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Potential for the Cultivation of Atemoya Hybrid Fruit Based on Climatic Factors in the Upper Mogiana, Northeast São Paulo State

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Authors' contributions

This work was carried out in collaboration between all authors. This work was a part of research findings of the author AG, that managed the experimental process and wrote the first manuscript. The authors DIT and LCS managed the literature searches, and contributed to manuscript writing and formatting. All authors read and approved the final manuscript.

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ABSTRACT

In order to determine whether climatic factors are suitable for atemoya production, and with the goal of providing an alternative crop for agricultural planning and production, the water balance was assessed using temperature and precipitation historic series data for twelve municipalities in the Northeast region of São Paulo State. Potential evapotranspiration (ETP), water surplus (EXC), water withdrawal (RET), water deficiency (DEF), and water replenishment (REP) were determined through the classical water balance Thornthwaite procedure . With the monthly and annual values of DEF and EXC, we obtained the indices for water (Ih), aridity (Ia), and humidity (Im). Based on the results, it is evident that atemoya can be grown in these areas in the Northeast region of São Paulo State, as it presents favorable temperature and water conditions for crop development.

Keywords: Agro-climatic zoning; climate aptitude; Annona squamosa L. X Annona cherimoia Mill; soil moisture surplus; soil moisture deficit; soil moisture utilization; soil moisture recharge.

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1. INTRODUCTION

The atemoya fruit is a hybrid developed from a cross between the tropical sugar-apple (*Annona squamosa*), which is widely dispersed throughout Brazil and other warm climate regions, with cherimoya (*Annona cherimola*), a species native to the Andean regions of Chile, Peru, Bolivia, Ecuador, and milder climatic regions [1,2].

According to [3], the atemoya fruit arrived in Brazil during the second half of the 20th century, and has gradually been introduced into new fresh fruit markets. The fruit has significant potential for export to a wide range of countries due to its excellent organoleptic qualities.

Because of its ability to adapt to diverse climatic conditions, atemoya cultivation is distributed across several parts of the country, with the Thompson variety showing better performance in subtropical climates and the Geffner variety in the semi-arid northeast [4].

National production in Brazil began at the end of the 1990s and has been absorbed essentially by the internal market, obtaining an excellent price because of the high quality of the fruit and limited availability. Of the approximately 10,000 hectares of Annonaceae grown in Brazil, about 1,200 ha are atemoya, with around 43 % in São Paulo State, followed by the states of Paraná, Minas Gerais, and Bahia, each with approximately 18.8 % of production [5].

The period with the greatest incidence of flowers occurs naturally during the warmest months of the year, coinciding with the period of highest precipitation, which favors higher levels of fertilization of flowers and fruit formation [6].

The atemoya is sensitive to water stress, particularly in conditions with high air temperature and during the fruit development phase. Furthermore, water stress can diminish the number of fruit and their size, thus having an impact on productivity [7]. Therefore, the use of complementary irrigation to ensure uniform levels of soil water has become extremely important in reducing water stress and consequently favors an increase in yield and avoids splitting of the fruit [8].

The Upper Mogiana region, which is the focus of this study, is a traditional coffee producing region. Due to a number of reasons, including changes in climate, in the last few years the region has been adapting to the production of other cultivars, particularly sugar cane.

The objective of this study was to assess the climatic suitability of the region for atemoya with the goal of providing an alternative crop for agricultural planning and production for the Northeast region of São Paulo State.

2. MATERIALS AND METHODS

The current study is based on monthly measurements of precipitation and air temperature from 12 municipalities located in the Northeast region of São Paulo State. The data were used to assess the climate water balance based on the method described by Thornthwaite and Mather (1955) [9].

Table 1 presents the geographic coordinates as well as the meteorological historic data series collected for each municipality.

Fig. 1 shows the municipalities included in the study in the Northeast of São Paulo and slope for São Paulo state. Declivity values were classified following EMBRAPA [12].

In the study region, there are no areas with a slope greater than 20%. Slope levels below 20 % facilitate the management of field crops as they enable greater access for agricultural machinery.

The water balance for the period was assessed using temperature and precipitation data considering an available water capacity (AWC) of 125 mm; this value is widely used in agro-climatic studies for a wide range of perennial crops with deep root systems, such as grape, cashew, acerola, coffee, etc. [6]. Therefore, we estimated the potential evapotranspiration (ETP), water surplus (EXC), water withdrawal (RET), water deficiency (DEF), and water replenishment (REP) for each month.

With the monthly and annual values of DEF and EXC, we obtained the indices for water (Ih), aridity (Ia), and humidity (Im) using the following expressions:

$$I_h = \frac{100.EXC}{ETP} \quad (1)$$

$$I_a = \frac{100.DEF}{ETP} \quad (2)$$

$$\mathrm{Im} = Ih - Ia \quad (3)$$

These indices are essential for the climatic characterization of a region based on the method described in Thornthwaite (1948) [13] and in the study of crop adaptation for the region (Agricultural Zoning). They have also been widely used to characterize suitability and agricultural zoning for crops by numerous researchers [6,14,15,16].

The climatic ranges used to determine the potential for atemoya crop development are presented in Table 2 and adapted from [2,6,17,18,19].

The wide range of precipitation levels, and therefore moisture index, that the species can withstand is based on the fact that they are small trees with an abundant lateral root system. As such, although the species shows a decrease in productivity under water stress, it is able to endure such variations in precipitation [20].

Table 1. Municipalities included in the study with latitude, longitude, altitude, and historic meteorological data series

Municipalities, state	Latitude	Longitude	Altitude (meters above sea level)	Data from
Ituverava[1], SP	20º20'22" S	47º46'50" W	605 m	1996-2016
Batatais[2], SP	20º53'28" S	47º35'06" W	870 m	2002-2016
Buritizal[2], SP	20º 11' 28" S	47º 42' 30" W	855 m	1983-2016
Cristais Paulista[2], SP	20º23'50" S	47º25'13" W	996 m	1992-2016
Franca[2], SP	20º32'30" S	47º25'11" W	1002 m	1984-2016
Guará[2], SP	20º 25' 42" S	47º 49' 27" W	573 m	1943-2003
Igarapava[2,3], SP	20°02´18" S	47°44`49" W	560 m	1943-2016
Pedregulho[2], SP	20º 15' 25" S	47º 28' 36" W	1035 m	1943-2016
Restinga[2], SP	20º 36' 12" S	47º 28' 58" W	910 m	1995-2012
Rifaina[2], SP	20º 04' 50" S	47º 25' 17" W	575 m	1995-2016
São Joaquim da Barra[2], SP	20º34'53" S	47º51'17" W	625 m	1978-2016
São José da Bela Vista[2], SP	20º 35' 35" S	47º 38' 24" W	730 m	2000-2016

[1] Aw, according the Köppen classification, with humid summers and dry winters [10,11]. Data were obtained from the Agrometeorological Station of the Dr. Francisco Maeda Faculty (FAFRAM)

[2] data were obtained from the Centre for the Integration of Agrometeorological Information (CIIAGRO) and/or the National Meteorological Institute (INMET)

[3]) data were obtained from Igarapava Hydroelectric Dam and the Raizen Dam (Junqueira Unit)

Table 2. Climatic factors used in zoning for atemoya crops in the Northeast region of São Paulo State

Classification	P (mm)	T_a (ºC)	T_{mf} (ºC)	T_{nd} (ºC)	UR_p (%)	Im
Viable	600< P < 4200	$12<T_a<32$	< 32	> 13	70 < UR< 80	-20< Im< 80
Ideal	2000< P < 3000	$22<T_a<26$	< 32	$20<T_{nd}<26$	70 < UR< 80	-20< Im< 80
Restricted due to water deficiency	< 600	-	-	-	< 60	< -20
Restricted due to Temp. deficiency	-		>32	< 13 or >28	-	-
Unviable	>4200	<12 or > 32	>38	<13	> 85	<-60 or > 120

P – Annual Precipitation; T_a – Average annual temperature;
T_{mF} – Average temperature during main flowering period (December to February);
T_{nd} – Average temperature during fruit development (February to April);
UR_p – Average relative humidity during crop production;
Im – Humidity index obtained through annual water balance

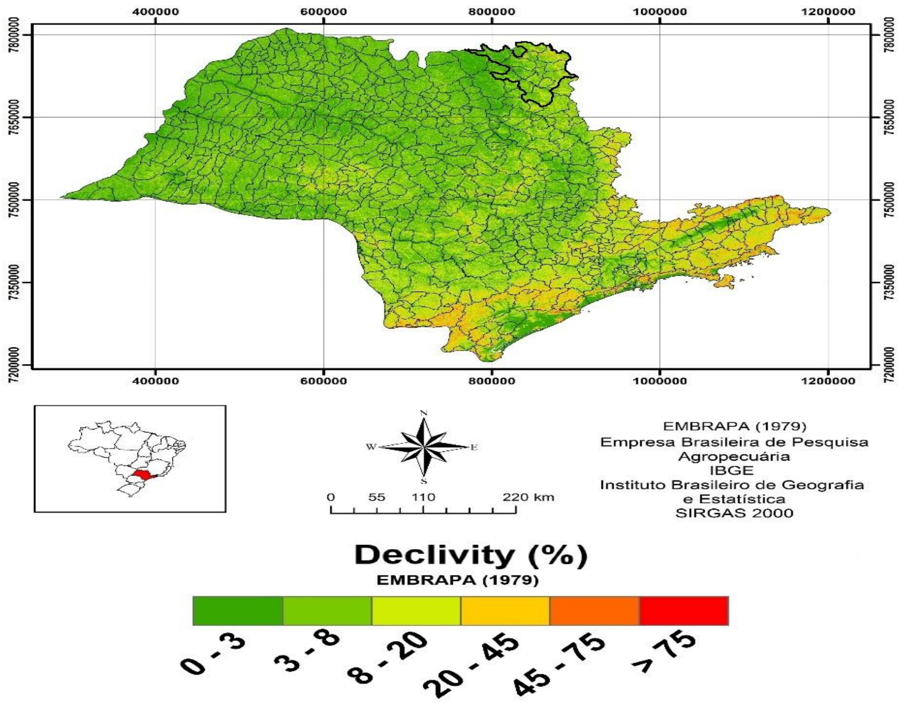
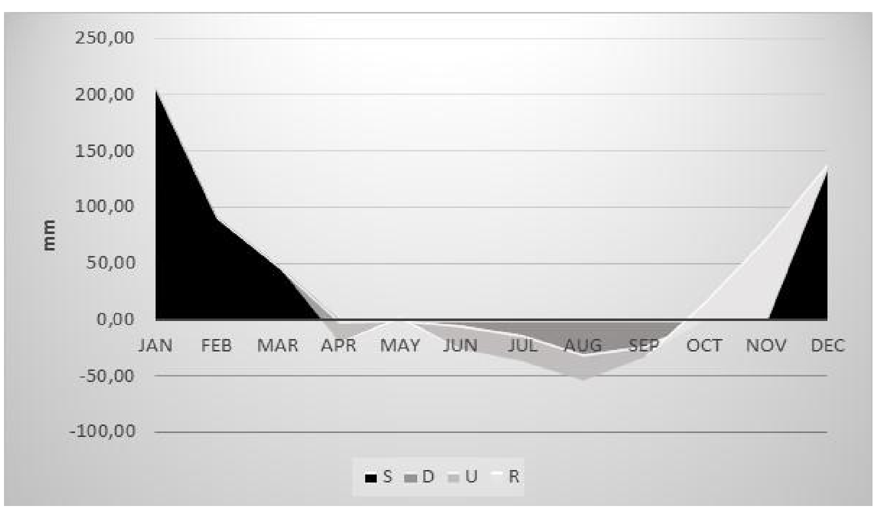


Fig. 1. Slope map of São Paulo with the 12 Upper Mogiana municipalities included in the study (outlined in black)

3. RESULTS AND DISCUSSION

Fig. 2 presents the results for the Climatological Water Balance showing the periods of water deficiency and surplus for each of the studied municipalities.

With the onset of the rainy season, the period of soil moisture surplus extends from November to March. When the rains begin to diminish, the consumption of the stored soil moisture starts to occur. By June, the period of water deficiency has begun since the precipitation that occurs from March to September in the region is insufficient to replenish the water storage capacity in the soil. In October, the soil moisture recharge can completely replenish the soil, achieving storage capacity in November.



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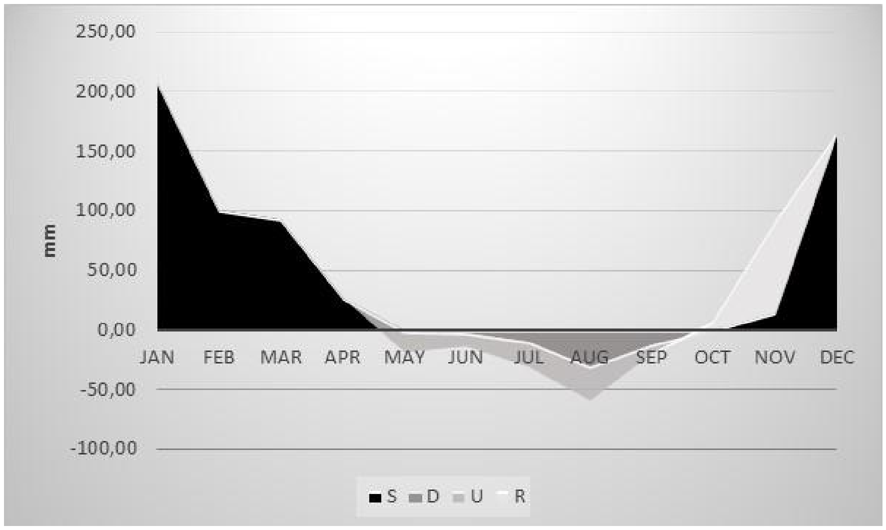
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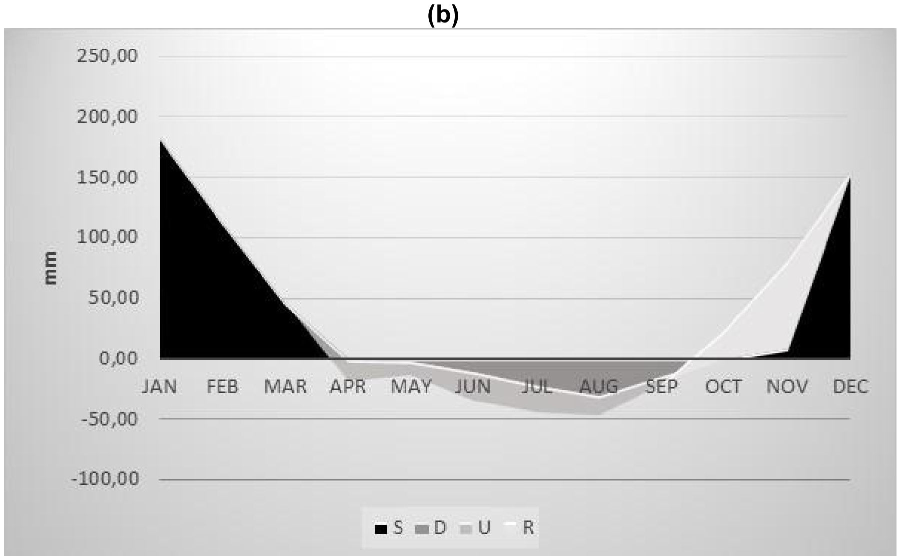
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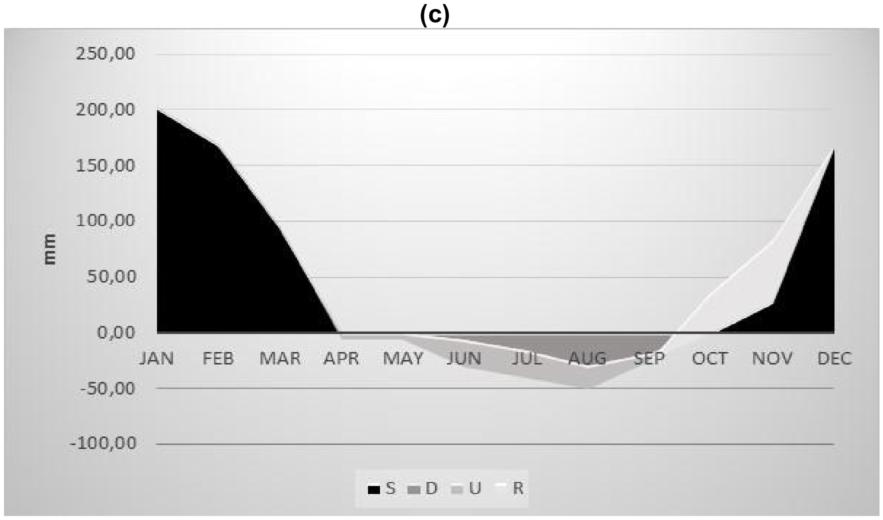
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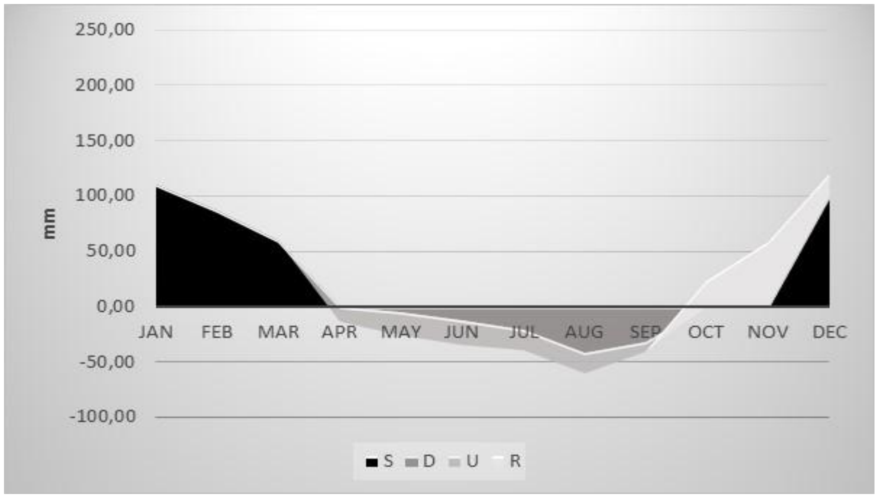
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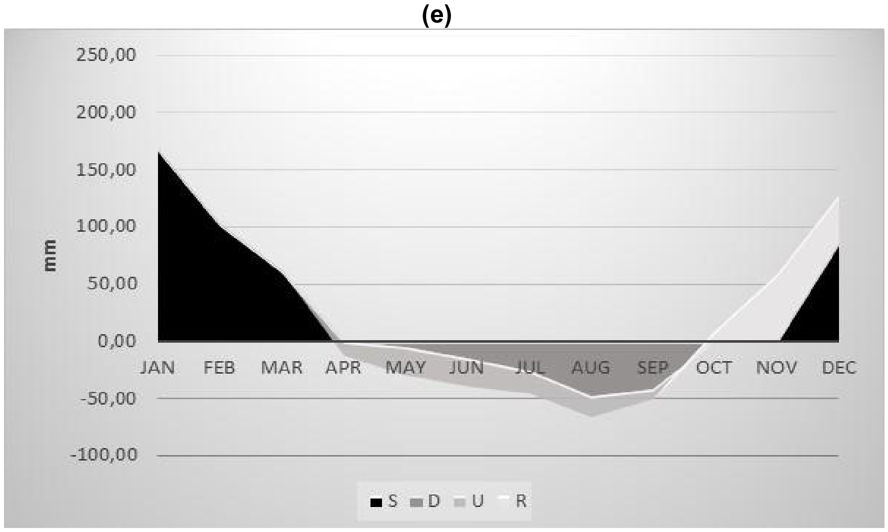
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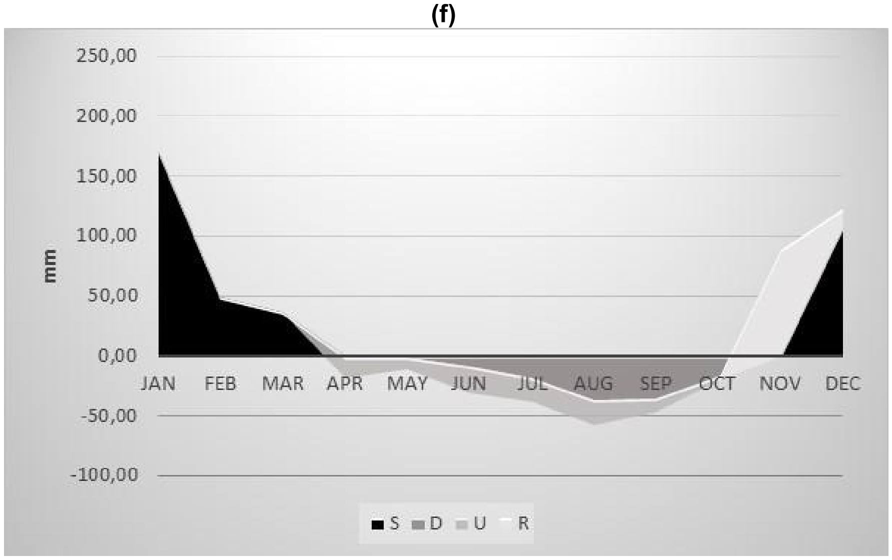
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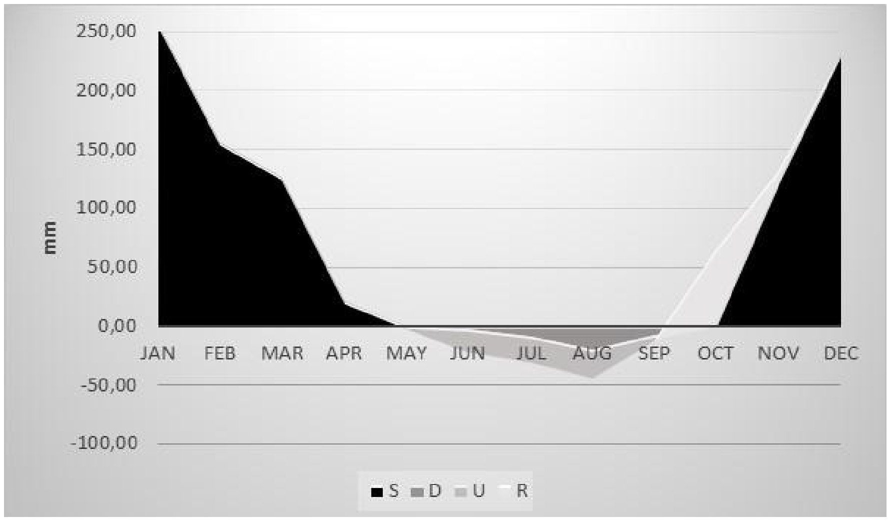
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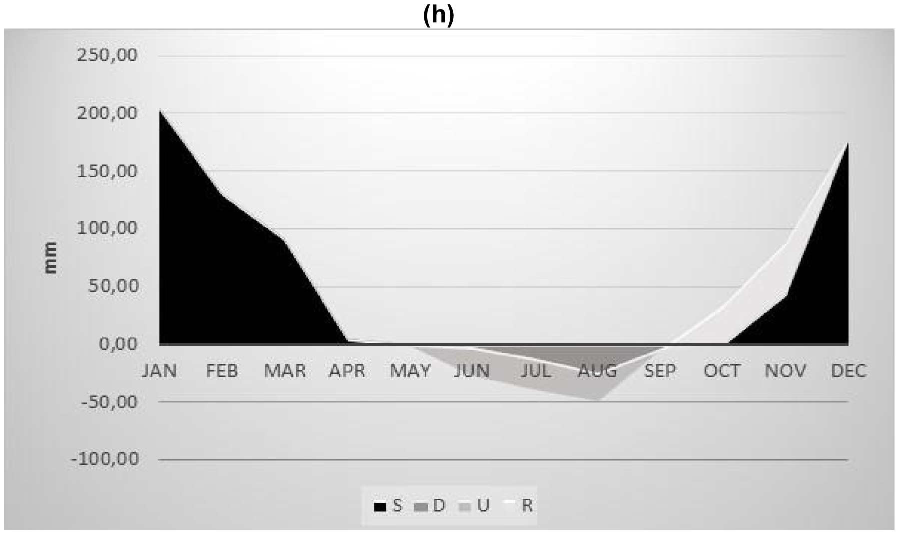
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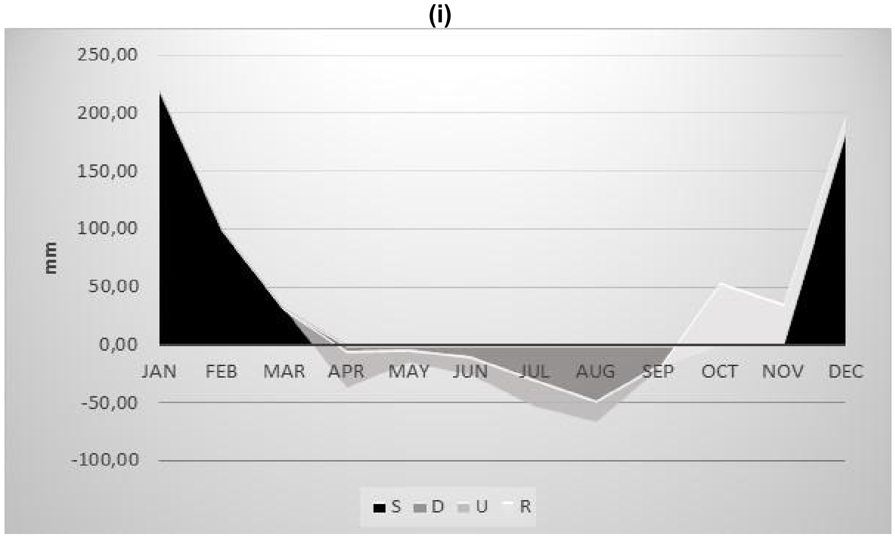
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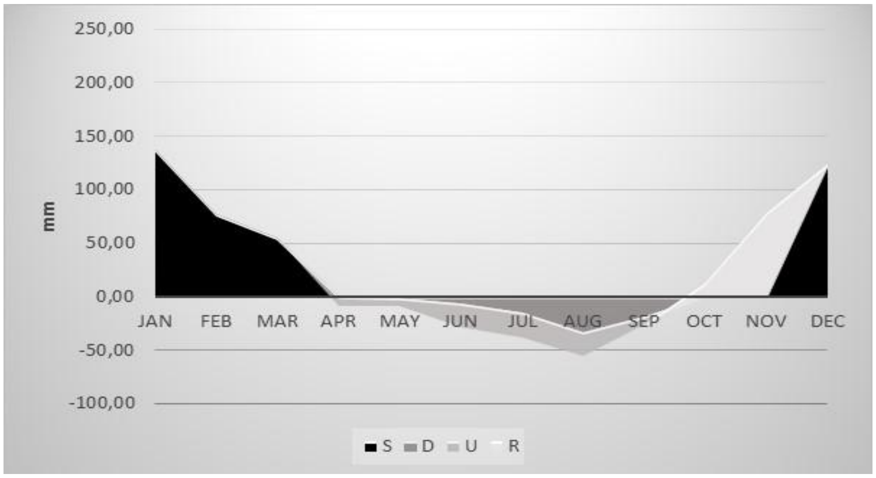

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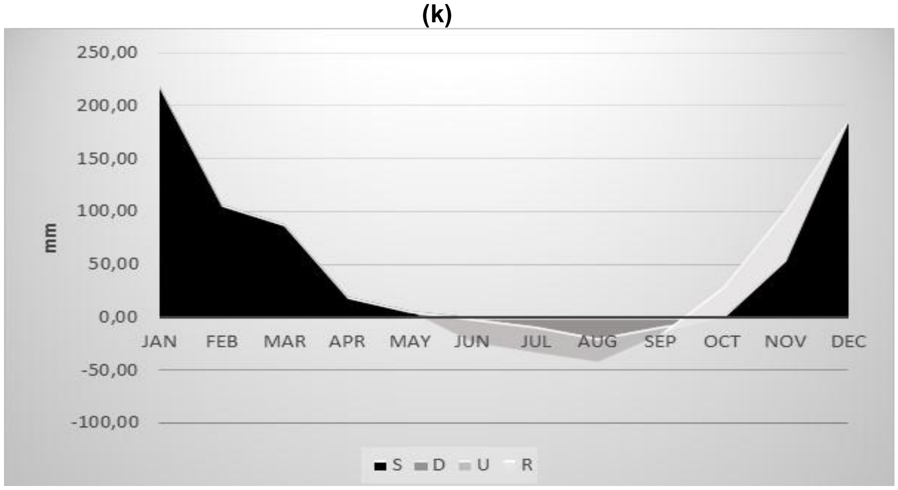

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Fig. 2. Results for the Climatological Water Balance for each of the studied municipalities, based on historic series data: (a) Batatais; (b) Buritizal; (c) Cristais Paulista; (d) Franca; (e) Guará; (f) Igarapava; (g) Ituverava; (h) Pedregulho; (i) Restinga; (j) Rifaina; (k) São Joaquim da Barra; and (l) São Jose da Bela Vista. References: S = Soil moisture surplus; D = Soil moisture deficit; U = Soil moisture utilization; R = Soil moisture recharge

The greatest water deficiency occurred in Igarapava with a total of 137 mm annually, followed by Ituverava (120 mm), Rifaina (115 mm), Cristais Paulista (84 mm), Batatais (76 mm), São Joaquim da Barra (74 mm), Franca (71 mm), Buritizal (58 mm), Restinga (44 mm), São Jose da Bela Vista (40 mm), Guará (40 mm), and finally Pedregulho (38 mm).

With the water balance data, the indices of water (Ih), aridity (Ia), and humidity (Im) were calculated for each municipality, based on equations 1, 2, and 3, respectively.

Based on historic series data (Table 1), in Table 3 we present the average values for each of the 12 studied municipalities for annual precipitation, annual temperature, temperature during flowering, temperature during fruiting, and values of the indices of water, aridity, and humidity.

The rainfall analysis shows that there is no water shortage in these locations as they present values greater than that required for the crop. Although the lowest level of precipitation was found for Ituverava (Table 2), all study sites fall within the limits indicated for the viable classification for the crop (rain of less than 2000 mm.year^{-1}).

Table 3. Average values for annual precipitation (P), annual temperature (T_a), temperature during flowering (T_{mf}), temperature during fruiting (T_{nd}), and values for the indices of water (Ih), aridity (Ia), and humidity (Im) for the studied municipalities

Municipality	P (mm)	T_a (ºC)	T_{mf} (ºC)	T_{nd} (ºC)	Ih	Ia	Im
Batatais	1514	25	25	24	41.9	6.6	35.3
Buritizal	1555	21	23	22	60.4	5.7	54.6
Cristais Paulista	1492	24	23	23	46.9	7.7	39.2
Franca	1637	23	23	23	63.3	6.8	56.5
Guará	1398	23	25	24	30.8	9.8	21.0
Igaparava	1470	23	25	24	35.4	11.5	23.9
Ituverava	1426	25	25	25	30.5	10.1	20.4
Pedregulho	1795	20	22	21	98.9	4.2	94.7
Restinga	1579	21	23	22	67.6	4.5	63.0
Rifaina	1599	23	25	24	45.4	9.8	35.6
São Joaquim da Barra	1500	25	25	25	33.1	6.2	27.9
São Jose da Bela Vista	1692	22	24	23	64.3	3.8	60.5

Table 4. Average monthly temperatures (T) for the studied municipalities

Municipality	T (°C)											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Batatais	24.8	25.2	24.5	23.2	20.1	19.2	19.1	20.8	23	24.5	24.5	25
Buritizal	23.0	23.1	22.8	21.2	19.2	18.2	18.1	20.2	22.0	22.7	22.6	22.8
Cristais Paulista	23.8	24	23.6	22.5	19.8	19.2	19	20.5	22.6	23.5	23.4	23.7
Franca	23.1	23.4	23.2	22.3	20.0	19.1	19.4	21.1	22.3	23.2	22.9	23.0
Guará	24.8	24.9	24.6	22.9	20.8	19.7	19.7	21.8	23.5	24.3	24.4	24.5
Igaparava	24.9	25.1	24.8	23.2	21.1	20.1	20	22.2	24	24.7	24.7	24.8
Ituverava	24.4	25.4	24.7	23.6	19.9	19.9	19.4	21.8	23.9	25.4	24.8	25.1
Pedregulho	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8
Restinga	22.6	22.7	22.4	20.7	18.6	17.6	17.5	19.5	21.3	22.1	22.1	22.3
Rifaina	24.9	25	24.7	23.1	21	20	19.9	22.2	23.9	24.7	24.6	24.7
SJ Barra	24.8	25.1	24.8	23.5	20.8	20.0	20.1	21.9	23.5	24.9	24.7	24.8
SJ Bela Vista	23.8	23.9	23.5	21.8	19.7	18.7	18.6	20.6	22.4	23.2	23.2	23.5

In above Table 4, we present the average monthly temperatures for each study location. In the months corresponding to the flowering period (December to February)[18], the average monthly temperatures show that all sites can be classified as ideal for atemoya (Table 2). When we consider the average temperatures for the three months during the period of fruit development (February to April), all values are also within the ideal range for the crop [2,6,17,18,19].

Based on our analysis, we have found no climatic restrictions that limit the cultivation of atemoya in the Northeast region of São Paulo State, as it presents favorable temperature and water conditions for crop development.

4. CONCLUSION

The results obtained in this study support the adoption of policies to enhance atemoya cultivation in the Upper Mogiana in the Northeast of São Paulo State. The crop presents low climate risk and provides an alternative for agricultural planning and production. We suggest that the decision to develop atemoya plantations should also consider the soils and soil fertility in each region, as well as the results of socioeconomic surveys undertaken in the region, as recommended in Agricultural Zoning practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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