(DOI): 10.5935/PAeT.V6.N1.01

This article is presented in English with abstracts in Spanish and Portuguese

Brazilian Journal of Applied Technology for Agricultural Science, Guarapuava-PR, v.6, n.1, p.7-19, 2013

Artigo Científico

Spatial distribution of climatic water balance in different rainfall regimes in the State of Pernambuco

Alexsandro Oliveira da Silva[1]

João Thomas Gabriel Queluz[2]

Antônio Evaldo Klar[3]

Abstract

To know the weather from year to year is of great value to a proper agricultural planning. The study was conducted in the State of Pernambuco, with data basis of temperature and rainfall of at least 20 years of observations of 45 meteorological stations. The function of density probability of the incomplete gamma distribution was used to evaluate the occurrence of dry, normal and rainy years. The monthly climatic water balance was estimated by the method proposed by Thornthwaite and Mather (1955) and interpolation of data for the plot was made using the Kriging method. The results indicated that the highest rainfall occurred in the Zone da Mata in the south of the State with around 2800 mm year^{-1}. The water excess presented its highest levels in the Zona da Mata mesoregion with availability of nearly 1200 mm year^{-1} for the rainy years and water deficit was higher in the Sertão Mesoregion of Sertão of San Francisco reaching 1000 mm year^{-1}, being required full irrigation for the crops.

Key words: Water deficit, evapotranspiration, irrigation.

Distribuição espacial do balanço hídrico climatológico em diferentes regimes de chuva no Estado de Pernambuco

Resumo

Saber as condições climáticas anuais é de grande valor para um planejamento agrícola adequado. O estudo foi realizado no Estado de Pernambuco, com bancos de dados de temperatura e de precipitação pluvial de séries históricas de no mínimo 20 anos de observações de 45 estações climatológicas. A função de densidade de probabilidade da distribuição gama incompleta foi utilizada para avaliar a ocorrência de anos secos, normais e chuvosos. O balanço hídrico climático mensal foi estimado pelo método proposto por Thornthwaite & Mather (1955) e a interpolação dos dados para a plotagem foi feita utilizando o Método de Krigagem. Os resultados indicaram que as maiores precipitações ocorreram na Zona da Mata, Sul do Estado com cerca de 2800 mm ano^{-1}. O Excedente hídrico apresentado atingiu seus maiores índices na Messoregião da Zona da Mata com disponibilidade de aproximadamente 1200 mm ano^{-1} para anos chuvosos, e o deficit hídrico apresentou-se maior nas Mesorregiões do Sertão do São Francisco e Sertão alcançando os 1000 mm ano^{-1}, sendo exigido irrigação plena para cultivo.

Palavra-chave: Deficit hídrico, evapotranspiração, irrigação.

Distribución espacial del balance hídrico climático en diferentes regímenes de lluvias en el Estado de Pernambuco

Resumen

Conocer las condiciones climáticas anuales es de gran valor para una adecuada planificación agrícola. El estudio fue conducido en el Estado de Pernambuco, con bases de datos de series temporales de precipitación y temperatura de al menos 20 años de observaciones de 45 estaciones meteorológicas. Se utilizó la función de densidad de probabilidad de la

Received in: 19/10/2012 Accepted for publication: 02/04/2013

1 Doctoral student of Agronomy – Irrigation and drainage. Universidade Estadual Paulista. UNESP/FCA. Fazenda Eperimental Lageado. Caixa Posta 237, CEP18610-307, Botucatu-SP. Email: alexsandro_oliveira01@hotmail.com. Corresponding author

2 Master student of Agronomy – Irrigation and drainage. Universidade Estadual Paulista. UNESP/FCA. Fazenda Eperimental Lageado. Email: queluz@fca.unesp.br

3 Dr. Professor of the Department of Agronomy, Rural Engineering Department, Universidade Estadual Paulista. UNESP/FCA. Fazenda Eperimental Lageado. Email: klar@fca.unesp.br

distribución gamma incompleta para evaluar la ocurrencia de años secos, normales y húmedos. El balance hídrico mensual ha sido estimado mediante el método propuesto por Thornthwaite y Mather (1955) y se obtuve la interpolación de los datos para plotage por el método de Krigage. Los resultados indicaron que las mayores precipitaciones se produjeron en la Zona da Mata, Sul del Estado con cerca de 2.800 mm año^{-1}. El excedente hídrico presentado llegó a sus niveles más altos en la Mesorregión de la Zona da Mata, con disponibilidad de aproximadamente 1.200 mm año^{-1} para los años lluviosos, y el déficit hídrico fue mayor en las Mesorregión del Sertão de Sao Francisco y Sertão, alcanzando 1.000 mm año^{-1}, requiriendo riego completo para desarrollar la agricultura.

Palabras clave: Déficit hídrico, evapotranspiración, riego.

Introduction

The agrometeorological information assume an important role in the planning of an irrigated crop, being the climatologic water balance the main information to be considered (PEREIRA et al., 2002). In this context, the knowledge of the annual weather conditions and the rainfall forecast for the year is of huge value for an adequate agricultural planning. The annual climatic risks and the lack of meteorological data in certain regions make the agricultural producers to demand a greater quantity of water for the crop than is really necessary, leading to extra expenses burdening even more the production and putting into risk all the productive potential of the crop, due to the weather interference in its physiological cycle. Thus, indentifying the periods with excess in water deficit and its respective intensities, it is defined the type of crop system to be used, rainfed or irrigated, and the period in which each of them should be conducted (MONTEIRO, 2009).

Due this, the knowledge of spatial variability of the climatologic elements as the water deficit of the soil, water excess, potential evapotranspiration (PET), real evapotranspiration (RET) and water availability (RET/ PET) become indispensable in planning and implantation of an agricultural activity (PEREIRA et al., 2002; SENTELHAS et al., 2008; CASTRO et al., 2010), and thereby, benefit producers in regions that do not have posses stations of climate observations for the irrigation management in their areas. There are several studies about the methods of spatial interpolation of climatic data, however the same do not consider in their studies the different pluvial regimes which happen in a series of years, having only an average representative of the rainfall without considering the weather phenomena which alter the rain regimes and temperature of the regions, such as the el niño, which interferes significantly in the rainfall regimes of the Brazilian Northeast as Stated MOURA et al. (2009).

The water balance is an accounting system of monitoring ground water, and results from the application of the principle of conservation of mass to the water in a volume of vegetated soil, it can be an excellent tool to study the viability of the implementation and monitoring of irrigation systems or drainage in a region (PEREIRA et al., 1997). Due to the variability of rainfall in the regions and capacity of storage of the soil can differ significantly from a year to another, making that the management of irrigated areas fit to the changes to a greater efficiency of water use, mainly for the semi-arid, as is the case of the west region of the Pernambuco State, in which the variability of rains is elevated.

The objective of this study is to evaluate the climatic water balance in different rainfall regimes and the spatial distribution of the same to the State of Pernambuco for the appropriate irrigation management.

Material and Methods

The study was conducted in the State of Pernambuco, situated between the parallels 7°18'17'' and 9°28'43' of south latitude and the meridians of 34º48'15" and 41º21'22" of longitude at west, in the Brazilian Northeast. Pernambuco is subdivided into five mesoregions: Sertão of São Francisco, Sertão, Agreste, Zona da Mata and Metropolitan Recife as shows Figure 1ª. Two climatic types according to Köppen characterize the State, the weather As' and BSh, i. e. rainfall in autumn and winter in the coastal part of the State and semiarid warm in the outback (Annual average temperature > 18 °C), respectively. The database used in the study originated from records of weather stations (SUDENE, 1990). The stations selected for the study were those that presented historical series of at least 20 years of observations, being used in the work 45 weather stations (Figure 1B).

For that could be made the spatial distribution of the information through the GIS (Geographic

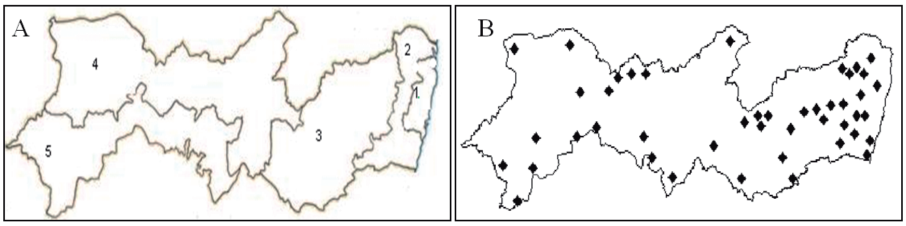

Figure1. Map of Pernambuco with Mesoregions (A): Metropolitan (1), Zone of Forest (2), Agreste (3), Sertão (4) and Sertão of San Francisco (5). SUDENE climatologic stations in the State of Pernambuco (B).

Information System) used in this study, were used data of stations which are found distributed in the five mesoregions of the State of Pernambuco. The dataset was georeferenced through the latitudes and longitudes of stations, where in a file of the type "*worksheet*", containing information X, Y and Z, where X is the latitude, Y is longitude of the stations and Z is the value of the variable to be spatialized. The vector map of the contour of the State of Pernambuco, used as a "mask", was obtained through the ITEP / LAMEPE - Technological Institute of Pernambuco / Meteorology Laboratory of Pernambuco. The interpolation of the data for the plotting in the contour of the State was made using the Kriging method within the program Surfer ® demo version 8.3 (Golden Software, 2006).

The probability density function of incomplete gamma distribution was used to assess the occurrence of dry years, normal and rainy in all the data of the stations as shown in equation 1:

$$g(x;y;\mu) = \left[\frac{1}{\Gamma(y)}\right]\left[\frac{y}{\mu} y x^{y-1} e^{\frac{-xy}{\mu}}\right] \quad (1)$$

Where *y* and μ are parameters to be defined for the particular sample which whether is needed to adjust the distribution, μ is the sample average. The symbol is being used to designate the known gamma function, that is (equation 2):

$$\Gamma(z) = \int_o^\infty t^{z-1} e^{-t} dt \ (2) \quad (2)$$

Being *e* the base of the natural logarithms: The function of distribution associated to the equation (1) is(equation 3):

$$G(x,y,z) = \left[\frac{1}{\Gamma(y)}\right] . \int_o^v v^{y-1} e^{-v} dv \ (3) \quad (3)$$

Where: $v = \gamma x/\mu = x/\beta$, com $G(x, \gamma, v) = 0$ when $x \leq 0$ e $\beta = \mu/\gamma$.

In this work we applied the incomplete gamma distribution as made by MOURA et al., (2008) applying to the total annual rainfall. The parameters β and γ were obtained with the method of verisimilitude. The values of precipitation were divided into: "dry" periods, those in which the total annual rainfall was equal to or less than 25% probability; "normal" periods with probability greater than 25% and less than or equal to 75%, and "rainy" periods with probability higher than 75%.

Due to lack of climatic variables, beyond the temperature and rainfall in the climatologic stations analyzed, the potential evapotranspiration was calculated from the method proposed by THORNTHWAITE (1948) and by means of the data, we calculated the climatic water balance monthly, by the method proposed by THORNTHWAITE and MATHER (1955), with the assistance of the program "SEVAP", assuming a Maximum Capacity of Storage of water in the soil (CAD) equal to 100 mm. The parameters of the calculated water balance were real evapotranspiration (RET), potential evapotranspiration (PET), water storage in the soil (WS), accumulated negative (ACUM NEG) alteration of water in the soil (ALT), water deficit in the soil (WD) and water excess (EXC).

Results and Discussion

In possession of all the climatologic water balance data of the 45 meteorological stations distributed in the State, an analysis was performed of these variables for each mesoregion.

Rainy years

The amount of rainfall in rainy years reached for the mesoregion Zona da Mata around 2700 mm year^{-1}, with with the highest rainfall concentrated in the months from April to July (Figure 2A). The Agreste mesoregion presented annual rainfall averages of 1400 mm year $^{-1}$ with higher concentrations in the months from April to June (Figure 2B). The Sertão do São Francisco and Sertão mesoregions presented 800 and 950 mm year^{-1} respectively with higher concentrations of rain in the months from January to April (Figure 2C and 2D). Despite do not affecting none of the metabolic processes of the plants, the rains affect directly the growth and development of crops as States HOOGENBOOM (2000) described by MONTEIRO (2009), besides contributing to the water availability of the soils for absorption of water by some crops.

The potential evapotranspiration presented variations during the whole period, in the Zona da Mata reached the highest ratios in the months from January to February with an average of 140 mm month^{-1} (Figure 3A). In the Agreste mesoregion of the State, the PET reached the highest values in the months from January to February and from October to December (Figure 3B). To the mesoregions of the Sertão do São Francisco and Sertão there was an average of 160 mm month^{-1} (Figure 3C and 3D). The highest values of PET were found in the seasons of less rains during the year as found by LEMOS et al. (2007) in studies of evapotranspiration in Minas Gerais.

The figure 4 presents the spatial distribution of the components of climatologic water balance for the whole State. The Zona da Mata mesoregion presented the best conditions for the cultivation of rainfed, due to the high rainfall ratios with an average of 2200

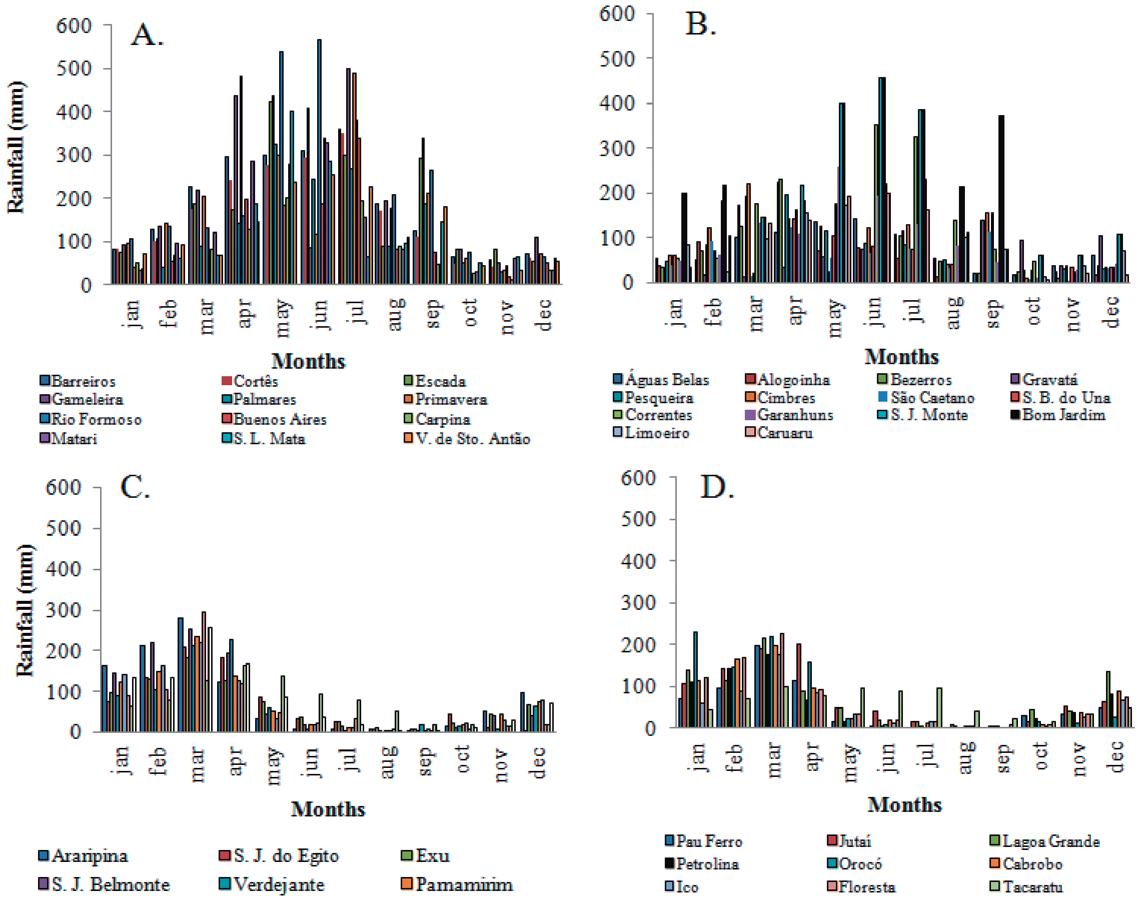

Figure 2. Rainfall for the rainy years of the mesoregions: Zona da Mata Zone of Forest (A), Agreste (B), Sertão (C) and Sertão do São Francisco (D).

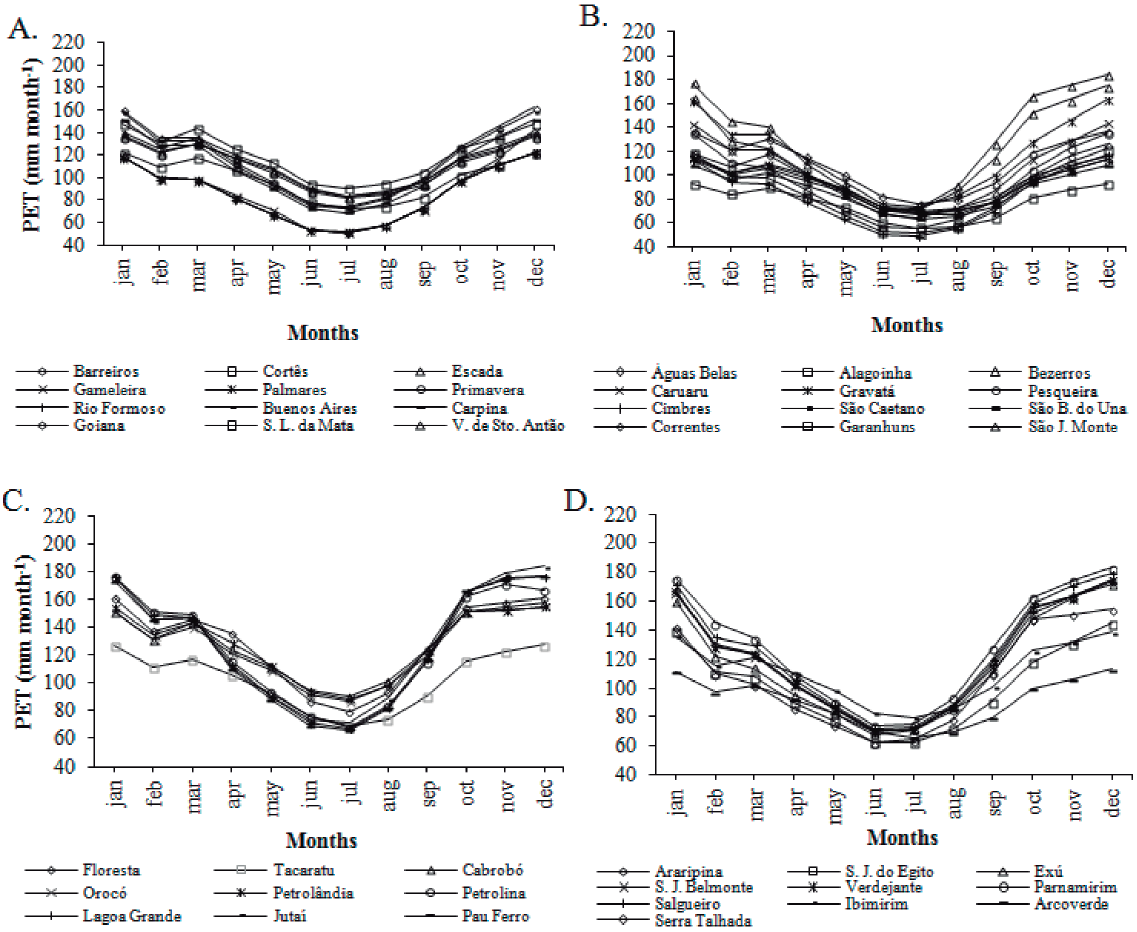

Figure 3. Monthly potential evapotranspiration for rainy years of the Zona da Mata (A), Agreste (B), Sertão (C) and Sertão do São Francisco (D).

mm year^{-1} (Figure 4A) and average PET of 1200 mm year^{-1} (Figure 4B) being representative for the crops of sugarcane, in which, according to MONTEIRO (2009), the tillering and development of the same, corresponds to the conditions of temperature and high rainfall. The Agreste mesoregion presented values of average rainfall of 1500 mm year^{-1} (Figure 4A), potential evapotranspiration (Figure 4B) with an average of 1050 mm year^{-1}, relative evapotranspiration of 0.7 mm year^{-1} (Figure 4C), ideal for temporary crops as the carrot, in which, according to SANTOS et al. (2009) the consumption for the crop is of approximately 800 mm year^{-1} in conditions of full irrigation. The Sertão and Sertão do São Francisco mesoregions presented water deficit of 550 and 750 mm year^{-1}, respectively, (Figure 4E) and water excess of 130 and 100 mm year^{-1}, this conditions are ideal for the annual crops as the vine (*Vittis*), which according to MONTEIRO (2009) must have an water supply in the phase formation of berries and a period of maturation in conditions of low rainfall and high temperatures, but is necessary to take into consideration a necessary agricultural planning for the favoring of this crop in the Pernambuco Sertões.

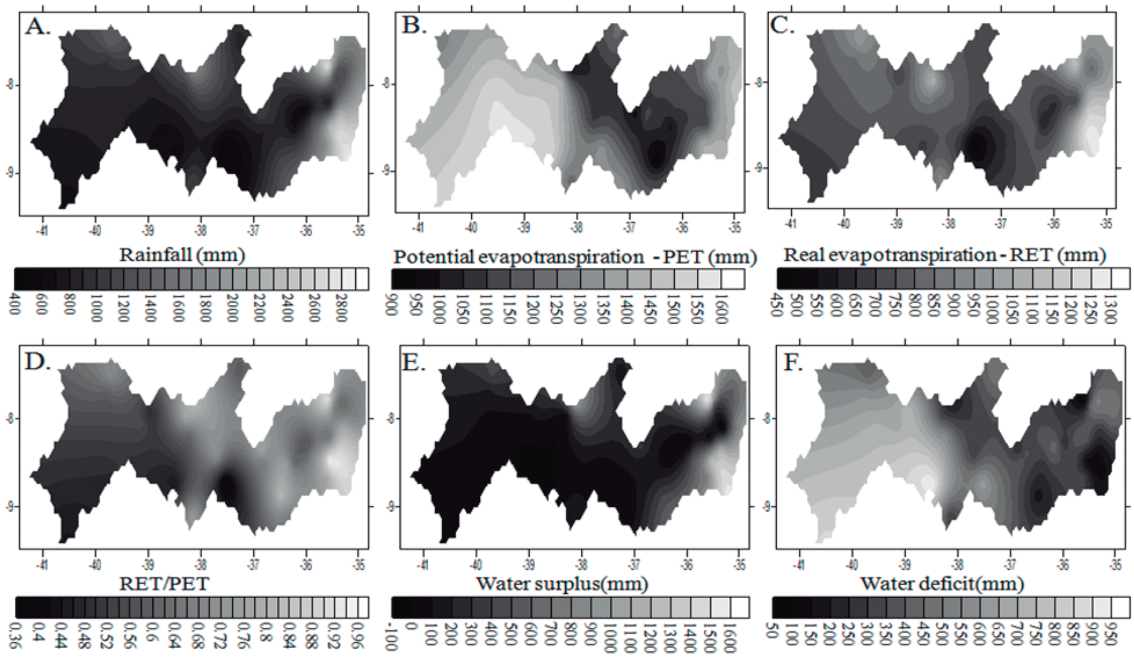

Figure 4. Spatial distributions of annual precipitation in Pernambuco (A), Potential evapotranspiration (B), real evapotranspiration (C), water availability (RET/ PET) (D), water excess (E) and water deficit (F) obtained by rainy years using kriging.

Regular years

The years with regular rains regime presented variations in the rainfall in all mesoregions, presenting the highest values in the Zona da Mata mesoregion with an average rainfall of 150 mm month^{-1} (Figure 5A) the Agreste region presented average rainfall of 115 mm month^{-1} (Figure 5B), while the Sertão region presented ratios of 40 mm month^{-1} (Figure 5C) and the smallest values were found in the Sertão do São Francisco region with an average of 30 mm month^{-1} (Figure 5D).

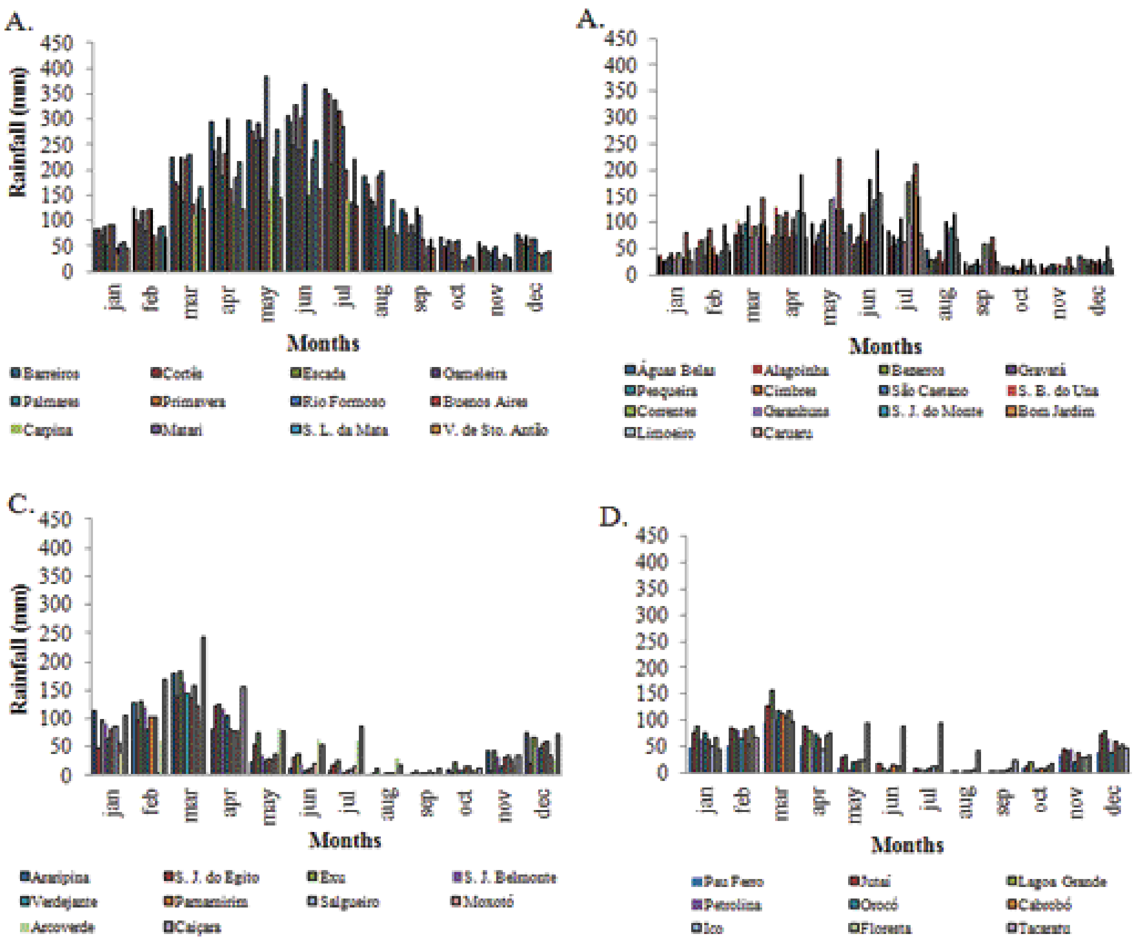

Figure 5. Rainfall for regular years in the State mesoregions: Zona da Mata (A), Agreste (B), Sertão (C) and Sertão do São Francisco (D)

The potential evapotranspiration presented averages of 112 mm month^{-1} for the Zona da Mata (Figure 6A), 93 mm month^{-1}, for the Agreste mesoregion (Figure 6B), 111 mm month^{-1}, for the Sertão (Figure 6C) and 123 mm month^{-1}, for the Sertão do São Francisco (Figure 6D). The irrigation management must be done mainly in the months from January to May in the Sertão mesoregions. SILVA et al. (2011) States that even in the different rain regimes, the cultivation in rainfeds does not become adequate for the Sertão regions of the State, being only necessary for crops which are not adapted to the use of irrigation.

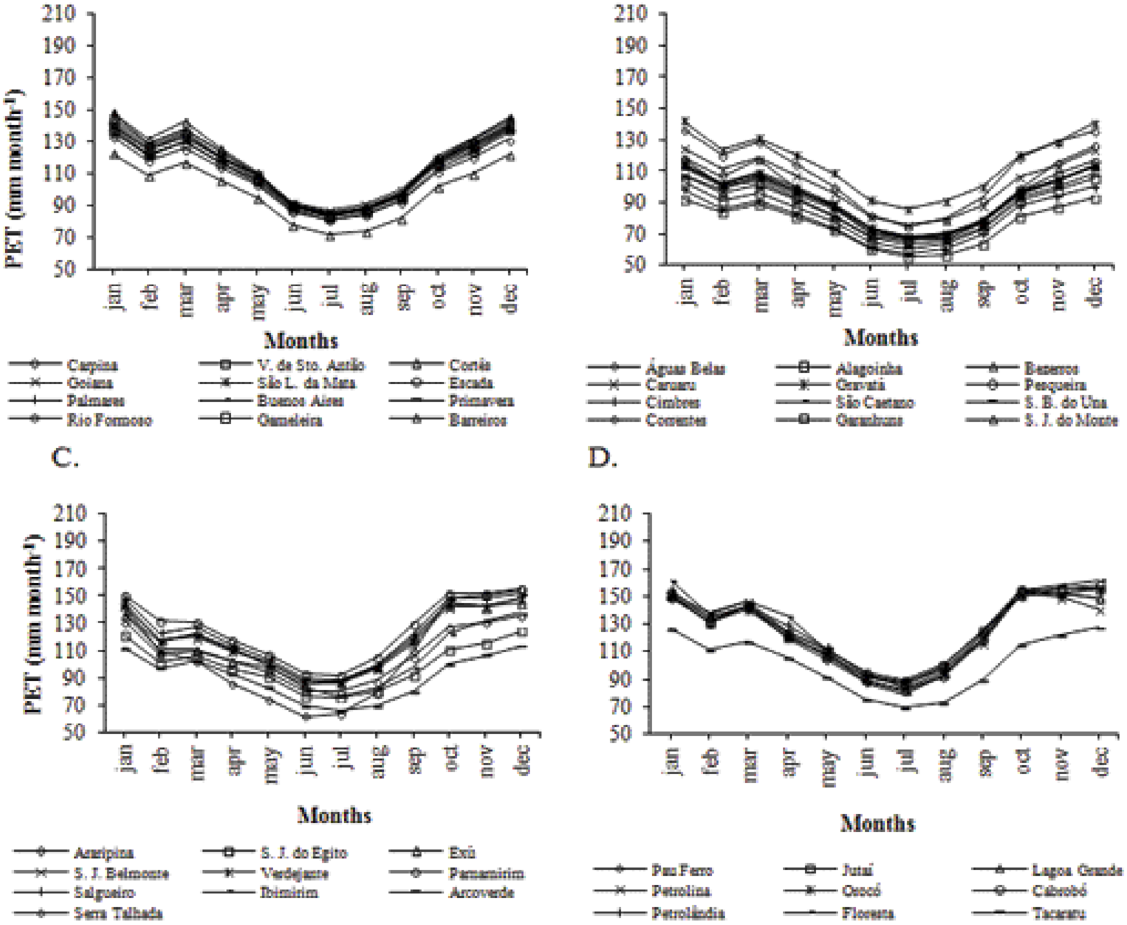

Figure 6. Potential evapotranspiration years of regular rainfall: Zone of Forest (A), Agreste (B), Sertão (C) and Sertão do São Francisco (D).

Figure 7A shows the spatial distribution of the State rainfall regime, the Zona da Mata mesoregion presented the highest rates of rainfall with variation between 2300 to 1800 mm year^{-1}. The potential evapotranspiration achieved high levels in the Sertão and Sertão do São Francisco mesoregions with 1300 and 1400 mm year^{-1}, respectively, the lowest values were found in the southern Agreste, due to the low temperatures and high altitudes in the region (Figure 7B), being propitious for the development of plants sensible to high temperatures as affirmed by MEDEIROS et al. (2009) studying the zoning of the *Alpinia purpurata* for the State. The spatial distribution of the real evapotranspiration presented the highest rates in the Zona da Mata with 1200 mm year^{-1}, and the smallest values in the entire Sertão region with 350 mm day^{-1} (Figure 7C). The greater water availability (Figure 7D) and water excess (Figure 7E) are found in the south part of the Zona da Mata, due to the high levels of rainfall, stimulating the cultivation in rainfed, as indicated by SILVA et al. (2011) studying the zoning of the Surinam cherry crop for the State. The water deficit (Figure 7F) was higher in the Sertão and Sertão do São Francisco, reaching the 1000 mm year^{-1}, being necessary irrigation almost the whole year for this regions.

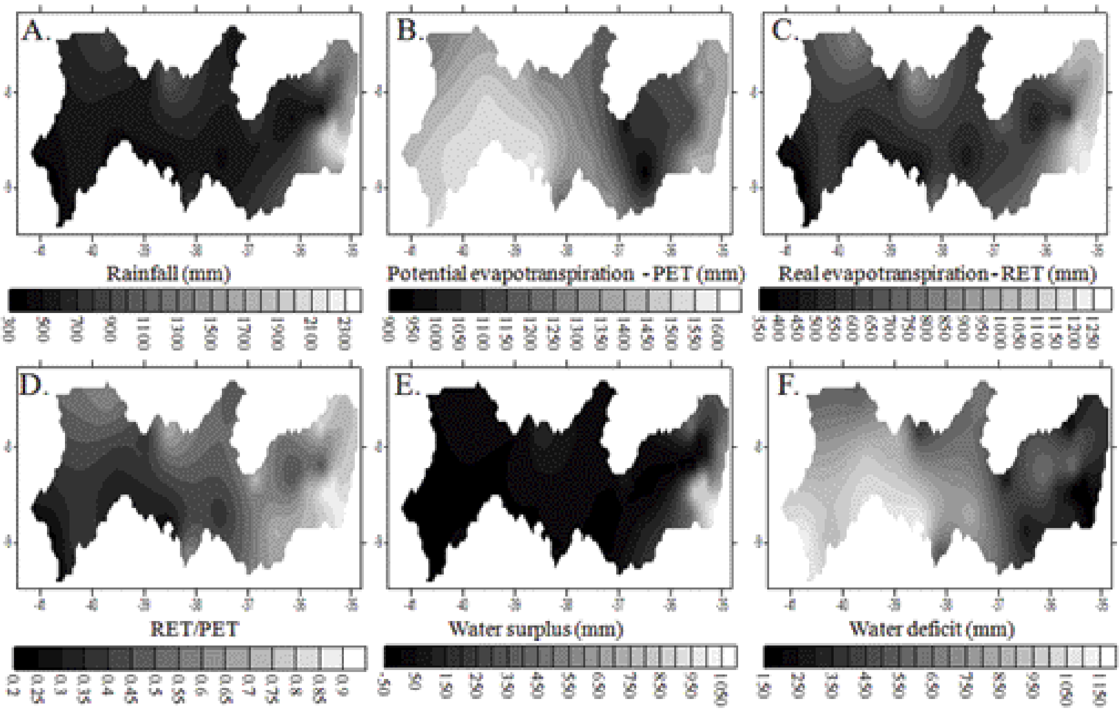

Figure 7. Spatial distributions of annual precipitation in Pernambuco (A) Potential evapotranspiration (B) Real evapotranspiration(C), water availability (RET/PET) (D), water excess (E) and water deficit (F) for regular years.

Dry years

The rain regime in the dry years presented for the Zona da Mate mesoregion the highest rates from March to August with an average of 230 mm month^{-1} (Figure 8A). The Agreste mesoregion presented an average of 73 mm month^{-1}, with greater levels in the months from March to July (Figure 8B). The Sertão and Sertão do São Francisco mesoregions presented averages of 22 mm month^{-1} and greater levels from January to April (Figures 8C and 8D).

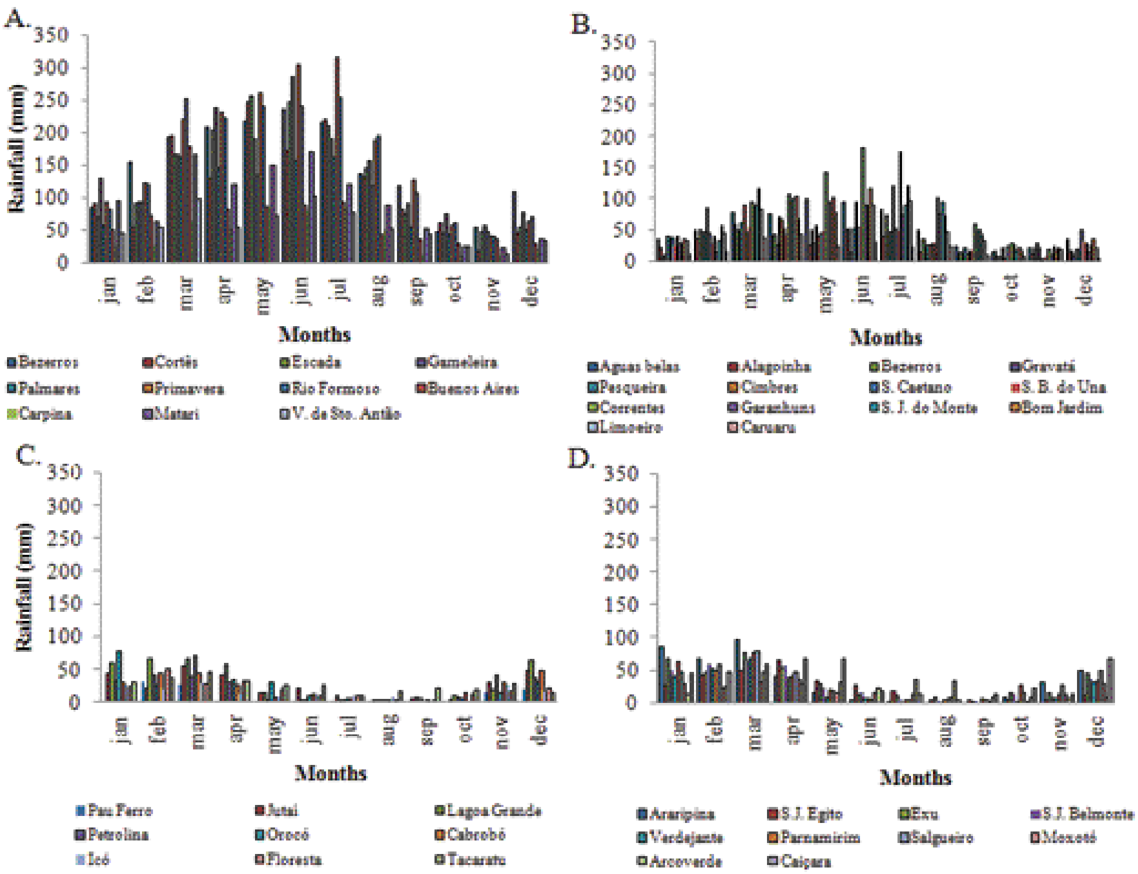

Figure 8. Rainfall for dry years in the regions of the State: Zona da Mata (A), Agreste (B),Sertão (C) and Sertão do São Francisco (D).

The potential evapotranspiration for the mesoregion presented monthly average of 111 mm month^{-1}, with higher water demand in the months from January to March and from October to November (Figure 9A). In the Agreste mesoregion the PET presented average of 99 mm month^{-1} (Figure 9B) and greater levels in the months from October to December. The Sertão (Figure 9C) and Sertão do São Francisco (Figure 9D) mesoregions presented averages of 120 and 124 mm month^{-1}, respectively.

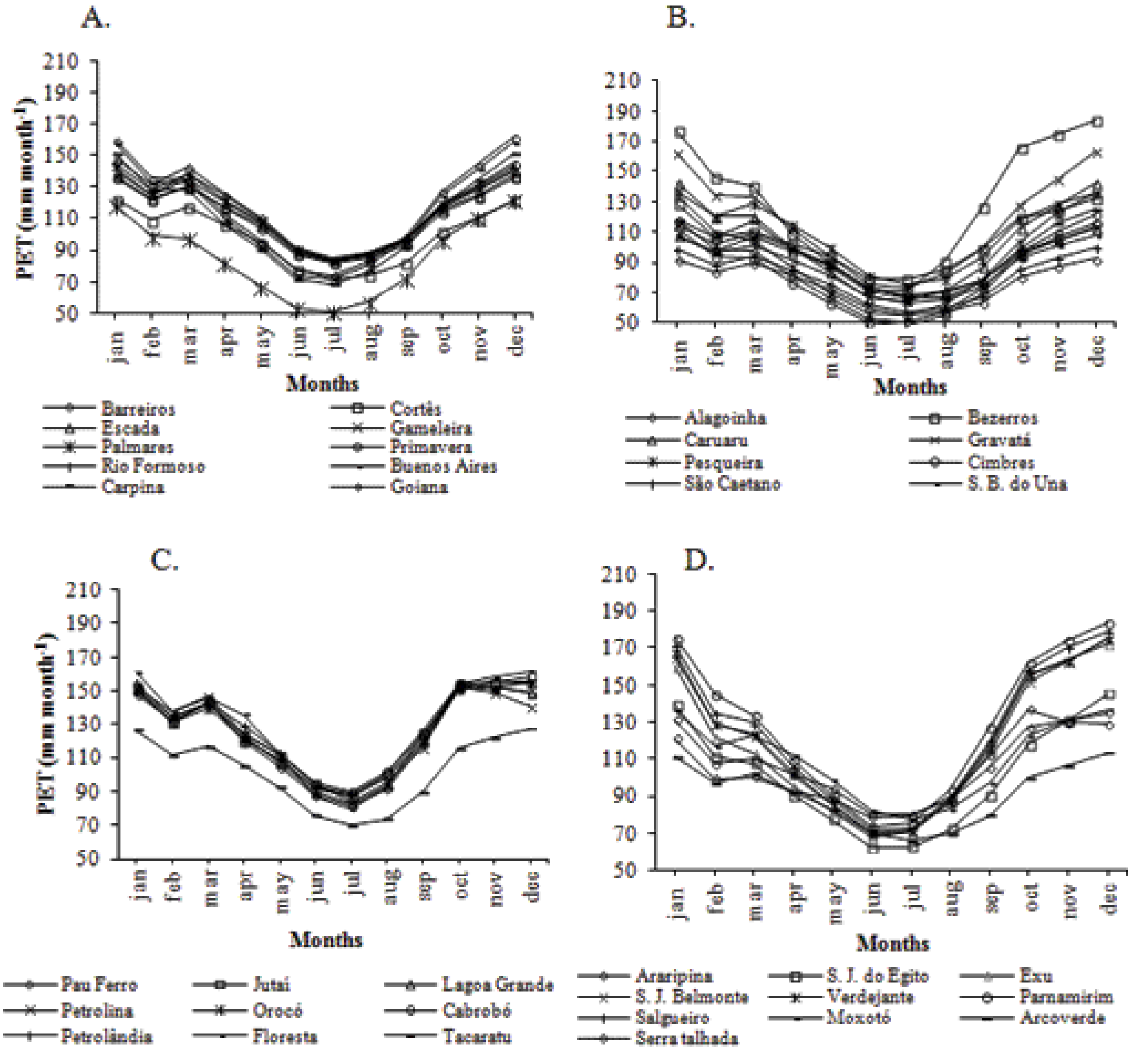

Figure 9. Potential evapotranspiration for dry years: Zona da Mata (A), Agreste (B), Sertão (C) and Sertão do São Francisco (D).

The spatial distribution presented rainfall of 1700 mm year^{-1} for the Zona da Mata mesoregion, 1200 to 1000 mm year^{-1} for the Agreste region, 100 to 400 mm year^{-1} for the Sertão and Sertão do São Francisco mesoregions, in average (Figure 10A). The PET presented variability in all mesoregions, with the lowest values in the southern Agreste with 1000 mm year^{-1} (Figure 10B). The RET (Figure 10C) presented low rates in the Sertão and Sertão do São Francisco mesoregions with 400 year^{-1}, probably due to the low water availability during the whole year in the region (Figure 10D). Figure 10E presents the spatial distribution of the water excess for the State, it was observed in this, the lowest values for the Sertão and Sertão do São Francisco mesoregions, showing the necessity of irrigation for the crops during the whole year. The water deficit (Figure 10F) achieved the lowest values in the Zona da Mata, due to the high level of rains during the year in the region, and the highest rates in the Sertão and Sertão do São Francisco with 1450 mm year^{-1}. According to SILVA et al. (2010) in studies of zoning, the cultivation in areas of elevated periods of water deficit, like the Sertão and Sertão do São Francisco mesoregions, the crops must present adaptability to the weather, beyond being adequately irrigated.

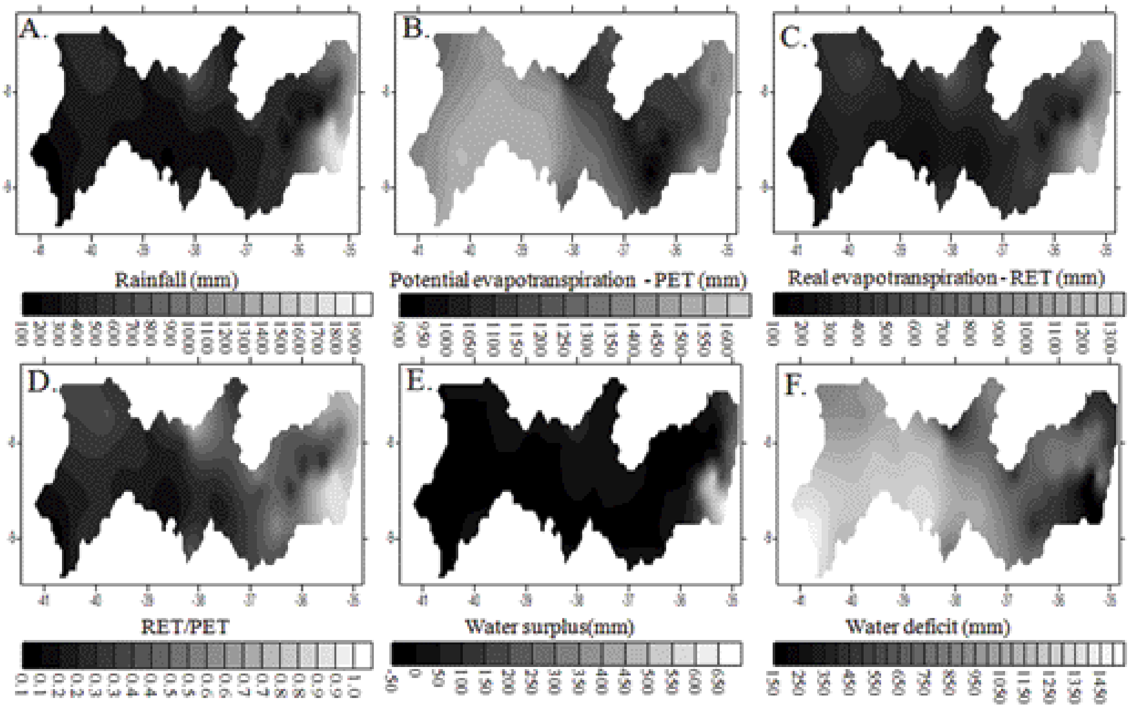

Figure 10. Spatial distributions of annual precipitation in Pernambuco (A) Potential evapotranspiration (B) Real evapotranspiration (C), water availability (RET/PET) (D), excel water (E) and water deficit (F) for dry years.

Conclusion

The results obtained in this study suggest that the spatialization of values of climatologic water balance through the geostatistic can assist the producers with a more adequate management of irrigation and, consequently, provide a considerable decrease in the demand for water for the irrigation. In this context, the spatialization of the environmental data becomes an important tool for the management of water resources. However, the rainfall regimes and the variations of temperature due to the climatic phenomena should be taken into consideration, for the determination of the studies with spatial distribution.

References

CASTRO, F. da S.; PEZZOPANE, J.E.M.; CECÍLIO, R.A.; PEZZOPANE, J.R.M.; XAVIER, A.C. Avaliação do desempenho dos diferentes métodos de interpoladores para parâmetros do balanço hídrico climatológico. **Revista brasileira de engenharia agrícola e ambiental**, v.14, n.8, p.871-880, 2010.

GOLDEN SOFTWARE. Sufer® - version 8.03. Golden, 2003. Software. http://www.goldensoftware.com/demo.shtml. 13 jan. 2006.

HOOGENBOOM, G. Contribuition of agrometeorology to the simulation of crop production and its application**. Agricultural and Forest Meteorology**, v.103, p.135-157, 2000.

LEMOS FILHO, L.C. de A. CARVALHO, L.G.; EVANGELISTA, A.W.P.; CARVALHO, L.M.T.; DANTAS, A.A.A. Análise espaço-temporal da evapotranspiração de referência para minas gerais. **Ciência e Agrotecnologia**, v.31, n.5, p.1462-1469, 2007.

MOURA, G.B.A.; ARAGÃO, J.O.R.; MELO, J.S.P.; SILVA, A.P.N.; GIONGO, P.R.; LACERDA, F.F. Relação entre a precipitação do leste do Nordeste do Brasil e a temperatura dos oceanos. **Revista brasileira de engenharia agrícola e ambiental**, v.13, n.4, p.462-469, 2009.

MONTEIRO, J.E.B.A. **Agrometeorologia dos cultivos**: **o fator meteorológico na produção agrícola.** Brasília: Instituto Nacional de Meteorologia, 2009. 530p.

MEDEIROS, S.R.R.; MOURA, G.B.; GIONGO, P.R.; SILVA, A.P.N. Potencial agroclimático para a *Alpinia purpurata* no Estado de Pernambuco. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.13, n.2, p.165-169, 2009.

MOURA, G.B.A.; MELO, J.S.P.; GIONGO, P.R.; LIRA JÚNIOR, M.A.; SILVA, A.P.N. Relação entre condições hídricas e o crescimento vegetal da cana-de-açúcar no município Itambé, Pernambuco. **Revista Caatinga**, v.21, n.5, p.171-177, 2008.

PEREIRA, A.R.; ANGELOCCI, L.R.; SENTELHAS, P.C. **Agrometeorologia**: fundamentos e aplicações práticas. Guaíba: Agropecuária, 2002. 478p.

SANTOS, F.X. MONTENEGRO, A.A.A.; SILVA, J.R.; SOUZA, E.R. Determinação do consumo hídrico da cenoura utilizando lisímetros de drenagem, no agreste pernambucano. **Revista brasileira de ciências agrárias,** v.4, n.3, p.304-310, 2009.

SENTELHAS, P.C.; SANTOS, D.L.; MACHADO, R.E. Water deficit and water surplus maps for Brazil, based on FAO Penman-Monteith potential evapotranspiration. **Ambiágua**, v.3, n.3, p.28-42, 2008.

SILVA, A.O.; SILVA, A.N.P.; MOURA, G.B.A.; LOPES, P.M.O.; MEDEIROS, S.R.R. Zoneamento agroclimático da pitangueira para três cenários distintos de precipitação pluvial em Pernambuco. **Revista caatinga**, v.24, n.1, p.104-115, 2011.

SILVA, A.O.; MOURA, G.B.A.; SILVA, E.F.F.; LOPES, P.M.O.; SILVA, A.P.N. Analise-espaço temporal da evapotranspiração de referência sob diferentes regimes de precipitações em Pernambuco. **Revista caatinga**, v.24, n.2, p.135-142, 2011.

SUDENE. **Normais Climatológicas da Área da SUDENE**. Superintendência do Desenvolvimento do Nordeste. Convênio com o Serviço de Meteorologia, Recife. 1990. n.pág.

PEREIRA, A.R.; VILLA NOVA, N.A.; SEDIYAMA,G.C. **Evapo(transpi)ração.** Piracicaba: FEALQ, 1997. 183 p.

THORNTWAITE, C.W. An approach toward a rational classification of climate, **Geographical Review,** n.1, p.55-94, 1948.

THORNTHWAITE, C.W.; MATHER, J.R. The water balance. **Publication in Climatology**, Laboratory of Climatology, Centerton, v.8, n.1. 1955.