ISSN: 2447-3359

REVISTA DE GEOCIÊNCIAS DO NORDESTE

Northeast Geosciences Journal

v. 7, nº 1 (2021)

https://doi.org/10.21680/2447-3359.2021v7n1ID19704

RADIATION BALANCE IN AGRICULTURAL EXPANSION AREAS IN SOUTHEAST OF PIAUÍ

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Abstract

Agricultural areas have been intensifying in the State of Piauí, this development results in damage to native vegetation, causing environmental impacts. Studies that evaluate these impacts are extremely important to quantify the changes caused on the surface. Thus, the objective was to identify changes in soil cover and evaluate its impacts on the radiation balance, vegetation indices and surface temperature in an agricultural expansion area in southwest Piauí. The evaluated area is located in the municipality of Baixa Grande do Ribeiro, using images from the Landsat 5 TM and Landsat 8 satellites, obtained between the years 1990 and 2018. The Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Albedo (α), Radiation Balance, Long Wave Radiation (ROLs) and Surface Temperature (Ts) were evaluated. A reduction of 32.25% in native vegetation and a growth of 1,219.1% in agricultural exploitation were identified. The natural vegetation of the Cerrado showed lower temperature, albedo and ROLs and a higher radiation balance, when compared to exposed soil areas. Agricultural exploration in the southwest of Piauí has been promoting changes in the region's natural vegetation, causing environmental impacts, promoting an increase in surface temperature and decreasing the availability of energy. It is necessary to carry out more work that provides more information on these changes and also on the performance of public policies for agricultural and environmental planning purposes.

Keywords: Solar radiation; Deforestation; Cerrado.

BALANÇO DE RADIAÇÃO EM ÁREAS DE EXPANSÃO AGRÍCOLA NO SUDOESTE DO PIAUÍ

Resumo

Áreas agrícolas vêm se intensificando no Estado do Piauí, esse desenvolvimento resulta em danos à vegetação nativa, causando impactos ambientais. Estudos que avaliem esses impactos, são de extrema relevância para quantificar as modificações causadas na superfície. Assim, objetivou-se identificar mudanças da cobertura do solo e avaliar seus impactos no balanço de radiação, índices de vegetação e temperatura da superfície em área de expansão agrícola no sudoeste do Piauí. A área avaliada está inserida no município de Baixa Grande do Ribeiro, utilizou-se imagens dos satélites Landsat 5 TM e Landsat 8, obtidas entre os anos de 1990 e 2018. Avaliou-se o Índice de Vegetação da Diferença Normalizada (NDVI), Índice de Vegetação Ajustado ao Solo

(SAVI), Albedo (α), Saldo de Radiação, Radiação de Ondas Longas (ROLs) e Temperatura da Superfície (Ts). Identificou-se a redução de 32,25% vegetação nativa e crescimento de 1.219,1% da exploração agropecuária. A vegetação natural do Cerrado apresentou menor temperatura, albedo e ROLs e maior saldo de radiação, quando comparada às áreas de solo exposto. A exploração agrícola no Sudoeste do Piauí, vem promovendo modificações na vegetação natural da região, causando impactos ambientais, promovendo o aumento da temperatura da superfície e diminuindo a disponibilidade de energia. Faz-se necessário a realização de mais trabalhos que forneçam mais informações sobre essas modificações e ainda da atuação de políticas públicas para fins de planejamento agrícola e ambiental.

Palavras-chave: Radiação solar; Desmatamento; Cerrado.

BALANCE DE RADIACIÓN EN ZONAS DE EXPANSIÓN AGRÍCOLA DEL SUROESTE DE PIAUÍ

Resumen

Las áreas agrícolas se han ido intensificando en el Estado de Piauí, este desarrollo da como resultado daños a la vegetación nativa, provocando impactos ambientales. Los estudios que evalúan estos impactos son de suma importancia para cuantificar los cambios provocados en la superficie. Así, el objetivo fue identificar cambios en la cobertura del suelo y evaluar sus impactos en el balance de radiación, índices de vegetación y temperatura superficial en un área de expansión agrícola en el suroeste de Piauí. El área evaluada se ubica en el municipio de Baixa Grande do Ribeiro, utilizando imágenes de los satélites Landsat 5 TM y Landsat 8, obtenidas entre los años 1990 y 2018. Se evaluaron el índice de vegetación de diferencia normalizada (NDVI), el índice de vegetación ajustado al suelo (SAVI), el albedo (α), el balance de radiación, la radiación de onda larga (ROL) y la temperatura de superfície (Ts). Se identificó una reducción del 32,25% en la vegetación nativa y un crecimiento del 1,219,1% en la explotación agrícola. La vegetación natural del Cerrado mostró menor temperatura, albedo y ROL y un mayor balance de radiación, en comparación con las áreas de suelo expuestas. La exploración agrícola en el suroeste de Piauí viene promoviendo cambios en la vegetación natural de la región, provocando impactos ambientales, promoviendo un aumento de la temperatura superficial y disminuyendo la disponibilidad de energía. Es necesario realizar más trabajos que brinden más información sobre estos cambios y también sobre el desempeño de las políticas públicas con fines de planificación agrícola y ambiental.

Palabras-clave: Radiación solar; Deforestación; Cerrado.

1. INTRODUCTION

Agricultural exploration was introduced in the Cerrado biome in the 1970s through rural credit subsidized by the Federal Government, showing considerable expansion in the following decades (LEMES et al., 2008). The most expressive agricultural region in this biome is MATOPIBA, composed of the States of Maranhão, Tocantins, Piauí, and Bahia, whose initials generate the acronym, for having deep soils, flat topography, and favorable climate, it stands out in the Brazilian agricultural scenario as a large agricultural frontier, especially in the cultivation of grains and fibers (BORGHI et al., 2014).

The State of Piauí in favor of its extensive area of the natural vegetation of 18,723,318 ha (MAPBIOMAS, 2019), has great potential for agricultural expansion, especially in the southwestern mesoregion, where there is greater agricultural expressiveness in municipalities such as Bom Jesus, Uruçuí, Santa Filomena and Baixa Grande do Ribeiro. The municipality of Baixa Grande do Ribeiro is distinguished in the region for having the largest planted area of soybean (180,661 ha) in the State (SIDRA, 2019).

The contribution of agricultural production in the region in the development of Brazilian agribusiness is evident, in addition to the generation of jobs and income for the local population and the growth of industry and commerce (LOPES, 2014). However, the degradation caused in the Cerrado by this activity has made relevant changes in the biome, resulting in too much deforestation, soil compaction, erosion, silting of rivers, contamination of groundwater, and loss of biodiversity, causing an imbalance in the ecosystem (CUNHA, 2008).

The conversion of native vegetation in extensive deforested areas to monoculture provides changes in the dynamics between vegetation and the atmosphere, in which we can mention the change in the radiation and energy balance at the surface and, consequently, in the surface temperature, air humidity, evapotranspiration, albedo, and gas exchange processes, due to the constant modification of the leaf architecture of the vegetation (DUBREUIL and DELAHAYE, 2010; SOUZA et al., 2013).

The identification of this modification and its impacts can be carried out via remote sensing, which through its ability to identify and evaluate changes in the structure, physiognomy, and dynamics of the vegetation cover, in addition to its multispectral character, enables the analysis of agrometeorological components such as albedo, radiation balance, vegetation indices and evapotranspiration (MARQUES et al., 2017; ANDRADE et al., 2018).

In this sense, it is evident the importance of works of this nature in the MATOPIBA region, because of the scarcity of studies that aim to quantify the environmental impacts of this agricultural exploration in the region (OLIVEIRA and AQUINO, 2020; 2020), especially in surface radiative processes. Thus, the present study aimed to identify changes in soil cover and evaluate its impacts on the components of the radiation balance, vegetation indices, and surface temperature in an agricultural expansion area in the southwest of the State of Piauí.

2. METHODOLOGY

The study area is located in the northern portion of the municipality of Baixa Grande do Ribeiro, inserted in the southwestern mesoregion of the state of Piauí (Figure 01). The municipality has a hot and humid climate, classified by Köppen as Awa (Rainy tropical with a dry season in winter and the average temperature of the hottest month above 22 °C) (ALVARES et al., 2013), located in an area with transitional vegetation between the Cerrado and Caatinga biomes. This municipality is located at 08º20'0.7"S and 45º5'40"W with an average altitude of 519 m, climatologically the region presents

precipitation and an average temperature of 986.7 mm year-1 and 27.7 °C, respectively (INMET, 2019).

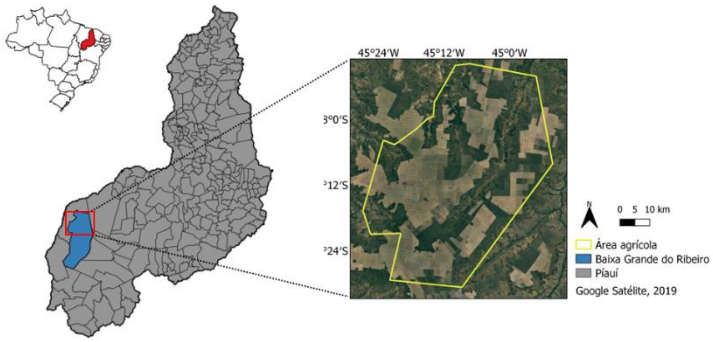

Figure 01- Location of the agricultural area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

The municipality of Baixa Grande do Ribeiro has an estimated population of 11,586 inhabitants and a GDP per capita of R$21,051.99. In the agricultural context, it stands out in the State of Piauí for having the second-highest productivity (3518 kg ha^{-1}) and the largest planted area (180,661 ha) for the cultivation of soy (SIDRA, 2019).

Images from the Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) and Landsat 8 TIRS (Thermal Infrared Sensor) sensors were used. The Landsat 5 images are composed of seven spectral bands, with a spatial resolution of 30 m in bands 1, 2, 3, 4, 5, and 7 and 120 m in band 6 (thermal). Those obtained by Landsat 8 have a spatial resolution of 30 m for the reflective bands 1 to 7 and 100 m in the thermal bands 10 and 11, and the panchromatic band 8 with a resolution of 15 m. The Global Digital Elevation Model Version 2 (ASTER GDEM V2) was obtained by the Advanced Spaceborne Thermal Emission and Reflection Radiometer sensor, both with a spatial resolution of 30 m, and vector files of the neighborhood and land-use division. (NASA, 2019).

The satellite and ASTER GDEM V2 images of the region were obtained from the United States Geological Survey (USGS, 2019) and selected considering the absence or little cloud cover (less than 10%) and obtained in the dry period (INMET, 2019). Thus, they were selected in orbit 220 and at point 66, with the satellite crossing time around 13:00 (UTC) (Table 01).

Table 01 - Images projected on the Landsat 5 and Landsat 8 satellites. Source: USGS (2019)

Satellite	Date	Hour (UTC)
Landsat 5	09/09/1990	12:26 p.m.
	09/20/2000	12:44 p.m.
	08/12/2003	12:43 p.m.
	09/02/2005	12:54 p.m.
	08/09/2008	12:52 p.m.
	08/15/2010	12:56 p.m.
Landsat 8	09/08/2013	13:08 p.m.
	08/26/2014	13:06 p.m.
	09/30/2015	13:06 p.m.
	08/15/2016	13:06 p.m.
	08/18/2017	13:06 p.m.
	08/21/2018	13:06 p.m.

The images obtained were limited to an area that presents greater agricultural expressiveness in the municipality (Figure 01) and the processing of these was carried out in the QGIS 3.8.3 Software (QGIS Development Team, 2019), converting the data from digital numbers to radiance and spectral reflectance. From these products, the Normalized Difference Vegetation (NDVI) and Soil Adjusted (SAVI) indices were obtained; Albedo (α); Surface temperature (Ts) and, the components of the radiation balance (Long Wave Radiation emitted by the surface - ROLs and Radiation Balance - Rn), these variables were obtained once a year on the date corresponding to obtaining the image, consisting of 12 images (Table 01); through the processing of the SEBAL algorithm (BASTIAANSSEN et al., 2005), whose steps are described in detail in Gomes et al. (2013).

The evolution of forested and agricultural areas, in hectares, for the period from 1985 to 2018, was obtained on the MapBiomas platform (MAPBIOMAS, 2019). In this same platform, the maps of land cover and use from collection 2 of the annual series of maps of land cover and use of Brazil, available between the years 2000 and 2016, were acquired.

The observed meteorological data used in the processing of SEBAL came from the meteorological station of the National Institute of Meteorology (INMET), located in the municipality of Bom Jesus - PI, which was collected at the same time as the satellite crossing (10:00 - Time of Brasília). The station is installed on the premises of the Federal University of Piauí (UFPI / CPCE).

The identification of the impact of agricultural expansion on vegetative indices and meteorological variables was carried out through linear regression using Software R version 3.6.1 (R CORE TEAM, 2019), relating the annual expansion of land use areas (agriculture and native forestry) with the average annual variation of environmental and radioactive variables obtained.

3. RESULTS AND DISCUSSION

Agriculture and livestock have been expanding in the region in recent decades, where natural vegetation is being replaced by agricultural areas, especially for soybean cultivation, as shown in Figure 02. The natural vegetation present in the territory corresponding to the municipality showed a 32.25% reduction. On the other hand, agricultural exploration showed growth of 1,219.1% from 1985 to 2018. The soybean crop grew by 16,275.8% from 1993 to 2018.

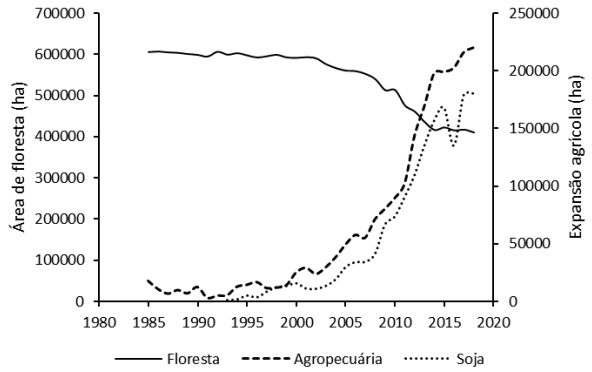

Figure 02 - Evolution of forested areas, agricultural use and soy cultivation in the municipality of Baixa Grande do Ribeiro - PI. Source: MAPBIOMAS (2019); SIDRA (2019).

The land use and cover for the evaluated agricultural area, belonging to the municipality of Baixa Grande do Ribeiro - PI can be seen in Figure 03. In 2000, the predominant soil cover in the region was natural vegetation (open forest, dense forest, and countryside vegetation) with the occurrence of few sites explored with agriculture and pasture. Over the years, it is noticeable the opening of new agricultural areas, the establishment of agriculture, and the consequent reduction of natural vegetation, especially for the insertion of the soy monoculture, as shown in Figure 02, the growth in areas destined for this cultivation is proportional to agricultural expansion.

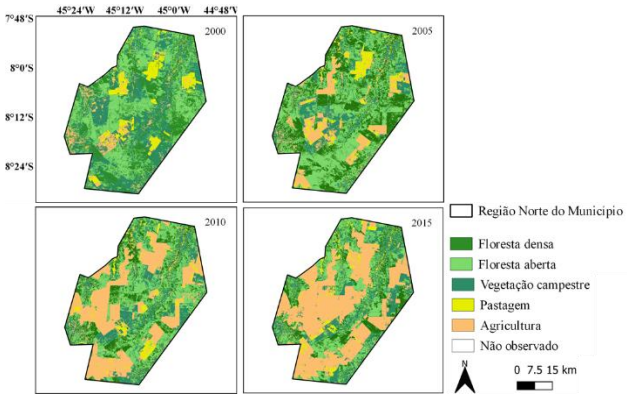

Figure 03 - Land cover map of the agricultural area belonging to the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

In the Uruçuí-Preto sub-basin, which contains part of the territorial extension of Baixa Grande do Ribeiro, Silva et al. (2014) found an agricultural expansion of 539% and a reduction in the natural area of the Cerrado of 44.45%, between the years 1984 and 2010. Santos et al. (2017) identified a 54.81% decrease in native vegetation, a 297.98% increase in exposed soil, throughout the southwestern region of Piauí.

According to Silva et al. (2014), the beginning of the increase in deforestation in the Cerrado and the exacerbated expansion of areas of exposed soil (agricultural plot) in the south of the State of Piauí, is a consequence of the arrival of numerous soy producers in the region in the 90s, coming from the Rio Grande do Sul, Paraná, and Mato Grosso. Soy production began in 1990, mainly in the municipalities of Bom Jesus, Gilbués, and Uruçuí (REIS et al. 2009).

Despite the evident change in land use and land cover in the analyzed area, it was not possible to verify a significant association of this advance in agriculture in all the variables studied. An association was found both for agricultural expansion and the reduction of the native forest only for SAVI and α (Figure 04).

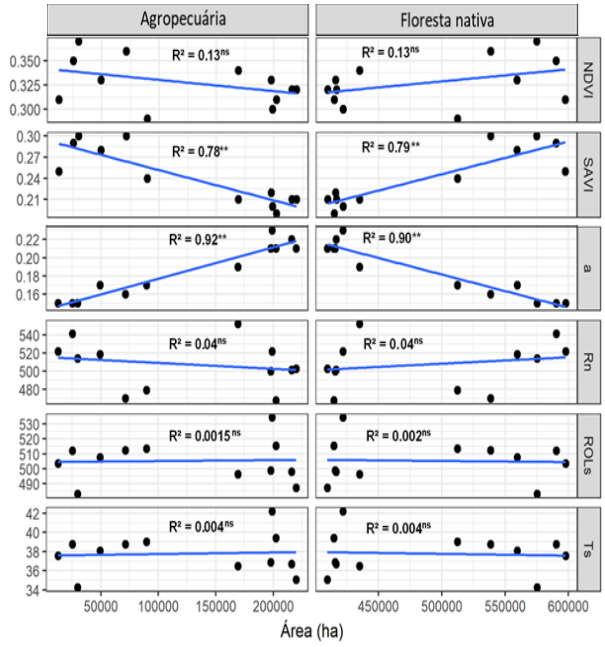

Figure 04 - Linear regression between the mean values of the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Albedo (a), Radiation Balance (Rn), Long Surface Wave Radiation (ROLs), Surface Temperature (Ts) and; area of agricultural expansion (ha) and reduction of native forest (ha), in the municipality of Baixa Grande do Ribeiro - PI. R2 - Coefficient of determination. Source: Own (2019).

In Figure 04, it can be seen that the SAVI is inversely proportional to the increase in agricultural expansion at the level of $p < 0.01$ probability, and expected situation, given that deforestation causes a drastic decrease in this index. On the other hand, when related to the forested area, there is an increase in

SAVI. It is emphasized that in the period in which the images were obtained, there is no presence of crops in the region, precisely so that the analysis of the impact of the removal of native vegetation as possible.

There was no significant adjustment (p = 0.24) in the relationship between agricultural and forested areas and the NDVI (Figure 04), possibly because this index is not as sensitive to the influence of the exposed soil as the SAVI (RÊGO et al., 2012). Concerning albedo, significant adjustments were obtained for both variations in land cover, in which, with agricultural expansion, there was an increase in albedo caused by soil exposure. Albedo is reduced according to the presence of vegetation on the surface since plants, especially large ones, have a high capacity for absorbing solar radiation as a result of multiple reflections inside the canopy (MONTEIRO et al., 2014)

As for the components of the radiation balance (Rn and ROLs) and surface temperature, there was no adjustment of the data to the model used to the reduction of the Cerrado and implantation of agriculture (Figure 04). However, it is noted that there is a trend in the dispersion of data, indicating that as the area of native forest increases and the area of agriculture decreases, there is an increase in Rn and a decrease in Ts and ROLs. It is known that exposed soils have a higher surface temperature when compared to vegetated surfaces, as reported by Fausto et al. (2016) who found a difference of 6.7ºC in the surface temperature between Cerrado areas and exposed soil, higher temperatures indicate a greater amount of longwave radiation emitted by the surface.

The variables were spatialized for better visualization and identification of discrepancies. To albedo (Figure 05), it can be seen that in 1990, most of the area had an albedo configuration ranging from 0.10 to 0.17, a typical range of reflectances of natural vegetation in the Cerrado (FAUSTO et al., 2014). Over time, there is an increase in this variable, which reaches the ranges of 0.22 - 0.36 and 0.36 - 0.475, predominantly in the year 2018. This temporal progression of albedo, as already mentioned previously, it is related to the removal of vegetation, since deforestation increases the reflectance of the surface.

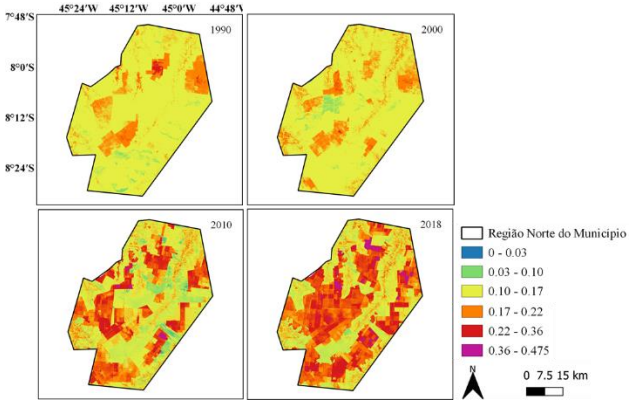

Figure 05 - Temporal evolution of surface albedo in an agricultural expansion area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

As can be seen in Figure 05, the constitution of agricultural plots leads the region to have a predominant albedo ranging from 0.22 to 0.475. Correia et al. (2002) mention that the high values of α indicate smooth, dry, and light-colored surfaces, however, smaller magnitudes of this variable are associated with rough, moist, and dark-colored surfaces. Similar results were found in regions of exposed soil in the Cerrado of Mato Grosso (23% albedo) by Fausto et al. (2016) and by Silva et al. (2017) who identified albedo values between 0.23 to 0.55 in exposed soils in Minas Gerais.

Regarding a SAVI, it can be seen in Figures 06 that in the years 1990 and 2000 there was a predominance of SAVI in the range of 0.22 - 0.42, indicating the presence of vegetation in most of the region. Currently, there is the presence of SAVI ranging from 0.04 - 0.22 in the largest portion of the area, highlighting the reduction of soil cover by native vegetation and an increase in exposed soil. Silva and Cruz (2016) describe that SAVI values from 0 to 0.19 are linked to the presence of exposed soil.

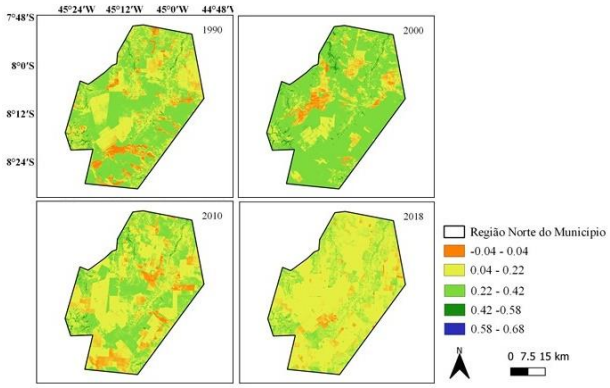

Figure 06 - Time evolution of the Soil-Adjusted Vegetation Index (SAVI) in an agricultural expansion area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

Leite et al. (2017) found SAVI of 0.24 for exposed soil area in São Paulo. Silva et al. (2016) report that SAVI ranging between 0 and 0.25 are found in the urban perimeter and areas with exposed soil.

It is noted that the areas used for agricultural purposes in all years, presented between 300 and 500 Wm^{-2}, while the forested areas had Rn between 500 and 700 Wm^{-2} (Figure 07). This distribution of Rn is because the vegetated surfaces, having lower albedo (Figure 05) and lower surface temperature (Figure 08), have the emission of heat in the form of reduced long waves (Figure 09), resulting in a greater balance of radiation and availability of energy.

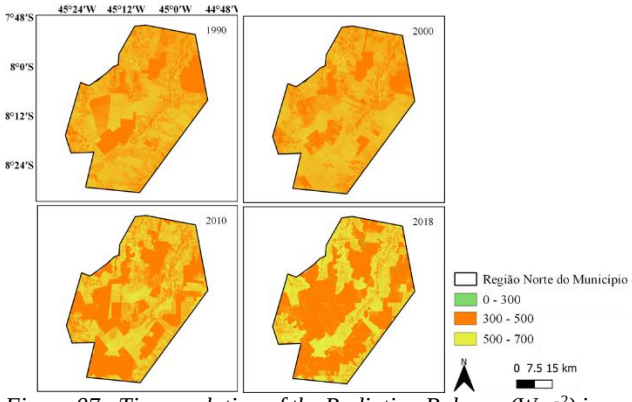

Figure 07 - Time evolution of the Radiation Balance (Wm^{-2}) in an agricultural expansion area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

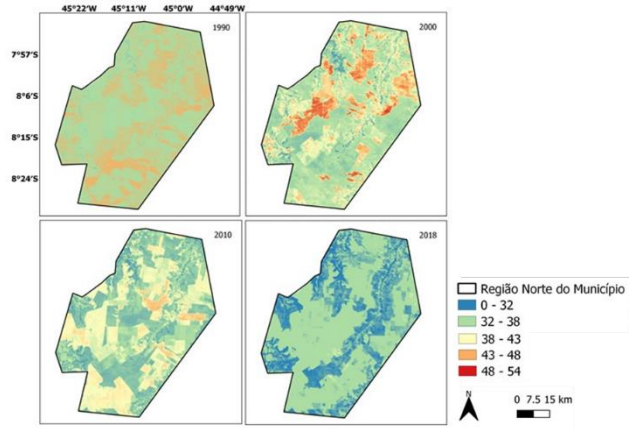

Figure 08 - Temporal evolution of Surface Temperature (°C) in an agricultural expansion area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

Figure 09 - Temporal evolution of Long Wave Radiation on the surface (Wm^{-2}) in an agricultural expansion area in the municipality of Baixa Grande do Ribeiro - PI. Source: Own (2019).

Daily radiation balance in exposed soil areas (160 Wm^{-2}) lower than areas with Cerrado vegetation (200 Wm^{-2}) were identified by Fausto et al. (2016), results also associated with albedo and surface temperature, according to the data presented in this study. The tendency to have higher Rn in the Cerrado to the exposed soil was also described by Silva et al. (2017), considering that they obtained lower values of α in areas of denser vegetation and lower values in areas of thin vegetation and exposed soil.

The removal of native vegetation in the region implied an increase in Ts and α, which reduced the availability of energy on the surface. The elevation of Ts can cause thermal discomfort because the absence of vegetation causes less absorption of short wave radiation and a greater directing of this energy in the form of sensitive heat, responsible for the heating of the air/surface (BIUDES et al., 2009; 2015). Besides, this change in the amount of energy available at the surface in the form of a balance of radiation, causes a change in the biophysical components of the energy balance, disrupting the balance once established in the ecosystem, causing disturbances in the soil-plant-atmosphere system (BIUDES et al., 2012). Oliveira and Aquino (2020) recorded impacts of deforestation on water resources and soil conservation in the region, including changes in hydrological behavior, exposure of the soil and triggering of erosive processes, and silting of water bodies.

Thus, it is noted that the introduction of farmers and the expansion of agricultural exploration in the region have promoted an intense modification in the natural space of the Cerrado and changes in the landscape for the implantation of the monoculture of grains, which cause the development of both ecological and environmental problems in socioeconomic transformations of local citizens (SILVA et al., 2014).

4. FINAL CONSIDERATIONS

Agricultural development in the southwest of Piauí has guaranteed intense changes in the native vegetation of the Cerrado. A 32.25% reduction in native vegetation and a growth of 1,219.1% in agricultural exploitation were identified. This replacement of the biome by agricultural areas has an impact on the radioactive components that act on the surface, causing an increase in Ts and α, which decrease the availability of energy on the surface, and consequently alters the energy balance and the entire dynamics of the vegetation-atmosphere interaction.

According to the data shown, it is evident that the present work brings unprecedented results to the region and emphasizes the relevance of studies aimed at assessing the impact of these changes on the ecosystem in the radiative processes at the surface, because of the disordered agricultural expansion in these regions. Mainly need studies that assess the energy balance and its impacts on surface heating, evapotranspiration, rainfall dynamics, soil conservation, and local biodiversity, also considering the presence of agricultural vegetation in crops. Besides, public policies are necessary for agricultural and environmental planning aiming at obtaining sustainable agriculture that allows the mitigation of impacts in the medium and long term and their effects on the environment and society, allowing maintenance of aspects of biotic and abiotic resources for future activities.

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Received in: 17/01/2020
Accepted for publication in: 05/03/2021