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Vol. 10(25), pp. 2506-2515, 18 June, 2015
DOI: 10.5897/AJAR2014.9077
Article Number: BB08E3353513
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Agro-climatic zoning for citriculture in the Agreste region of Pernambuco State, Brazil

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Received 14 August, 2014; Accepted 26 April, 2015

The objective of this study was to accomplish an agro-climatic zoning for the Agreste region of Pernambuco State, Brazil, with the aim to identify agro-climatic zones for citrus cultivation. Monthly climatic data of 100 stations from over 20-year observation series (1911 to 1990) were selected within and close to the study area. From climatic data of mean air temperature and rainfall, we calculated the climatic water balances using available water capacity (AWC) of 50 and 100 mm. From data of both potential and estimated actual evapotranspiration, agro-climatic zones were established in agreement with the Water Requirement Satisfaction Index (WRSI). According to our study, the annual temperature variation in the Agreste mesoregion of Pernambuco State, with minimum temperature of 16.4°C and maximum of 33.4°C, is not a limiting factor for citrus production. Fifty municipalities in the region are located in the favorable agro-climatic zone for citrus cultivation, what represents an area of 12,000 km^2 yet to be explored since less than 0.5% of it is being cultivated. Other 16 municipalities are located in the intermediate zone, with moderate risk, while five of them are in the adverse zone, presenting high climatic risk and water deficit.

Key words: Citrus production, temperature, water balance, orange, tropical region.

INTRODUCTION

Facing the uncertainty that shapes future climatic changes on the planet productive system, it is essential to identify agro-climatic boundaries according to crop requirements, decentralizing production and improving agricultural planning. The agro-climatic zoning aims decision making of producers and increases chances of success on the use of the property natural resources (Assad, 2001).

Citrus plants, of Asian origin, were introduced to Brazil, probably in Bahia State, during the first colonizing expeditions (Lopes et al., 2011). The *Citrus* genus are composed of medium-sized plants that produce white fragrant flowers and hesperidium-type fruits containing vesicles filled by a fluid of great commercial interest (Araújo and Roque, 2005). The world main cultivated species are *Citrus sinensis* (L.) Osbeck, the sweet oranges; *C. latifolia* Tanaka ex Q. Jiménez, the limes; and *C. reticulata* Blanco, the mandarins (Pompeu Junior,

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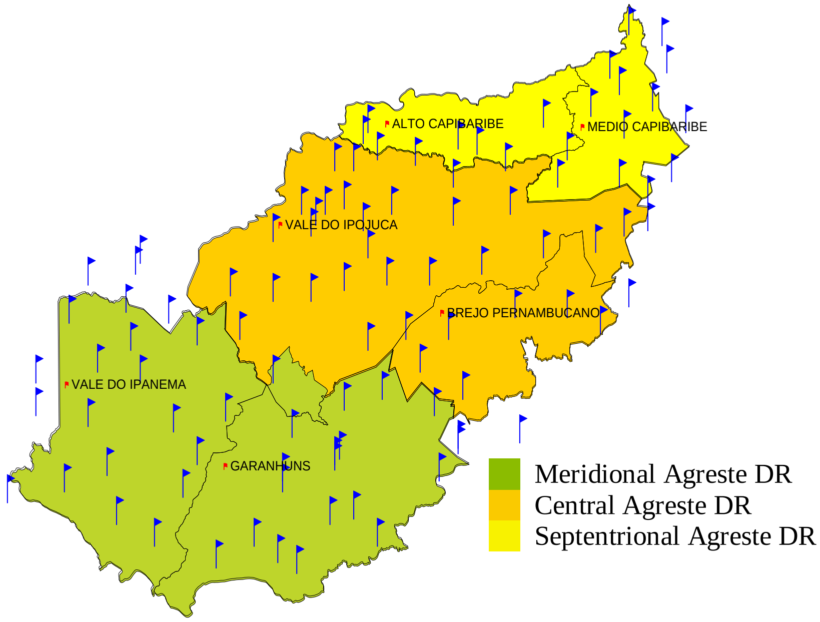

Figure 1. Agreste mesoregion of Pernambuco State, Brazil, with Development Regions (DR) and respective microregions, and pluviometric stations from which data were collected for this study.

2001). From all of the citrus fruits produced and traded in Brazil, sweet oranges comprise 90.3%, limes and lemons, 5.1%, and mandarins, 4.6% (IBGE, 2013).

The citrus cultivated area, in Brazil, consists of around 782,000 ha, with a mean of 833 trees ha^{-1}; production in 2012 was about 19,298,835 tons (FAO, 2014). In 2005, Pernambuco State was classified as the 13th greatest citrus producer in the country, achieving the main yield of 38.51 t ha^{-1} of sweet oranges, limes, and mandarins (IBGE, 2005). From 1962 to 2009, the Brazilian citriculture sector exported, according to 2009 values, nearly US$60 billion, resulting in a mean of US$1.3 billion per year (Neves et al., 2014).

The Garanhuns region in Pernambuco State presents expansion potential for cultivation of dessert citrus due to its altitude (Passos et al., 2005). According to Erickson (1968), the lowest base temperature for citrus growth is 12.8°C; growth is paralyzed below it. When superior to 37°C, there is no growth, so the ideal temperature ranges from 21 to 32°C. Furthermore, the development of citrus plants is very influenced by climatic indices related to temperature, which define the plant cycle according to degree days (Wrege et al., 2004).

Considering different citrus cultivation regions in the world, the annual rainfall is seasonal and varies from 1,000 to 2,000 mm, normally presenting a dry season with evapotranspiration extremes ranging from 600 to 1,300 mm per year (Ortolani et al., 1991). In this sense, the water balance is an important tool in agro-climatic zoning, as it allows monitoring of water quality in the soil as well as understanding of its relationship with crop development and growth (Pereira et al., 2002).

The Brazilian citrus agribusiness is highly competitive in the international market. Some factors contribute to this situation, such as action of important research institutions, low production costs, appropriate climate, proximity of the productive sector that favors production flow, and good product insertion in the international market.

By not having robust studies for the expansion and adaptation of culture in the Brazilian Agreste a thorough study is needed to distinguish and increase the planting areas, contributing to the increase in production. Therefore, the objective of this study was to accomplish an agro-climatic zoning for the Agreste region of Pernambuco State, Brazil, defining agro-climatic zones for citrus cultivation.

MATERIALS AND METHODS

The Agreste mesoregion of Pernambuco State, Brazil, is located between the latitudes 7°30' and 9°23' S, and longitudes 35°18' and 37°32' W, with an area of 24,387 km^2 and means of 820 m altitude, 22.5°C annual temperature, and 782.4 mm annual rainfall. It is divided into three Development Regions (DR): Meridional Agreste with 26 municipalities; Central Agreste with 26 municipalities; and Septentrional Agreste with 19 municipalities. Each DR is also divided into two microregions (Figure 1).

Agreste is an intermediate region between areas of wet and dry climate (Forest Zone and Sertão/Backwoods, respectively), presenting similar climates at the borders. The Intertropical Convergence Zone (ITCZ) is more effective near Sertão/Backwoods, and March is the wettest month. Regarding the border with the Forest Zone, the Eastern Systems are more

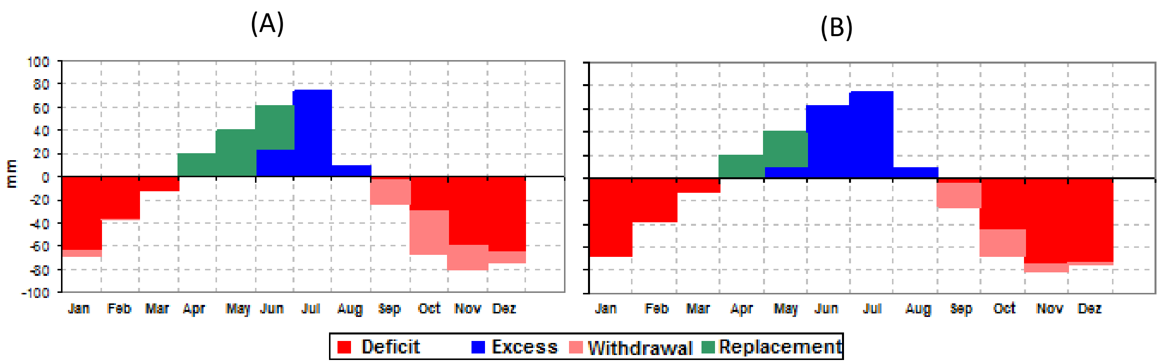

Figure 2. Normal Water Balance for Garanhuns microregion for Available Water Capacity (AWC) of 100 mm (A) and 50 mm (B).

important than ITCZ, and June is the wettest month (Araújo Filho et al., 2000).

Data of monthly mean rainfall of 100 selected stations were used (Figure 1) with the aim to establish a satisfactory period of climatic observations and better spatial distribution with data series from more than 20 years of records (1911 to 1990) distributed in and around the study area and borders with Sertão/Backwoods and Forest Zone. To estimate the mean air temperature according to the geographical coordinates (latitude, longitude, and altitude) of the stations that had only rainfall records, we used the software Estima T version 2.0 (Cavalcanti et al., 2006), which groups, by area, states of Northeast Region with coefficients of quadratic regression for estimates of monthly mean, maximum, and minimum temperatures as established by Cavalcanti and Silva (1994).

The potential evapotranspiration (ETP) was estimated according to the method described by Thornthwaite (1948). The climatic water balance for available water capacity (AWC) of 50 and 100 mm was calculated using BHnorm 6.1 software from an EXCEL™ spreadsheet elaborated by Rolim et al. (1998), who used the method described by Thornthwaite and Mather (1955) adjusted according to criteria reported by Mendonça (1958). As a result, the water balance provided estimates of actual evapotranspiration (ET), water deficit (DEF), water excess (EXC), and soil water storage (STO) for each month.

The map of the Agreste region of Pernambuco State was used to prepare the maps Agro-climatic. After the Climatic Water Balance was calculated, the obtained values were inserted in EXCEL™ spreadsheets. Contour maps (isolines) were generated by the software SURFER® version 8.0 (2002). Kriging was the applied estimate method.

Among the commonly used estimate methods, the Kriging geostatistical may be considered the best linear estimator without bias, which aim is to minimize estimate variance (Landim et al., 2002). The parameters used to define Agreste agro-climatic suitability were based on monthly means of rainfall and temperature.

The water balance results from normal rainfall and temperature data were used to elaborate maps of total annual potential and actual evapotranspiration, water deficit, and water excess. To visualize those Agreste agro-climatic zones indicated for citriculture, maps with results of the Water Requirement Satisfaction Index (WRSI) were developed.

RESULTS AND DISCUSSION

The results, as a histogram of the water balance extract for Garanhuns micro-region, enables observation of DEF, EXC, and areas of soil water withdrawal (negative alteration, ALT-) and soil water replacement (positive alteration, ALT+) (Figure 2A and B). We observed that the rainy season starts in April; June is the wettest month. The same occurs in Médio Capibaribe and Brejo Pernambucano, however with a shorter period. For all micro-regions, the lowest soil moisture percentage is concentrated in October and November, what corroborates with Rossato et al. (2004).

The Brazilian Agreste region of Pernambuco State presents spatial and seasonal variation of the total annual rainfall among the Development Regions Meridional, Central, and Septentrional Agreste; the latter shows minor spatial variation for lower values than 800 mm per year. Within each DR, there is variation from east to west, which extremes present the highest total annual rainfall that exceeds 900 mm. According to Araújo Filho et al. (2000), this is a characteristic of border regions, which are influenced by specific meteorological systems, such as Intertropical Convergence Zone (ITCZ) at the western border, and Eastern Systems alongside the Forest Zone (Figure 3).

The rainfall regime in Agreste is favorable for citrus cultivation in all microregions. However, the microregions Garanhuns, Brejo Pernambucano, and Médio Capibaribe, that border the Forest Zone, are more favorable for several varieties according to their water requirements, as those microregions present total annual rainfall between 1,000 and 2,000 mm, with rainy season between April and August. According to the 900 mm isoline highlighted on the map, we could identify the regions with minimum annual rainfall limit cited in the literature for most citrus.

Restrictions on the need to take measures to mitigate effects of moisture deficit during the dry season include: larger plant spacing; appropriate rootstocks; cultural practices to minimize drought effects, such as supplemental irrigation; and pruning to reduce foliage volume and soil water consumption.

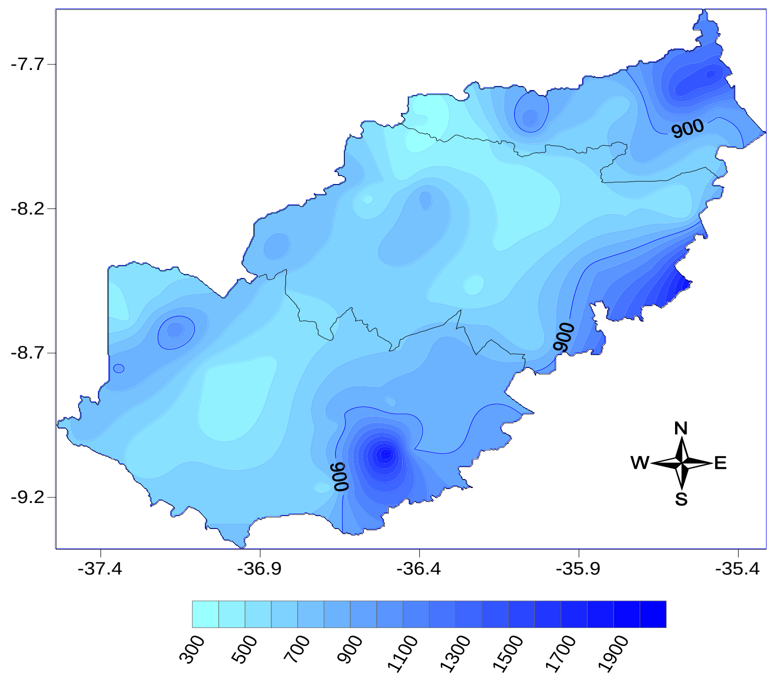

Figure 3. Map of total annual rainfall (mm) in the Agreste region of Pernambuco State, Brazil.

According to Cruz et al. (2003), although citriculture is socioeconomically important in Brazil Northeast, yield in that region is considered low due, mainly, to water deficit that occurs over more than six months per year, corresponding, in general, to high temperatures. In this sense, an alternative management is necessary to increase citrus cultivation under conditions of water deficiency, reducing effects of the atmospheric demand on plants and soil. Therefore, the need to improve collection and storage of rainwater is evident, so that cultivation during the dry season is secured.

The Agreste region of Pernambuco State presents mean minimum temperatures ranging from 16.4 to 20.9°C, and mean maximum from 24.0 to 33.4°C; the lowest temperatures vary from central Meridional Agreste to western Central Agreste, besides a small area located northwest of Septentrional Agreste. There is lower spatial variability for minimum temperatures ranging from 16.4 to 19.9°C; for maximum temperatures varying from 24.0 to 29.5°C, the opposite occurs. That is why citrus orchards in the region present variation on the phenological stage. In regions characterized as high swamps, the relief acts as temperature attenuator, since the air temperature decreases according to the altitude at a rate of 0.6°C each 100 m, what corroborates with Pereira et al. (2002), who described the adiabatic process physical principle for humid air (-0.6°C/100 m).

From the compound map of altitude and temperature, we verified that the annual mean temperature varies from 19.9 to 24.9°C (Figure 4). There is an increased thermal fluctuation according to the altimetric variation.

Altitude in Agreste varies between 100 and 1,050 m (Figure 4). Bluish areas indicate altitudes ranging from 700 to 1,050 m, and annual mean temperatures, from 19.9 to 22.9°C. High swamps are found in these regions, presenting characteristic and favorable microclimates for farming. Passos et al. (2005) reported that mandarin species and hybrids do respond to perspectives of cultivation at high altitudes, once some farmers in Bahia State cultivated the Ponkan variety under such conditions, and obtained superior quality, regarding fruit color and weight, to those produced in other regions.

The annual Potential Evapotranspiration (ETP) corresponds to the sum of monthly estimates obtained by the model described by Thornthwaite (1948), which shows the water that is, in theory, lost to the atmosphere. The Agreste region presents ETP varying between 880 to 1,400 mm per year. Spatialization of ETP values lower than 1,000 mm comprises northern Meridional Agreste to central and western Central Agreste, plus a small area located northwest of Septentrional Agreste (Figure 5).

The Actual Evapotranspiration (ET) indicates, quantitatively, the water evapotranspirated along a determined period of time, since it is limited by rainfall during that same period. Considering AWC of 100 mm, variation of the total annual ET in Agreste varies between 350 and 1,150 mm. There is greater spatial variability for ET values superior to 700 mm in central and western Meridional Agreste, and from the central area of Central

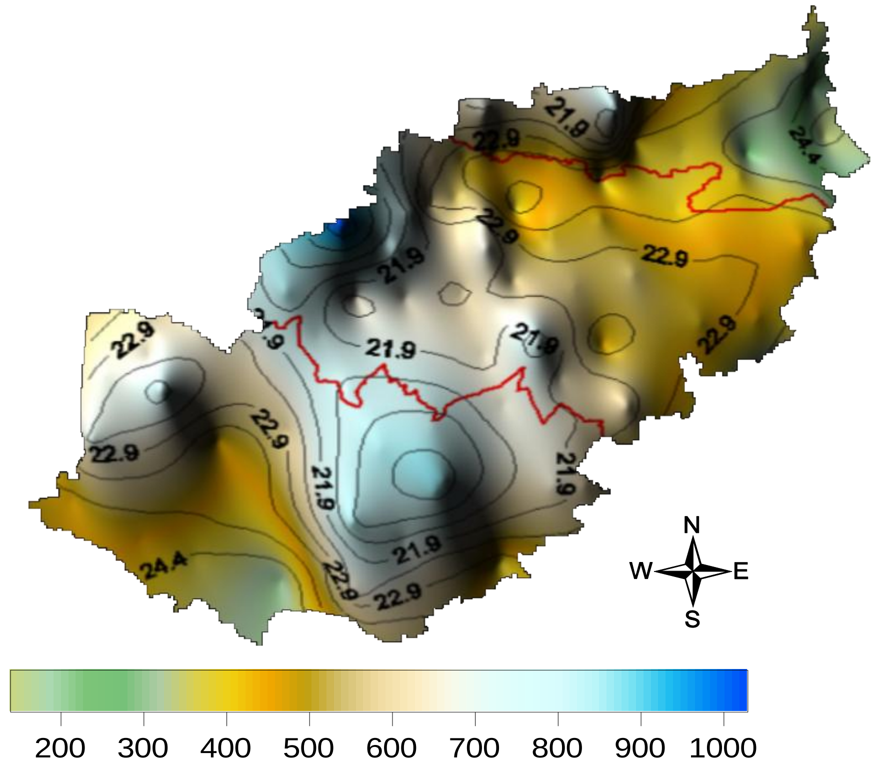

Figure 4. Compound map of annual mean temperature (°C) and Altitude (m) in the Agreste region of Pernambuco State, Brazil.

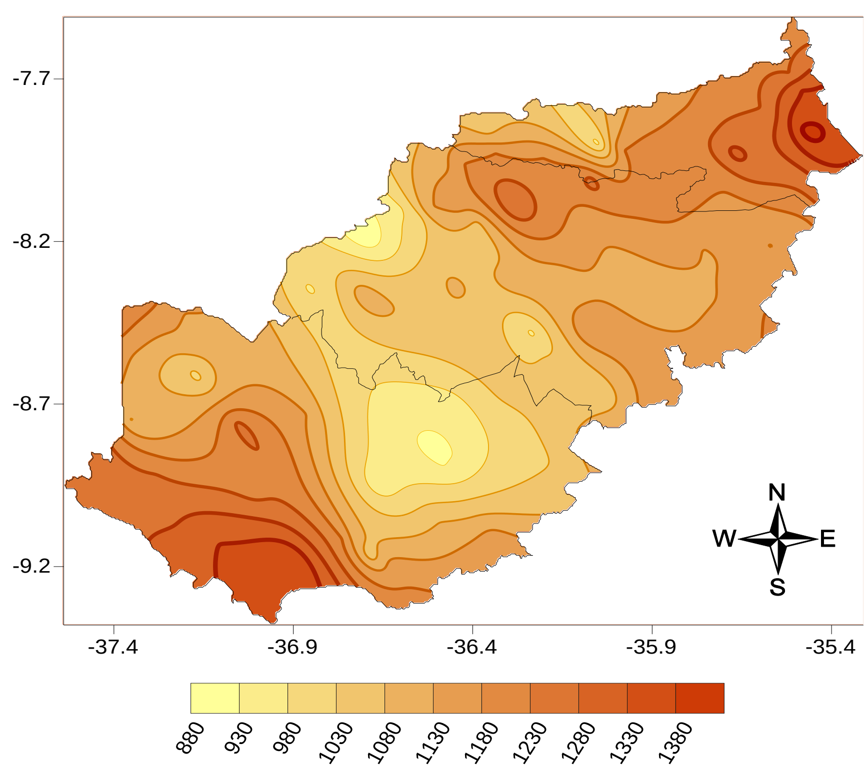

Figure 5. Map of accumulated potential evapotranspiration (mm) in the Agreste region of Pernambuco State, Brazil.

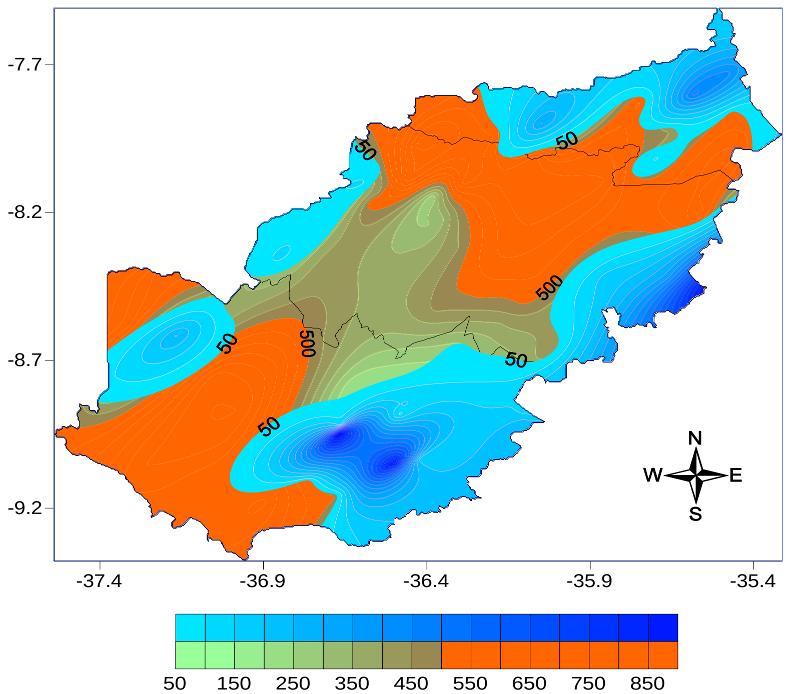

Figure 6. Map of limit zones of water excess (mm) regarding water deficit for Available Water Capacity of 100 mm, for the Agreste region of Pernambuco State, Brazil.

Agreste to western Septentrional Agreste. However, for AWC of 50 mm, these same areas present lower spatial variability, as rainfall ranges from 300 to 600 mm per year.

Analysis of accumulated Water Deficit (DEF) in Agreste, for AWC of 100 and 50 mm, indicated the same deficiency range, that is, from 100 to 900 mm; water deficits lower than 500 mm for both AWCs are better spatialized in and among microregions. Therefore, citriculture may be developed in the Agreste region of Pernambuco State with differentiated and decentralized results. According to Rolim et al. (1998), the effect of water stress on crop growth and yield depends on water deficit intensity and duration, and on crop species or variety. Coletti (2000) highlights that, for citrus, the water deficit may favor flower induction since the stress period is controlled; if extreme, it may damage plants, promoting excessive flower production, what would cause undue fruiting, thus lower fruit quality; moreover, extreme conditions of water stress may delay flowering, resulting in late harvest and respective trading price problems.

Valipour (2014a) verifying the importance of solar radiation, temperature, relative humidity and wind speed in the calculation of reference evapotranspiration shows the importance of these factors for each region evaluated, due to varying weather conditions. Thus the importance of performing agro-climatic zoning for each micro-region that wants to enter or expand a particular culture.

Although Valipour (2014b) indicate that the method of estimating the FAO reference evapotranspiration model Penman Monteith did not obtain greater efficiency in the province of Iran, other research has shown its efficiency (Moeletsi et al., 2012; Sahoo et al., 2012; Valiantzas, 2013) and in Brazil this method has proven quite efficient to calculate the reference evapotranspiration (Junior Borges et al., 2012).

The compound map of DEF and EXC zones (Figure 6) shows blue areas indicating EXC ranging from 50 to 900 mm per year, with larger areas located in northern Médio and Alto Capibaribe, and along the eastern and western borders of Central and Meridional Agreste. Garanhuns microregion is highlighted in Meridional Agreste with greater area and EXC spatial variability. In these locations, rainfall volume is superior to 800 mm per year.

In regions with null water excess, DEF ranges from 50 to 900 mm. Water deficits superior to 500 mm are indicated by the orange color, where altitude varies between 350 and 550 mm. In the area comprising northern Meridional Agreste to the central region of Central Agreste, water deficit ranges from 250 to 500 mm, and altitude, from 650 to 900 mm. Since altitude contributes to decreased mean temperatures, the thermal condition may act as a DEF attenuator; when also considering the orange areas, we observed that rainfall varies from 400 to 500 mm, and DEF, from 500 to 800 mm. On the other hand, the green area indicates rainfall varying between 500 and 700 mm, and DEF, between

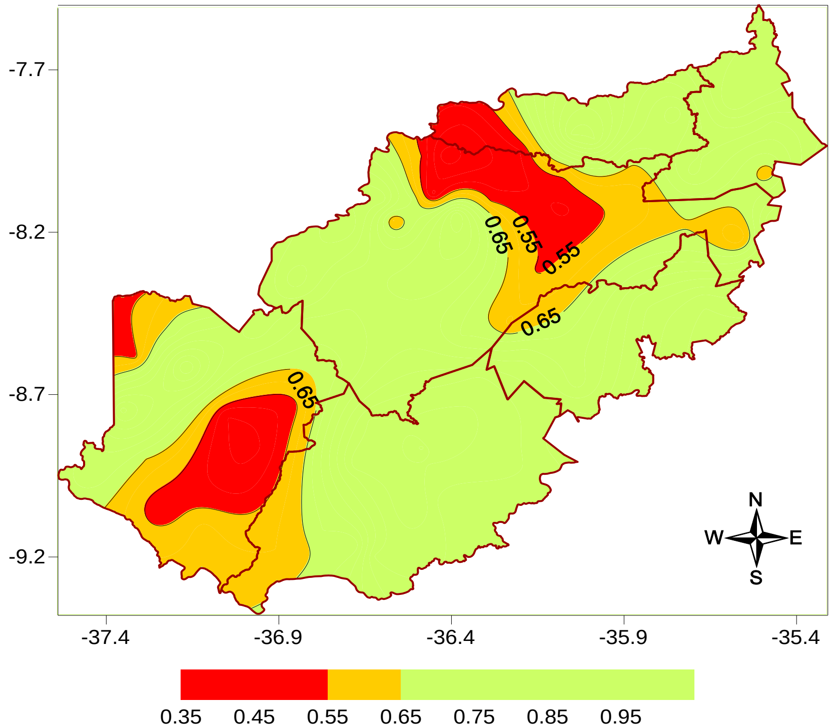

Figure 7. Map of agro-climatic zones in the Agreste region of Pernambuco State, Brazil, defined according to the Water Requirement Satisfaction Index (WRSI) for AWC of 100 mm. WRSI ≥ 0.65 – Favorable agro-climatic zone, with low climatic risk; WRSI ≥ 0.55 and < 0.65 – Intermediate agro-climatic zone, with moderate climatic risk; and WRSI < 0.55 – Adverse agro-climatic zone, with high climatic risk and water deficit.

250 and 500 mm.

The agro-climatic zoning for citrus cultivation in the Agreste region of Pernambuco State (Figure 7) was established according to the Water Requirement Satisfaction Index (WRSI), which indicates the water amount consumed by the plant and desired amount to ensure maximum productivity. The WRSI is defined by the relationship between the actual evapotranspiration and maximum evapotranspiration (ET/ETm). Considering the climatic characteristics of the Agreste region, the following classes of climatic risk were defined:

WRSI ≥ 0.65 – Favorable agro-climatic zone, with low climatic risk;
WRSI ≥ 0.55 and < 0.65 – Intermediate agro-climatic zone, with moderate climatic risk;
WRSI < 0.55 – Adverse agro-climatic zone, with high climatic risk and water deficit.

The maximum evapotranspiration capacity (ETm) was obtained based on the mean crop coefficient (Kc) of 0.8, and it was equivalent to 80% ETP for citrus plants that had been cultivated for more than two years. The applied coefficient resulted from studies by SegHidro, in Campina Grande, Paraíba State, Brazil (EMATER, 2006).

The Agreste region of Pernambuco State comprises 21 municipalities in zones of moderate and high climatic risk, as follows: Altinho, Bezerros, Buíque, Cachoeirinha, Cumaru, Gravatá, Iati, Itaíba, Passira, Pedra, Riacho das Almas, São Caetano, Tacaimbó, Taquaritinga do Norte, Toritama, and Tupanatinga; plus Águas Belas, Brejo da Madre de Deus, Caruaru, Jataúba, and Santa Cruz do Capibaribe, which are those with greater area under high climatic risk. Cachoeirinha, Iati, Jataúba, São Caetano, Tacaimbó, and Toritama municipalities do not have orange or lime production. The others have already been cultivating citrus regardless the climatic limitation.

Among those municipalities located in the favorable agro-climatic zone, with low climatic risk, Angelim, Barra de Guabiraba, Belo Jardim, Bom Conselho, Bom Jardim, Bonito, Brejão, Camocim de São Félix, Correntes, Feira Nova, Garanhuns, João Alfredo, Lajedo, Limoeiro, Machados, Orobó, Palmeirina, Sairé, São João, and São Joaquim do Monte do produce orange and lime.

On the other hand, the municipalities Agrestina, Alagoinha, Caetés, Calçado, Canhotinho, Cupira, Jucati, Jupi, Jurema, Lagoa do Ouro, Lagoa dos Gatos, Panelas, Paranatama, Pesqueira, Poção, Salgadinho, Saloá, Sanharó, Santa Maria do Cambucá, São Bento do Uma, São Vicente Férrer, Surubim, Terezinha, and

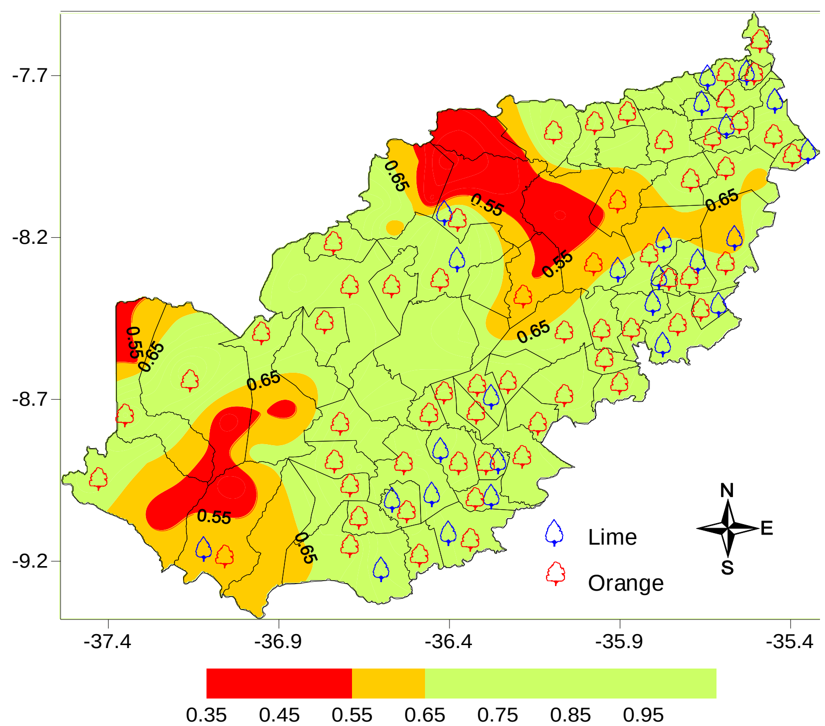

Figure 8. Map of agro-climatic zones with citrus producer municipalities in the Agreste region of Pernambuco State, Brazil.

Vertentes only produce oranges. There are still six municipalities under low climatic risk that do not have citrus production, as follows: Capoeiras, Casinhas, Frei Miguelinho, Ibirajuba, Venturosa, and Vertente do Lério.

We may state that the citriculture satisfactory yield in Agreste depends either on varieties resistant to the dry season, or on an alternative management of soil coverage to reduce the evaporative demand. There accesses moderately tolerant and intolerant to dry for cultivation in Brazil (Nascimento et al., 2012; Suassuna et al., 2012; Smith et al., 2015), most using rootstock of Santa Cruz Rangpur lime (Citrus limonia Osbeck).

Comparing maps of agro-climatic zones, Water Deficit, and Water Excess, we observe that, for WRSI < 0.65, DEF varies from 600 to 900 mm. Similarly, WRSI ≥ 0.65 is found where either DEF < 500 mm per year or there is EXC. In zones of moderate climatic risk, i.e., WRSI between 0.55 and 0.65, there is an annual water deficit ranging from 500 to 600 mm; Vale do Ipanema that is located southwest of Meridional Agreste DR, and northwestern Vale do Ipojuca present the largest areas under these characteristics.

Analysis of the map comprising 60 citrus producer municipalities in Agreste (IBGE, 2007), and agro-climatic zones for AWC of 50 mm, indicates that 44 municipalities that produce lime and/or orange are located in favorable agro-climatic zones, with low climatic risk; however, 16 of them are either in intermediate or adverse agro-climatic zones, with moderate to high climatic risk, the latter presenting great water deficit varying from 600 to 900 mm (Figure 8).

Therefore, there are satisfactory conditions for the development of citriculture in the Agreste region of Pernambuco State as indicated by favorable agro-climatic zones in green, comprising 50 municipalities (Figure 8). Among those that do have citrus cultivation, mean yield of oranges and limes is 35.8 and 39.8 t ha^{-1}, respectively (IBGE, 2007).

In the intermediate zones, in yellow, that covers 16 municipalities (Figure 8), mean yield of oranges and limes is 30 and 25 t ha^{-1}, respectively (IBGE, 2007). Five municipalities are under high climatic risk. It is notorious that orange and lime production is favored in Brejo Pernambucano, Médio Capibaribe, and Garanhuns microregions, which areas present water excess around 950 mm.

Conclusions

In Agreste mesoregion, Pernambuco State, Brazil, the annual temperature variation, with minimum of 16.4°C and maximum of 33.4°C, is not considered a thermal factor of risk for citrus production.

Considering Agreste agro-climatic conditions, there are more than 12,000 km^2 favorable for citrus cultivation, what is a significant area to be explored, once the current cultivated locations comprise less than 0.5% of that total.

Water excess of around 950 mm, or water deficit lower than 500 mm per year, are not limiting factors for citrus cultivation. In Pernambuco Agreste, 50 municipalities are in favorable agro-climatic region, with small climate risk; 16 in the intermediate agro-climatic region, with average risk and 5 in unfavorable agro-climatic region with high climatic and high water deficit risk.

Conflict of Interest

The authors have not declared any conflict of interests.

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