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Development and water requirements of cowpea under climate change conditions in the Brazilian semi-arid region

Edmilson G. Cavalcante Junior[1], José F. de Medeiros[2], José Espínola Sobrinho[2], Vladimir B. Figueirêdo[2], João P. N. da Costa[1] & Wesley de O. Santos[1]

[1] Universidade Federal Rural do Semi-Árido. Mossoró, RN. E-mail: ediguatu@yahoo.com.br (Corresponding author); jppoty@hotmail.com; wesleysantosagro@bol.com.br
[2] Universidade Federal Rural do Semi-Árido/Departamento de Ciências Ambientais e Tecnológicas, Mossoró/RN, jfmedeir@ufersa.edu.br; jespinola@ufersa.edu.br; vlademir@ufersa.edu.br

Key words:
temperature
relative humidity
evapotranspiration

ABSTRACT
This study aimed to determine the impacts that climate change may cause on the development and evapotranspiration of cowpea, in semi-arid climate region of Northeast Brazil. The study was conducted in the municipalities of Apodi, Ipanguaçu and Mossoró, in the state of Rio Grande do Norte. In order to evaluate the influence of climate change on crop water consumption, changes in air temperature and relative humidity were simulated using the PRECIS climate model. Two scenarios of emissions were evaluated based on the report of the Intergovernmental Panel on Climate Change: a pessimistic named A2 and an optimistic B2. The duration of the crop cycle showed an average reduction of 14 and 23 days for the optimistic and pessimistic scenarios, respectively. Temperatures will be well above the limit tolerated by crop, which could have a negative impact on its development and yield. There will be a decrease in total evapotranspiration of 4.8%, considering the optimistic scenario, and 8.7% in the pessimistic scenario.

Palavras-chave:
temperatura
umidade relativa
evapotranspiração

Desenvolvimento e necessidade hídrica do feijão-caupi sob condições de mudanças climáticas no semiárido brasileiro

RESUMO
Propõe-se, com o presente trabalho, verificar os impactos que as mudanças climáticas podem provocar sobre o desenvolvimento e a evapotranspiração do feijão-caupi em uma região de clima semiárido do Nordeste brasileiro. O trabalho foi desenvolvido nos municípios de Apodi, Ipanguaçu e Mossoró, estado do Rio Grande do Norte. Para verificar a influência das mudanças climáticas no consumo hídrico da cultura foram simuladas alterações na temperatura e na umidade relativa do ar, por meio do modelo climático PRECIS. Foram avaliados dois cenários de emissões baseados no relatório do Intergovernmental Panel on Climate Change: um pessimista denominado A2 e um otimista B2. Os aumentos da temperatura na região provocarão redução do ciclo de desenvolvimento da cultura de 14 e 23 dias considerando os cenários otimista e pessimista, respectivamente. As temperaturas se manterão muito acima do limite tolerado pela cultura, o que poderá repercutir negativamente no seu desenvolvimento e, em contrapartida, no rendimento. Ocorrerá diminuição na evapotranspiração total de 4,8% considerando-se o cenário mais otimista e de 8,7% no cenário mais pessimista.

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Introduction

The global climate change induced by increasing concentrations of greenhouse gases (GHGs) in the atmosphere tends to cause increment in temperatures, changes in rainfall patterns and increase in the frequency of extreme events. According to the report of the IPCC (Intergovernmental Panel on Climate Change), the increase in temperature threatens the cultivation of various agricultural crops and may worsen the already serious problem of hunger in more vulnerable parts of the planet.

Cowpea (*Vigna unguiculata* (L.) Walp.), also known as “feijão macassar” or “feijão-de-corda”, is a species with wide global distribution, especially in tropical regions, because their climate conditions are similar to those of its probable place of origin: Africa (Brito et al., 2009). The production of cowpea in the Northeast and North regions is made by entrepreneurs and family farmers using traditional practices (Freire Filho et al., 2011).

Considering that the climatic condition will be changed indeed, it is possible to formulate some hypotheses on the dynamics of agriculture in Brazil and worldwide (Pellegrino et al., 2007). Among the climatic elements that influence the development and water consumption of the bean crop, temperature and relative humidity stand out. The evapotranspiration of crops would be directly affected by possible changes in the climatic conditions. Some studies have been conducted in order to investigate the likely impacts of climate change on the bean crop (Campos et al., 2010; Saraiva & Souza, 2012; Diaz-Ambrona et al., 2013).

Based on the above, the present study aimed to verify the impacts that climate changes (temperature and relative humidity) can cause on the development and evapotranspiration of cowpea in a semi-arid climate region of Northeast Brazil.

Material and Methods

The study was carried out in the municipalities of Apodi, Ipanguaçu and Mossoró, in the state of Rio Grande do Norte, Brazil. According to Köppen’s classification, the climate of these municipalities is BSh, a dry semi-arid climate (Alvares et al., 2014).

In the municipality of Apodi, RN, the study was conducted at the experimental farm of the Rio Grande do Norte Agricultural Research Company (EMPARN) (5° 37’ 38” S; 37° 49’ 55” W; 150 m). The soil in the experimental area was classified as eutrophic Cambisol, according to EMBRAPA (1999). The region has mean annual temperature of 27.1 ºC, mean maximum temperature of 34.1 ºC, mean minimum temperature of 22.8 ºC and mean rainfall of approximately 893 mm $year^{-1}$, according to data of the National Institute of Meteorology (INMET).For the municipality of Ipanguaçu, RN, the same experimental farm belonging to the EMPARN (5°32’38” S; 36°52’31” W; 22 m) was used and the soil in the area is classified as Fluvic Neosol (EMBRAPA, 1999). According to data of EMPARN, the municipality has mean minimum temperature of 20.7 °C, mean maximum temperature of 34.9 °C, general mean temperature of 27.7 °C and mean rainfall of approximately 575.3 mm $year^{-1}$.

In Mossoró, RN, the study was conducted at the Rafael Fernandes Experimental Farm, belonging to the Federal Rural University of the Semi-arid Region (5°03’37” S; 37°23’50” W; 72 m); the soil in the area is classified as latosolic dystrophic Red Yellow Latosol (EMBRAPA, 1999). The region has mean annual temperature of 26.2 °C, mean maximum temperature of 33.4 °C, mean minimum temperature of 21.9 °C and mean rainfall of approximately 787.9 mm $year^{-1}$ (INMET).

Each experiment had an area of 720 m^2 cultivated with cowpea at spacing of 0.90 m between rows and 0.20 m between plants. Each crop was planted almost on the same date in the three sites, comprehending the period of March to May 2014, which encompasses the rainy period of the region. Complementary irrigations were necessary because there were some dry spells during the experimental period. In the Apodi area, planting was performed on March 13, 2014 and harvest on May 25, 2014, in a total of 74 days. In the Ipanguaçu area, planting was performed on February 27, 2014 and harvest on May 11, 2014, with a total of 74 days. In the Mossoró area, the period from planting to harvest was comprehended between March 14 and May 31, 2014, totaling 79 days.

Crop evapotranspiration (ETc) in different stages was determined through weighing lysimeters. Each lysimeter was placed on a precision electronic scale connected to a sensitive element (load cell), attached to a data acquisition system (data logger). The lysimeters had dimensions of 1.5 x 1.8 m (area of 2.70 m^2) and depth of 0.9 m.

For the calculation of the mean crop coefficients, the crop cycle was divided into four phenological stages, defined according to the methodology of Doorenbos & Pruitt (1977) as follows: I) Initial stage: from planting to 10% of soil cover; II) Growth stage: from the end of initial stage to total soil cover; III) Intermediate stage: from total soil cover to the beginning of maturation and IV) Final stage: from the end of stage III to harvest.

Reference evapotranspiration (ETo) was estimated through the Penman-Monteith method, parameterized by FAO (Allen et al., 2006). The meteorological data necessary for the determination of ETo (mean, maximum and minimum temperatures; maximum and minimum relative air humidity; wind speed and global radiation) were obtained in automatic weather stations installed close to the experimental areas.

The cumulative degree-days (DD) were determined using the methodology of Ometto (1981), which, according to Renato et al. (2013), is the most recommended for simulations, especially in climate change scenarios that project higher increments in air temperature, because this methodology uses upper and lower basal temperatures and considers a higher penalty for days in which the maximum temperature exceeds the basal temperature. In this method, the thermal sum has five restrictions, each one with a certain equation for the calculation of DD (Eqs. 1 to 5):

1) TB > TM > Tm > Tb

$$DD = \frac{TM - Tm}{2} + Tm - Tb \quad (1)$$

2) TB > TM > Tb > Tm

$$DD = \frac{(TM - Tm)^2}{2(TM - Tm)} \quad (2)$$

3) TB > Tb > TM > Tm

$$DD = 0 \quad (3)$$

4) TM > TB > Tm > Tb

$$DD = \frac{2(TM - Tm)(Tm - Tb) + (TM - Tm)^2 - (TM - TB)}{2(TM - Tm)} \quad (4)$$

5) TM > TB > Tb > Tm

$$DD = \frac{1}{2}\frac{(TM - Tb)^2 - (TM - TB)^2}{TM - Tm} \quad (5)$$

where:

DD - degree-day, °C;
TM - maximum temperature of the day, °C;
Tm - minimum temperature of the day, °C;
Tb - lower basal temperature, °C; and
TB - upper basal temperature, °C.

The lower basal temperature used in the model for the bean crop was 10 °C and the upper basal temperature was 35 °C (Miranda & Campelo Júnior, 2010).

In order to verify the influence of the climate changes on water consumption and crop development, alterations predicted for the year 2100 in temperature and relative air humidity were simulated. Two scenarios of emissions based on the IPCC's report were evaluated based: one pessimistic called A2 and one optimistic called B2. The scenario A2 is characterized by a world that operates independently, auto-sufficient nations, increasing population growth and economic development oriented for the region. The scenario B2 describes a planet in which the emphasis is on local solutions for economic, social and environmental sustainability. It is a world with continuation of the increase in global population at a rate lower than that in scenario A2.

The data of temperature and relative air humidity used in the simulations, for the future scenarios (A2 and B2), were the outputs of the PRECIS (Providing Regional Climates for Impact Studies) climatological model, which is based on the third generation of the regional model of the Hadley Centre (HadRM3). The regional model HadRM3 has horizontal resolution of 50 km with 19 levels in the vertical (from surface to 30 km in the stratosphere) and four levels in the soil. The spatial resolution is 0.44 x 0.44° (latitude x longitude), which corresponds to an approximate grid of 50 x 50 km. More details about the PRECIS system can be obtained in Jones et al. (2004).

Two situations were evaluated: the first, which considers the crop coefficients obtained in the experiments, and the second, in which the coefficients were fitted to the evaluated conditions of climate change. The fit of the crop coefficients to the climate change conditions were performed according to the equation proposed by Allen et al. (2006) (Eq. 6):

$$Kc = Kc_{actual} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (6)$$

where:

Kc - adjusted crop coefficient;
Kc_{actual} - crop coefficient (if ≥ 0.45);
u_2 - mean wind speed of the stage at height of 2 m, m s^{-1};
RH_{min} - mean minimum relative humidity during the stage, %; and
h - mean height of the plants in the stage, m.

Since the model provided only data of mean relative humidity, a form of proportion was used to determine maximum and minimum relative humidity, i.e., the same percentage of change simulated for the mean relative humidity was attributed to the maximum and minimum values. These data were necessary for the simulations of reference evapotranspiration and fit of the crop coefficient.

Based on the Kc values obtained in the experiments and with the new ETo values from the scenarios (A2 and B2), a new ETc was generated, comparing the crop water demands for the actual climatic conditions with those for the two evaluated scenarios.

Results and Discussion

The mean duration of each crop stage, crop coefficients (Kc) obtained in each experiment and the coefficients adjusted to the evaluated conditions of climate change are shown in Table 1. There was little influence of the climate changes on cowpea Kc, since the coefficients fitted to the evaluated scenarios were virtually equal to those obtained under the actual conditions, which is due to the fact that the bean crop is relatively short (40 cm) and its aerodynamic properties are little influenced by the reduction in the RH simulated by the model. According to Allen et al. (2006), crops that are significantly taller than the reference crop have more accentuated aerodynamic properties and are more prone to modifications in their crop coefficients, under conditions of drier air and stronger winds.

The mean Kc values of the three experiments were 0.44, 0.78, 1.09 and 0.52 for the stages I, II, III and IV, respectively. For the conditions of the Gurgueia Valley, PI, Bastos et al. (2008) obtained Kc values of irrigated cowpea superior to those of the present study. The mean crop coefficient for the initial stage was 0.8; for vegetative growth, it ranged from

Table 1. Mean duration of the phenological stages of cowpea, cumulative degree-days per stage (CDD), mean crop coefficient (Kc) and Kc adjusted to the climate changes, in different sites in the state of Rio Grande do Norte

Stage	Duration (days)	CDD (°C)	Kc				
			Apodi	Mossoró	Ipanguaçu	Mean	Adjusted
I - Initial	17	307	0.43	0.39	0.49	0.44	-
II - Vegetative growth	18	326	0.87	0.77	0.70	0.78	0.80
III - Flowering	26	463	1.04	1.19	1.03	1.09	1.11
IV - Physiological maturation	15	265	0.40	0.61	0.55	0.52	0.55

0.8 to 1.1; in the reproductive stage, it ranged from 1.1 to 1.4; and in the final stage from 1.4 to 0.3. Lima et al. (2011), working with evapotranspiration of cowpea under rainfed conditions in Areia-PB, observed mean values of 0.99 for the Kc of the vegetative stage (initial + vegetative growth), 0.88 for the reproductive stage and 0.83 for maturation.

Table 2 shows mean, maximum and minimum values of air temperature during the experiments and the projections of these variables for the two evaluated scenarios (B2 and A2). The temperatures showed substantial increases, reaching the maximum value of up to 45 °C in the municipality of Ipanguaçu.

According to the model and considering the scenario B2 (Table 2), increments (means of the three municipalities) of 4.1, 5.4 and 2.7 °C are predicted for mean, maximum and minimum temperatures, respectively. For the scenario A2, the expected increments in mean, maximum and minimum temperatures are 7.8, 10.3 and 5.2 °C, respectively. The expected increase in maximum temperature, in the scenario A2, overestimates those indicated by Marengo (2006), who claims that during the summer a more intense heating is expected in tropical regions of Brazil, especially in the Amazon and Northeast, which may vary from 6 to 8 °C in 2080.

The projection of RH generated by the model estimates mean reductions of 9.8 and 16.1% for the scenarios B2 and A2, respectively, indicating that, according to the model and besides the higher temperatures, the air is expected to be drier, thus increasing the power of extraction of water vapor by the atmosphere.

If the predictions of the model are correct, the cultivation of bean, as well as various other crops, will be seriously compromised in the region. Based on the evaluated scenarios, the temperatures may lead to serious damages in crop development, such as spontaneous flower abortion, retention of pods in the plants and a considerable decrease in the number of seeds per pod. Photosynthesis in C3 plants (bean) is projected to respond more strongly to the enrichment of CO_2 compared with C4 plants (Minuzzi & Lopes, 2015), which somehow may lead to greater benefit to crops that use the C3 mechanism. The increment in the concentration of atmospheric CO_2 is beneficial until a certain limit of temperature. Under conditions of very high temperatures, such as those simulated by the model, the plant begins to have difficulty to perform photosynthesis.

These comments are addressed by Campos et al. (2010), who studied the impact of global heating on cowpea cultivation in the state of Paraíba and observed that, with the increase in air temperature of 3 and 6 °C, the areas favorable to cowpea cultivation in this state will be considerably reduced in the next decades and there may be a restriction of 100% in the cultivation of cowpea in some areas of the state considering an increase of 6 °C in air temperature.

Another effect of the increase in the temperatures is the acceleration of crop development. The cycle of each plant species is related to the daily thermal sum necessary to complete its development. The total of cumulative degree-days (DD) necessary for the crop to achieve maturity was on average 1360 DD. With the increase in temperature, the species tended to achieve maturity increasingly early.

The results of the simulations showed a substantial decrease in the time for crop development in both scenarios of climate change expected for the year 2100. The duration of the cycle in the actual condition, which was on average 76 days (mean of three sites) became 62 days in the scenario B2 (Figure 1).The alterations predicted for the scenario A2 (pessimistic scenario) resulted in a more pronounced decrease, with mean of only 53 days, 23 days less than the actual condition. These results are close to those obtained by Diaz-Ambrona et al. (2013), who estimated reductions of 3 to 20 days in the cycle of the bean crop in different regions of Honduras. Renato et al. (2013) observed reduction of 11 days in the cycle of the bean crop considering random increments of 0 to 5 °C in the values of air temperature, for the conditions of Viçosa, MG.

Despite the increase in the daily rate (Figure 2), the cumulative evapotranspiration at the end of the crop cycle was lower in both evaluated scenarios (Figure 3), due to the reduction in the crop cycle.

The reduction in total crop evapotranspiration, considering the mean of the 3 municipalities, was approximately 4.8% for scenario B2 and 8.7% for scenario A2. Minuzzi & Lopes (2015) also observed that the net irrigation requirement of second-season maize in Central Western Brazil tends to decrease and attributed this behavior to the reduction in the duration of the crop cycle caused by the expected increment in air temperature. These results are in agreement with those reported by Islam et al. (2012) and Tao & Zhang (2011), who observed reduction in irrigation demand by the maize crop under conditions of

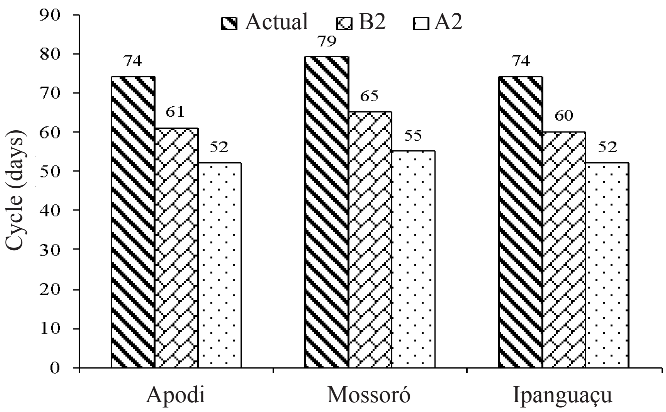

Figure 1. Cowpea crop cycle for different scenarios of climate changes (Actual, A2 - pessimistic and B2 - optimistic) in the municipalities of Apodi, Mossoró and Ipanguaçu

Table 2. Mean values of mean (Tmed), maximum (Tmax) and minimum (Tmin) temperature (°C) and relative humidity (RH) in the period of March to May for different scenarios of climate changes, simulated by the PRECIS model

Site	Actual				B2 – Optimistic				A2 - Pessimistic			
	Tmed	Tmax	Tmin	RH	Tmed	Tmax	Tmin	RH	Tmed	Tmax	Tmin	RH
Apodi	27.3	33.0	23.5	73.7	31.2	38.2	26.1	63.1	35.1	43.3	28.8	56.1
Mossoró	26.5	32.4	22.5	70.5	30.5	37.7	25.1	61.7	34.1	42.4	27.6	55.5
Ipanguaçu	27.4	34.6	22.1	71.2	31.7	40.4	25.0	61.3	35.3	45.1	27.4	55.6

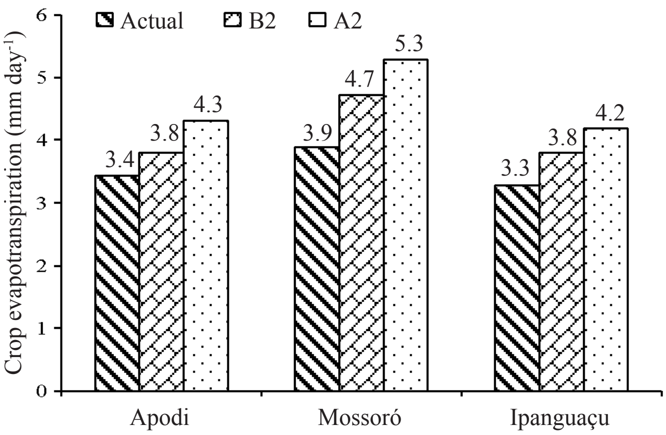

Figure 2. Mean daily evapotranspiration of cowpea for different scenarios of climate changes (Actual, A2 - pessimistic and B2 - optimistic) in the municipalities of Apodi, Mossoró and Ipanguaçu

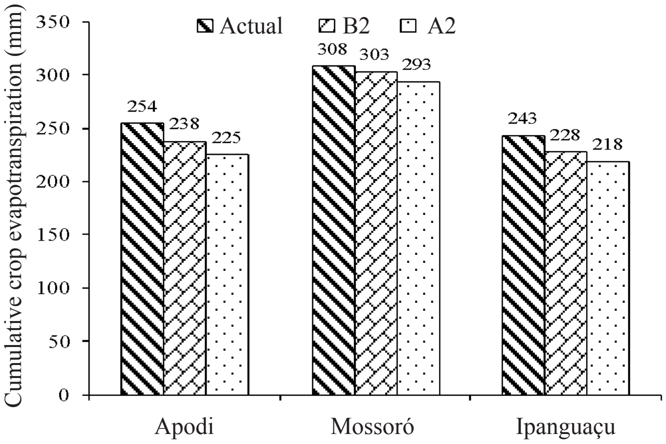

Figure 3. Total evapotranspiration of cowpea for different scenarios of climate changes (Actual, A2 - pessimistic and B2 - optimistic) in the municipalities of Apodi, Mossoró and Ipanguaçu

climate changes in the United States and China, respectively. Different results were reported by Saraiva & Souza (2012) in a study conducted in the irrigation district of Curu-Pentecoste in the state of Ceará, in which they observed that the water demand of the cowpea crop will increase by 7.5% in the case of scenario B2 and 12.8% in the case of scenario A2. Such difference can be attributed to the fact that the previously mentioned study did not consider the influence of temperature on the duration of the crop cycle.

The expected increase in the daily rate of evapotranspiration will have direct effect on the irrigation systems, because even with reduction in total evaporation there will be the need for higher intensity of irrigation to meet the daily demand of the crop. The regions that do not meet this new demand will have to reduce the size of their irrigated areas or search for crops/cultivars with lower daily water demand.

Conclusions

1. The climate changes had no influence on cowpea Kc under the conditions of the present study.

2. There will be a reduction of 4.8% in total evapotranspiration, considering the more optimistic scenario and 8.7% for the more pessimistic scenario.

3. The increments of temperature in the region will cause reductions in crop development cycle of 14 and 23 days considering the optimistic (B2) and pessimistic (A2) scenarios, respectively. The temperatures will be much higher than the limit tolerated by the crop, which may have negative effects on its development and, consequently, on its yield.

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