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CLIMATE CHANGE IMPACTS ON WATER DEMAND OF MELON PLANTS IN JAGUARIBE-APODI REGION, BRAZIL

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ABSTRACT: The aim of this study was to evaluate the impacts of climate change on irrigation water demand of melon plants grown in Jaguaribe-Apodi Irrigation District (DIJA), which is located between the states of Ceará and Rio Grande do Norte, in Northeastern Brazil. Future scenarios were developed using the Eta-CPTEC/HadCM3 climate change projections, after being submitted to downscaling method. We used a set of climate data from the same model for the period of 1961 through 1990, and further projections after bias correction. Local geographic coordinates were interpolated using GIS techniques. Reference evapotranspiration (ET_o) was estimated from the monthly minimum and maximum mean temperatures, using a limited data method. The rainfall, temperature, ET_o, and water demand future projections were mapped for the area of investigation to analyze spatial variability. ETA model simulations for climatic change showed growth in irrigation water demands due to evapotranspiration increase (from 28.4% to 33.4%), even though rainfall increases (between 61.9% and 89.9%). The increase in the average gross water demand is varied from 37.5% to 78.2% within the period of 2031 to 2060, respective to the common planting season.

KEYWORDS: evapotranspiration, GIS techniques, irrigation, *Cucumis melo* L.

INTRODUCTION

The melon crop has a strategic economic importance for the Northeast of Brazil, where 85% of national production comes from. It is a competitive region because it provides short crop cycles (66 days) if compared to Spain or France (about 120 days). The main production cluster of the country is Mossoró and Assu region, in Rio Grande do Norte state (241 thousand tons/year – harvested from 7,943 ha). The second is Low Jaguaribe, in Ceará State (153 thousand tons/year – harvested from 5,431 ha) (AGRIANUAL, 2013). These two areas have high solar radiation levels, high temperatures (maximums around 30 °C), and low rainfall indexes (700 to 800 mm annually), being distributed over the course of few months in the year (February to May), which means that they are on the threshold of environmental necessary growing conditions to the referred crop.

Studies on future scenarios of climate change in Ceará and Piauí states, from statistic downscaling of ECHAM4 and HadCM2 Global Circulation Models (KROL & BRONSTERT, 2007), showed rainfall changes over the region (2070/2090 time slice, compared to 1961/1990). Nevertheless, contradictory results were observed, showing a 50% reduction by ECHAM4 and a 21% increase by HadCM2.

GONDIM et al. (2012) applied the regional model PRECIS (Providing Regional Climates for Impacts Studies), version 1.2, using boundary conditions of HadRM3P Regional Climate Model (ALVES & MARENGO, 2010) with bias removed, on Jaguaribe river basin. These authors identified an influence of climate change on irrigation water demand - which depends on temperature and rainfall - as well as how the interaction between the two climate variables will behave. Additionally, they concluded that irrigated agriculture in the study region may become more water demanding once irrigation water needs are supposed to grow by the combined action of

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increasing reference evapotranspiration and rainfall reduction, even without any irrigation area expansion.

A specific study on banana trees projected the annual irrigation water demand increase for 2040 related to initial conditions of 1,989 mm to 2,536 mm and 2,491 mm (27,50% and 25,24%) for scenarios A2 and B2 Intergovernmental Climate Change Panel (IPCC), respectively (GONDIM et al., 2011).

These results present uncertainties, especially related to rainfall response to atmospheric greenhouse gas concentration increase. As global circulation models of climate change predict are more precise, new studies should be undertaken.

TURRAL et al. (2013) cited water as an important issue to be addressed in studies involving climate changes and food security, aiming to ensure more accurate projections about agricultural impacts and delineate local adaptation measures.

Given the above-mentioned, the objective of this study was to evaluate climate change impacts on irrigation water needs for melon crops in Jaguaribe/Apodi, a region located between Ceará and Rio Grande do Norte states - Brazil, considering three planting months (July, August, and September) – which is adopted traditionally by local farmers, as well as performing regionalized climate change projections by means of the Eta-CPTEC/HadCM3 model.

MATERIAL E METHODS

The study area is located between the latitudes of 4°20'30” - 5°30'00”S and the longitudes of 37°05'00” - 38°30'00”W, representing a surface area of 8,954 km^2. It includes 11 municipalities, 4 from Rio Grande do Norte state (Tibau, Mossoró, Baraúna, and Grossos) and 7 from Ceará state (Aracati, Icapuí, Limoeiro do Norte, Quixeré, Jaguaruana, Russas, and Itaiçaba). The altitude varies from 1.5 m to 206 m above sea level.

The regional Eta model (MESSINGER et al., 2012) coupled to the HadCM3 global circulation model, referred here to as Eta-CPTEC/HadCM3, which was implemented in Brazil by the Center for Weather Forecast and Climatic Studies (CPTEC) of the National Institute for Space Research (INPE). This model combination is the so-called dynamic downscaling (regionalization), which is expected to provide a considerable improvement of projection resolution to be available for climate change studies. Coupling models are fundamental for a regional-scale impact assessment, being the reason for what we selected the aforementioned model.

Regionalized Eta-CPTEC/HadCM3 has a horizontal resolution of 40 km with 38 vertical levels, each 90 s time-step. For climate change reasons, the model uses a fixed representation of the CO_2 concentration of 330 ppm (A1B greenhouse gas emission scenario, accordingly to NAKICENOVIC et al., [2000]). An ensemble of three model members was used (medium, superior, and inferior model output limits), accordingly to sensitive responses to average temperature increases, hereafter referred to as control, high, and low. Further information on Eta-CPTEC/HadCM3 model is available at CHOU et al. (2011) and MARENGO et al. (2011).

A future time slice from 2031 to 2060, whose baseline was from 1961 to 1990, was applied to evaluate climate change impacts. Rainfall, temperature, reference evapotranspiration (ET_o), and projections of irrigation water needs were mapped using ordinary kriging geostatistical techniques associated with a Geographic Information System to elaborate thematic maps (GONDIM et al., 2012).

Using the Eta-CPTEC/HadCM3 model, monthly average maximum and minimum temperature (T_{max} and T_{min}), and rainfall were generated at a 40-km spatial resolution for the time slice from 1961 to 1990, as well as for the future projections from 2031 to 2060. Bias correction (EHRET et al., 2012) for all the prediction variables was obtained by differences between the model climate baseline (1961 to 1990) and the interpolated high-resolution data from Climatic Research Unit (CRU), University of East Anglia (MITCHEL & JONES, 2005).

Crop water needs (CWN) may be defined as the amount of water required by plants with no stress during vegetal development, being estimated by the equation below:

$$CWN = ET_oPMKcfc - ppt_{efective} \tag{1}$$

where,

CWN, Crop Water Needs (mm);

ET_oPM, Penman-Monteith reference evapotranspiration (mm);

Kc, Crop Coefficient (non-dimensional);

fc, crop cover factor (non-dimensional), and

$ppt_{effective}$, effective rainfall (mm).

The Food and Agriculture Organization of the United Nations (FAO) recommended adopting Penman-Monteith reference evapotranspiration combined method, the so-called FAO Penman-Monteith (ET_oPM), as a global standard to estimate crop water needs. A minimum climatic data model to estimate ET_oPM from maximum (T_{max}) and minimum (T_{min}) temperature only was applied by using limited data methodology, accordingly to ALLEN et al. (1998). A similar method was used by SENTELHAS et al. (2010) and ROCHA et al. (2011).

Table 1 shows melon crop coefficient, development stage, and number of days after planting (DAP), as well as the crop factor, accordingly to MIRANDA et al. (2008).

TABLE 1. Crop coefficients (Kc), crop factor (fc), days after planting (DAP) during melon growing stages for three different crop seasons.

	Kc	f.c.	DAP	n° of month days do mês
I – Planted on Jul. 1st to Sept. 6th				
Stage 1			0-23	
July	0.26	0.1		23
Stage 2			24-42	
July	0.76	0.4		8
Aug.	0.76	0.8		11
Stage 3			43-60	
Aug.	1.20	1		18
Stage 4			61-65	
Aug.	0.97	1		2
Sept.	0.97	1		3
II – Planted on Aug. 1st to Oct 6th				
Stage 1			0-23	
Aug.	0.26	0.1		23
Stage 2			24-42	
Aug.	0.76	0.4		8
Sept.	0.76	0.8		11
Stage 3			43-60	
Sept.	1.20	1		18
Stage 4			61-65	
Sept.	0.97	1		3
Oct.	0.97	1		2
III – Planted on Sept 1st to Nov. 6th				
Stage 1			0-23	
Sept.	0.26	0.1		23
Stage 2			24-42	
Sept.	0.76	0.4		7
Oct.	0.76	0.8		12
Stage 3			43-60	
Oct.	1.20	1		18
Stage 4			61-65	
Oct.	0.97	1		1
Nov.	0.97	1		4

Stage 1- initial; Stage 2 – vegetative development; Stage 3 – fruiting; Stage 4 – maturation.

Once CWN is equal to the crop evapotranspiration (ETc), irrigation water needs (IWN) is the CWN divided by irrigation efficiency, so that we accounted for the water losses by evaporation, runoff, and soil leaching. Thus, IWN values were estimated by:

$$\mathrm{I}WN = \frac{CWN}{WEf} \tag{2}$$

where,

WEf, is irrigation efficiency (decimal),

IWN, irrigation water needs (mm).

WEf was fixed at 85.0%, which is achievable by drip irrigation systems, being largely used by local melon farmers.

For climate change assessment, we considered the minimum, maximum, average and monthly deviation of the analyzed climate variables for a 30-year time slice for the present climatology, forecasting changes in terms of percentage.

RESULTS AND DISCUSSION

Tables 2 and 3 describe the 30-year average monthly maximum (T_{max}) and minimum (T_{min}) temperature statistics of the baseline (1961 to 1990) and Eta-CPTEC/HadCM3 future projections (2031 to 2016) for control, high, and low model members (CHOU et al., 2011). The differences between initial and projected future conditions are expressed as changing percentage (%), and spatial variability expressed by the standard deviation.

TABLE 2. Minimum temperature values of baseline (from 1961 to 1990) and future (from 2031 to 2060) climatology data.

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1961 to 1990												
Minimum	21.1	21.4	21.7	21.5	20.8	19.3	18.6	18.6	18.6	18.9	19.6	20.3
Maximum	26.4	26.4	26.3	26.1	25.7	25.2	25.1	25.3	25.8	26.2	26.5	26.5
Average	23.2	23.4	23.5	23.3	22.7	21.6	21.1	21.3	21.5	22.0	22.6	23.0
Standard Deviation	1.4	1.4	1.3	1.3	1.4	1.6	1.8	1.8	1.9	1.9	1.8	1.6
2031 to 2060 Control (1)												
Minimum	24.3	24.0	24.1	24.2	24.0	23.4	23.3	22.8	23.2	23.8	24.1	24.1
Maximum	25.9	25.7	25.5	25.3	25.1	23.9	23.3	23.6	24.1	24.7	25.3	25.8
Average	25.3	25.2	25.1	25.0	24.8	23.7	23.3	23.3	23.7	24.3	24.8	25.3
Standard Deviation	0.4	0.4	0.3	0.3	0.3	0.1	0,0	0.2	0.3	0.3	0.3	0.4
Change (%)	9.1	7.7	6.8	7.3	9.3	9.7	10.4	9.4	10.2	10.5	9.7	10.0
2031 to 2060 High (2)												
Minimum	24.3	24.0	24.1	24.2	24.4	23.8	23.6	23.4	23.4	23.5	23.9	24,0
Maximum	26.8	26.6	26.3	26.2	25.8	24.9	23.9	24.1	24.7	25.6	26.3	27.1
Average	26,0	25.8	25.7	25.6	25.4	24.4	23.8	23.8	24.2	25,0	25.5	26.0
Standard Deviation	0.6	0.7	0.6	0.5	0.3	0.3	0.1	0.2	0.3	0.5	0.6	0.8
Change (%)	12.1	10.3	9.4	9.9	11.9	13.0	12.8	11.7	12.6	13.6	12.8	13.0
2031 to 2060 Low(3)												
Minimum	24.3	24.0	24.1	24.2	24.2	23.3	23.0	22.9	23.2	23.8	24.1	24.2
Maximum	26.0	25.7	25.6	25.4	25.2	24.0	23.5	23.6	24.2	24.7	25.2	25.8
Average	25.4	25.2	25.1	25,0	24.9	23.7	23.3	23.3	23.8	24.3	24.7	25.3
Standard Deviation	0.4	0.4	25.1	0.3	0.2	0.2	0.1	0.2	0.3	0.2	0.3	0.4
Change (%)	9.5	7.7	6.8	7.3	9.7	9.7	10.4	9.4	10.7	10.5	9.3	10.0

Model output members (1) Control. (2) High (3) Low sensitivity to average temperature increases.

TABLE 3. Maximum temperature values of baseline (from 1961 to 1990) and future (from 2031 to 2060) climatology data.

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1961 to 1990												
Minimum	27.4	27.5	27.4	27.2	27.0	26.8	26.9	27.2	27.6	27.9	27.8	27.6
Maximum	32.3	32.7	31.8	31.0	30.7	30.4	30.6	31.3	32.2	33	33.2	32.7
Average	30.2	30.4	29.7	29.3	29.1	29.0	29.1	29.6	30.2	30.8	30.9	30.5
Standard Deviation	1.3	1.4	1.1	1.0	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.3
2031 to 2060 Control (1)												
Minimum	34.1	33.2	31.8	32.3	31.9	32.5	32.5	33.8	34.4	35	34.9	34.7
Maximum	35.3	34.6	34	33.6	33.3	33.8	33.1	34.7	35.7	36.2	36.1	35.9
Average	34.9	34.1	32.8	33.2	32.9	33.4	33.0	34.3	35.1	35.6	35.5	35.3
Standard Deviation	0.3	0.3	0.5	0.3	0.3	0.3	0.1	0.2	0.3	0.3	0.2	0.3
Change (%)	15.6	12.2	10.4	13.3	13.1	15.2	13.4	15.9	16.2	15.6	14.9	15.7
2031 to 2060 High (2)												
Minimum	35.1	34.0	32.8	33.3	33.2	33.6	33.6	34.3	34.8	35.5	35.6	35.3
Maximum	36.5	35.6	35.2	34.9	34.9	35.1	34.2	35.5	36.2	37.0	37.1	36.7
Average	35.9	35.0	34.0	34.4	34.5	34.7	34.0	35.0	35.5	36.3	36.4	36
Standard Deviation	0.3	0.3	0.5	0.4	0.4	0.4	0.1	0.3	0.3	0.3	0.3	0.3
Change (%)	18.9	15.1	14.5	17.4	18.6	19.7	16.8	18.2	17.5	17.9	17.8	18
2031 to 2060 Low(3)												
Minimum	34.3	33.4	31.9	32.6	32.2	32.7	32.7	33.8	34.4	34.9	34.9	34.7
Maximum	35.6	34.7	34.0	33.9	33.6	34.1	33.3	34.8	35.7	36.3	36.0	36.0
Average	35.1	34.3	32.8	33.4	33.2	33.6	33.2	34.4	35.1	35.6	35.5	35.4
Standard Deviation	0.3	0.3	0.5	0.3	0.3	0.3	0.1	0.2	0.3	0.3	0.3	0.3
Change (%)	16.2	12.8	10.4	14.0	14.1	15.9	14.1	16.2	16.2	15.6	14.9	16.1

Model output members (1) Control. (2) High (3) Low sensitivity to average temperature increases.

If compared to baseline data, the study identified increases of 28.4%, 29.3%, and 33.4% in ET_oPM for control, high, and low model output members, respectively (Table 4); these results are caused by higher T_{max} and T_{min}. Large differences were not observed among model members in terms of projected annual ET_oPM (1,784mm, 1,796mm and 1,853mm, respectively), this is the reason why this study presented control model results only.

Future increases in rainfall were projected according to the initial conditions, being of 89.9%, 61.9%, and 62.6%, respectively. The standard deviation, which expresses spatial variability, increased for future rainfall (except for the high model member, 95 mm $year^{-1}$) and decreased for ET_oPM, according to Table 4 (from 315 mm $year^{-1}$ in the baseline to values between 38 and 125 mm $year^{-1}$ in future projections). Thus, rainfall spatial variability is supposed to be higher than that of reference evapotranspiration.

TABLE 4. Annual impacts and future changes (%) for ET$_o$PM and rainfall during the period of 2031 to 2060 compared to the baseline climatology (1961 to 1990).

Statistics	ET$_o$PM (mm year^{-1})				Rainfall (mm year^{-1})			
	Baseline	Control$^{(1)}$	High$^{(2)}$	Low$^{(3)}$	Baseline	Control$^{(1)}$	High$^{(2)}$	Low$^{(3)}$
Minimum	625	1,679	1,694	1,729	366	744	690	572
Maximum	1,821	1,854	1,865	1,939	968	1,418	1,111	1,318
Average	1,389	1,784	1,796	1,853	546	1,037	884	888
Standard Deviation	315	38	37	45	125	155	95	161
Change (%)		28.4	29.3	33.4		89.9	61.9	62.6

Model output members (1) Control. (2) High (3) Low sensitivity to average temperature increases.

As shown in Table 5, even though rainfall is projected to increase by the control model output, IWN is expected to increase by 78.2%, 37.5%, and 57.5% for the planting months of July (I), August (I), and September (III), respectively. These increases result in growing water demands from 1.9, 2.6, and 2.4 mm day^{-1} to 3.4, 3.6, and 3.7 mm day^{-1}, respectively. The projected rainfall increases had no influence on water demand once they are foreseen to happen during the rainy season (from February to May). On the other side, no changes are projected during the dry month, which is when farmers grow melon (July to December), according to Figure 1 (below 40 mm monthly).

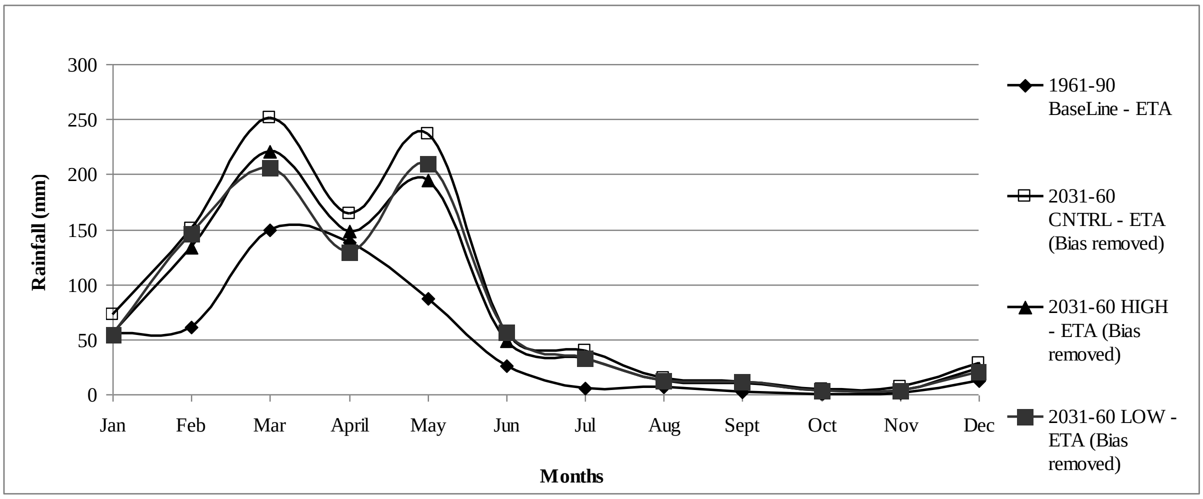


FIGURE 1. Monthly rainfall of the baseline (1961-1990) and future (2031-2060) climatology data for control and models of high and low sensitivity.

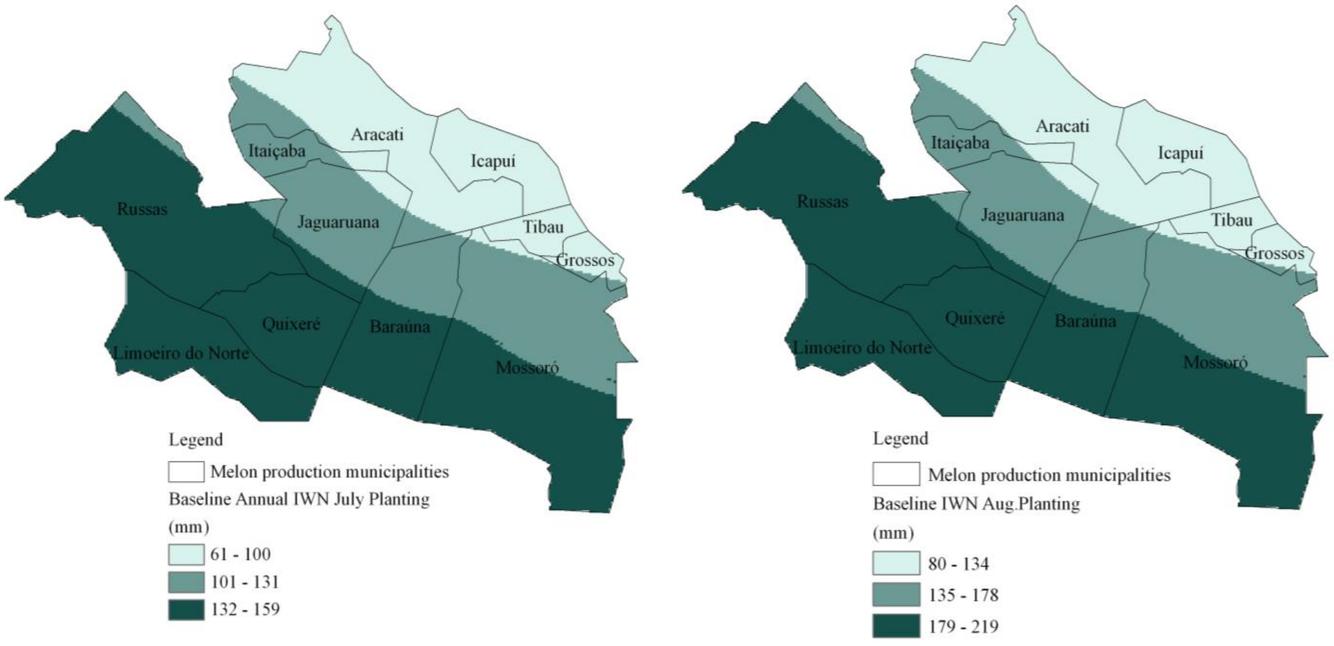
Based on Table 5, we see that planting melons in July may result in lower water demands (10 to 20 mm per crop cycle, respectively) than doing it in August or in September. Increased water demand for irrigation with increased precipitation should be associated with the sustainability of the exploited aquifers. Hence, it is important to check whether there will be an effective recharge during wetter months, as projected by the model.

TABLE 5. Gross irrigation water demand (IWN) per melon crop cycle (mm cycle^{-1}) for baseline (1961 to 1990) and future (2031 to 2060) values, at planting times I, II, and III.

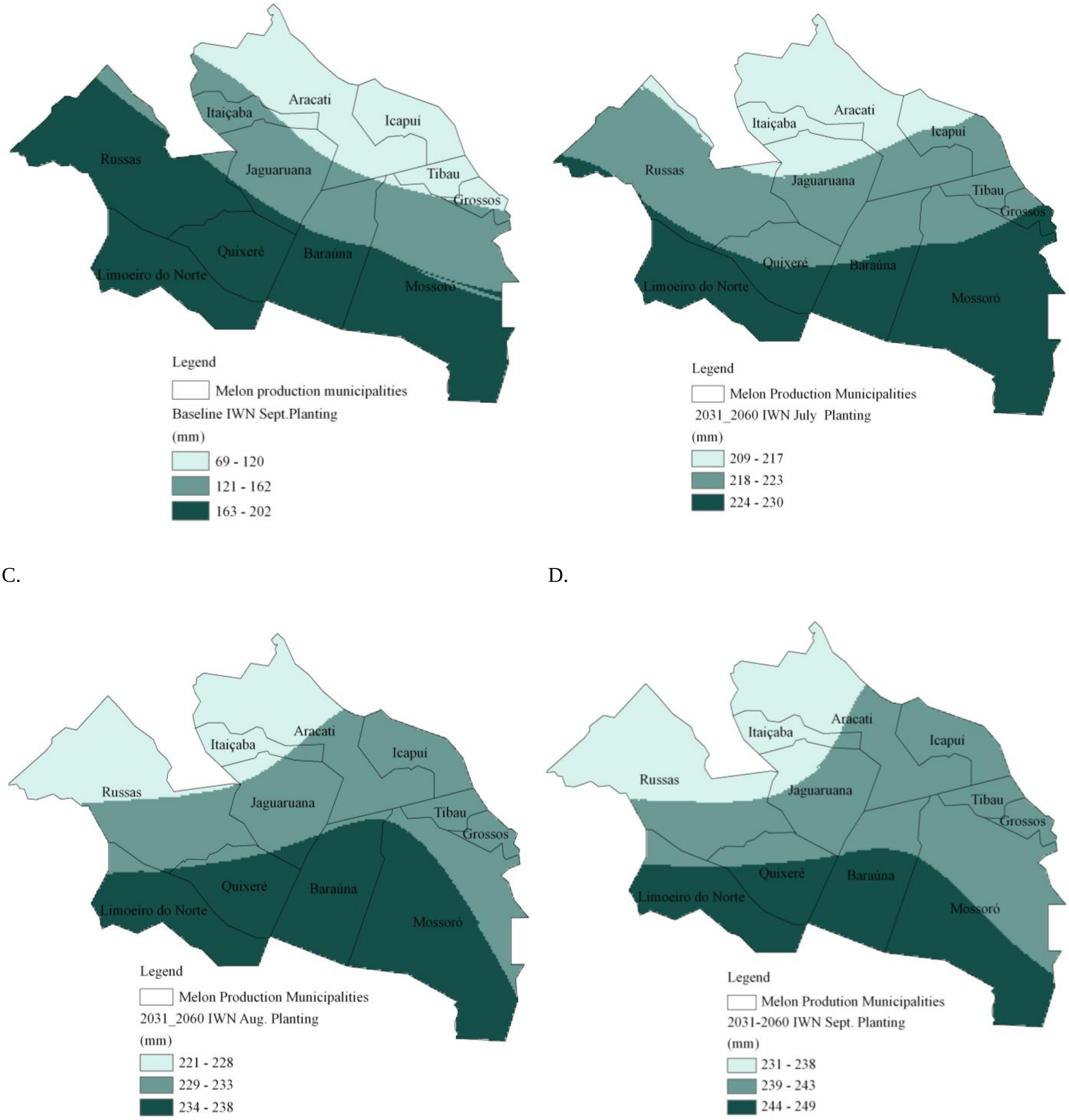
IWN (mm)	1961 to 1990 Base			2031 to 2060 Control		
(mm cycle^{-1})	I$^{(1)}$	II$^{(2)}$	III$^{(3)}$	I$^{(1)}$	II$^{(2)}$	III$^{(3)}$
Minimum	61	80	69	209	221	231
Maximum	159	219	202	230	238	249
Average	124	168	153	221	231	241
Standard Dev. Deviation	26	37	35	5	4	4
Change (%)				78.2	37.5	57.5

Planting dates in $^{(1)}$ Jul 1st, $^{(2)}$ Aug 1st and $^{(3)}$ Sept 1st.

The thematic maps in Figure 2 point out that IWN ranged from 61mm to 219 mm per crop cycle for the baseline data, and from 209 mm to 249 mm for the future time slice. A spatial gradient shows increases from seashore towards semi-arid lands (in the countryside). Higher water demand is expected for planting on September 1, so more irrigation water will be required in October, the month of which more evapotranspiration occurs in the region. However, as the standard deviation decreases, less spatial variability is predicted across the region in the future (Table 5).



A. B.



C. D.

E. F.

FIGURE 2. Thematic map of gross demand for irrigation water (in mm) for the period of 1961 to 1990, planting in July (A), August (B), September (C); and future values for 2031 to 2060, planting in July (D), August (E) and September (F).

In a study in Russas – CE, which is located in the study area, MIRANDA et al., (2008) observed that the application of 252 mm water during an irrigated melon crop cycle promoted a yield of 25.000 kg ha^{-1}. This water quantity is more similar to that estimated for August planting by the Eta/CPTEC/HadCM3 model for 1961 to 1990 time slice (179 a 219 mm), and for the projections of September (239 a 243 mm). It is worth mentioning that water needs were estimated based on crop coefficients and ET$_o$ made available by MIRANDA et al. (1999) and without irrigation efficiency citation.

Local farmers are used to drip-irrigate melon crops. Therefore, it should be considered that the irrigation efficiency adopted here for this system (85%) might be inaccurate, having seen the results observed by NUNES (2006), which shows values from 35.5% to 92.9%.

KROL & BRONSTERT (2007) applied the models ECHAM 4 and HadCM2; these authors verified that seasonal rainfall anomalies for this region (2070 to 2090 compared to 1961 to 1990 time slice) diverged, showing a 50% reduction by the ECHAM4 model and 21% increase by the HadCM2 one. After 2015, future projections made by the HadCM2 model and no climate change scenario, water reservoir shows varied level, with no significant trend. The ECHAM4 model projected a high water decline in Ceará state; and after 2030, it predicted a less water withdrawal as a result of rainfall reduction and demand that may not be met. Conversely, the HadCM2 model shows no water withdrawal decrease. In addition, irrigated agriculture is supposed to expand until 2025; however, an increasing demand for water may not be supplied after 2025 due to decreasing rainfall projections by ECHAM4. These contrasting results of the models demonstrate the vulnerability of irrigated agriculture and may change significantly (KROL & BRONSTERT, 2007).

BARBIERI et al. (2010), while assessing climate change impacts in the Northeast of Brazil, concluded that the local farming sector will be severely impaired by cropland inadequacy, as a consequence of rising temperatures, playing a role as migration and vulnerability driver since water supply is an essential factor.

GONDIM et al. (2011) assessed the water demand of banana trees, and GONDIM et al. (2012) evaluated irrigation water demand at river basin level, both studies by applying a high resolution model (HadRM3P). As a result, they projected an increasing demand for irrigation water as a function of future reference evapotranspiration increment and rainfall reduction.

MONTENEGRO & RAGAB (2012) considered water supply as an essential factor for the Northeast of Brazil when assessing areas of groundwater exploitation and recharge. The inadequacy of crop-growing areas was also reported by SILVA et al. (2012) when assessing climate change scenarios for maize crop zoning in the same region.

In this present study, the irrigation water demand for the melon crop in this region was assessed by a regionalized global model (Eta-CPTEC/HadCM3). The findings showed that, even though rainfall is projected to increase, water demand will follow the same trend. Therefore, the water use for irrigation purposes should be done rationally, as a climate change adaptation strategy.

CONCLUSIONS

According to the scenarios developed by the models, climate change is expected to increase irrigation water demand of melon crop and in all planting months, even if there is an annual rainfall increase. Once such increase is expected for rainy months, the following dry season will be impaired; unfortunately, this is when the melon crop ought to be irrigated.

Increases in temperature result in growing rates of reference evapotranspiration and, consequently, higher demands on irrigation water. Even if planting in July promote irrigation water increases, it may lead to less water demand if compared to those in August and in September.

The increasing demand for irrigation water in association with higher rainfall levels may assist in a sustainable crop management since a most intense rainy season may recharge aquifers, as projected by the applied model.

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