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TITLE: COULD CLIMATE CHANGE REDUCE REGIONAL IRRIGATION WATER NEEDS?

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SUMMARY: Watermelon is an emerging crop that is dependent on irrigation water supply because growing season generally coincides with dry months in Central Brazil. This study attempted to evaluate climate change impact on watermelon irrigation water needs (IWN) across the production region in the state of Goiás, Brazil. Baseline hindcasts (1961-1990) and climate projections from (2031-2060) Eta-CPTEC/HadCM3 regional climate model were used in this impact assessment. IWN projections were calculated using bias-corrected climate projections for monthly rainfall and surface temperature. Penman Monteith evapotranspiration is expected to decrease around 10% due to higher increases in the minimum rather than the maximum temperatures. Watermelon IWN is expected to increase 8.7% during April planting and to decrease 12.1% during July planting for the 2032-2060 time period. These contradictory results represent an annual average increase of 9 mm and a decrease of 19 mm, respectively. This may be explained by greater decreases in rainfall during April planting month.

KEYWORDS: climate change, irrigation, watermelon, evapotranspiration.

PODERIA AS MUDANÇAS CLIMÁTICAS REDUZIR AS NECESSIDADES DE ÁGUA PARA IRRIGAÇÃO?

RESUMO: Melancia é uma importante cultura dependente de suprimento hídrico porque a estação de cultivo geralmente coincide com meses secos no Brasil Central. Este estudo procurou avaliar impactos das mudanças climáticas nas necessidades de água para irrigação da melancia ao longo da região produtora do Estado de Goiás, Brasil. Climatologia de base (1961-1990) e projeções (2031-2060) do modelo de mudanças climáticas regionalizado Eta-CPTEC/HadCM3 foram utilizadas neste estudo de impacto. Projeções de demanda de água para irrigação foram estimadas usando projeções de variáveis climáticas corrigidas de precipitação e temperatura superficial mensais. Foi projetada uma redução aproximada de 10% na evapotranspiração de referência pelo método de Penaman-Monteith FAO devido a maiores aumentos na temperatura mínima do que nas máximas. Por outro lado, a necessidade hídrica para irrigação da melancia foi projetada aumentar na climatologia de 2031-2060 8,7% para plantios em abril e decrescer 12,1% para plantios em julho. Esses resultados representam aumentos anuais médios de 9 mm e decréscimo de 19 mm, respectivamente. Podem ser explicados também por maiores reduções na precipitação durante a estação de plantio ocorrida em abril.

PALAVRAS-CHAVE**:** mudanças climáticas, irrigação, melancia.

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INTRODUCTION

Climate change has the potential to impact hydrological cycle processes, such as rainfall. The latter affects run-off, temperature and air humidity. These three are related to evaporation, river flow and plant evapotranspiration, which may also affect water availability and irrigation water requirement.

Watermelon is an emerging crop due to its market opportunities and high yields when the crop is irrigated. It has been spreading increasingly in Central Brazil because of water availability, harvested fruit quality and proximity of important urban consumers.

One of the challenges to assess climate change on agriculture is the resolution of models. Regional Climate Models allow impact assessments of smaller areas to occur, contrary to global models that are applied on continental and global scales (Dibike and Coulibaly 2005), due to higher resolution of RCMs that enable a more detailed impact analysis at the local level.

Binder (2006) recommended the use of detailed climate change projections in the watershed scale and hydrological models to assess climate change impacts on water resources, thus requiring the use of regional climate models (RCMs). Dynamic downscaling techniques involve a regional circulation model coupled to global circulation model with coarser resolution that defines atmospheric boundary conditions over a finite domain (Wilby et al. 2002).

The main objective of the present study was to evaluate the impacts of climate change on irrigation water needs for the watermelon crop in the state of Goias, located in the central region of Brazil.

MATERIALS AND METHODS

The study area is located between 12º and 19º south and 48º and 53º west, comprising of 268,873 km^2. Annual temperatures range from 14.8 to 32.4˚C; rainfall from 1,036 to 2,251 mm a year and potential evapotranspiration exceeds 1,600 mm a year. Altitude in the target area varies from 195 to 1,184 m above sea level (178 to 1,800 in Goiás state), according to surface elevation model (SRTM). It involved most of the surface of the centrally located state of Goiás. This region plants 7,746 ha of watermelon crop annually (major watermelon crop area per state in Brazil) and produces 241,636 tons each year (about 12% of the Brazilian production) (IBGE, 2010).

The regional Eta model (Messinger et al. 2012) coupled to the Global HadCM3 (Johns *et al.* 2003), referred to here as the Eta-CPTEC/HadCM3, was implemented in Brazil by *Centro de Previsão de Tempo e Estudos Climáticos* - CPTEC of *Instituto Nacional de Pesquisas Espaciais* – INPE. Such combination of a regional model to a global one is known as dynamic downscaling, which provides improved resolution for the information that will be used in climate change assessments.

The regionalized model used in this study has a 40 km horizontal resolution within 38 vertical levels, in a 90s time step. For climate change, the model uses a constant 330 ppm CO_2 concentration driving force (Nakicenovic et al. 2000 A1B green gas emission scenario). Three members of the model were selected, which displayed high, medium and low sensitivity in global mean temperature responses, which together with unperturbed experiments, provided multiple runs of the Eta-CPTEC regional model, hereafter referred to as the high, control and low runs. A more detailed description of Eta-CPTEC/HadCM3 is available by Chou et al (2011) and Marengo et al (2011).

Using Eta-CPTEC/HadCM3, the monthly averages of the surface temperature and rainfall were generated for a 40 km spatial grid resolution dataset for the period of 1961-1990 (model baseline), as well as for the average 2031-2060 time slice. Bias corrected projections for all climate variables were obtained by accounting for the differences between monthly Eta-CPTEC/HadCM3 hindcasts for the baseline period and respective high resolution interpolated Climatic Research Unit (CRU) data sets (Mitchel and Jones 2005). Data for the baseline period (1961-1990) was extracted from the monthly 1901-2000 CRU time series available at (CRU. Acessed December 2013, http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.10/data_dec/.).

Crop water needs is defined as the quantity of water plants need to use for crop development without stress (Fischer et al. 2007) and is estimated by:

$$CWN = ET_o PM Kc \ (1)$$

Where,
CWN - crop water needs, mm
ET_oPM - Penman-Monteith reference evapotranspiration, mm
Kc -s crop coefficient (dimensionless);

Values of Kc were obtained from the Embrapa Tropical Agroindustry (2012) database: 0.41; 1.36; 0.71 for initial, middle and final development stages, lasting 23; 31 and 14 days, respectively. This represents a complete crop growing season of 70 days for watermelon in tropical central Brazil.

The Penman-Monteith equation for calculation of the daily reference evapotranspiration assumes the reference crop evapotranspiration is given by Allen at al (1998).

The ET_o estimation via Penman-Monteith method (ET_oPM) requires mean daily, ten-day or monthly maximum and minimum air temperature (T_{max} and T_{min}). Actual vapor pressure (e_a), net radiation (R_n) and wind speed measured at 2 m (u_2) are also required. If some of this required data is missing or cannot be calculated, it is strongly recommended to indirectly estimate the missing climatic data and the use of FAO Penman-Monteith method for the calculation of ET_o. The use of the alternative ET_oPM estimation method, requiring only limited meteorological data, involves the assumptions by Allen et al (1998). In this study, it was estimated, using T_{max} and T_{min} directly available from the Eta-CPTEC/HadcM3 output.

The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Therefore, the difference between the maximum and minimum air temperature can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface, as given by Allen et al (1998):

$$R_s = k_{Rs}\sqrt{(T_{max} - T_{min})}\ R_a \ (2)$$

Where,
Rs - the solar radiation at the regional location, MJ m^{-2} day^{-1}
Ra - extraterrestrial radiation, MJ m^{-2} day^{-1}
Tmax - maximum temperature, °C
Tmin - minimum temperature, °C,
k_{Rs} - the adjustment coefficient, 0.16;. ..;0.19, $°C^{-0.5}$.

The procedure for estimating EToPM with missing climatic data has been successfully applied by Popova et al (2006) in Bulgaria, Jabloun & Sahli (2008) in Tunisia and Sentelhas et al (2010) in Canada. The choice of k_{Rs} (0.16) was based by interior location criteria, where land masses dominate and air masses are not strongly influenced by a large body of water (Allen et al 1998).

The model output, represented by grids covering the study area, was interpolated by applying geostatistical ordinary linear Kriging (Isaak and Srivastava, 1989) using geographical information system (GIS) in order to produce continuous EToPM and IWN maps for the baseline period and to model projections for the 2031-2060 average time slice (control, high and low model members). Atorre et al (2007) reported that Kriging produces the lowest error values among various interpolation methods, applied to a number of climate and bioclimate variables, when compared with inverse distance weighting and multilayer neural networks approaches. A similar methodology was used by Fortes et al (2005) for mapping irrigation water demand, including spatial variability.

Simulations were processed for two different growing months. The first simulation started in April, which is the beginning of the dry season and supplemental irrigation is required. The second simulation was in July, when watermelon must be irrigated under present climate conditions. The crop development phases were: 1) initial, from the beginning up to 30% of the land covered by plants; 2) crop development, from the end of the initial phase to the stage when plants completely cover land surface, when flowering and fruit maturation occur; and 3) end season, from harvest to plant senescence.

Irrigation water needs (IWN) are estimated by dividing the crop water needs (CWN) minus effective rainfall (ppt_{ef}) by the field irrigation efficiency (Ea), in order to account for the evaporation, run-off and soil deep percolation losses.

$$IWN = \frac{CWN - ppt_{ef}}{Ea} \quad (3)$$

Where,
CWN – crop water needs, mm
PPt_{ef} – Effective rainfall, mm
Ea – irrigation efficiency, dimentionless.

The crop patterns in the target area have been characterized (type of irrigated crop, irrigation technology, respective areas, and crop schedules. Thus, a field Ea value of 85% was considered for the pivot (40% of the area) and 47% for the furrow irrigation (60% of the area), which are the irrigation technologies adopted by the watermelon farms in the region. The estimated final weighed irrigation efficiency of 62.2% was applied.

RESULTS AND DISCUSSION

This impact assessment indicated annual decreases on ET_oPM of 11.1%, 6.8% and 10.0% (control, high and low model members), relative to the baseline period (Table 3), as a result of greater increases on minimum rather than on maximum temperatures, which reduces vapor pressure deficit potential and consequently reduces ET_oPM. This fact brought different results as those reported from other climate change and irrigation water needs assessments, such as by Díaz et al (2007) in Spain, by Silva et al (2007) is Sri Lanka and by Krol et al (2007) in northeast of Brazil. Regarding to rainfall, the model indicated annual decreases of 6.8%, 8.9% and 2.7% (control, high and low model members), relative to the baseline period (Table 3), in the same time period. These results impacted IWN (Table 4), which is expected to increase by 8.7% for crops planted in April and to decrease 12.1% for crops planted in July. These *percentages* represent an average annual increase of 9 mm and decrease of 19 mm, respectively on IWN relative to the baseline period. These contradictory results may be explained by greater decreases on average rainfall in April (55.4%), May (71.8%) and June (22.2%) than in July (12.5%) and September (38.8%). On the other hand, Randall et al (2007) warned that climate change projections for rainfall are still much more uncertain than for temperature, requiring the availability of more precise models in order to establish if changing plant date should be a possible future adaptation strategy to save irrigation water.

The standard deviation, which represents projected spatial variability across the basin is expected to increase for ET_o and rainfall (Table 3) and to decrease for IWN (Table 4) in the future.

Table 1 Summary of projected annual impacts on ET_o and rainfall (P) for selected scenarios (mm) and changes (%) relative to the baseline period

Model members **(1)** control. **(2)** high and **(3)** low sensitivity to average temperature increase.

Table 2 IWN for crop cycle (mm) for watermelon (1961 - 1990) and projections (2031 – 2060).

Planted on April 1st **(1)** and July 1st. **(2)** .

The thematic maps (Figs. 1, 2, 3 and 4) show IWN (mm) for the baseline (1961-1990) ranging from 72 to 129 mm annualy, for crops planted in April and 129 to 194 mm for crops planted in July. Future IWN for the 2031-2060 period ranges from 91 to 141 mm for crops planted in April and from 119 to 181 mm for crops planted in July. IWN projections relative to the baseline period may even reach higher or lower values throughout the region, depending on the planting month. In this study, IWN projected increases for planting in April were basically due to greater decreases projected rainfall.

The impacts of higher temperatures and higher atmospheric CO_2 concentrations on crop growth rates and yields are not being modeled. These impacts may influence crop seasons and consequently affect crop coefficients, which are used for estimating monthly crop water requirements. Increases in CO_2 concentrations may induce stomata closure and therefore reduce water for transpiration, as suggested by Tubiello and Ewert (2002).

Fig. 1 IWN Baseline (mm) 1961-1990 planting in March

Fig. 2 IWN Baseline (mm) 1961-1990 planting in October

Fig. 3 IWN (mm) 2031-2060 Control, planting in March

Fig. 4 IWN (mm) 2031-2060 Control, planting in October

CONCLUSIONS

Global warming will potentially impact irrigation water demands. Therefore, the purpose of this study was to assess the impacts of climate change on irrigated watermelon crop, by considering two planting dates, crop areas, and the efficiency of the adopted irrigation systems. Climatic changes are expected to decrease ET_oPM (11.1%, 6.8% and 10.0%) for control, high and low applied model members, respectively, due to higher increases on minimum rather than maximum temperatures. On the other hand, IWN is expected to increase 8.7% for the April crop and to decrease 12.1% for the July crop, as a consequence of the projected rainfall decreases (greater in April, May and June) in Goias state, which is located in the central region of Brazil. These represent average increases of 9 mm and decreases of 19 mm annually in the 2032-2060 time period, from the baseline period. In the future, changes to crop season may have effect on water demand in the region, which may constitute an important adaptation measure.

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Table 1

Statistic	ET_oPM (mm year^{-1})				Rainfall (mm year^{-1})			
	Baseline	Control (1)	High(2)	Low(3)	Baseline	Control (1)	High(2)	Low(3)
Minimum	1488.0	1321.0	1369.0	1339.0	1348	1071	1049	1036
Maximum	1787.0	1701.0	1813.0	1728.0	1950	2031	1982	2251
Mean	1638.0	1457.0	1526.0	1475.0	1644	1533	1497	1599
Standard Deviation	66.0	79.0	97.0	83.0	134	230	208	266
Changes (%)		-11.1	-6.8	-10.0		-6.8	-8.9	-2.7

Table 2

IWN (mm) (mm cycle^{-1})	1961 to 1990 Baseline		2031 to 2060 Control	
	I$^{(1)}$	II$^{(2)}$	I$^{(1)}$	II$^{(2)}$
Minimum	72	124	91	119
Maximum	129	194	141	181
Mean	103	157	112	138
Standard Deviation	12	16	10	14
Changes (%)			8.7	-12.1

Figure 1

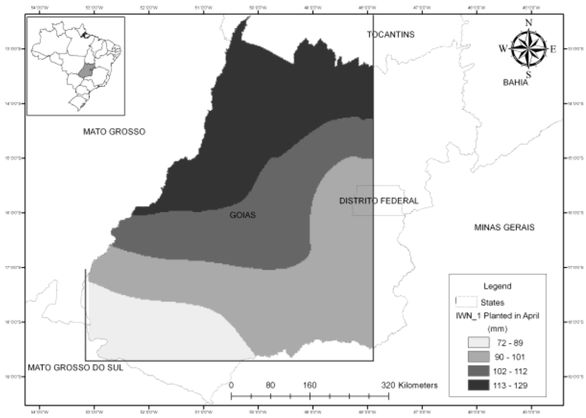

Figure 2

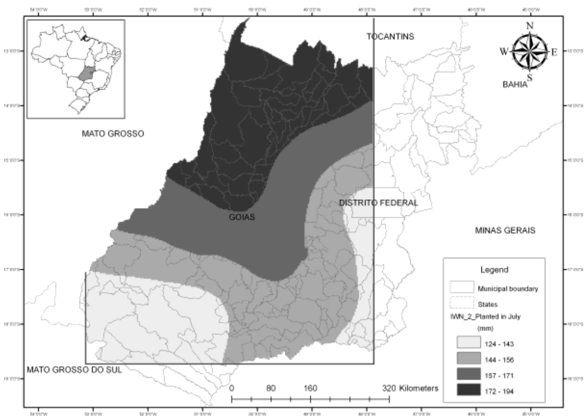

Figure 3

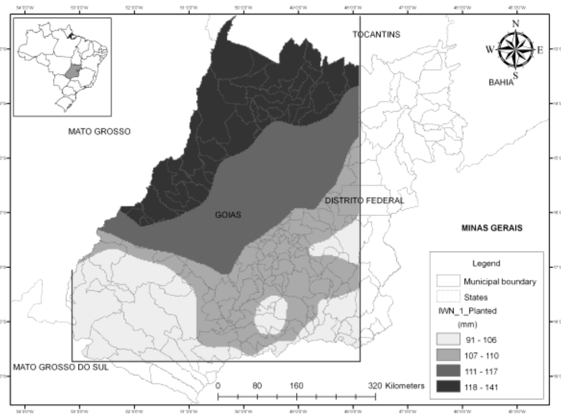

Figure 4