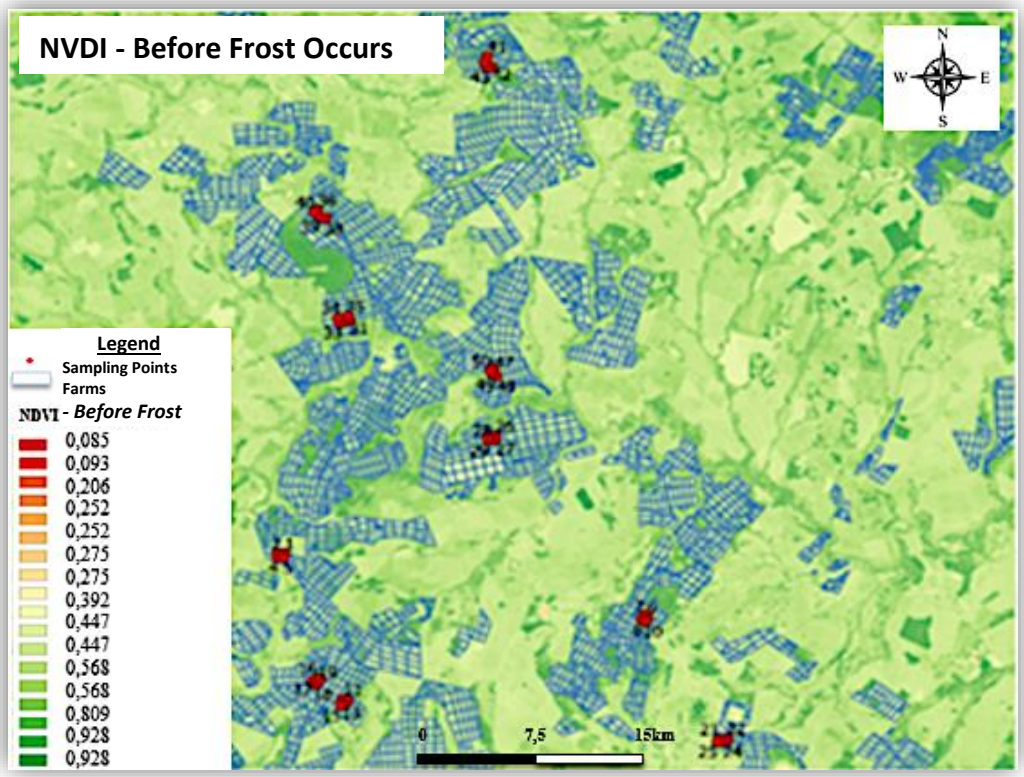

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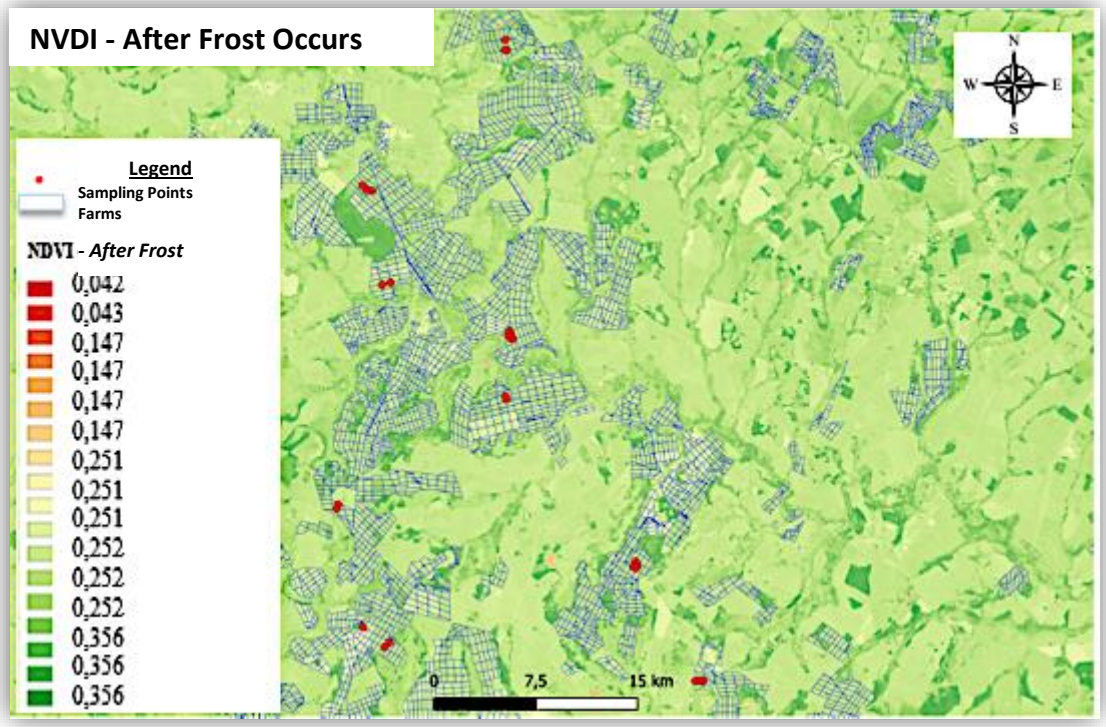
Figure 2. Normalized Difference Vegetation Index (NDVI) after 30 days of frost.



The reflectance spectrum of a normal green leaf, in a range of 400 nm and 2500 nm, can be subdivided into three spectral regions: visible; near infrared; and shortwave infrared. In visible light, the reflectance is very low (red and blue), peaking at 550 nm, that is, a significant decrease in absorption, which explains why vegetation is seen in green. This is caused by two absorption bands of chlorophyll, centered at approximately 450 nm and 650 nm.

When the absorption is approximately 700 nm, it then passes into the near-infrared region, an increase in reflectance begins, this point being called red edge. It is considered the limit between absorption by chlorophyll in the red and near-infrared scattering, caused by the internal structure of the leaves. In the near-infrared spectral region between 700 nm and 1300 nm, healthy green leaves demonstrate high reflectance values (45-50%), high transmittance (45-50%), and low absorptance (less than 5%) (Hoffer, 1978).

Robinson et al. (2014) state that the dry mass of sugarcane is composed of 0.3% to 2.0% nitrogen. It is understood that such quantity is present in the constitution of amino acids, proteins, amides, nucleic acids, nucleotides and enzymes. In leaves, a fraction of this nitrogen is directed to photosynthetic metabolism, in the construction of photoreceptors (chlorophylls) and carboxylation enzymes, ribulose-1,5-bisphosphate carboxylase/oxygenase (Rusco) and phosphoenolpyruvate carboxylase (PEPC). Thus, nitrogen availability is related to photosynthetic capacity, as well as plant productivity throughout its development (Marchiori et al., 2014).

Slovaková et al. (2011) divide plants according to their degree of sensitivity to cold: sensitive plants (generally below 15 °C, being harmed by the cold); resistant plants (able to tolerate

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the cold; however, they suffer damage when ice is formed in their tissues); and frost-resistant plants (able to tolerate very low temperatures: -50°C to -100°C). Based on this, it is understood that plants with C4 metabolism, such as sugarcane, require high thermal conditions to achieve efficient photosynthesis.

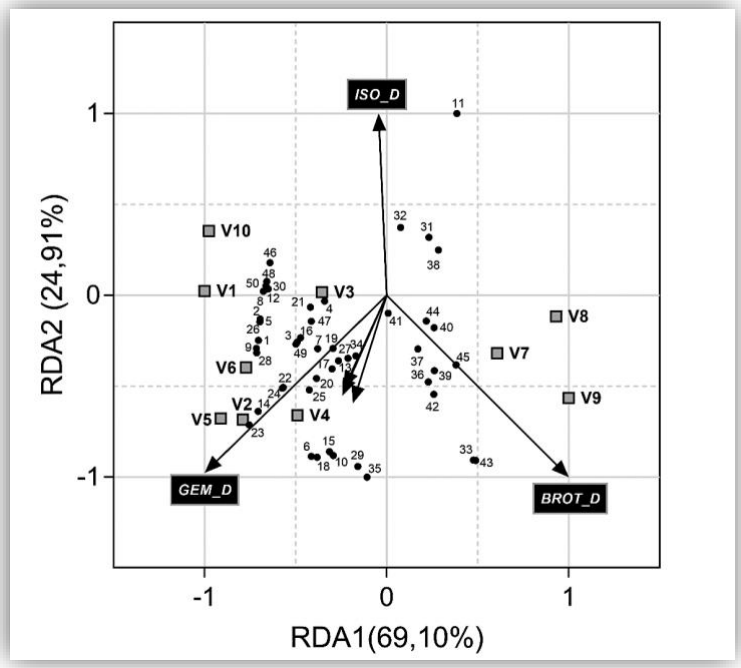
The C4 cycle can be divided into three phases: carboxylative, decarboxylative and regenerative. Atmospheric CO2 is fixed in the cytoplasm of mesophyll cells through a reaction catalyzed by PEPcase (carboxylative phase), containing oxaloacetic acid. After their formation, malate or aspartate are exported to the cells of the perivascular sheath, where they are exposed to decarboxylation reactions. The malate is broken down, releasing a molecule of CO_2, which is fixed by Rubisco and transformed into sugars (Kerbauy, 2019).

Rubisco corresponds to 50% of the soluble leaf protein in C3 leaves, whereas in C4 and CAM plants, its amount is only 25% of the soluble leaf protein, while PEPcase corresponds to 10% of the soluble leaf protein in C4 and CAM plants (Kerbauy, 2019).

Therefore, with the variation in NIR compared to red light, it was possible to identify a relationship with plant vigor. Therefore, we verified that there was a change in color in the sugarcane leaves in the regions affected by frost, proving that NDVI is an agricultural technology that can help manage crops with precision.

It was found that monitoring the evaluated parameters was extremely important to identify the quality and productivity of the crop. To this end, the analysis was deepened through spatial dependence, in order to verify the pattern of relationships between the parameters (Figure 3).

Figure 3. *Triplot* of the redundancy analysis between pith process (*ISO_D*), bud death (*GEM_D*) and lateral sprouting (*BROT_D*) of the sugarcane varieties (V1, V2, V3...V10) affected after frost, at the sampled points (point scatter).



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The relationship between the explanatory (varieties and sampling points) and response variables (pith process, bud death and lateral sprouting) are reflected by the angles between the vectors. Furthermore, the variables are more representative of the corresponding axis under observation, the further the vectors move away from the center of origin.

In general, the apical bud and lateral shoot of the varieties with the highest scores were 90109001; CTC6; CTC4; IACSP955000; B867510, and CTC15, on the RDA1 and RDA2 axes, respectively. As for the response variables, in RDA1, those that contributed most to the construction of the axis were lateral sprouting after frost (*BROT_D*) and bud mortality after frost (*GEM_D*), and in RDA2, internode pith process after frost (*ISO_D*).

The relationship of the variables is formed followed by the direction sign of the correlation between them and the axes: RDA1 [1 - ^{9} - ^{14} - ^{23} - ^{28} - ^{V1} - ^{V2} - V5 - V6 - V10 - GEM_D - V8 $^{+}$ *BROT_D* $^{+}$], RDA2 [6 - 10 - 15 - 18 - 29 - 33 - 35 - 43 - V4 - V6 - 11 $^{+}$ *ISO_D* $^{+}$]. The other variables had smaller or did not express relative contributions in the construction of the axes, as well as in the analysis of interactions.

In figure 3, it is possible to observe that the varieties 90109001, CTC15, CTC6 and CTC4 were those that showed the greatest damage, with the apical bud dead after frost, and the varieties RB966928, IACSP955000 and CTC20 were those that had the highest occurrence of lateral sprouting . Other data were not affected by frost.

According to Monteiro (2009), strong frosts promote the death of stem buds, thus resulting in the invasion of pathogens, reducing sucrose and its purity, increasing the acidity of the plant. Losses are minimized by bringing forward the cutting, the youngest sugarcane plants are left in the field for the development of new shoots, thus replacing the stalks affected by the intense cold.

In relation to frost, pith process occurs due to floral induction. Low temperatures in sugarcane crops inhibit flowering and, as a result, the formation of new internodes is interrupted, thus enabling the pith process to begin (Miranda et al., 2008).

Apical dominance is a response to the balance between auxin and cytokinin, with auxin being produced at the apex and translocated to the base in the plant, while cytokinin is produced in the roots and has acropetal movement. With the elimination of the shoot apex, cytokinins accumulate in the lateral buds, promoting their development (Kerbauy, 2019).

Auxins, gibberellins and cytokinins activate the expression and synthesis of proteins necessary for cell cycle phase changes. Cold stress induces the synthesis of abscisic acid (ABA). This phytohormone acts on plant responses to stress, as a primary regulator in the initiation and maintenance of seed and bud dormancy. ABA influences many aspects of plant development, acting as an antagonist of auxin, cytokinin and gibberellins.

A plant under stress, including temperature stress/one, can induce ethylene biosynthesis and leaf abscission, and senescence may occur (Taiz and Zeiger, 2008). Tropical and subtropical plants are more sensitive to frost, while those from temperate climates are more

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tolerant. Less tolerant plants subjected to low temperatures, when again under moderate temperatures, start to produce ethylene in response to stress.

Plants sensitive to cold, at low temperatures, have a decrease in lipid fluidity, with a transition from the liquid-crystalline phase to a gel phase in the cell membranes, resulting in changes in metabolism that can lead to the death of the plant. Frost causes damage due to the formation of ice in intercellular spaces, which rupture membranes and organelles, resulting in desiccation of the cell, which can lead to death due to mechanical forces that act on the protoplasm and plasma membrane and the precipitation of proteins. Freezing temperatures for long periods lead to the destruction of membranes and excessive dehydration (Taiz and Zeiger, 2008).

4. CONCLUSION

The death of apical buds was the most significant effect of frost in sugarcane cultivation.

No significant damage was observed during pith process.

The NDVI images were extremely important for carrying out this analysis, as it was possible to observe that it reduced after the frost.

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