Climate change scenarios and their impact on water balance and sugarcane yield in Southern Brazil

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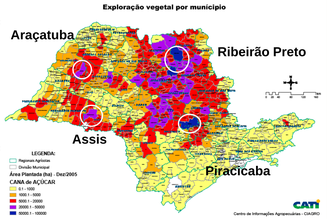
Introduction

Sugarcane is one of the main extensive crops in Southern Brazil, covering around 8 million ha. The crop is mainly produced under rainfed conditions, which makes the sugarcane sector very susceptible to climate variability and change. The study of the agro-environmental vulnerability of the sugarcane crop is an essential aspect to determine the yield potential, the climate risks and to conduct the crop planning at medium and long terms. Based on the economic and social importance of sugarcane crop for Southern Brazil and the expected future scenarios of climate change for this region, reported by the IPCC and the First Brazilian Report on Climate Change, the present study had as objectives to assess the impacts of different climate changes scenarios on the water balance and on the potential and actual yields for the main sugarcane production regions of the state of São Paulo, Brazil..

Material and Methods

The present study was developed for the four main sugarcane regions in the state of São Paulo, Brazil, named: Araçatuba (lat: 20º52'S, long: 48º29'W; alt: 415 m); Assis (lat: 22º38'S, long: 50º24'W, alt: 560 m); Jaboticabal (lat: 21º15'S; long: 48º19'W; alt: 595 m) and Piracicaba (lat: 22º42'S; long: 47º38'W; alt: 546 m). Ten-day period data of Tair, Sunshine hours and Rainfall, for a 30-year period (1981-2010), were obtained from INMET and ANA for these locations.



Twelve future scenarios were created for the years of 2030, 2060 and 2090 by combining changes in temperature and rainfall for each region. A combination of the three A1 scenarios was used (IPCC 2007). These scenarios (A1T, A1B and A1FI) were adopted because they present a full range of variations for air temperature, from 1 to 6ºC, agreeing with the predictions presented in the first Brazilian Report on Climate Change of 2013. 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%).

ETP, rainfall and SWHC for each location and scenario were used to estimate the ten-day serial water balance by the method of Thornthwaite and Mather (1955). The outputs of the water balance were: soil water content (SW); actual evapotranspiration (ETa); water deficit (WD); and water surplus (WS).

The sugarcane potential yield (Yp) was estimated by Agro-Ecological Zone model (AZM) (Doorenbos and Kassam 1979), whereas attainable yield (Ya) was calculated by penalizing Yp by the relationship between the relative crop water deficit, observed in each crop phase, and the water deficit sensitivity index – Ky. The average Yp and Ya for each region were obtained by weighting the yield data by the representative area of each type of cane

The results, in terms of water balance and crop yield, were analyzed by comparing the changes promoted by the future scenarios in relation to the present one, represented by the period from 1981 to 2010.

Results

Table 1 – Present (C0) and future scenarios of climate change (C1 a C12) considering the combinations of increase in temperature (ΔT), variation in rainfall (ΔP), alteration in productivity due to increased CO_2 (ΔYield CO_2) and the technological advances (ΔYield TT)

Scenarios	Year	ΔT (ºC)	ΔP (%)	ΔYield CO_2 (%)	ΔYield TT (Mg ha^{-1})
C0	Present	0	0	0	0
C1	2030	2	-10	2	9.7
C2	2030	2	-5	2	9.7
C3	2030	2	5	2	9.7
C4	2030	2	10	2	9.7
C5	2060	4	-10	5.5	24.2
C6	2060	4	-5	5.5	24.2
C7	2060	4	5	5.5	24.2
C8	2060	4	10	5.5	24.2
C9	2090	6	-10	10.2	38.8
C10	2090	6	-5	10.2	38.8
C11	2090	6	5	10.2	38.8
C12	2090	6	10	10.2	38.8

Table 2 – Annual reference (ETo) and actual (ETa) evapotranspirations, water deficit (WD) and water surplus (WS), obtained from the water balance for a 10-day period for the current climate (C0) and future scenarios of climate change (C1 to C12), in Araçatuba, Assis, Jaboticabal and Piracicaba, São Paulo state, Brazil

Climate	Araçatuba				Assis				Jaboticabal				Piracicaba			
Scenarios	ETo	ETa	WD	WS	ETo	ETa	WD	WS	ETo	ETa	WD	WS	ETo	ETa	WD	WS
	(mm year^{-1})															
C0	1503	1024	480	209	1227	1166	61	244	1338	1090	248	288	1212	1066	146	181
C1	1785	1097	689	0	1526	1274	252	39	1649	1178	472	89	1505	1130	375	16
C2	1785	1160	625	0	1526	1312	214	68	1649	1204	445	122	1505	1168	337	50
C3	1785	1217	569	53	1526	1379	147	129	1649	1252	397	188	1505	1229	276	108
C4	1785	1241	544	83	1526	1407	119	161	1649	1274	375	228	1505	1251	254	137
C5	1979	1090	890	0	1792	1290	502	0	1886	1235	651	37	1773	1124	650	0
C6	1979	1154	826	0	1792	1367	425	0	1886	1270	617	65	1773	1192	582	0
C7	1979	1270	709	7	1792	1441	352	0	1886	1328	559	126	1773	1294	480	37
C8	1979	1299	681	34	1792	1496	297	87	1886	1353	533	159	1773	1330	444	63
C9	2119	1087	1032	0	1992	1279	713	0	2049	1272	777	0	1981	1118	864	0
C10	2119	1149	970	0	1992	1355	637	0	2049	1311	738	28	1981	1183	798	0
C11	2119	1277	843	0	1992	1498	494	14	2049	1380	669	84	1981	1317	664	0
C12	2119	1337	783	1	1992	1545	447	41	2049	1409	640	114	1981	1367	614	19

Table 3 – Average Yp and Ya sugarcane yield, considering the influence of each scenario simulated: ΔT - temperature increases; ΔP - variation of precipitation; ΔYield CO_2 - yield increases as a consequence of increased CO_2 concentration in the atmosphere; ΔYield TT - technological trend, in Araçatuba, Assis, Jaboticabal and Piracicaba, São Paulo State, Brazil

Variables		Araçatuba		Assis		Jaboticabal		Piracicaba	
		Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya
		(Mg ha^{-1})							
Present	-	128	73	118	91	122	89	117	88
ΔT (ºC)	2	133	78	129	111	129	95	125	94
	4	134	76	134	106	134	82	130	86
	6	131	74	131	102	135	78	131	81
ΔP (%)	+5	128	77	118	92	122	94	117	91
	-5	128	70	118	89	122	86	117	85
	+10	128	81	118	94	122	98	117	95
	-10	128	65	118	86	122	82	117	82
ΔYield CO_2 (%)	2	130	75	121	93	125	92	120	90
	5.5	135	77	125	96	129	95	124	93
	10.2	141	81	130	100	135	99	129	97
ΔYield TT (Mg ha^{-1})	9.7	138	84	129	101	129	101	128	99
	24.2	153	98	143	116	143	115	142	113
	38.8	167	113	158	130	157	130	156	128

Table 4 – Weighted potential (Yp) and actual (Ya) sugarcane yield for plant and ratoon (early, medium and late) crops, considering the influence of each future scenario simulated for Araçatuba, São Paulo State, Brazil

Scenario	Plant		Early ratoon		Mid ratoon		Late ratoon		General	
	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya
	(Mg ha^{-1})									
C0	168	101	128	81	109	52	133	85	128	73
C1	196	136	148	147	130	66	155	103	150	104
C2	196	139	148	150	130	69	155	105	150	107
C3	196	144	148	155	130	75	155	109	150	112
C4	196	146	148	157	130	77	155	112	150	115
C5	221	153	170	115	151	79	177	118	172	108
C6	221	156	170	117	151	82	177	120	172	110
C7	221	162	170	122	151	87	177	125	172	115
C8	221	165	170	124	151	90	177	127	172	118
C9	242	171	192	130	167	92	199	133	191	122
C10	242	174	192	133	167	96	199	137	191	126
C11	242	180	192	137	167	102	199	142	191	131
C12	242	183	192	140	167	104	199	144	191	133

Table 5 – Weighted potential (Yp) and actual (Ya) sugarcane yield for plant and ratoon (early, medium and late) crops, considering the influence of each future scenario simulated for Assis, São Paulo State, Brazil

Scenario	Plant		Early ratoon		Mid ratoon		Late ratoon		General	
	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya
	(Mg ha-1)									
C0	156	123	118	94	101	73	123	97	118	91
C1	186	155	140	115	124	100	145	117	142	116
C2	186	158	140	120	124	104	145	122	142	120
C3	186	164	140	125	124	112	145	128	142	126
C4	186	166	140	127	124	115	145	130	142	129
C5	216	167	164	123	146	109	170	125	166	124
C6	216	172	164	128	146	115	170	130	166	130
C7	216	180	164	137	146	123	170	140	166	139
C8	216	183	164	140	146	127	170	144	166	142
C9	236	174	186	135	160	123	193	138	185	137
C10	236	184	186	143	160	129	193	146	185	144
C11	236	191	186	151	160	140	193	153	185	153
C12	236	194	186	154	160	142	193	156	185	156

Table 6 – Weighted potential (Yp) and actual (Ya) sugarcane yield for plant and ratoon (early, medium and late) crops, considering the influence of each future scenario simulated for Jaboticabal, São Paulo State, Brazil

Scenario	Plant		Early ratoon		Mid ratoon		Late ratoon		General	
	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya
	(Mg ha^{-1})									
C0	161	123	122	93	104	71	127	97	122	89
C1	189	132	144	92	127	87	149	95	145	97
C2	189	137	144	95	127	90	149	97	145	100
C3	189	144	144	101	127	95	149	102	145	105
C4	189	147	144	103	127	97	149	104	145	108
C5	217	144	167	104	148	100	174	108	169	109
C6	217	149	167	107	148	103	174	111	169	112
C7	217	158	167	113	148	108	174	116	169	119
C8	217	161	167	116	148	111	174	118	169	121
C9	236	156	189	116	163	117	196	120	187	123
C10	236	162	189	122	163	118	196	125	187	127
C11	236	170	189	127	163	125	196	130	187	133
C12	236	174	189	130	163	127	196	133	187	136

Table 7 – Weighted potential (Yp) and actual (Ya) sugarcane yield for plant and ratoon (early, medium and late) crops, considering the influence of each future scenario simulated for Piracicaba, São Paulo State, Brazil

Scenario	Plant		Early ratoon		Mid ratoon		Late ratoon		General	
	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya	Yp	Ya
	(Mg ha^{-1})									
C0	154	117	117	94	100	70	122	96	117	88
C1	182	132	140	85	123	85	145	102	141	96
C2	182	141	140	91	123	91	145	106	141	101
C3	182	145	140	112	123	100	145	113	141	113
C4	182	147	140	104	123	104	145	116	141	113
C5	211	148	164	109	146	93	169	110	165	109
C6	211	152	164	113	146	98	169	114	165	113
C7	211	160	164	121	146	108	169	122	165	122
C8	211	163	164	125	146	114	169	126	165	127
C9	230	155	186	119	160	106	192	124	184	121
C10	230	167	186	128	160	110	192	130	184	127
C11	230	172	186	134	160	123	192	136	184	136
C12	230	174	186	137	160	131	192	138	184	140