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Onset and end of the rainy season and corn yields in São Paulo State, Brazil

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Resumen

En este estudio se investigaron las relaciones entre la temporada de lluvias y las cosechas de maíz en el estado de São Paulo, Brasil. Los resultados mostraron que las cosechas de maíz y las precipitaciones se correlacionan fuertemente en una gran parte de la región, particularmente en la parte noreste, este, noroeste y oeste del estado (valores positivos superiores a 0.5 y significativos a un nivel de confianza de 95%).

El análisis de las tendencias en la duración de la temporada de lluvias y la precipitación acumulada asociada, mostraba una tendencia a mayor volumen de precipitación y una más corta temporada de lluvias. Esto puede ser debido al calentamiento global. Aunque se correlacionan positivamente las cosechas de maíz y la lluvia, un aumento en el futuro de eventos de intensas lluvias puede conducir a deslizamientos de tierras, inundaciones y, en consecuencia, provocar daños a los cultivos. Durante el período 1970-2003 hubo un aumento de duración en la temporada de lluvias y en el volumen de precipitación en fuertes episodios de El Niño, mientras que en el caso de los eventos de La Niña la temporada de lluvias fue más corta y hubo una disminución de las precipitaciones.

Los resultados de los estudios de caso, teniendo en cuenta El Niño 1997-98 y La Niña 1998-99 sugirieron que el aumento (disminución) de la duración de la temporada de lluvias durante el evento de El Niño (La Niña) está asociado con el aumento (disminución) de las cosechas de maíz en el estado de São Paulo. Se necesitan estudios adicionales con un récord de datos de los rendimientos de maíz mayor de 14 años y teniendo en cuenta otros episodios de El Niño/LaNiña para hacer una conexión convincente entre las cosechas de maíz y eventos ENOS en el estado de São Paulo.

Palabras clave: Temporada de lluvias en el estado de San Pablo, cosecha de maíz, El Niño/La Niña.

Abstract

The relationships between the rainy season and corn yields in São Paulo State were investigated. The results showed that rainfall and corn yields are strongly positively correlated in most of the region, particularly in the northeastern, eastern, northwestern and western parts of the state (i.e. values are higher than 0.5 significant at 95% confidence level). The analysis of the trends in the duration of the rainy season and the associated accumulated precipitation showed a tendency of higher precipitation and shorter rainy seasons. It has been suggested to be due to global warming. Although rainfall and crop yields were positively correlated, an increase in heavy rainfall events in future may lead to landslides, flash floods and consequently crop damage.

During the period 1970-2003 there was an increase of the rainy season and rainfall in strong El Niño episodes while in the case of La Niña events the rainy season was shorter and the rainfall decreased. Results of case studies considering the 1997-98 El Niño and the 1998-99 La Niña suggested that the increase (decrease) of the duration of the rainy season during the El Niño (La Niña) event is associated with the increase (decrease) of corn yields in São Paulo State. Further studies with a record of corn yields longer than 14 years and considering other El Niño/La Niña episodes are needed to obtain a firm connection between corn yields and ENSO events in São Paulo State.

Key words: Rainy season in São Paulo State, corn yields, El Niño/La Niña.

Introduction

Climate variability has a great impact on agricultural productivity. A better knowledge of climate and its variability is essential to improve climate prediction, as well as to give important information to minimize the impact of adverse climate conditions. Climate variability in the tropics as revealed by rainfall variability affects crop yields. Studies of Handler (1984), Nicholls (1984), Gasques (1988) and Cane *et al*. (1994) indicate a possible connection between El Niño-Southern Oscillation (ENSO) and food production. In the particular case of Brazil, the ENSO phenomenon has specific regional influence on the precipitation patterns (Grimm *et al*., 1998, 2000; Fontana and Berlato, 1997; Berlato and Fontana, 1997; Kousky *et al*., 1984) and consequently, on Brazil's agricultural productivity. Rao *et al*. (1997) verified that rainfall correlates significantly well with corn yields in several states of Northeast Brazil (NEB). Since rainfall is affected by ENSO events, they found good success in predicting annual corn yields in NEB from prior observations of the Southern Oscillation (SO) index in some states of that region. However, the relationship between rainfall and crop yields remained largely unexplored for the other parts of Brazil.

São Paulo city is located in southeastern Brazil. It is the most populous and plays an important role in the economy of the country because of its high industrial activity, hydroelectric power generation and high agricultural productivity. The regime of precipitation in this region shows characteristics of a monsoon system, where the rainy season takes place in the austral summer and the dry season takes place in the austral winter. The three wettest and driest months correspond to DJF and JJA, respectively (Rao and Hada, 1990). Studies on the onset and end of the rainy season in the southeastern Brazil have been made using different methods, which show different results. Marengo *et al*. (2001), using Outgoing Longwave Radiation data (OLR), suggested that the rainy season in the region begins between the end of September and beginning of October. Cavalcanti *et al*. (2001), using daily data of precipitation from the Instituto Nacional de Meteorología (INMET) for the period 1979-1997, showed that there is a large variability in the beginning of the rainy season in southeastern Brazil. However, on the average it begins between the end of October and beginning of November. In a recent study, Franchito *et al*. (2008) showed that when OLR data are used, the beginning and the end dates of the rainy season are wrongly anticipated and delayed, respectively. This is because OLR sensors contribute to an overestimation of convective rainfall due to the presence of high cirrus clouds (Fu and Liu, 2003; Franchito *et al*., 2008).

Our purpose is to investigate the relationships between the onset and end of the rainy season and corn yields in São Paulo State. An attempt has been made to examine the influence of ENSO events on the duration of the rainy season and associated accumulated precipitation on corn yields. The present study aims to provide useful information for the management of agricultural resources in the region.

Data and Methodology

Rainfall daily data for 249 rain gauge stations for a period of 34 years (1970-2003) for São Paulo State are obtained from Departamento de Águas e Energia Elétrica de São Paulo (DAEE). Corn yields for the period 1990-2003 are obtained from Instituto Brasileiro de Geografia e Estatística (IBGE).

The method to determine the onset and end of the rainy season is the same used by Franchito *et al*. (2008). For each rainy gauge station (i) for each pentad (j) for each year (k), the value of the accumulated precipitation at each 5 days [p(i,j,k)] is compared to [P_5(i)], which represents the 5 days accumulated precipitation assuming the annual rainfall was uniformly distributed during the whole year. Starting from January 1st, the ratio r (i,j,k) = p (i,j,k) / P_5 (i) is calculated, where P_5 (i) = P (i) / 73, and P (i) is the mean annual rainfall. As criterion for the beginning (end) of the rainy season it is assumed that at least 50% of the values of r (i,j,k) are higher (lower) than 1 (threshold value) for at least three consecutive pentads or for two pentads followed by three pentads among four consecutive pentads. As mentioned by Franchito *et al*. (2008) this criterion is sufficiently sensitive and very useful to the necessities of many sectors of society, such as agriculture and human activities.

The 249 rain gauge stations are grouped in 27 regions with 1° x 1° (latitude x longitude) (Fig. 1). The daily precipitation in each region is obtained by averaging the daily precipitation values of stations. This method allows the filling of the data gaps so that a continuous daily precipitation data series is obtained. The method of Franchito *et al*. (2008) is applied to the rainfall data series for each of the 27 regions and thus the onset and end dates of the rainy season are obtained. The duration of the rainy season and the rainfall amounts are compared with corn yields data in several agricultural regions according to IBGE classification, which are also shown in Fig. 1.

Results

a) Relationships between corn yields and rainfall

Figs. 2a-b show the dates of the beginning of the rainy and dry seasons, respectively, for the 27 regions of São Paulo State of Fig. 1. The later and early beginning of the rainy and dry seasons are shown in Figs. 2c-d, respectively. Also dates obtained by adding (substracting) one standard deviation (SD) indicate the range of the onset of the rainy and dry seasons. As can be seen, for 85% of the regions, the rainy season begins between the end of October and the first week of November. In eastern São Paulo State the beginning of the rainy season occurs in the last week of October and in southeastern São Paulo it occurs between the first and second week of November (Fig. 2a). The earliest onset of the rainy season occurs in general between the first and second week of September (59% of the regions). However, in northern São Paulo

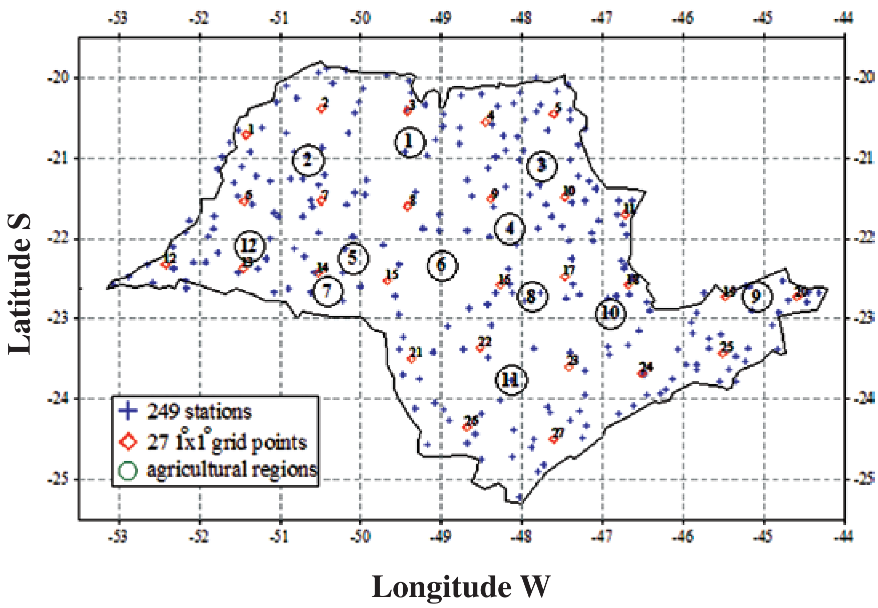

Fig. 1: Location of the DAEE rain gauge stations in São Paulo State; also shown are the 27 regions of 1° x 1° latitude x longitude (small circles) and the 12 agricultural regions (IBGE classification) (large circles).

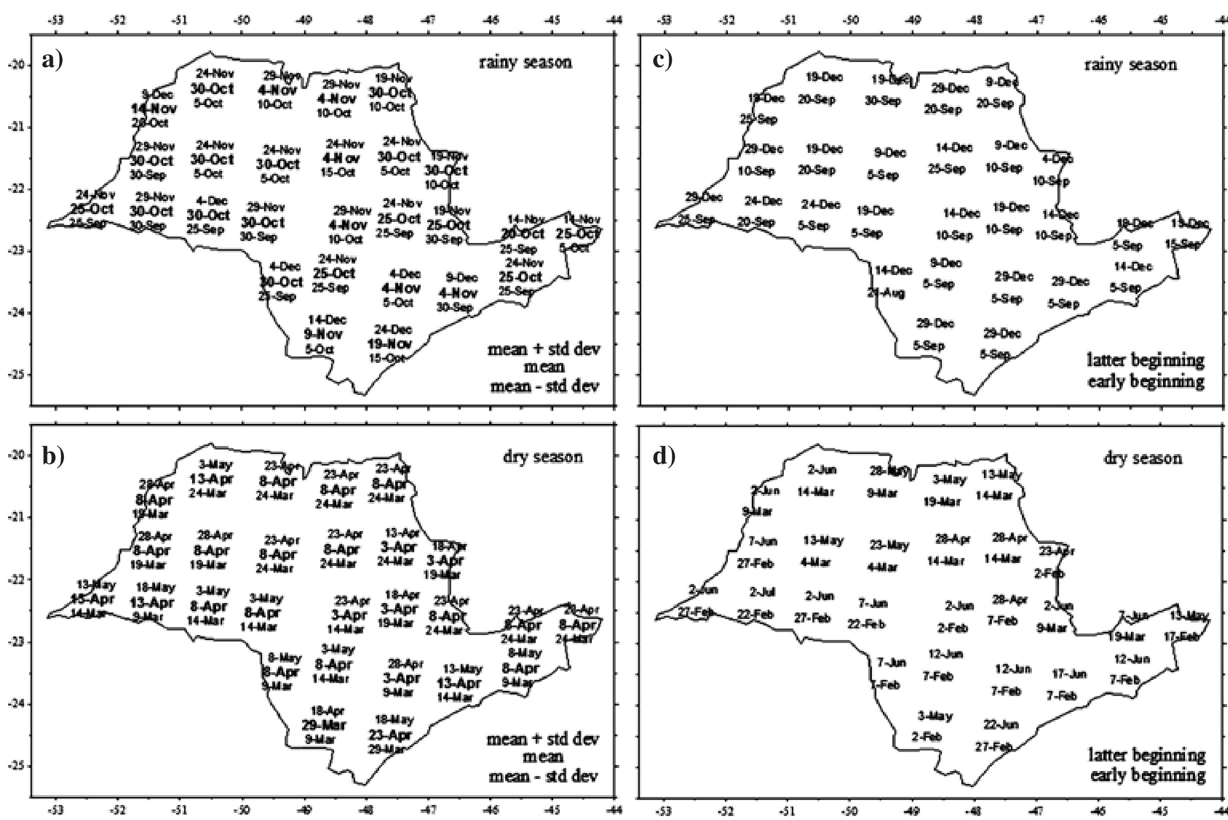

Fig. 2. Estimate of the dates of the onset of the rainy and dry seasons in São Paulo State for each region of 1° x 1° (latitude x longitude). Dates obtained by adding (substracting) one standar deviation (SD) indicates the range of the onset of the rainy (a) and dry (b) seasons. Also shown the earlier onset and late delay of the onset of the rainy (c) and dry (d) seasons.

the onset occurs in the last two weeks of September. The maximum delay of the onset of the rainy season occurs in the last two weeks of December for 63% of the regions. The maximum delay of the rainy season, which occurs in the end of December, takes places on the southern and southeast parts of the state (Fig. 2c).

In general, for 77% of the regions, the beginning of the dry season occurs between the first and second week of April. The earliest onset of the dry season is between the first and second week of March in the north (20% of the regions) and at the end of February in the west of the state (20% of the regions). For 33% of the regions, the earliest beginning of the dry season occurs during the first two weeks of February. The maximum delay of the dry season occurs during the first two weeks of June (59% of the regions). At the northern and northwestern zones of the state the maximum delay of the dry season occurs between the first week of May and first week of June (Fig. 2d).

The trend (in days) of the onset or demise of the rainy season in the period 1970-2003, for the 27 blocks of 1° x 1° (latitude x longitude) of Fig. 1, is shown in Table 1. To compute the significance of the trend, the two-sided Student t-test (Fisher and Yates, 1974) is used. It can be seen that in 12 (4) blocks there is a tendency of more than 20 days to delay the onset (demise) dates. In other regions, such as blocks 1, 4, 17 and 21 there is a tendency to anticipate the demise date. In 7 (12) of the 27 blocks, no trend in the onset (demise) dates is noted. Since there are more regions where the rainy season onset is delaying compared to the demise delay, there is a tendency of a shorter rainy season to occur. This can be seen in 14 of the 27 blocks. Although there is a tendency of a shorter rainy season, in general the accumulated precipitation shows a tendency to increase. As can be seen in Table 1, at least in 13 blocks, the accumulated precipitation shows an increasing trend.

In order to investigate the relationships between the rainy season and corn yields in São Paulo State correlation coefficients (c.cs) between the rainfall and corn yields for the period 1990-2003 are calculated for the 12 agricultural regions showed in Fig. 1. As can be seen in Table 2, there is a strong positive correlation between the rainfall and corn yields in most of the regions. The c.cs are higher than 0.45 (significant at a 90% confidence level by the two sided Student t-test) in 8 of the 12 regions considered. In 5 of these regions the c.cs are higher than 0.5 (significant at a 95% confidence level). From Fig. 1 and Table 2, these 5 regions with higher c.cs are located at the northeastern (2), eastern (1), northwestern (1) and in the western zone (1) of the state. The c.cs are less significant in the central, central-eastern and southern regions of the state.

Table 3 shows that there is an increasing trend in corn yields for the 12 agricultural regions of São Paulo State (Fig. 1) in the period 1990-2003. This can be due to various factors, such as climate variations and improvement of agricultural techniques among others. In the present study the impact of climate conditions on corn yields is investigated, particularly the influence of precipitation. It is showed that the duration of the rainy season is to reduce, while the tendency of the accumulated precipitation during the rainy season is to increase. Thus, it is suggested that the amount of precipitation rather than the duration of the rainy season has higher impact on corn yields in São Paulo State.

Another climate variable that has large influence on agricultural productivity is air temperature. Table 4 shows the trend in air temperature (in °C) for the period 1971-2002 for the 12 agricultural regions in São Paulo State (Fig. 1). As can be noted, there is an increasing temperature trend. Model and observation studies have shown that the temperature is increasing globally. Recently, the IPCC AR4 (International Panel for Climate Change Fourth Assessment) evaluations showed that the global warming is mainly due to anthropogenic cause (IPCC, 2007a). Among the anthropogenic gases, CO_2 has more influence in the increase of mean temperature (http://rrz.uni_hambirg.de/Klima2000/eng/eng_helf.html). The IPCC AR4 studies also indicate that the frequency of ex-treme events is increasing. These events are associated with heavy rainfall. Thus, the results presented here (shorter rainy season, positive trend of rainfall amounts and positive trend in temperature) may be a consequence of climatic change due to global warming (IPCC, 2007b).

In the analysis above the factors such as fertility, sowing time and improvements in agricultural techniques are not taken into account. Despite these limitations, the c.c values between rainfall and corn yields strongly indicate the influence of rainfall on corn yields in the São Paulo region. However, a further increase of accumulated precipitation during shorter rainy season in future can be harmful to agriculture. These events of heavy rainfall in shorter periods may result in landslides, flash floods and consequently crop damage (IPCC 2007b, Goswami *et al*., 2006).

b) El Niño and La Niña cases

In this section the effect of the El Niño and La Niña events on the duration of the rainy season, and the associated accumulated rainfall on corn yields in São Paulo State is investigated. During the period 1970-2003 there were 7 El Niño events and 4 La Niña events. Analysis of the rainy season duration and the accumulated precipitation in the 12 agricultural regions of São Paulo State shows that in general during strong El Niño

Table 1

Trend (in days) of delay (+) and anticipation (-) of onset and demise of the rainy season, trend in the increase (+) or decrease (-) in the duration of the rainy season and the accumulated precipitation during the rainy season in the period 1970-2003. Only values with significance higher than 75% confidence level by the two sided Student t-test are shown.

			begining of wet period		begining of dry period		duration of wet period		accumulated precipitation during wet period		percentage of annual precipitation during wet period	
Block (1x1)	period (years)	n-2	trend (days)	Significance (%)	trend (days)	Significance (%)	trend (days)	Significance (%)	trend (days)	Significance (%)	trend (days)	Significance (%)
1	34	29	41	95	-26	95	-67	99.5	-128	85	-14	95
2	34	32					-14	75				
3	33	31	24	95			-17	75				
4	33	30	11	75	-17	85	-27	90	-25	85		
5	34	31	17	85			-14	75				
6	33	30	27	90	19	85			50	85		
7	34	30			14	80			116	85		
8	34	31			15	80			114	90	6	85
9	34	32		11	75			65	75			
10	34	32	13		75	17	85			53	85	
11	34	30	22	90	25	95			-12	95		
12	33	23	35	90	28	90			78	90		
13	34	26	18	80					145	90		
14	34	26	16	80					94	75		
15	33	26							147	90		
16	34	31	21	90			-32	85			-5	75
17	34	29			-18	85	-31	85	74	85		
18	34	31	42	99.5	21	90	-21	85	-48	90	-5	85
19	34	31	32	95			-29	90	-81	75	-7	90
20	34	31	10	75	9	75			114	85		
21	31	21	34	90	-21	85	-55	99	-100	85	-9	90
22	34	27	31	95			-33	90			-7	90
23	34	27	26	90			-31	90			-7	90
24	31	28	21	85			-28	90			-7	90
25	34	27							171	95	9	90
26	34	26	15	80	22	85			187	95	5	75
27	34	19	14	80	-69	99.5	-83	99.5	-121	75	-11	90

Table 2

Correlation coefficient between the rainfall during the rainy season and corn yields in the 12 agricultural regions shown in Fig. 1 in São Paulo State. * and ** indicate significance at 90% and 95% confidence levels respectively.

City	Region	c.c.
São José do Rio Preto	1	0.46*
Araçatuba	2	0.52**
Ribeirão Preto	3	0.53**
Araraquara	4	0.54**
Marília	5	0.41
Bauru	6	0.33
Assis	7	0.59**
Piracicaba	8	0.46*
V. do Paraíba Paulista	9	0.73**
Campinas	10	0.32
Itapetininga	11	0.34
Presidente Prudente	12	0.45*

Table 3

Trend in corn yields (in ton/hect.year) for the 12 agricultural regions in São Paulo State (Fig. 1) for the period 1990-2003.

region	n-2	trend ton/(hec.yr)	significance level (%)
1 - São José do Rio Preto	13	0.14	99
2 - Araçatuba	13	0.11	99
3 - Ribeirão Preto	13	0.06	95
4 - Araraquara	13	0.10	99
5 - Marília	13	0.14	99
6 - Bauru	13	0.17	99
7 - Assis	13	0.05	85
8 - Piracicaba	13	0.17	99
9 - Vale do Paraíba Paulista	13	0.09	99
10 - Campinas	13	0.16	99
11 - Itapetininga	13	0.20	99
12 - Presidente Prudente	13	0.07	99

Table 4

Trend of the minimum, average and maximum monthly air temperature (ºC) during the period 1971-2002 for the 12 São Paulo State agricultural regions. The confidence level (%) of the temperature trend is calculated using the two sided Student t-test. The monthly air temperature data series are from the Climate Research Unit (site: http://www.cru.uea.ac.uk/cru/).

Region	Parameter	T_min	T_med	T_max
1	ΔT(ºC)	1.15	1.10	1.03
	%	**97.5**	**99.5**	**99.5**
2	ΔT(ºC)	1.23	1.15	1.06
	%	**97.5**	**99.5**	**99.5**
3	ΔT(ºC)	0.92	0.90	0.88
	%	**95**	**99**	**99.5**
4	ΔT(ºC)	0.85	0.79	0.72
	%	**95**	**95**	**97.5**
5	ΔT(ºC)	0.98	0.86	0.75
	%	**95**	**95**	**95**
6	ΔT(ºC)	0.91	0.81	0.72
	%	**95**	**95**	**95**
7	ΔT(ºC)	0.91	0.77	0.62
	%	**90**	**90**	**90**
8	ΔT(ºC)	0.80	0.71	0.62
	%	**90**	**90**	**95**
9	ΔT(ºC)	1.32	1.31	1.28
	%	**97.5**	**99.5**	**99.5**
10	ΔT(ºC)	0.94	0.87	0.80
	%	**95**	**97.5**	**97.5**
11	ΔT(ºC)	0.87	0.76	0.64
	%	**95**	**90**	**90**
12	ΔT(ºC)	0.86	0.71	0.56
	%	**90**	**90**	**90**

episodes there is an increase of both the rainy season and the rainfall. On other hand, the rainy season is shorter and the rainfall decreases during La Niña episodes. To investigate the influence of ENSO events on crop yields, two cases are considered: the 1997-98 El Niño, which was the strongest of the last century (Coughlan, 1999), and the 1998-99 La Niña, which was a moderate episode. Table 5 shows the variation of the duration of the rainy season and corn yields for 7 agricultural regions of Fig. 1 during the El Niño and La Niña cases. As can be seen, in the 1997-98 El Niño, there was an increase of the rainy season (17 to 72 days) for all the 7 regions considered, except in Piracibaca (which is located in the center of the state). The beginning of the rainy season occurred earlier by 20 to 30 days, while the end of the rainy season was around the climatological mean, except in Assis (west of the state), where it was delayed by 35 days.

In the case of the 1998-98 La Niña event, the rainy season was delayed by 10 to 40 days in the agricultural regions considered, while the end of the rainy season was anticipated by 10 to 35 days in the most of the regions. However, in Aracatuba (northwestern São Paulo) and Assis (western São Paulo) there was a delay of the end of the rainy season by 22 and 15 days, respectively. In the 7 agricultural regions considered, the rainy season was reduced by 18 to 75 days during the La Niña event.

As shown in results, section (a), the calculation of the trend using the entire data series indicates that the increase of precipitation in short rainy season seems to have higher impact on corn yields in São Paulo State. However, from

Table 5

Deviations of the duration of the rainy season and corn yields in 7 agricultural regions of São Paulo State during the 1997-98 El Niño and 1998-99 La Niña. Also shown are the dates of the onset and end of the rainy season. The location of these regions is indicated by circles in Fig. 1.

	Agricultural region	São José do Rio Preto (1)	Araçatuba (2)	Ribeirão Preto (3)	Piracicaba (8)	Assis (7)	V. do Paraíba Paulista (9)	Presidente Prudente (12)
Mean	Duration (days)	155	158	158	160	158	168	165
	onset	4 Nov	30 Oct	29 Oct	25 Oct	1 Nov	21 Oct	30 Oct
	end	8 Apr	6 Apr	5 Apr	3 Apr	8 Apr	7 Apr	13 Apr
	ton/ha	3.3	3.5	3.0	4.1	2.7	2.5	2.6
anomaly La Niña 1998/1999	Duration (days)	25	57	22	-30	72	17	65
	onset	5 Oct	25 Sep	5 Oct	29 Nov	25 Sep	30 Sep	25 Sep
	end	3 Apr	28 Apr	3 Apr	8 Apr	13 May	3 Apr	13 May
	kg/ha	75	79	64	10	591	-210	60
anomaly El Niño 1997/1998	Duration (days)	-50	-18	-48	-45	-23	-28	-75
	onset	4 Dec	9 Dec	4 Dec	25 Nov	9 Dec	9 Nov	9 Dec
	end	19 Mar	28 Apr	24 Mar	24 Mar	23 Apr	29 Mar	9 Mar
	kg/ha	-122	219	-179	540	-219	-300	-10

Table 5, it can be seen that there was an increase of the rainy season in the El Niño case, while in the La Niña event a decrease occurred. Also, there is an increase (decrease) of corn yields during the El Niño (La Niña) event. Thus, it is suggested that during ENSO episodes the duration of the rainy season seems to have a great impact on corn yields in São Paulo State. Further studies with a record of corn yields longer than 14 years and considering other El Niño/La Niña episodes are needed to make convincing connection between corn yields and ENSO events in São Paulo State.

Conclusions

In this study the relationships between the rainy season and corn yields in São Paulo state were investigated. First, the dates of the onset and end of the rainy and dry seasons were determined. Pentad data for 249 rain gauge stations for a period of 34 years (1970-2003) were grouped in 27 regions of 1° x 1° latitude x longitude. The results showed that in general the beginning of the rainy season occurs between the end of October and the first week of November and the beginning of the dry season occurs between the first and second week of April. In most of São Paulo State the earlier onset of the rainy season is between the first and second week of September, while in the northern region it occurs in the last week of September. The later onset of the rainy season takes places in general between the first and second week of December, although in the southern region it occurs in the end of December. The earlier onset of the dry season occurs on different dates in the several regions of São Paulo. It occurs between the first and second week of March in the northern zone, at the end of February in the western area, and in the beginning of February in most part of the central and southeastern regions. The later delay of the dry season occurs between the first and second week of July in most of São Paulo, while in the northern and northwestern regions it occurs between the last week of April and first two weeks of May.

Trends in the duration of the rainy season and the associated accumulated precipitation were calculated for the 27 blocks 1° x 1° in São Paulo State. The results showed that in general the trend in the duration of the rainy season is negative while the trend in the accumulated rainfall during the rainy season is positive. Although there is a trend of a shorter rainy season, the tendency of the accumulated rainfall is to increase. Trend in crop yields was calculated for the 12 agricultural regions of São Paulo State, showing an increase in the agricultural productivity. Since the trend in the duration of the duration of the rainy season is negative, while the trend in the accumulated precipitation is positive, it is suggested that the increase of precipitation in a shorter rainy season seems to have higher impact on corn yields in São Paulo State. Trend in air temperature was also calculated, indicating that the air temperature is increasing. Higher rainfall and shorter rainy season indicate that the frequency of extreme events with heavy precipitation is increasing. According to IPCC AR4 evaluations the frequency of extreme events is increasing. So, the present results may be associated with global warming. Although rainfall and crop yields were positively correlated, an increase in heavy rainfall events in future may lead to landslides, flash floods and consequently crop damage.

Correlation coefficients between the rainfall and corn yields were computed for 12 agricultural regions of São Paulo. For 8 of the 12 regions the c.c values were higher than 0.45 (significant at a 90% confidence level), while in 5 regions (2 at the northeastern, and 1 in the eastern, northwestern and western zones of the state) the c.cs values are higher than 0.5 (significant at 95% confidence level). The central, central-eastern and southern regions showed c.cs with less significance.

During the period 1970-2003 there was an increase of the rainy season and rainfall in strong El Niño episodes while in the case of La Niña events the rainy season was shorter and the rainfall decreased. Results of case studies considering the 1997-98 El Niño and the 1998-99 La Niña indicated that the rainy season duration in the agricultural regions during the El Niño event increased between 17 and 72 days, while in the La Niña event there is a decrease of the duration of rainy season between 18 and 75 days. In most of the agricultural regions there was an increase (decrease) of corn yields in the El Niño (La Niña) case. This suggests that the increase (decrease) of the duration of the rainy season during the El Niño (La Niña) event is associated with the increase (decrease) of corn yields in São Paulo State. Further studies with a record of corn yields longer than 14 years and considering other El Niño/La Niña episodes are needed to make convincing connection between corn yields and ENSO events in São Paulo State.

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