Characterization of Center Pivot Irrigation Systems in the Irecê-Bahia Agricultural Region Based On Random Forest Classification

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Abstract. *This study purposes identify the changes in center pivot irrigation systems areas using MODIS time series as well as identify the possible abandoned areas or cycle numbers decrease between 2014 and 2020. For this, were used MODIS time series and extraction of basics metrics from NDVI and EVI indexes and polar features. Using the extracted data, was performed a Random Forest classification. The results indicate the predominance of only one agricultural cycle in the center pivots, although some cases of two agricultural cycles were identified. The abandoned center pivots vary according to year and are related to the water availability per cycle.*

1. Introduction

Over the last years, agricultural techniques have been improved to increase the production of different crops. One of these techniques, mainly in the scope of precision agriculture is the center pivot irrigation systems. This technique increases the efficiency of water use when compared to other irrigation systems [Albuquerque et al. 2020].

The adoption of center pivot irrigation systems could be implemented in any region even in those with low or no water availability. In Brazil, there are about twenty thousand center pivots adding up an irrigated area of 1,2 million hectares This fact makes Brazil one of the biggest in the world using this type of irrigation system. Those center pivots are distributed around the five Brazilian regions [Embrapa 2016].

Most of those center pivots are located in Midwest and Southeast, in the edges of Cerrado Biome but too in another region like the northeastern hinterland in Caatinga Biome where the only way to irrigate is using center pivot irrigation systems [Melo et al. 2014]. The Caatinga Biome is configured as a dry ecosystem and covers about 11% of Brazilian territory. Regarding the botanical aspects, Caatinga is considered the only Biome exclusively Brazilian among the six Biomes presented in this country [Fundaj 2019].

This Biome is located in the states of Alagoas, Bahia, Ceará, Minas Gerais, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, and Sergipe. The predominant climate in this region is semiarid where the precipitation rates vary from 400 to 1100 millimeters throughout the year. Nevertheless, in the hinterland, located to it is greatest extent in the central portion of the state of Bahia, the annual precipitation rate varies from 400 to 633 millimeters [Becerra et al. 2015] it's a lower rate in comparison with Amazon Biome, for example, where the precipitation volume is the 2300 millimeters per year [Germer et al. 2007]. Therefore, this study purposes identify the changes in center pivot irrigation systems areas using MODIS time series as well as identify the possible abandoned areas or cycle numbers decrease using a Random Forest approach.

2. Materials and Methods

In this work, the study area is in Agricultural Region of Irecê in Bahia state, at Caatinga Biome. This region comprises sixteen municipalities. It is São Gabriel, Jussara, Central, Uibaí, Ibititá, João Dourado, Ibipeba, Barra do Mendes, Barro Alto, Canarana, Cafarnaum, Itaguaçu da Bahia, Lapão, Presidente Dutra, América Dourada and Irecê and adding up an area of 17,214 square kilometers. The study area is showed in Figure 1.

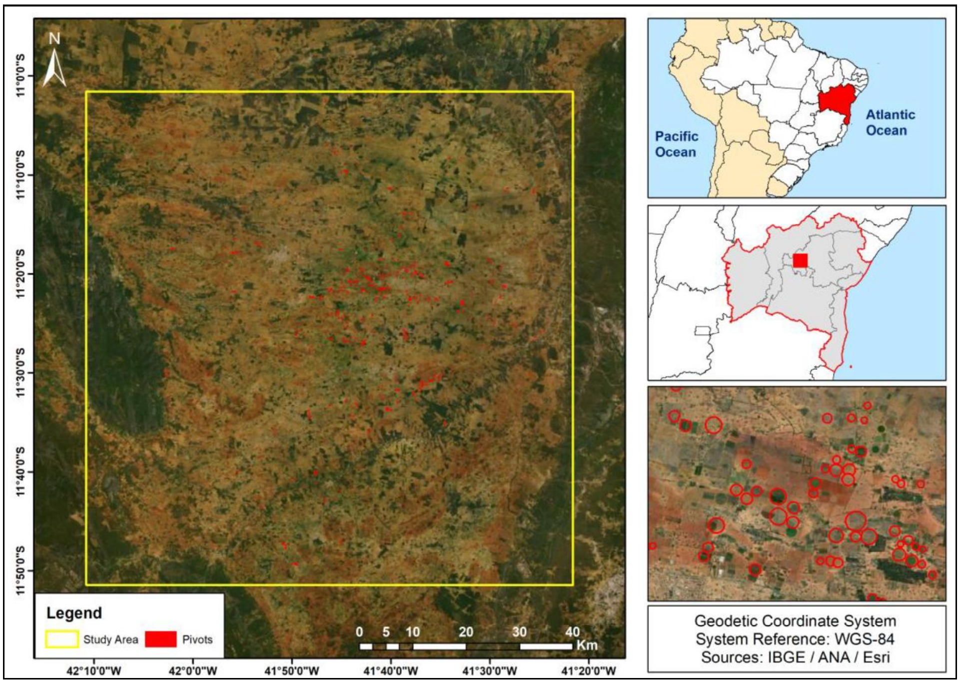

Figure 1. Study area.

The agricultural production in the Irecê region started with grains plantation in the sixties when the Brazilian Company for Agriculture Research (EMPRAPA, in Portuguese) have started the plantation of Soy in some areas in that region [Carvalho 2002]. Over the years were constructed various center pivot irrigation systems to support the soy plantation. These structures were inserted aiming to complement the water disponibility in the soil and provide the correct soil moisture to soy plantation and increase the production [Landau et al. 2016].

However, about the nineties, the soy production migrated totally to the west region of Bahia state, located in the Cerrado Biome. The Cerrado Biome provides better conditions for the development of soy and other crop types like corn, broomcorn, and cotton. Furthermore, soy planting areas in the Irecê region were converted into planting of other crops, for example, bean, tomato, onion, and castor most recently. These changes brought a bigger crop variability in the region, including irrigated areas until 2012 [EMBRAPA, 2020].

Since 2012 a heavy drought has been reaching the Bahia's semiarid and causing significant changes in the agricultural dynamics of that region. Besides that, the intensive use of agricultural areas without the correct management causes soil degradation, and the degradation was intensified by the drought. [Tomasella et al. 2018]. The combination of these factors made many areas reduced the number of agricultural cycles or just were abandoned and stop producing. Figure 2 below shows the flowchart of this study.

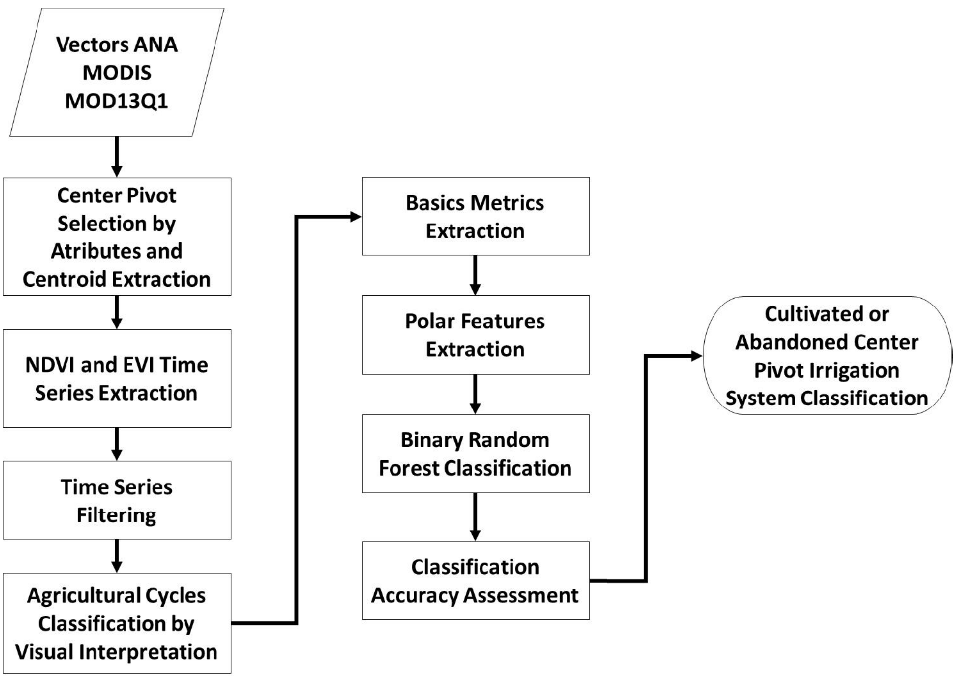

Figure 2. Flowchart.

First, was used the center pivot geometries obtained from Water National Agency (ANA, in Portuguese) dated from a 2014 survey. For the study area, were selected 459 center pivots of radius greater than 100-meters, due to the also used MODIS MOD13Q1 product of 250-meters resolution. This stage was executed in Geographic Information System (GIS) environment. The time range that was chosen to calculate the time series was 2014 to 2020, including six crop seasons defined between October first of the initial year and September thirty of the following year [Conab 2019].

The Normalized Difference Vegetation Index (NDVI) [Rouse et al., 1974] and Enhanced Vegetation Index (EVI) [Justice et al., 1998] time series were obtained from the already quoted MOD13Q1 [Didan, 2015] product from MODIS sensor. This product was obtained using the Satellite Image Time Series Analysis for Earth Observation Data Cubes (SITS) package implemented in R language using RStudio software. The previously extracted center pivots centroids were used as a spatial attribute to get the time series. Furthermore, the series was filtered using the Whittaker [Whittaker, 1923] filter to remove noise according to a visual analysis.

The filtered series were classified according to the agricultural cycle into the classes single cropping, double cropping, and abandoned center pivot. In sequence, were extracted six basics metrics from the NDVI and EVI indexes: absolute mean derivative; mean; minimum value; maximum value; standard deviation; and amplitude. Moreover, polar features were also extracted. Polar features represent the time series projected into polar coordinates in the [0, 2π] interval. After this projection, it was possible to calculate the areas per quadrant in the intervals of ([π, 3π/2], [π/2, π], [0, π/2] and [π3/2, 2π] [Körting et al. 2013].

In sequence, the Random Forest (RF) classifier [Breiman 2001] was trained to classify two classes: cultivated or abandoned center pivot. For this, 70% of the previous classification of the 2017/18 agricultural year in single and double cropping was used as cultivated samples and previously abandoned class as the abandoned samples. The used parameters by RF classifier were the basics metrics and polar features for the whole series. Thus, empirically the number of trees was set as 1000, and the number of variables available for splitting at each tree node was set as 5.

Using the data of the remaining 30% of the visual classification, a confusion matrix was calculated as well as the overall accuracy of the whole series classification. It is important to highlight that 2017/18 crop season was chosen as the sample year due to the better representativity among the series period. A paired t-test with a probability of 5% was used to assess the difference observed in the accuracy of classifications using NDVI and EVI.

3. Results

The agriculture irrigated by center pivots characterization is shown in Figure 3. The results indicate the predominance of only one agricultural cycle in the center pivots, although some cases of two agricultural cycles were identified. The abandoned center pivots vary according to year and are related to the water availability per cycle [Fundaj 2020]. The years 2015/16 and 2019/20 presented the biggest number of active center pivots while 2016/17 presented the biggest number of abandoned center pivots. Table 1 shows the overall accuracy of the proposed binary classification.

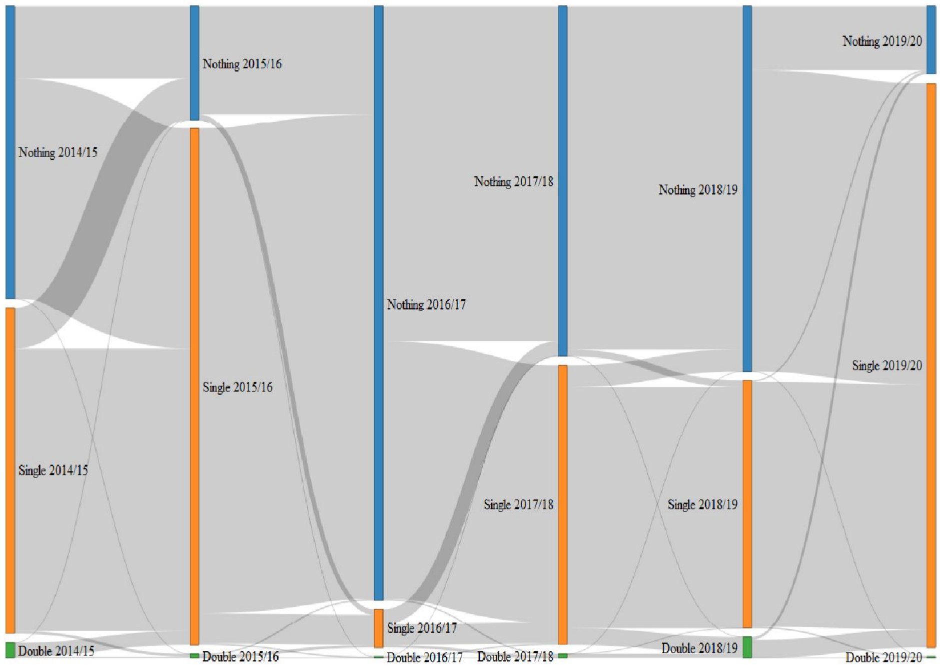

Figure 3. Agriculture irrigated by center pivots characterization between 2014 and 2020 in the Irecê agricultural region.

Table 1. Binary classification overall accuracy.

Index	2016/17	2017/18	2019/20
EVI	0.94	0.86	0.88
NDVI	0.95	0.87	0.89

Based on a paired t-test with a probability of 5% the accuracy of NDVI and EVI do not statistically differ. The worst performance was observed for the 2017/18 agricultural year and the best for the 2016/17 agricultural year that 95% of the center pivots were classified as abandoned.

The result of binary classification had a similar result when compared to the visual classification. Just a few pivots had class change, this is possibly due to the presence of some cover not classified as agriculture that the cycle less than six months and low vegetative strength. The results for the 2016/17 and 2019/20 binary classifications are shown in Figures 4 and 5.

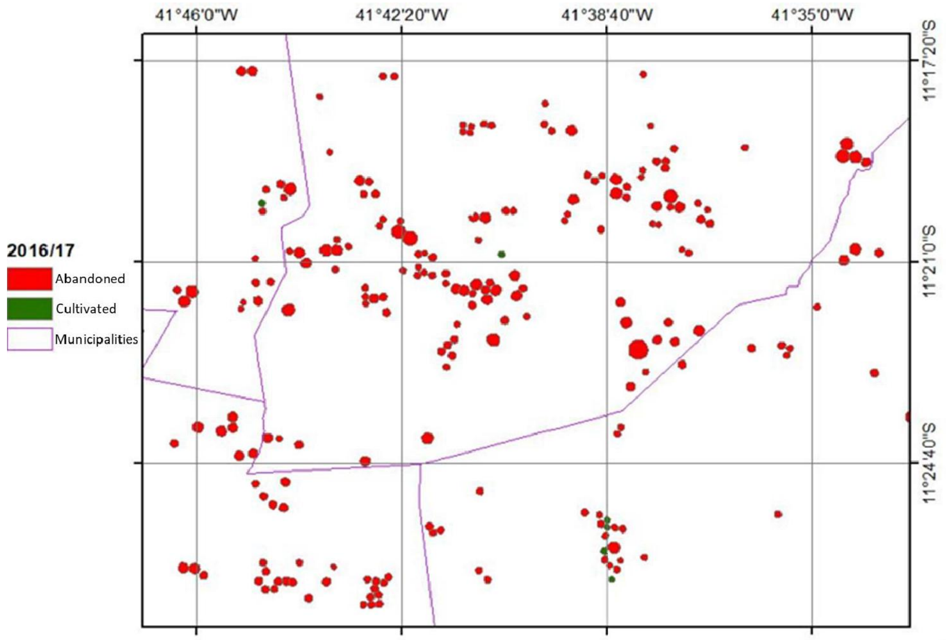

Figure 4. Result of Binary Classification of 2016/17 Agricultural Year.

During 2016 the region had precipitation rates below the median causing the abandonment of center pivot irrigation systems purposing the maintenance of water levels of lakes and water reservoirs in the region. In 2019, the precipitation rates elevate in the region, causing the reconnect of the irrigation systems and plantation of crops.

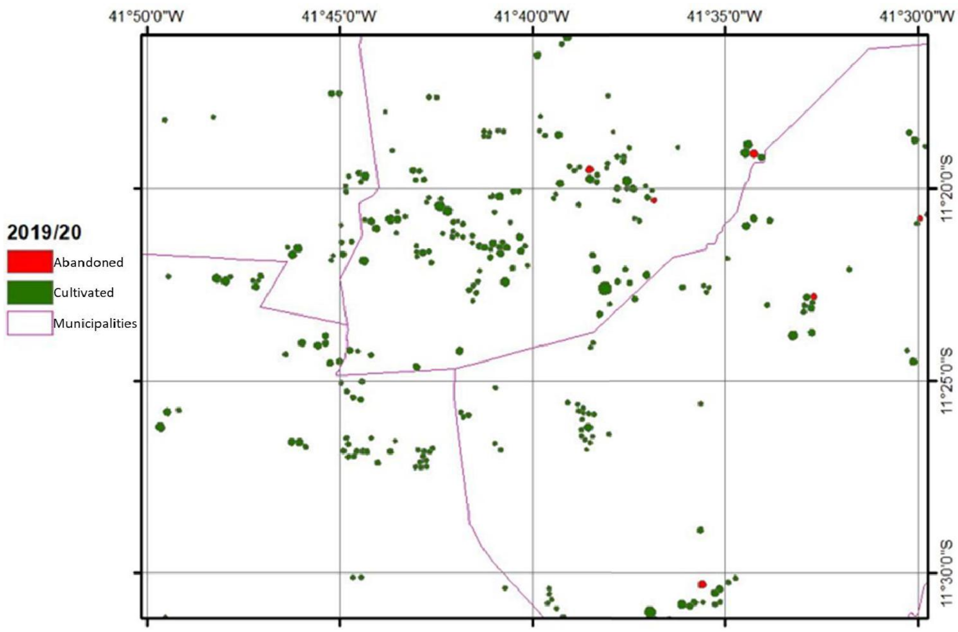

Figure 5. Result of Binary Classification of 2019/20 Agricultural Year.

It is important to highlight that the metrics were effective in distinguishing between the areas with an agricultural cycle and areas without an agricultural cycle.

4. Discussion

The water availability for irrigation is the main limiting factor of center pivot agriculture in the Irecê region, causing area abandons as observed in 2016/17 crop season. According to the Bahia's Farmers and Irrigators Association (AIBA, in Portuguese) in 2016/17 season, 60% of the 120 thousand irrigated hectares does not receive irrigation due to the drought that occurred in the region. In the analyzed region, this corresponds to 94,11% deactivated pivots, according to results obtained. In 2017/18 and 2018/19 seasons was observed 55,5% and 56,2% abandoned pivots respectively. In 2019/20 season was observed the biggest number of active pivots of the whole time series, a total of 89,1%. However, even in years of full agricultural production like 2015/16 and 2019/20 seasons is possible to notice the single cropping predominance.

This fact could be associated with the constant conflict of water use in the region that also reflects in the center pivots dimensions when compared to center pivots in Cerrado Biome. The occupation characteristic in the analyzed region also differs from Cerrado in terms of agricultural cycles, for example, in Cerrado it is possible to observe a majority of double and triple cropping.

The metrics extraction in time series is an important tool for agricultural characterization since the agricultural dynamics can be well explained when analyzed in time series. Bendini et al. (2019) proved the applicability of phenological metrics in different agricultural levels in Cerrado Biome. Morevover, Rufin et al. (2019) affirm that the metrics obtained in time series are relevant alternative in agricultural mapping with a large crop variability, that is the case of central pivots.

The reduced size of the analyzed pivots caused some noise in the time series due to a bigger spectral mixture in the pixels of the 250-meter spatial resolution of MOD13Q1 product. Thus, in future studies, is recommended the use of fine spatial resolution sensors in the time series and a greater temporal resolution too, like combined OLI from Landsat and MSI from Sentinel-2, in the way to avoid these issues. Bendini et al. (2019) have successfully used a dense EVI Landsat-like time series to extract phenological metrics for a RF crop classification in Cerrado.

The obtained results showed consistently, considering the agricultural dynamics of Irecê region. However, it is understood that new studies with more detailed aspects are necessary to understand deeper the Irecê region agricultural dynamics. The water monitoring, associated with the legal licenses of center pivots is fundamental in the maintenance of Caatinga Biome, mainly in the study area, due to the desertification process occurring there [Tomasella, 2018].

5. Conclusions

The agriculture in Irecê region, in the Bahia State, even in irrigated areas, is characterized by only one agricultural cycle during the agricultural year. The analyzed pivots suffered changes over the years due to droughts affecting the region. The center pivots dimensions also influenced the analyses. The medium size of the pivots is 90% smaller than pivots in Cerrado Biome, for example. The metrics extracted from vegetation indexes time series of MODIS sensor presented a satisfactory performance in the identification of agricultural patterns in Bahia's hinterland.

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