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Climate change scenarios and their impact on the water balance of sugarcane production areas in the State of São Paulo, Brazil

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ABSTRACT

The evidence of climate changes has increased the demand for biofuel such as the ethanol from sugarcane, which has major comparative advantages in economic and environmental terms in relation to other biofuel sources. The sugarcane production in the State of São Paulo is highly influenced by the soil water availability, which is the main factor causing inter-annual yield variability. With the expected climate change, the crop water balance in the sugarcane production regions may be affected, which will also bring consequences for crop production. Based on that, the objective of this study was to assess the impacts of different climate changes scenarios on potential (ETP) and actual (ETA) evapotranspiration, as well as on water deficit (WD) and water surplus (WS) for four sugarcane production regions in the state of São Paulo, Brazil. For that, twelve climate changes scenarios, with increasing temperatures and rainfall variation, were considered for the years of 2030, 2060 and 2090, based on 2007 IPCC´s report. The results indicated that ETP will increase substantially as a function of higher air temperatures projected for the future scenarios. However, for ETA the elevation will not be so intense due to the variations projected for the rainfall scenarios. In general, the expectation is the reduction of the soil water availability in all locations by 2090, with substantial increase in the WD, around 550, 650, 530 e 720 mm for the worst scenario in relation to the present conditions, respectively for Araçatuba, Assis, Jaboticabal and Piracicaba.

Keywords: Global warming, climatological water balance, evapotranspiration, water deficit.

Cenários de Mudanças Climáticas e seus Impactos no Balanço Hídrico de Regiões Canavieiras do Estado de São Paulo, Brasil

RESUMO

Os indícios de mudanças climáticas tem elevado a demanda por álcool proveniente da cana-de-açúcar que apresenta grandes vantagens comparativas em termos econômicos e ambientais em relação a outros biocombustíveis. A produção da cana-de-açúcar no Estado de São Paulo é altamente influenciada pela disponibilidade de água no solo, sendo este o principal fator responsável pela variabilidade interanual da sua produtividade. Sendo assim, as mudanças climáticas deverão impactar o balanço hídrico das regiões produtoras e, consequentemente, a produção da cana-de-açúcar. Desse modo, o objetivo deste estudo foi avaliar os impactos dos cenários projetados de mudanças climáticas na evapotranspiração potencial (ETP) e real (ETA), no déficit hídrico (WD) e no excedente hídrico (WS) de quatro regiões produtoras de cana-de-açúcar no Estado de São Paulo. Para tanto, foram considerados doze cenários de mudanças climáticas para os anos de 2030, 2060 e 2090, baseados no relatório do IPCC de 2007. Os resultados indicam aumentos acentuados da ETP em função do aumento da temperatura do ar nos diferentes cenários. No entanto, para a ETA esses aumentos não serão tão acentuados devido à variação no regime hídrico. Espera-se uma redução na disponibilidade hídrica em todas as localidades para o ano de 2090, com aumento significativo do WD, da ordem de 550, 650, 530 e 720 mm para o pior cenário em relação à condição atual, respectivamente para Araçatuba, Assis, Jaboticabal e Piracicaba.

Palavras-chave: Aquecimento global, balanço hídrico climatológico, evapotranspiração, deficiência hídrica.

1. INTRODUCTION

The projections of global climate change promoted by the anthropic action, having as consequence the increasing greenhouse effect, is becoming more and more accepted by the scientific and agricultural communities around the world (Marengo, 2008). As a consequence of that, there is an special concern by creating new sources of renewable energy which has increasing the demand by biofuels, including the sugarcane ethanol, which has several advantages in relation to other sources.

In this context, Brazil has a competitive advantage in relation to other countries, since it is the most traditional sugarcane producer in the world, with more than 8 million of hectares planted and a production of 571.5 million of tons during the 2011/12 growing season, with 287.6 million of tons for producing 22.9 billion liters of ethanol (CONAB, 2011). The state of São Paulo is the main sugarcane producer in the country, counting with more than 200 mills. In this state, the sugarcane is produced in different environments with diverse climatic conditions which affect the cane yield (Teramoto, 2003), as well as all the activities related to the production, transport and storage (Pereira et al., 2002).

In the state of São Paulo, the rainfall inter-annual variability is the main cause of sugarcane yield fluctuation, since it affects the soil water balance and, consequently, the water availability for plants. So, any change in the water balance variables, mainly rainfall and/or evapotranspiration, will promote changes in the plant water consumption. Based on the results of Marks et al. (1993), Medeiros (2003) and Villani et al. (2011), an increase in air temperature will lead to a higher evapotranspiration which in a non-changing rainfall regime or in a scenario of less rainfall will promote an increase in the water deficit for plants and, as consequence, a decrease in crop yield by a reduced evapotranspiration. Also, any change in the rainfall regime, with an increase or a decrease in the precipitation amount will result in changes in the water balance (Horikoshi and Fisch, 2007), with positive or negative impacts on agriculture. Results from the study carried out by Liberato and Brito (2010) showed that the climate changes projected for Occidental Amazon will result in a drier climate, with reduction in the soil water availability. In agriculture, such reduction associated with temperature changes will affect plant phenology, crops geographic distribution (crop zoning) and crop yield (Crimmins et al., 2011; Li et al., 2011; Pérez and Sierra, 2012).

As agriculture is among the economic activities the most vulnerable to climatic conditions, the climate change will have a strong impact on crop zoning, yield, and quality. Based on that, the assessment of the factors of environmental vulnerability for sugarcane production is of high importance, mainly considering that this crop is the most efficient for sugar and ethanol production (Zullo Jr. et al., 2008). So, the objective of this study was to evaluate the impact of different climate change scenarios on the water balance of four sugarcane production regions in the state of São Paulo, in order to subsidize the strategies to be adopted by the authorities, growers and sugar mills to face the challenges of sugarcane production in the future climatic conditions.

2. MATERIAL AND METHODS

The present study was developed for four sugarcane regions in the state of São Paulo, Brazil, named: Araçatuba (lat.: 20º52' S, long.: 48º29' W; alt.: 415 masl); Assis (lat.: 22º38' S, long.: 50º24' W, alt.: 560 masl); Jaboticabal (lat.: 21º15' S; long.: 48º19' W; alt.: 595 masl) and Piracicaba (lat.: 22º42' S; long.: 47º38' W; alt.: 546 masl).

The weather data of the locations listed above were obtained from different sources. Ten-day period data of air temperature were estimated with multiple linear models proposed by Pedro Jr. et al. (1991), based on the normal data from the Brazilian Meteorological Service (INMET) and Agronomic Institute of Campinas (IAC), as a function of latitude, longitude and altitude. The daily average sunshine hours data for each 10-day period were also estimated by multiple linear models, as proposed by Monteiro (2012). Sunshine hours were used to estimate global solar radiation (Rg) by the Angstron-Prescott´s method (Pereira et al., 2002). The daily rainfall data of a 30-year period, from 1979 to 2008, was obtained from the Brazilian Water Agency (ANA), for each location, and transformed in the same 10-day time scale. For the description of the present conditions, the monthly climate data was considered, whereas for the comparisons among the present and future scenarios the annual time scale was analyzed.

Twelve future scenarios were created for the years of 2030, 2060 and 2090 by combining changes in temperature and rainfall for the four regions. A combination of the three A1 scenarios was used (IPCC, 2007). These scenarios (A1T, A1B and A1Fl) were adopted because they present a full range of variations for air temperature, from 1.4 to 6.4^{o}C. Based on that, the actual temperature data base was increased by 2, 4 and 6^{o}C. For rainfall, as the projections for the state of São Paulo have a great uncertainty associated to, the future scenarios were based on the percentages in relation to the present scenario (-10, -5, +5 and +10 %) suggested by the 2007 IPCC´s report for all this region of Brazil. The changes for rainfall were applied for each rainfall event of the 30-year series in order to evaluate the inter-annual variability of this variable as well as of water balance variables. Table 1 presents all the combinations of the proposed future scenarios, having as reference the average data from 1979 to 2008, mentioned as scenario C0, which refers to the normal data obtained in the end of 2008.

Air temperature data, from C0 to C12 scenarios, were used to estimate potential evapotranspiration (ETP) considering the method of Thornthwaite (1948) adjusted by Camargo et al. (1999). Such method uses the effective temperature (Tef) which is calculated as a function of daily extreme temperatures. This ETP method was chosen among several others for using only air temperature and photoperiod as variables, and for presenting accurate estimates for the state of São Paulo, as presented by Camargo et al. (1999).

ETP, rainfall and soil water holding capacity (SWHC) for each location and scenario were used for estimating the 10-day serial water balance by the method of Thornthwaite and Mather (1955), which was programmed in an Excel spreadsheet by Rolim et al. (1998). The outputs of the water balance are: soil water content; actual evapotranspiration (ETA); water deficit (WD); and water surplus (WS).

The water balance simulations were conducted annually for the actual 30-year database and considering this data with the possible changes presented by the 2007 IPCC´s report. The SWHC for each location was estimated according to the predominant soil in the region, since the water retention by the soils is a function of their physical characteristics (Prado et al., 2008). Based on that and considering a root depth of 100 cm for sugarcane crop, the SWHC ranged from 70 to 120 mm, as presented in Table 2.

Table 1. Present (C0) and future scenarios of climate change (C1 up to C12) considering the combinations of increase in temperature (ΔT) and variation in rainfall (ΔP).

Scenarios	Year	ΔT (°C)	ΔP (%)
C0	2008	0	0
C1	2030	+2	-10
C2	2030	+2	-5
C3	2030	+2	+5
C4	2030	+2	+10
C5	2060	+4	-10
C6	2060	+4	-5
C7	2060	+4	+5
C8	2060	+4	+10
C9	2090	+6	-10
C10	2090	+6	-5
C11	2090	+6	+5
C12	2090	+6	+10

Table 2. Soil types for each location and their respective water holding capacity (SWHC) in the studied regions**.**

Location	Soil Type	SWHC (mm)
Araçatuba, SP	Sandy-Loam	70
Assis, SP	Loam	90
Jaboticabal, SP	Clay-Loam	120
Piracicaba, SP	Loam	90

The results were analyzed by comparing the changes promoted by the future scenarios in relation to the present one, considered as 2008.

3. RESULTS AND DISCUSSION

3.1. Climate characteristics of the studied areas: present conditions

Table 3 presents the seasonal variation of air temperature in the four studied areas, regarding the average extreme (Tmax – maximum and Tmin – minimum temperature) and the daily average temperature (Tavg) values. As all the locations are in the tropical region, with latitudes between 21 and 23° South, the seasonal variation is low, with Tavg ranging between 18 and 26°C along the year. The hottest region is in the West of the state of São Paulo, Araçatuba, where altitude is lower and the continentality effect is more evident. Annual Tavg is 23.8°C. In Assis and Piracicaba, temperatures are very similar, being Piracicaba a little bit cooler than Assis. In terms of annual average temperature the differences are of only 0.2°C.

Jaboticabal has temperature between the conditions presented for Araçatuba and Assis/Piracicaba, with an annual average temperature of 22.5ºC.

Regarding the solar energy variables (Table 4), it is clear that there are no much differences among the four locations studied. The seasonal variation of sunshine hours follows the rainfall regime, having an inverse relationship between them. This variable ranges from 6.4 h in the rainy season (summer) to 8.2 h in the dry season (winter). Photoperiod or maximum sunshine hours is an astronomical variable and consequently is influenced by latitude. As latitude is very similar among the four locations, ranging from 21 to 23^{o}, there is no much variation in photoperiod for them, ranging seasonally from 10.6 to 13.4 h in average. Finally, for global solar radiation the values follow basically the photoperiod variation, but are also modulated by the sunshine hours. The Rg variation along the year is, in average, from 13.1 MJm^{-2}day^{-1} in June to 22.6 MJm^{-2}day^{-1} in November.

Table 3. Estimated normal maximum (Tmax), minimum (Tmin) and average (Tavg) air temperature, in ^{o}C, for Araçatuba, Assis, Jaboticabal and Piracicaba, in the state of São Paulo, Brazil.

Location	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Araçatuba	Tmax	31.7	31.9	31.7	30.5	28.6	27.6	27.9	30.5	31.5	31.7	31.8	31.4	30.6
	Tmin	20.1	20.3	19.6	17.1	14.5	13.2	12.6	14.3	16.4	18.0	18.6	19.7	17.0
	Tavg	25.9	26.1	25.7	23.8	21.6	20.4	20.3	22.4	24.0	24.9	25.2	25.6	23.8
Assis	Tmax	30.2	30.3	29.9	28.2	26.2	25.0	25.3	27.4	28.3	28.9	29.5	29.4	28.2
	Tmin	18.8	19.0	18.3	15.6	12.9	11.4	10.9	12.3	14.3	15.9	16.8	18.1	15.4
	Tavg	24.5	24.7	24.1	21.9	19.6	18.2	18.1	19.9	21.3	22.4	23.2	23.8	21.8
Jaboticabal	Tmax	30.3	30.4	30.2	29.0	27.3	26.2	26.6	29.0	30.2	30.3	30.3	30.0	29.1
	Tmin	19.0	19.2	18.5	16.0	13.4	12.1	11.5	13.1	15.2	16,9	17.5	18.5	15.9
	Tavg	24.7	24.8	24.4	22.5	20.4	19.2	19.1	21.1	22,7	23.6	23.9	24.3	22.5
Piracicaba	Tmax	30.0	30.1	29.7	28.0	26.0	24.9	25.1	27.2	28.2	28.7	29.3	29.3	28.0
	Tmin	18.7	18.9	18.1	15.5	12.8	11.3	10.7	12.1	14.1	15.8	16.7	18.0	15.2
	Tavg	24.4	24.5	23.9	21.8	19.4	18.1	17.9	19.7	21.2	22.3	23.0	23.7	21.6

Table 4. Estimated normal sunshine hours (n), maximum sunshine hours (N) and global solar radiation (Rg, MJm^{-2}day^{-1}) for Araçatuba, Assis, Jaboticabal and Piracicaba, in the state of São Paulo, Brazil.

Location	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Araçatuba	n	6.9	6.7	6.6	7.0	7.0	6.9	7.4	8.1	8.0	7.7	7.7	7.0	6.9
	N	13.1	12.7	12.1	11.5	11.0	10.8	10.9	11.3	11.9	12.5	13.0	13.2	12.0
	Rg	21.5	20.5	19.2	17.2	15.0	13.7	14.6	17.5	20.0	21.5	22.6	21.7	18.3
Assis	n	6.8	6.5	6.4	6.6	6.6	6.6	7	7.6	7.5	7.3	7.4	6.8	7.2
	N	13.1	12.7	12.1	11.5	11.0	10.8	10.9	11.3	11.9	12.5	13.0	13.2	12.0
	Rg	21.3	20.3	18.7	16.7	14.5	13.3	14.2	16.9	19.3	20.9	22.1	21.3	18.8
Jaboticabal	n	6.8	6.5	6.5	6.8	6.9	6.8	7.3	8	8	7.6	7.6	7.0	7.1
	N	13.2	12.7	12.1	11.5	11.0	10.7	10.8	11.3	11.9	12.5	13.0	13.3	12.0
	Rg	21.4	20.2	18.8	16.8	14.6	13.3	14.3	17.1	19.9	21.3	22.4	21.7	18.5
Piracicaba	n	6.7	6.6	6.6	6.8	6.9	7.0	7.6	8.2	7.9	7.6	7.7	7.0	7.2
	N	13.3	12.8	12.2	11.5	10.9	10.6	10.7	11.2	11.9	12.5	13.1	13.4	12.0
	Rg	21.3	20.4	18.8	16.6	14.3	13.1	14.2	17.0	19.5	21.3	22.6	21.9	18.4

Different from solar energy variables, rainfall varies significantly among the four regions. The annual rainfall in Assis and Jaboticabal normally is higher than 1400 mm, whereas in Piracicaba it is around 1240 mm and in Araçatuba it remains below 1180 mm. The seasonal variation is similar among locations, with a rainy summer, with the total rainfall from October to March representing around 75% of the annual total, and a dry winter. The rainfall regime is mainly caused by convective rains, during the summer, and the influence of high pressure at central Brazil, during the winter, which inhibit the rainfall. The only few rain events during the winter is due to the penetration of cold fronts from south of Brazil.

When the water balance was determined for each location using the 30-year series (1979-2008), the average water surplus and average water deficit were determined for each one of the 36 ten-day periods of the year. These data are presented in Figures 1 to 4 and show the current water availability regime along the year for these locations.

Table 5. Normal monthly (mm month^{-1}) and annual (mm year^{-1}) rainfall for Araçatuba, Assis, Jaboticabal and Piracicaba, in the state of São Paulo, Brazil, from 1979 to 2008. Source: Brazilian Water Agency.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Araçatuba	224	174	132	61	39	39	24	15	49	124	118	173	1172
Assis	231	173	147	96	97	64	40	36	88	118	142	180	1412
Jaboticabal	286	205	148	73	61	26	23	22	59	109	153	238	1403
Piracicaba	207	188	143	79	73	51	29	27	54	99	124	167	1239

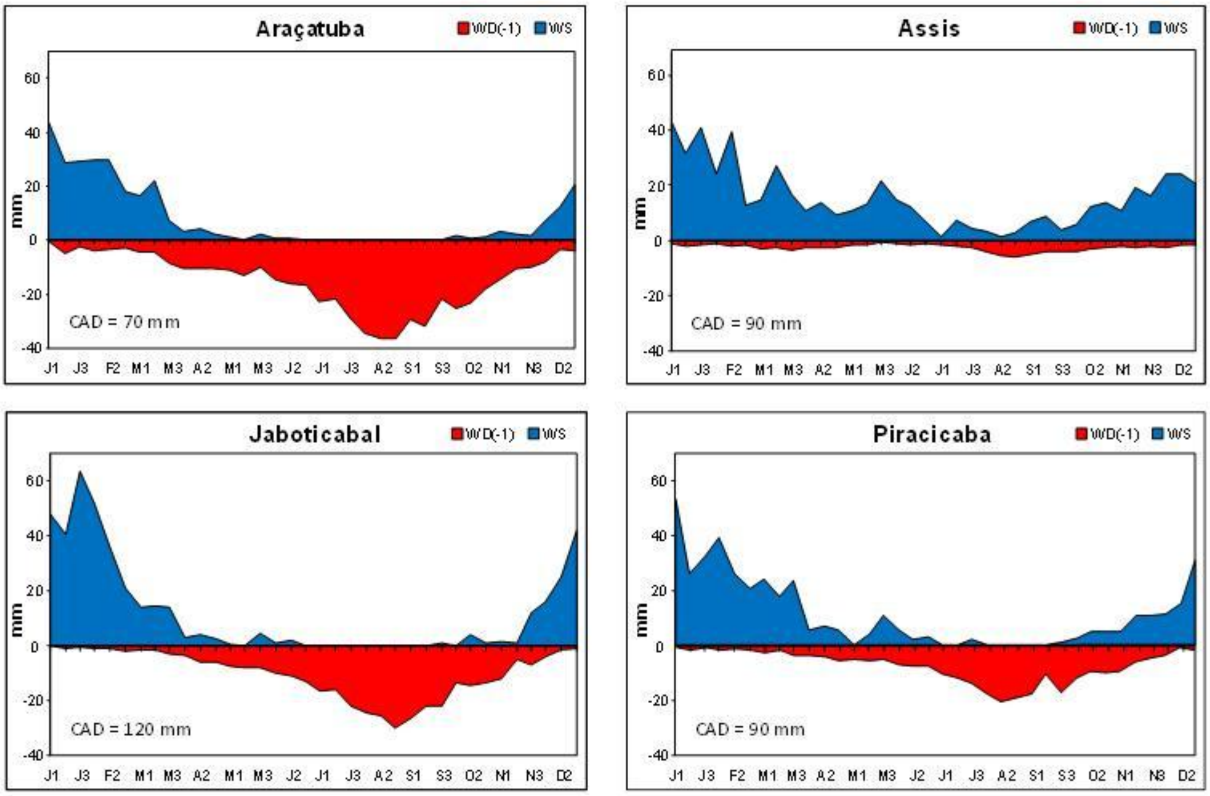

Figure 1. Average water balance (Water Deficit = WD; Water Surplus = WS) for Araçatuba, Assis, Jaboticabal and Piracicaba, state of São Paulo, Brazil, for the 10-day time scale, considering the soil water holding capacity of 70, 90, 120 e 90 mm, respectively. WD was multiplied by -1 just to make the graphic representation. The symbols in the X-axis correspond to the 10-day period considered in a sequence from the first 10-day period of January (J1) to the last one in December (D3 – not shown).

Figure 1 shows the great difference observed among the four locations, with Assis presenting a predominance of water surplus along the year, with very low water deficiency, even during the winter, when there is the dry season and the monthly rainfall decreases substantially. In Araçatuba, the water deficit is the most intense, showing its highest values during August. Water deficit also can be observed, with less intensity, during the rainy season, showing that there is a higher possibility of dry spells, which are local named as *veranicos*, than the other locations. Jaboticabal and Piracicaba are in a transition between the wetter climate of Assis and the drier climate of Araçatuba, with Jaboticabal a little bit drier during the winter than Piracicaba, but with very similar water surplus conditions during the summer.

The wet season in Araçatuba, Jaboticabal and Piracicaba, in average, lasts from November to March, with the water surplus totaling, respectively, 209, 288 and 181 mm. In Assis the water surplus is better distributed along the year, totaling 244 mm. For water deficit, the predominance is from April to October, except for Assis, which has very few water deficits, but occurring all year long. In average, the annual water deficit is around 480 mm in Araçatuba, 248 mm in Jaboticabal and 146 mm in Piracicaba. In Assis, however, the annual water deficit is less than 1/5 of what happen in Araçatuba, which means only 61 mm per year.

3.2. Climate characteristics of the studied areas: future scenarios

Based on the future temperature and rainfall scenarios, the potential (ETP) and actual (ETA) evapotranspiration were estimated, as well as the water balance for each one of the locations studied (Tables 6 and 7). Based on these results, there is an expectation of very high values of ETP in the future scenarios, in accordance to the higher temperature, with increases, in relation to the present conditions, ranging from 19 to 41% in Araçatuba, from 24 to 62% in Assis, from 23 to 53% in Jaboticabal, and from 24 to 63% in Piracicaba (Table 6). Similar results were reported by Marks et al. (1993) and Horikoshi and Fisch (2007), working respectively in a basin and municipality scales.

Even considering that ETA is influenced by ETP, the changes in this variable in the future scenarios demonstrated that it will be also influenced by the magnitude of the changes in the rainfall regime. For Araçatuba and Piracicaba, the minimum changes in ETA were obtained in the scenario C9 (2090: ΔT= +6ºC; ΔP= -10%), whereas in Assis and Jaboticabal this happened in the scenario C1 (2030: ΔT= +2ºC; ΔP= -10%). For the highest values of ETA, all locations will have them under the scenario C12 (2090: ΔT= +6ºC; ΔP= +10%), which combine the increase of ETP, caused by temperature increase, with the higher rainfall amount, resulting in a higher ETA.

For the water deficit and water surplus (Table 7), the changes will be very similar for all scenarios, since WD will increase and WS will decrease. However, the magnitude of such changes will vary according to the macroclimate conditions of each region. For Araçatuba, WD will increase from 13.5% in the scenario C4 (2030: ΔT= +2ºC; ΔP= +10%) to 115.2% in the worst scenario, C9 (2090: ΔT= +6ºC; ΔP= -10%). As Araçatuba is the driest region among those studied, the change in WD will be the smallest. However, it will be the most affected in relation to the water surplus; it can become zero if the following scenarios happen: C1, C2, C5, C6, C9, C10 and C11. In Assis, there will be the greatest change in WD. As this region has very small WD in the present scenario, any change will promote a considerable percentage of variation. Because of that, the WD changes will vary between 94.5% in scenario C4 to more than 1160% in scenario C9. In relation to the WS, the scenarios C5, C6, C7, C9 and C10 will not have excess of water in order to recharge the water table. Similar condition for both WD and WS will be occurring in Piracicaba, where WD will increase between 73.4 and 589.8% and no WS will be observed in the scenarios C5, C6, C9, C10 and

C11. Finally, in Jaboticabal, the changes in WD will be between what will happen in the other locations, with WD increase ranging between 51% in C4 and 314% in C9. On the other hand, Jaboticabal will be the only location with WS = 0 just in one scenario (C9).

Based on the results of Table 7, a reduction in the water availability (WD increase and WS decrease) is expected for all the scenarios of climate change, even when a rainfall increase is projected. The worst scenario, C9 (2090: ΔT= +6ºC; ΔP= -10%) will result in an increase of 553, 652, 529 and 717 mm for WD in relation to C0, respectively for Araçatuba, Assis, Jaboticabal and Piracicaba. WS will decrease abruptly, reaching zero in several scenarios, which means decreases of 209, 244, 288 and 181 mm for the same locations.

The results obtained with the present study is in accordance to other ones conducted in different parts of the world, as in Columbia river basin, in USA (Marks et al., 1993), in northern Jalisco, México (Ibarra-Montoya et al., 2011), in La Pampa province, Argentina (Pérez and Sierra, 2012), in Louess Plateau of China (Li et al., 2011), and in Brazil, like in Taubaté, in the Paraíba Valley (Horikoshi and Fisch, 2007), in the Occidental Amazon (Liberato and Brito, 2010), and in the Northeast semi-arid region (Medeiros, 2003). However, the results presented in this study is much more drastic then presented by these authors, which is related to the fact that the climate change scenarios were applied in all the historical series of rainfall data (from 1979 to 2008) in a 10-day time scale and not only in the monthly normal data. The results presented in this study in terms of WD and WS are the average of the results from the water balance processed for each year of the data series, representing a more comprehensive way to determine the actual average of these variables, as also considered by Gouvêa et al. (2009). The use of normal data can induce to an underestimation of the water balance parameters, giving an unreal vision of the expected water availability conditions for the future, which means much less impact.

Table 6. Annual potential (ETP) and actual (ETA) evapotranspiration in mm year^{-1}, obtained by the serial climatological water balance, for the present condition (C0) and future scenarios of climate change (C1 to C12), in the locations of Araçatuba, Assis, Jaboticabal and Piracicaba, state of São Paulo, Brazil.

Climate Scenarios	**Araçatuba**		**Assis**		**Jaboticabal**		**Piracicaba**	
	ETP	**ETA**	**ETP**	**ETA**	**ETP**	**ETA**	**ETP**	**ETA**
C0	1504	1024	1227	1166	1338	1090	1212	1066
C1	1785	1097	1526	1274	1649	1178	1505	1130
C2	1785	1160	1526	1312	1649	1204	1505	1168
C3	1785	1217	1526	1379	1649	1252	1505	1229
C4	1785	1241	1526	1407	1649	1274	1505	1251
C5	1979	1090	1792	1290	1886	1235	1774	1124
C6	1979	1154	1792	1367	1886	1270	1774	1192
C7	1979	1270	1792	1441	1886	1328	1774	1294
C8	1979	1299	1792	1496	1886	1353	1774	1330
C9	2119	1087	1992	1279	2049	1272	1981	1118
C10	2119	1149	1992	1355	2049	1311	1981	1183
C11	2119	1277	1992	1498	2049	1380	1981	1317
C12	2119	1337	1992	1545	2049	1409	1981	1367

The findings of this study are important information to provide a better understanding of the susceptibility of the environment to the climate change, even considering the uncertainties related to the climate scenarios projected to the future (Dessai and Van Der Sluijs, 2007). The global warming seems to be the worst impact, since, even with an increase in rainfall, the higher evapotranspiration will increase the water deficit, making the conditions for rainfed sugarcane crop critical, since the plants will face a drier winter with extremely low water availability in the soil. For irrigated sugarcane crops, the lower water availability in the rivers and reservoirs will be also a problem to be addressed, since it will be hard to apply enough water for sugarcane plants demand. This drastic scenario should be focused by authorities, scientists, sugarcane growers and sugar mills to prepare themselves for finding the best solutions of preparedness to deal with shortage of water in a world which is demanding each day more food (sugar) and energy (ethanol). The best solutions in this case would be the use of biotechnology to make available new water deficit resistant varieties and anti-transpirants that when applied on plants could reduce their transpiration (Fletcher and Nath, 1984).

Table 7. Annual water deficit (WD) and water surplus (WS) in mm $year^{-1}$, obtained by the serial climatological water balance, for the present conditions (C0) and future scenarios of climate change (C1 to C12), in the locations of Araçatuba, Assis, Jaboticabal and Piracicaba, state of São Paulo, Brazil.

Climate Scenarios	**Araçatuba**		**Assis**		**Jaboticabal**		**Piracicaba**	
	WD	**WS**	**WD**	**WS**	**WD**	**WS**	**WD**	**WS**
C0	480	209	61	244	248	288	146	181
C1	689	0	252	39	472	89	375	16
C2	625	0	214	68	445	122	337	50
C3	569	53	147	129	397	188	276	108
C4	544	83	119	161	375	228	254	137
C5	890	0	502	0	651	37	650	0
C6	826	0	425	0	617	65	582	0
C7	709	7	352	0	559	126	480	37
C8	681	34	297	87	533	159	444	63
C9	1032	0	713	0	777	0	864	0
C10	970	0	637	0	738	28	798	0
C11	843	0	494	14	669	84	664	0
C12	783	1	447	41	640	114	614	19

4. CONCLUSIONS

From the results obtained in this study, we concluded that climate change, independently of the scenario considered, will impose an increase in potential and actual evapotranspirations, resulting in higher water deficits in all regions. This will be of great concern for sugarcane growers since it can reduce the yields of rainfed crops. On the other hand, water surplus will be reduced, which will have impact on groundwater and, consequently, on the water reservoirs levels, making irrigation very restrict and expansive. The changes in rainfall, positive (+10%) or negative (-10%), will have less influence on the water availability of the regions than the changes in temperature and, consequently, in evapotranspiration. In relation to the method of analysis, the use of historical data, year by year, allowed to identify that the impacts of climate change on water availability will be even worse than predicted by the studies which took into account only normal average data.

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