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# DEVELOPMENT OF AN AGROCLIMATIC MODEL FOR THE MUNICIPALITY OF CACHOEIRAS DE MACACU – RJ

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## ABSTRACT

Agricultural activity, in general, has significant importance to the Brazilian economy. Understanding climate variability and changes in the growing region is necessary for a healthy grain yield. Air temperature and precipitation are the main variables responsible for changes in these patterns. Therefore, a proper comprehension of the impacts caused by these changes in crops can help farmers carry out healthy and sustainable agricultural activities. Thus, this study aims to elaborate an agricultural calendar for small farmers in the municipality of Cachoeiras de Macacu, Rio de Janeiro, to help them plan and manage different crops in the field and the optimal use of water resources according to the elaborated calendar. To this end, the following steps were performed: calculation of water surplus and deficit and agroclimatic suitability for the municipality of Cachoeiras de Macacu in the state of Rio de Janeiro; elaboration of a sustainable agricultural calendar for cultivating and planting annual and perennial crops produced in the region; and calculation of agroclimatic risk for crops to guide them regarding the risk associated with water availability. Preliminary results showed that the most favorable crops from the suitability viewpoint were açaí, onion, guava, and corn.

**Keywords:** Agroclimatic Simulation; Agroclimatic Risk; Cachoeiras de Macacu.

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## INTRODUCTION

For thousands of years, since the earliest civilizations, agriculture has been the main human activity. Agriculture is a term that represents the practice of farming in the fields using methods and techniques to produce vege**Table**s. This activity is part of the primary sector where land is cultivated and harvested for subsistence and trade. Over the years, there have been several significant transformations in agriculture, and the most powerful is in technologies related to planning, pest prevention, inputs, productivity, and land use. Along with applying these practices, interest in exploiting farmland has also grown.

Brazil has always depended mostly on agricultural production. According to the Brazilian Institute of Statistics (IBGE), the country located on the American continent is the fifth largest country globally, with nearly 850 million hectares and approximately 65% of its territory composed of natural vegetation. Before the 21st century, Brazilian agricultural evolution was commonly divided into three distinct periods: the period of horizontal expansion (1945 to 1970), characterized by the incorporation of agricultural land; the period of modernization (1970 to 1980), characterized by agricultural subsidies and incentives; and the period of increased commercial agriculture (1990 to 2005), characterized by increased intervention in markets (MUELLER, 2005).

In compliance with the studied phases, the National Supply Company (CONAB) noticed a significant increase in production and productivity and a stagnation in the exploited area between 1976 and 2010.

According to the IBGE, in the last decade, the growth of Brazilian agricultural exports was approximately 9%, contradicting the world economic crisis. Thus, to maintain this expansion and further improve cultivation, it is necessary to maintain the natural resources that are essential for agricultural activities. Therefore, it is necessary to protect and sustain the great “engine” that keeps the agricultural “machine” running: the environment.

Therefore, the agroclimatic risk helps to guide the exact period in which irrigation management should be applied. Hence, excessive use of water in irrigation management wastes the available water resources and can also result in lower production since there is excess water applied. This raises the cost of sales, thus harming the population with the high purchase costs (law of supply and demand). In this case, it is noted that the principle of sustainability is not being met, i.e., there is excessive use of available environmental resources and socioeconomic damage to producers and the local population.

In the lack of water, scarcity also damages the crops, creating the same consequence already mentioned. Although water resources are used in less quantity in this case, there is still damage to farmers and the local population. Therefore, going further, due to the disharmony between the environment and the socioeconomic part, this is also not the ideal scenario for sustainable development.

Thus, the favorable scenario for sustainability is provided by socioeconomic growth combined with environmental preservation. More clearly, there is an additional factor in this context: the use of environmental preservation in favor of financial savings and/or capital increase. In other words, preserving the environment is big business. This possibility becomes concrete as useful information is provided to producers, who can produce more without resorting to practices that are harmful to the environment.

Along these lines, the United Nations (UN) created the Food and Agriculture Organization of the United Nations (FAO), which is a specialized agency leading international efforts to defeat hunger to achieve food security for all and ensure regular access to high-quality, sufficient food for an active and healthy life.

Despite the recognized effort by FAO, Brazil still has great difficulty in assisting small farmers, especially in the dissemination of information. These farmers are characterized as owners of an area smaller than 50 hectares (Law No. 11,428/2013) and are responsible for 80% of the world’s food production. This is not a simple challenge as there are several difficulties, namely: the transportation to these locations since many agricultural regions in Brazil are in places of difficult access with poor roads and low conditions to obtain materials; the adaptation and dissemination of scientific language to facilitate farmers’ understanding of the information and make it useful; knowledge of the socio-environmental difficulties of the region and the population; and the small availability of in-situ meteorological and agrometeorological data to calculate and minimize the climatic risks of this region.

Seeking better planning of the management of different crops with sustainable use of water resources and given the problems encountered by FAO, this work aims to elaborate an agricultural calendar for small farmers to quantify and qualify the inherent risks for each crop, preserve and rationalize natural resource use, minimize costs, and maintain high productivity to supply the local population’s demands.

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## MATERIAL AND METHODS

The municipality of Cachoeiras de Macacu, selected for the present study, is located in the Metropolitan Region of Rio de Janeiro state. According to the IBGE, in 2017, its population was approximately 57,000 inhabitants, occupying an area of 954,749 square kilometers. Its economy is based on agriculture (cassava, sweet potato, guava, and corn, among others) and cattle ranching. Cachoeiras is a divided city since its southern region has lowland characteristics and a small part of the northern region is mountainous.

Despite its size and agricultural importance, the municipality of Cachoeiras de Macacu has few meteorological stations, with none available for consultation, making it even more difficult to study the weather and climate. Thus, studies for the region are greatly hampered.

Data from two meteorological stations located in the "lowland" part was used for this study. Therefore, the Macacu Farm weather station was used between 2007 and 2017, and the Japuíba rainfall station from the State Environment Institute (INEA) Flood Alert System between 2014 and 2017. **Figure** 1 and **Table** 1 show the location of these stations and a more detailed data description, respectively.

**Table** 1 shows that precipitation data from the Japuíba station of INEA were used in the simulations starting in 2014. This occurred because the data from the Japuíba station is more comprehensive for this period. Therefore, as the two stations are very close (approximately four kilometers apart) and have approximately the same altitude, we chose to use this station to avoid losing the quality of the averages calculated.

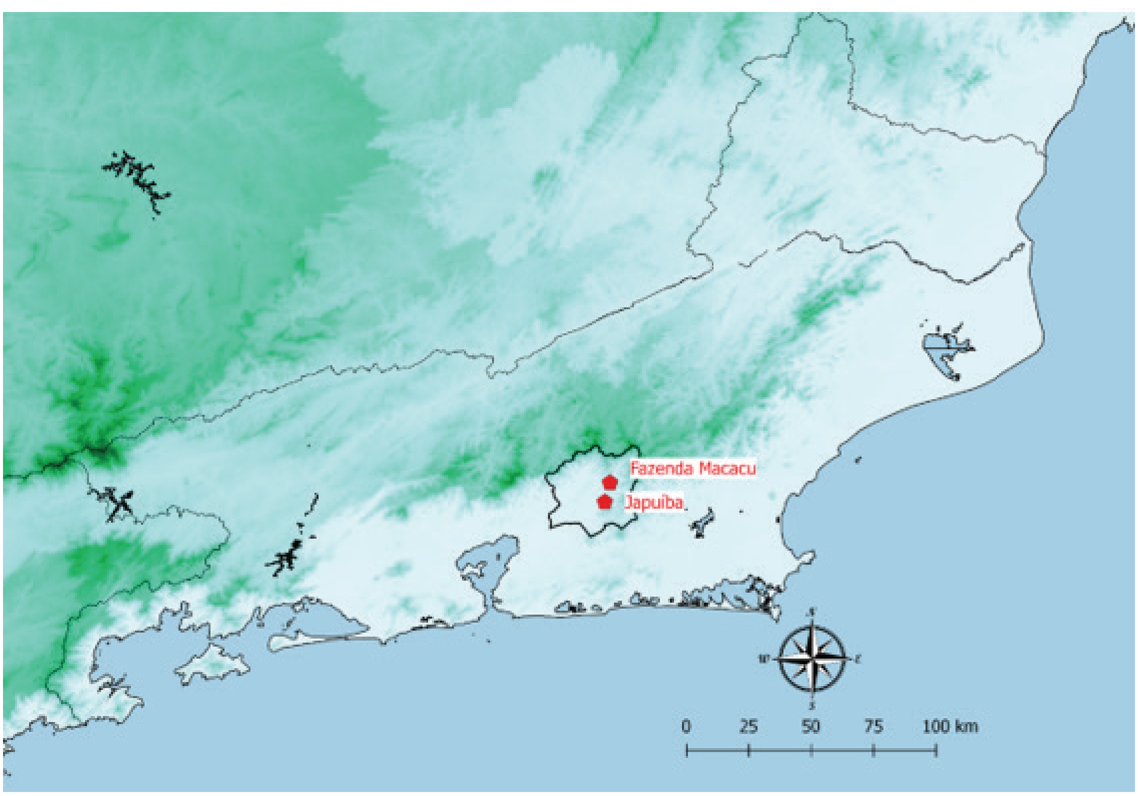


**Figure 1.** Location of the meteorological and rainfall stations used

**Table 1.** Stations and data used

| ESTATION | DATA | PURPOSE | PERIOD |
|---|---|---|---|
| Macacu Farm | Precipitation, temperature (maximum, minimum, and average), relative humidity, and radiation. | Calculation of BHC, agroclimatic suitability, agricultural calendar, and agroclimatic risk. | 2007-2017. |
| Japuíba (INEA) | Precipitation | Calculation of BHC, agroclimatic suitability, agricultural calendar, and agroclimatic risk. | 2014-2017. |

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In this work, an agroclimatic simulation was carried out for the crops of this region. This simulation calculated the Climatological Water Balance (CLB), agroclimatic suitability, and climate risk. The suitability provides information about the wet and dry seasons of the region in question, indicating the need or not for irrigation throughout the year to prevent excessive water resource use. The agricultural calendar will indicate which crops can be exploited and the most favorable planting dates. The climate risk will warn about the probability of drought events during the wet season. In this work, a percentage of 20% of maximum risk was used, according to Assad *et al.*(2008).

The methods adapted from Thornthwaite & Matter (1955) and Camargo (1962) were used to calculate the BHC. Thus, it is assumed that the soil is at its maximum available water capacity in the wet period, i. e., ARM = DWC, and the accumulated negative is equal to zero. After this consideration, the steps described below are performed.

The Hargreaves & Samani (1985) method was used to calculate the reference evapotranspiration (ETo), considering the data available at the Fazenda Macacu weather station and the precipitation at the Japuíba station. For this purpose, we used the average, minimum, and maximum daily air temperature and global radiation at the surface (equation 1) instead of global radiation at the top of the atmosphere, considering that this substitution presents better results for the region (COSTA, 2015).

$$ETo_{Harg\_Sam} = 0{,}0023 R_g (T_{máx} - T_{mín})^{0{,}5} (\bar{T} + 17{,}8) \quad (1)$$

In general, it is first necessary to calculate the difference between precipitation and ETo. However, in this work, the calculated ETc will be used to establish the conditions for culture. Therefore, if this difference is negative, there was water loss, and we have the so-called accumulated negative (NEGACUM) shown by equation (2). The ARM is calculated by equation (3) from the first negative accumulated. However, it is worth noting that as long as Prec-ETc is greater than zero (before the first negative value appears), NEGACUM and ARM will be given by equations (4) and (5), respectively, since the onset of the BHC in the wet period is considered.

$$NEG_{ACUM\ (t)} = Prec - ETc_{(t)}\ , where\ Prec - ETc_{(t)} < 0 \quad (2)$$

$$ARM_{(t)} = CAD\ e^{\left[\frac{NEG_{ACUM\ (t)}}{CAD}\right]} \quad (3)$$

$$In\ which\ \ ARM_{(t)} = CAD, while\ \ Prec - ETc > 0 \quad (4)$$

$$NEG_{ACUM\ (t)} = 0 \quad (5)$$

If the value of Prec-ETc continues to be negative in the second month, equations (6) and (7) are used to estimate accumulated negative and volume water storage, respectively.

$$NEG_{ACUM\ (t+1)} = NEG_{ACUM\ (t)} + Prec - ETc_{(t+1)}, in\ which\ Prec - ETc_{(t+1)} < 0 \quad (6)$$

$$ARM_{(t+1)} = CAD\ e^{\left[\frac{NEG_{ACUM\ (t+1)}}{CAD}\right]} \quad 7)$$

However, if the second month is positive, equation (8) is used. It is worth noting that if MRA is greater than CAD, the value used is the CAD value. Thus, the MRA value cannot be greater than CAD. Therefore, after finding the MRA value for the positive case, the accumulated negative is calculated by equation (9).

$$ARM_{(t+1)} = Prec - ETc_{(t+1)} + ARM_t, em\ que\ Prec - ETc > 0\ ;\ ARM_{(t+1)} \leq CAD \quad (8)$$

$$NEG_{ACUM\ (t+1)} = CAD\ \ln\left[\frac{ARM_{(t+1)}}{CAD}\right] \quad (9)$$

After performing these calculations of crop evapotranspiration, water storage in the volume and accumulated negatives, the change in storage (ALT), the actual evapotranspiration (ETr), the water deficiency (DEF), and the water surplus (EXC) are calculated. The change in storage is given by the difference between the current storage and the storage of the previous month - equation (10).

$$ALT_{t+1} = ARM_{t+1} - ARM_t \quad (10)$$

The actual evapotranspiration can be calculated in two different ways, given by equations (11) and (12). The water deficit can be found in equation (13) from these results.

$$When\ Prec - ETc \geq 0 \rightarrow ETr = ETc \quad (11)$$

$$When\ ALT \leq 0\ \rightarrow ETr = Prec + |ALT| \quad (12)$$

$$DEF = ETc - ETr \quad (13)$$

Finally, the water surplus is the amount of water remaining during the rainy season. At the end of the month, this surplus has been lost through deep drainage or runoff. Thus, this calculation can be done in two different ways, as provided by equations (14) and (15).

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$$When\ ARM < CAD \rightarrow EXC = 0 \quad (14)$$

$$When\ ARM = CAD \rightarrow EXC = Prec - ETc - ALT \quad (15)$$

ETc was calculated according to the equation (ETc=Kc·ETo), with Kc = Kcmax to minimize any risk of water stress.

For agroclimatic suitability, the monthly average data of air temperature, water deficiency, and optimal basal temperatures of the crops were used. It is necessary to understand the possible aptitudes in the thermal and hydric context. Thus, for this work, the following aptitude criteria were used:

Thermal Aptitude: when the climatological average temperature of the month is between the value of the minimum and maximum basal crop temperatures;

Thermal Inaptitude: when the climatological average temperature of the month is lower than the values of the minimum basal temperatures of the crop or higher than the values of the maximum basal temperature of the crops;

Hydric Aptitude: it occurs when there is no water deficit, i.e., the precipitation should be equal to or greater than the crop evapotranspiration, and the storage change should be greater than zero;

Hydric Inaptitude: it occurs when there is water deficiency, i.e., precipitation should be smaller than crop evapotranspiration, and the change in storage should be less than zero. A summary of the methods used is presented in equations (16), (17), (18), and (19).

**Thermal Aptitude:**

$$If\ \ \bar{T} \le Tb_{min}\ or\ \bar{T} \ge Tb_{máx} \rightarrow APT_{TERM} = \text{"UNABLE" or "UNFAVORABLE"} \quad (16)$$

$$If\ \ \bar{T} \le Tb_{min}\ or\ \bar{T} \ge Tb_{máx} \rightarrow APT_{TERM} = \text{"UNABLE" or "UNFAVORABLE"} \quad (17)$$

**Water Aptitude:**

$$f\ \ DEF \ne 0; Prec \le ETc \rightarrow APT_{HID} = \text{"UNABLE" or "UNFAVORABLE"} \quad (18)$$

$$If\ \ DEF \ne 0; Prec \le ETc \rightarrow APT_{HID} = \text{"UNABLE" or "UNFAVORABLE"} \quad (19)$$

Thus, with these considerations, **Table** 2 describes the possible agroclimatic aptitudes extracted through the thermal and hydric aptitudes. Note that when water inaptitude is associated with thermal aptitude, there is the so-called "agroclimatic constraint." In this case, irrigation must be used on the property to maintain the crop. Agroclimatic inaptitude occurs when there is thermal inaptitude since it is assumed that there is no way to minimize these effects.

**Table 2.** Agroclimatic skill classes

| Thermal aptitude | Water aptitude | Agroclimatic aptitude |
|---|---|---|
| ABLE | ABLE | **ABLE** |
| UNABLE | ABLE | **UNABLE** |
| ABLE | UNABLE | **RESTRICT** |
| UNABLE | UNABLE | **UNABLE** |

To calculate the agro-climatic suitability, the crops used were pumpkin, açaí, lettuce, sweet potato, eggplant, onion, carrot, cupuaçu, guava (at its normal rate and for commercial exploitation), jilo, corn, bell pepper, okra, and tomato. **Table** 3 shows each crop's optimal minimum and maximum basal temperatures, the crop coefficients used, and their references for the simulations. **Table** 4 shows the cycles used for the agricultural calendar (with references in the same bibliographies cited above).

**Table 4.** Crop cycle

| Crop | Cycle (Days) |
|---|---|
| Pumpkin | 60 |
| Lettuce | 60 |
| Sweet Potato | 90 |
| Eggplant | 90 |
| Carrot | 120 |
| Jilo | 90 |
| Bell pepper | 120 |
| Okra | 90 |
| Tomato | 90 |
| Onion | 120 |
| Corn | 60 |

Climate risk was defined by means of the crop's Water Requirement Satisfaction Index (WRSI), calculated as the ratio between crop evapotranspiration (ETc) and real evapotranspiration (ETr). For the crops considered in this work, the WRSI should be greater than or equal to 0.55 in 80% of the years of the climatological database, so that there is no climatic risk, i.e., the tolerated risk for drought occurrence is 20%. The value of 0.55 is the limit value for small crops (ASSAD *et al.*, 2008).

## RESULTS AND DISCUSSION

**Figure** 2 shows the climatological normals of temperature and precipitation for the municipality of Cachoeiras de Macacu (2007-2017). Although the World Meteorological

**Table 3.** Minimum and maximum basal temperatures of crops and crop coefficient

| Culture | Minimum basal temperature (°C) | Maximum basal temperature (°C) | Crop coefficient (Kcmáx) | References |
|---|---|---|---|---|
| Pumpkin | 20 | 27 | 1.4 | Lunardi et al., 1999; and Makishima, 2004 |
| Açaí | 18 | 30 | 1* | Nogueira et al., 1995 |
| Lettuce | 12 | 22 | 1.4 | Nunes et al., 2009; and Makishima, 2004. |
| Sweet Potato | 16 | 25 | 1 | Miranda et al., 1995; and Makishima, 2004. |
| Eggplant | 18 | 25 | 1.2 | Loose et al., 2014; and Makishima, 2004 |
| Onion | 12 | 30 | 1 | Costa et al., 2002, Oliveira et al., 2013; and Makishima, 2004. |
| Carrot | 8 | 25 | 1.1 | Marouelli et al., 2007; Souza et al., 1999; and Makishima, 2004. |
| Cupuaçu | 21 | 28 | 1* | De Souza et al., 2008 |
| Guava | 12 | 46 | 0.9 | Teixeira et al., 2003; and Da Silva et al., 2010 |
| Commercial Guava | 25 | 28 | 0.9 | Teixeira et al., 2003; and Da Silva et al., 2010 |
| Jiló | 18 | 25 | 1* | Pinheiro et al., 2015; and Makishima, 2004. |
| Corn | 19 | 32 | 1.3 | Da Silva et al., 2006; Tsunechiro et al., 2008; and Makishima, 2004. |
| Peppers | 18 | 25 | 0.7 | Albuquerque et al., 2012; and Makishima, 2004. |
| Okra | 22 | 25 | 1* | Makishima, 2004. |
| Tomato | 18 | 25 | 1.1 | Santana et al., 2011; Dusi et al., 1993; and Makishima, 2004. |

* Since there are no measurements, the standard values are used (Kc=1)

Organization (WMO) recommends using 30 years of data, in Cachoeiras de Macacu, the interval from 2007 to 2017 was used for the calculations due to the unavailability of data prior to the year 2007.

In the climatology of Cachoeiras de Macacu, the highest temperature value occurs in February (26.8 °C in summer), and the lowest value occurs in July (19.6 °C in winter). The highest precipitation value occurs in January (173 mm) and the lowest in August (24 mm). The average annual temperature is 22.9 ºC.

After establishing the climatology, **Table** 5 shows the results of agro-climatic simulations performed for the municipality of Cachoeiras de Macacu. This **Table** shows the agroclimatic suitability of the crops mentioned in the methodology. Considering that the corn and guava crops are among the most cultivated in the districts of Papucaia and Agrobrasil, **Figure**s 3 and 4 show the water deficit and surplus for the guava and corn crops, respectively.

The hydric condition was not a limiting factor in the agroclimatic aptitude for any considered crops. The limitations were due to the thermal conditions, and the average temperature of the unfavorable months for cultivation could be above or below the optimal basal temperature range for the crops considered in this study. Thus, the thermal conditions were unfavorable due to temperature deficiency for the pumpkin, cupuaçu, and commercial guava crops, i.e., in some months, the average air temperature was lower than the minimum basal temperature for these crops. Conversely, the problem for lettuce, sweet potato, eggplant, carrot, jilo, bell pepper, and tomato crops was excess temperature, i.e., the average temperature was higher in some months than the maximum basal temperature for these crops. In the case of okra, both types of thermal limitation occurred: deficit and excess temperature. For the açaí, onion, guava, and corn crops, there was no thermal limitation in any of the months of the year.

**Table** 6 presents a comprehensive sustainable agricultural calendar for the municipality of Cachoeiras de Macacu. The crops used were the same as in the agro-climatic suitability. However, for developing the agricultural calendar, crop cycles were considered.

Analyzing **Table** 6, it is clear that onions and corn can be cultivated all year round among the annual crops. Therefore, they are the most recommended crops for exploitation in the region. The most recommended crop in the sequence is pumpkin, which cannot be cultivated for only two months during winter, meaning that its planting can take place from August to May. The sweet potato, eggplant, carrot, jilo, bell pepper, and tomato crops can be grown between April and October from fall to mid-spring, and lettuce, between late fall and late winter, from May to

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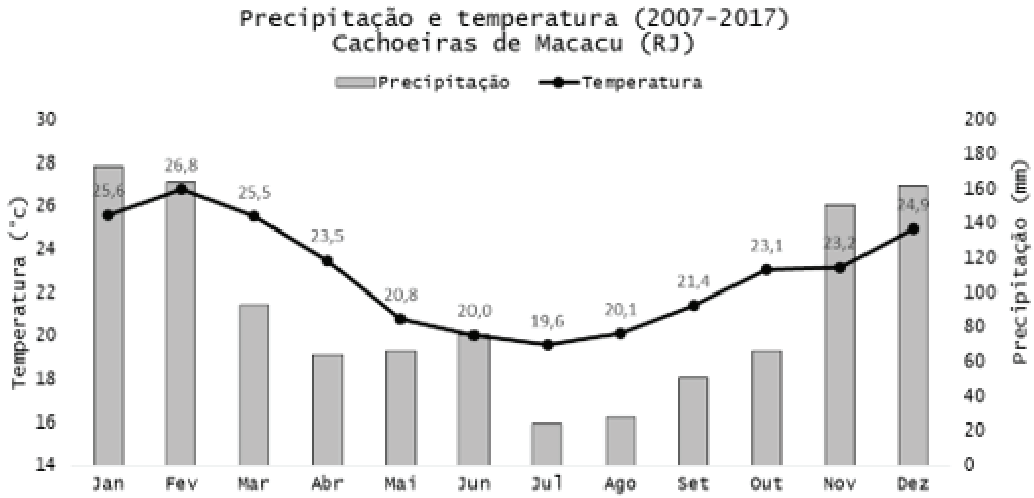


**Figure 2.** Climatological normals of precipitation and temperature for the Municipality of Rio de Janeiro from 1988 to 2017

Legend: Precipitation and temperature (2007-2017); Cachoeiras de Macacu (RJ); Precipitation temperature; Temperature (ºC) (Vertical left); Precipitation (mm) (Vertical right); Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

**Table 5.** Agroclimatic suitability for the Municipality of Cachoeiras de Macacu

| Agroclimatic suitability of Cachoeiras de Macacu (RJ) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Pumpkin | Açaí | Lettuce | Sweet Potato | Eggplant | Onion | Carrot | Cupuaçu | Guava | Commercial Guava | Jilo | Corn | Bell Peppers | Okra | Tomato |
| January | ABLE | ABLE | UNABLE | UNABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | UNABLE | UNABLE |
| February | ABLE | ABLE | UNABLE | UNABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | UNABLE | UNABLE |
| March | ABLE | ABLE | UNABLE | UNABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | UNABLE | UNABLE |
| April | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE |
| May | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE |
| June | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE |
| July | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE |
| August | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE |
| September | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | UNABLE | ABLE |
| October | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE |
| November | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE |
| December | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE | ABLE | UNABLE | ABLE | ABLE | ABLE | ABLE | ABLE |

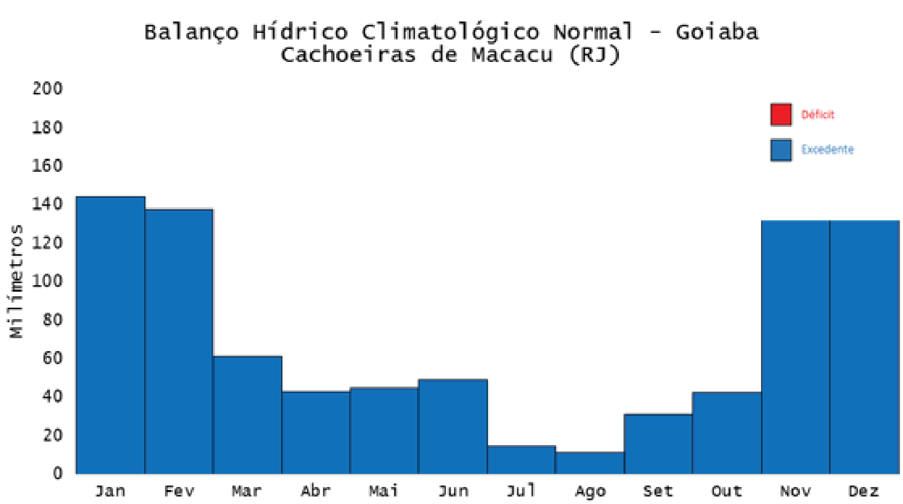


**Figure 3.** Water deficit and surplus of guava for the Municipality of Cachoeiras de Macacu

Legend: Climatological Water Balance – Guava; Cachoeiras de Macacu (RJ); Millimeters (Vertical left); Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

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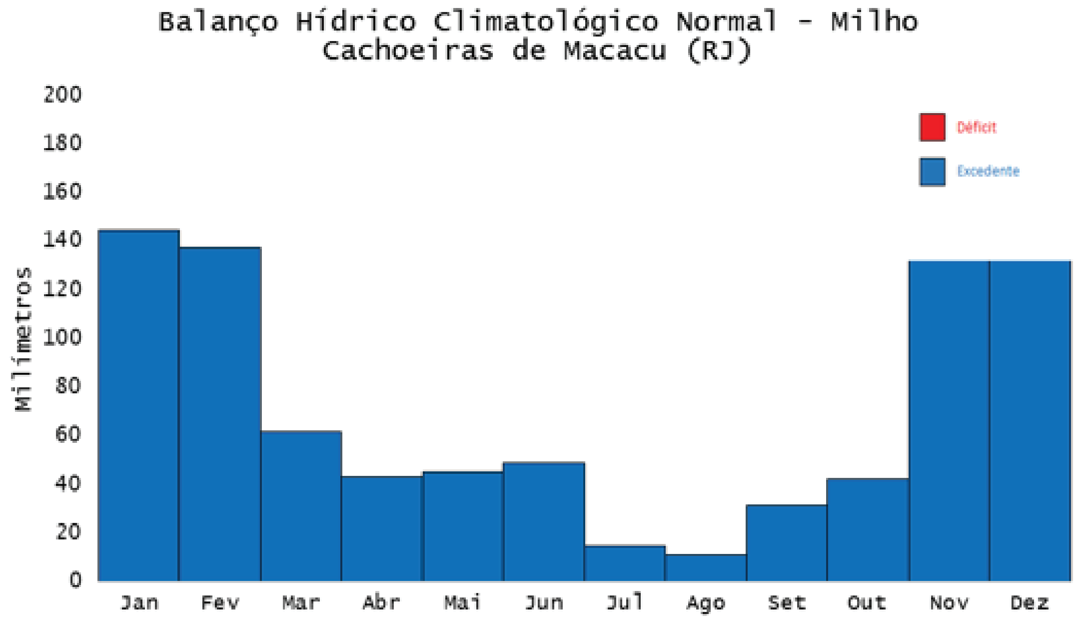


**Figure 4.** Déficit e excedente hídrico do milho para o Município de Cachoeiras de Macacu.

Legend: Climatological Water Balance – Corn; Cachoeiras de Macacu (RJ); Millimeters (Vertical left); Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

August. Okra, in contrast, can only be grown in one month during the spring: October.

Among the perennial crops studied (açaí, cupuaçu, and guava), it can be seen that only açaí and guava are favorable for planting in the region. As they are perennials, they need to be favorable in all months of the year, and because cupuaçu has unfavorable months, it is not considered sui**Table** for cultivation in this region.

The harvest possibilities in one year due to the length of the phenological cycle and the number of favorable months for cultivation are up to: six for maize (2/12); five for pumpkin (2/10); three for sweet potato (3/7), eggplant (3/7), jilo (3/7), tomato (3/7), and onion (4/12); two for lettuce (2/4), carrot, and bell pepper (4/6); and one for okra (3/1). The cycle length and favorable months are in parentheses.

The agroclimatic risk for the municipality of Cachoeiras de Macacu was evaluated due to the natural climatic variability, mainly concerning the hydric conditions for which drier or rainier years can occur compared to the historical average.

Therefore, **Table** 7 shows the agroclimatic risk per crop calculated from the percentage of monthly WRSI. Although there were no months with water scarcity based on the BHC's historical average, the climatic risk indicated that the likelihood of this event reaching medium to high levels cannot be ignored.

From **Table** 7, and based on the agroclimatic aptitude (**Table** 5), one can define the months of the vegetative cycle for each crop where the probability of needing irrigation is medium or high, namely:

Pumpkins can stay in the field from August to June, but with irrigation from February to April, in June, and from August to December.

Lettuce can stay in the field from May to September, but with irrigation, from June to September.

Okra can be in the field from October to December, but with irrigation.

From April to December, the following can remain in the field: sweet potato, carrot, jilo, and tomato, with irrigation in April and from July to December; eggplant, with irrigation in April and from June to December; and bell pepper, with irrigation from July to December.

During the entire year, the following can remain in the field: corn, with irrigation from February to April and June to December; onions, açaí, and guava, with irrigation in April and from July to December.

## CONCLUSIONS

Regarding the results found, it is concluded that:

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**Table 6.** Agricultural calendar for the Municipality of Cachoeiras de Macacu

| | ANNUAL CROPS | | | | | | | | | | | PERENNIAL CROPS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MONTHS SUITABLE FOR PLANTING | | | | | | | | | | | CROPS SUITABLE FOR PLANTING IN THE MUNICIPALITY OF CACHOEIRAS DE MACACU |
| | Pumpkin | Lettuce | Sweet Potato | Eggplant | Onion | Carrot | Jilo | Corn | Bell Peppers | Okra | Tomato | |
| January | X | | | | X | | | X | | | | Açaí and Guava |
| February | X | | | | X | | | X | | | | |
| March | X | | | | X | | | X | | | | |
| April | X | | X | X | X | X | X | X | X | | X | |
| May | X | X | X | X | X | X | X | X | X | | X | |
| June | | X | X | X | X | X | X | X | X | | X | |
| July | | X | X | X | X | X | X | X | X | | X | |
| August | X | X | X | X | X | X | X | X | X | | X | |
| September | X | | X | X | X | X | X | X | X | | X | |
| October | X | | X | X | X | | X | X | | X | X | |
| November | X | | | | X | | | X | | | | |
| December | X | | | | X | | | X | | | | |

**Table 7.** Agroclimatic risk for the Municipality of Cachoeiras de Macacu

| Agroclimatic Risk calculated using the WRSI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Pumpkin | Açaí | Lettuce | Sweet Potato | Eggplant | Onion | Carrot | Cupuaçu | Guava | Jilo | Corn | Bell Peppers | Okra | Tomato |
| January | LOW | LOW | MEAN | LOW | LOW | LOW | LOW | LOW | LOW | LOW | LOW | LOW | LOW | MEAN |
| February | HIGHT | LOW | MEAN | LOW | MEAN | LOW | LOW | LOW | LOW | LOW | MEAN | LOW | LOW | MEAN |
| March | HIGHT | LOW | HIGHT | LOW | LOW | LOW | LOW | LOW | LOW | LOW | HIGHT | LOW | LOW | LOW |
| April | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | MEAN | HIGHT | HIGHT | LOW | HIGHT | HIGHT |
| May | LOW | LOW | LOW | LOW | LOW | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | LOW | LOW | LOW | LOW |
| June | HIGHT | LOW | HIGHT | LOW | MEAN | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | LOW | LOW | LOW |
| July | HIGHT | MEAN | HIGHT | MEAN | HIGHT | MEAN | MEAN | MEAN | MEAN | MEAN | HIGHT | MEAN | MEAN | HIGHT |
| August | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | MEAN | HIGHT | HIGHT |
| September | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | MEAN | HIGHT | HIGHT |
| October | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT | HIGHT |
| November | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN | MEAN |
| December | HIGHT | MEAN | MEAN | MEAN | HIGHT | MEAN | MEAN | MEAN | MEAN | MEAN | HIGHT | MEAN | MEAN | HIGHT |

(i) All annual crops considered have favorable periods for at least one planting per year in the studied region;

ii) The thermal issue was the limiting factor for the non-occurrence of the favorable planting condition for the crops in some months of the year;

iii) The hydric issue was not a limiting factor for the favorable condition throughout the months of the year;

iv) The most indicated crops for the region are onions, corn, açaí, and guava, for their favorable conditions during the twelve months of the year;

v) In line with the results found in agroclimatic suitability, it can be seen that there is no climatological water deficiency in the region for guava and corn crops; however, since agroclimatic risk occurred practically all year round, these crops should be cultivated with irrigation management;

v) Drought weather risk occurred for all the considered crops, highlighting the need for irrigation management in the region in the months when the risk was "high."

This work showed that the agroclimatic simulation allowed establishing an agricultural calendar for the municipality of Cachoeiras de Macacu, aiming to help plan all farmers in the region in planting and possible irrigation management and avoid the risks inherent in planting certain crops outside their ideal period.

Therefore, with these needs met, one can conclude that the objectives sought in this study were achieved and, with the system implemented, there would be several benefits for society. Consequently, there are many challenges to be overcome, and research must move forward, along with the dissemination of environmental education in all sectors of society, guaranteed by the 1988 Federal Constitution (Article 225). In addition, elaborating and implementing new legal projects aimed at preserving the environment, making socioeconomic advances compatible, and elaborating and executing public inspection policies to verify compliance with the environmental policies described in our legal system is important.

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