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Temporal variability of ENSO effects on corn yield at the central region of Argentina

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ABSTRACT: The yield of corn is strongly affected by climatic conditions during the growing season. In the central region of Argentina, this crop is mainly managed under rainfed conditions. Hence, in most years, it is subjected to drought at some period during the growing season. El Niño Southern Oscillation (ENSO) is known to influence rainfall in this region, mainly during the warm semester, hence affecting summer crops yields. This study assessed the relationship between ENSO [analysed through the June–July–August Oceanic Niño Index (JJA-ONI)] and corn yields in the provinces of Buenos Aires, Entre Ríos and Santa Fe, which is the main corn-growing area in Argentina. This was performed for two contrasting periods regarding technology applied in the agricultural sector: 1972–1991 and 1992–2012. Remarkable increases in corn yield between periods were found for the entire region. Except for the province of Entre Ríos, we found statistically significant differences between periods in the trends of corn yield by performing the Chow test. Significant correlations ($P < 0.01$) between the JJA-ONI and corn yield were found in many counties of Buenos Aires, Entre Ríos and Santa Fe provinces. The correlation was higher in the second period for most counties. We consider that two hypotheses could explain this correlation increase: (1) in previous decades the best growing seasons (from a climatic point of view) were not fully exploited because of a low use of inputs and technology; and (2) the correlation between the ONI and rainfall could have increased in the last decades. We confirmed the latter hypothesis with rainfall data from conventional meteorological stations of 11 locations of the region under analysis. The JJA-ONI assessed in this research is available before farmers make their most relevant corn management decisions (fertilizer dose, sowing date, density, etc.), thus making this index highly valuable.

KEY WORDS

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1. Introduction

Corn is the main cereal produced in Argentina. It is annually planted in more than 4 Mha, with national average yields ranging from 5500 to 7800 kg ha^{-1} over the last years. The Buenos Aires, Entre Ríos and Santa Fe provinces (BA, ER and SF, respectively) account for more than 50% of the country's corn production [SIIA, Sistema Integrado de Información Agropecuaria (Integrated System of Agricultural Data) of the Ministry of Agroindustry]. This region presents humid and temperate weather with annual precipitation ranging from 800 to 1100 mm and decreasing westward. Most of the corn in this area is managed under rainfed conditions. Hence, yields are highly dependent on water availability during the growing season.

The sowing season in northern SF and ER starts by the end of August and finishes by the end of October. In BA, it starts from mid to late October and continues until November, depending on the frost-free period (USDA, 1994; Otegui *et al.*, 1995). The critical period (CP) to define the number of kernels per m^2 in corn (the variable most correlated with corn yield) takes place between −227 and 100 °C day from silking stage (Otegui and Bonhomme, 1998). In the area studied, the CP can occur at some time between November and January, depending on hybrid cycle and mean temperature after crop emergence (Fernández Long *et al.*, 2011; ORA, 2014). Water deficit during the CP decreases yields more than at any other stage (Andrade *et al.*, 1999; Cárcova *et al.*, 2003).

The Oceanic Niño Index (ONI) is one of the many indices used to determine the state of ENSO (Smith *et al.*, 2008). It is calculated as a 3-month running mean of the Extended Reconstruction of Sea Surface Temperature Version 4 (ERSST.v4) anomalies in the Niño 3.4 region (5°N–5°S, 120°–170°W), based on centred 30-year base periods updated every 5 years. ONI series is published monthly by the Climate Prediction Center and can be accessed at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml. The index operationally defines the warm phase of ENSO (El Niño) when the ONI values are higher than or equal to +0.5 °C for five consecutive overlapping 3-month seasons. Similarly, the cold phase of ENSO (La Niña) occurs when the ONI is lower than or equal to −0.5 °C for five consecutive overlapping 3-month seasons. When a phase does not meet the criteria for

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classifying it as either warm or cold, it is defined as neutral.

Rainfall in the Southeastern part of South America is highly influenced by ENSO (Ropelewski and Halpert, 1987, 1989; Grimm *et al.*, 2000; Montecinos *et al.*, 2000; Podesta *et al.*, 2002). Berri and Bertossa (2004) described the temporal and spatial effects of ENSO on the precipitation anomalies in many regions of Argentina and found a strong correlation between ENSO and precipitation anomalies in most of the central region of the country. The warm (cold) phase, El Niño (La Niña), has been associated with positive (negative) precipitation anomalies in the period September–December (Grimm *et al.*, 2000; Barros and Silvestri, 2002; Seiler and Vinocur, 2004; Vera *et al.*, 2004) in the central region of Argentina. According to Grimm *et al.* (2000), the positive (negative) rainfall anomalies associated to El Niño (La Niña) phases in Southern South America are mainly explained by a strengthening (weakening) of the subtropical jet, advection of cyclonic (anticyclonic) vorticity around Southern Brazil and enhancement (weakening) of northerly advection of moisture. ENSO has also been correlated with yields of different crops in many regions of the world (Hansen *et al.*, 1998; Potgieter *et al.*, 2002; Stige and Stave, 2006; Martinez and Jones, 2011; Royce *et al.*, 2011). In the central region of Argentina, many authors have also found correlations between ENSO phase and crop yields (Messina *et al.*, 1999; Ferreyra *et al.*, 2001; Podesta *et al.*, 2002; Travasso *et al.*, 2009; Fernández Long *et al.*, 2011), reporting yield increases associated with the warm phase of ENSO.

Since technological improvements (TI) allow increasing yields regardless of weather conditions, they should be considered when assessing the effect of weather variables on yield variability along time. The degree of decrease (increase) of corn yields during a dry (wet) season will vary with the amount of inputs used (pesticides, fertilizers and enhanced hybrids) and with the selected agronomic practices (no-tilling, sowing date and plant density).

Economic policies can strongly condition the degree of adoption of new technologies. A review by Sunding and Zilberman (2001) cited works by Coeymans and Mundlak (1993) and Cavallo and Mundlak (1982), who reported that growth and investments in the agricultural sector from 1940 to 1971 in Argentina and Chile were stimulated by free market policies. Schnepf *et al.* (2001) reported corn yield increases in the order of 75–105% in Argentina during the 1990s associated to economic and policy reforms coupled with agricultural research developments as use of fertilizers, simple hybrids, and no-till management. According to Schnepf *et al.* (2001), the Argentinean agricultural sector underwent an unprecedented modernization and expansion process during that decade associated to the elimination of grain export tariffs and the reduction of import duties, which facilitated farmers' access to technologies such as fertilizers, pesticides and machinery. Even after the strong economic crisis in 2001 in Argentina, followed by a devaluation of the currency and agricultural export restrictions, the use of agricultural inputs kept growing throughout the decade (CASAFE, 2011). In this decade, the devaluation and the high prices of commodities stimulated the development of the agricultural sector.

The main objective of this paper was to characterize the effects of ENSO (evaluated through the ONI before the corn sowing season) on corn yields in BA, ER and SF provinces in two contrasting periods regarding inputs use. A secondary objective was to find an ENSO index, applicable to future research on the development of predictive models useful for farmers' corn management decisions. The last objective was to address the possible causes of any differences between periods in the correlation between the ONI and corn yields.

2. Methods

2.1. Time series splitting

Historical corn yields from all counties of BA, ER and SF were obtained from official records (SIIA, 2013). The time series was split into two periods: Pi: 1972–1991; and Pii: 1992–2012. Such division was sustained by the following criteria: (1) differences in technology adoption associated to economic policies (unprecedented opening of the economy following the provisions of the 23.928 Austral Convertibility Law, passed in March 1991, which established an exchange rate between the local currency and the US dollar in a ratio of ten thousand Australs (A 10 000) per each dollar); (2) to compare periods of similar length.

We performed a lineal regression of corn yields against time (year) for each period, both at county and province levels, using the least squares technique (as described by Chernick and Friis (2003)) to obtain the TI (technological improvements)-related yield trend function as follows:

$$Yt = a + b * T \tag{1}$$

where Yt is the estimated corn yield of the year T, a is the y-intercept, and b is the slope ($b > 0$ indicates increasing Yt over time).

Counties with more than half data unavailable for one period were omitted for that period. In 2008, an extreme drought caused significant losses in most of the region assessed (Ravelo *et al.*, 2014). Therefore, this year was omitted for the TI trend equation (Equation (1)) for the following reasons: (1) corn yield data of 2008 was missing in 8% of the counties and (2) 50% of the counties lost more than half of the planted area (SIIA, 2013).

2.2. Spatial distribution of corn yield and percentage of yield increase between periods

In order to have a better understanding of corn yield spatial variability in the region, it was mapped at county level using Geographic Information Systems (GIS) for both periods (Pi and Pii). The percentage of yield increase between periods was plotted likewise.

2.3. Chow test to assess trend differences between periods

To identify the presence of a significant change in the linear trend of corn yield in 1992, associated to the opening of the economy initiated in March of 1991, we performed the Chow test (Chow, 1960; Lloyd-Hughes and Saunders, 2002). This test was applied using corn yield data from each province and from the whole area studied (SIIA, 2013) as follows:

$$\text{Chow} = \frac{\text{SSEc} - \left(\text{SSE}_{\text{Pi}} + \text{SSE}_{\text{Pii}}\right)}{k} \Big/ \frac{\text{SSE}_{\text{Pi}} + \text{SSE}_{\text{Pii}}}{L - 2k} \quad (2)$$

The test statistic follows a Fisher–Snedecor distribution and measures the ratio of the sum of squares errors (SSE) obtained from the regression of the entire time series (SSEc) against the SSE from both periods in the series (SSE of Pi; and SSE of Pii). L is the length of the entire series (41 years split into Pi: 20 years and Pii: 21 years). k represents the number of periods evaluated (two in this case). A change in the coefficients of the linear trends between periods will result in higher values of the test, thus rejecting the null hypothesis with lower probability of type I error. Finally, we obtained the P-value of the statistic.

2.4. Correlation between ONI and corn yield departure from trend (dY); and coefficient of variation of dY

We filtered TI-related yield increases by calculating corn yield departures from trend (dY) for each year and county, as proposed by Salazar *et al.* (2008):

$$dY = \frac{Y}{Yt} \quad (3)$$

where Y is the actual corn yield and Yt is the estimated corn yield, for year t.

We calculated the Pearson's correlation coefficient (r) between NDJ-ONI and dY for Pi and Pii for each county. NDJ-ONI was correlated with previous ONIs (Table 1). In line with the second objective of this research, we assessed the JJA-ONI as well, considering it presents a high correlation with NDJ-ONI for Pi and Pii. Furthermore, 50% (80%) for Pi, and 66% (57%) for Pii, of El Niño (La Niña) phases in the NDJ trimester were in the same phase by JJA. This JJA-ONI presents a high correlation with spring and summer rainfall in two locations from the western part of the ER province (Jozami *et al.*, 2015). Furthermore, it is available well in advance to be considered before major corn management decisions are made (sowing dates, fertilizer dose, hybrid selection, plant density, etc.). For Pi and Pii we calculated at every county, coefficient of variation (CV) of dY, r coefficient and coefficient of determination (r^2) between the JJA-ONI and corn dY.

GIS was used to map the following for both periods in each county: (1) r^2 between JJA-ONI and dY; (2) Pearson coefficient between JJA and NDJ-ONIs and dY; (3) Counties where r was significant at 5 and 1%, differentiating them from those without significant correlation and (4) CV of dY.

Table 1. Correlation between NDJ-ONI and previous ONIs for Pi and Pii.

	JJA	JAS	ASO	SON	OND
Pi	0.88	0.92	0.95	0.98	1.00
Pii	0.91	0.92	0.94	0.96	0.99

Table 2. Location of the CMS analysed.

Province	County	Longitude (W)	Latitude (S)
Buenos Aires	9 de Julio	60.95	35.46
	Balcarce	58.30	37.75
	Bordenave	63.02	37.85
	Pehuajó	61.83	35.87
	Pergamino	60.55	33.93
	San Pedro	59.68	33.68
	Tandil	59.33	37.23
Entre Ríos	Concepción	58.35	32.49
	Concordia	58.03	31.38
	Paraná	60.54	31.85
	Villaguay	59.01	31.87
Santa Fe	Ceres	61.96	29.87
	Rafaela	61.55	31.18
	Reconquista	59.70	29.18
	Rosario	60.83	32.92

2.5. JJA-ONI spatial score

Maps were performed showing, for each county, the percentage of El Niño (La Niña) years determined by JJA and NDJ-ONIs, with corn $dY > 1$ ($dY < 1$) for Pi and Pii.

2.6. Correlation between JJA-ONI and November–December–January detrended rainfall

To determine whether the relationship between the ONI and rainfalls has changed along time, we calculated the significance of the correlations between the accumulated NDJ detrended rainfall from each time series (Pi and Pii) with their immediately preceding JJA-ONI (e.g., 2000/2001 NDJ and 2000 JJA-ONI). During such trimester (NDJ) accumulated rainfalls are highly correlated with ENSO within the region (Berri and Bertossa (2004), Ropelewski and Halpert (1989); Seiler and Vinocur (2004)). Similarly, r^2 of JJA-ONI against NDJ detrended rainfall data from 11 conventional meteorological stations (CMS) was calculated. The time series of accumulated rainfall for November–December–January (NDJ) were obtained from the following CMS of the National Meteorological Service: 9 de Julio, Balcarce, Bordenave, Pehuajó, Pergamino, San Pedro and Tandil from the province of Buenos Aires; Concepción, Concordia, Paraná and Villaguay from the Entre Ríos province; and Ceres, Rafaela, Reconquista and Rosario from the Santa Fe province (Table 2).

3. Results

3.1. Time series splitting

Figures 1(a)–(c) show the evolution of corn yields from BA, ER and SF, respectively, for both periods. Figure 1(d)

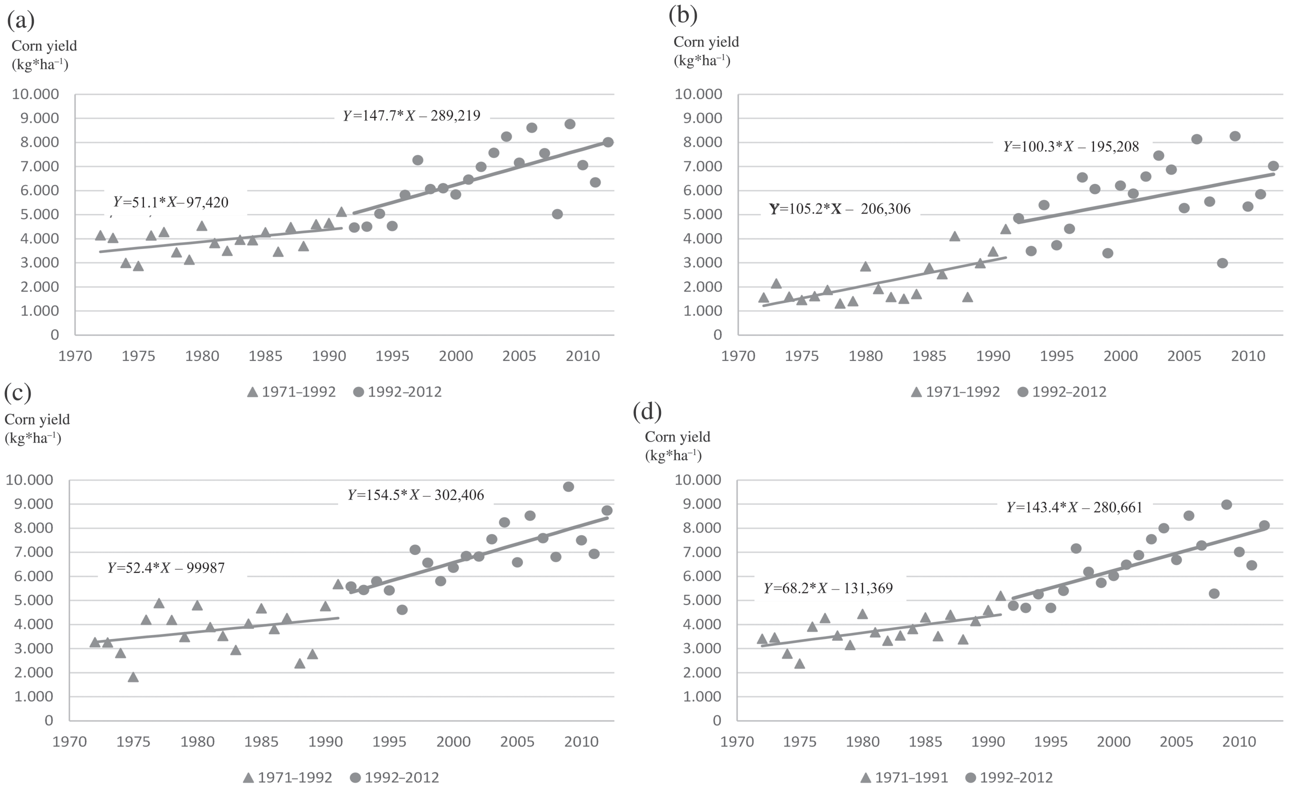

Figure 1. Average corn yields for Pi and Pii in Buenos Aires (a), Entre Rios (b), Santa Fe (c) provinces and the whole region (d).

shows corn yield for the whole area. The trend equation of Pi shows TI-related yield increases of 51 ± 43, 105 ± 58, 52 ± 76 and 68 ± 44 kg ha^{-1} year^{-1} for BA, ER, SF and the entire region, respectively. While a slope increase between periods of ca. 100 kg ha^{-1} year^{-1} was observed for BA and SF, the slope for ER decreased 5 kg ha^{-1} year^{-1}. However, ER was the only province with an increase in the *y*-intercept. Furthermore, it was the province with the highest interannual yield variability for both periods. This could be due to the high soil variability characteristic of this province (Jones, 2000)

3.2. Spatial distribution of corn yield and percentage of yield increase between periods

Figures 2(a) and (b) show average county corn yields for the periods Pi and Pii, respectively. The most productive area was located in the southern part of SF and north of BA during Pi. This highly productive area (darker counties in Figures 2(a) and (b)) shifted northwestward in Pii. The most productive counties showed low yield increases between periods (Figure 2(c)). This could be due to the fact that, during Pi, the highest yielding counties were closer to reaching corn potential yields than the rest. The displacement of corn by soybeans from the most fertile land might also explain the lower yield increases in Pi's highest yielding counties (Grau *et al.*, 2005). The western and northern counties of ER presented the highest yield increases (more than 150%) among all the counties analysed.

3.3. Chow test to assess trend differences between periods

The null hypothesis (Ho: the regression coefficients of corn yield against year are the same for both periods in the time series) was rejected for BA, ER, SF and the whole area studied with an α of 0.064, 0.17, 0.032 and 0.11, respectively. Except for ER, a significant trend increase between periods was noticeable. This low significance in the trend increase in corn yield for ER could be due to the high variability of soils in the province, since only the southwest part presents fertile land comparable to that of the main corn production areas from BA and SF.

3.4. Correlation between ONI and corn yield departure from trend (dY); and coefficient of variation of dY

Table 3 shows the distribution of ENSO phases in the time series, analysed by the value of the JJA and NDJ-ONIs. It can be noticed that in most years ENSO was in the neutral phase ($n = 24$) in JJA, while the warm and cold phases occurred in only 8 and 9 years, respectively. For NDJ, the phases were distributed more evenly with 14, 12 and 15 years with El Niño, La Niña and Neutral phases, respectively.

Figure 3 shows the r^2 between JJA-ONI and dY for every county. The fraction of dY variability explained by the JJA-ONI increased remarkably from Pi to Pii. However, the r^2 of many counties from the northern part of BA were lower in Pii. In Pi, the JJA-ONI explained between 26 and 37% of dY variability in 7% of the counties assessed,

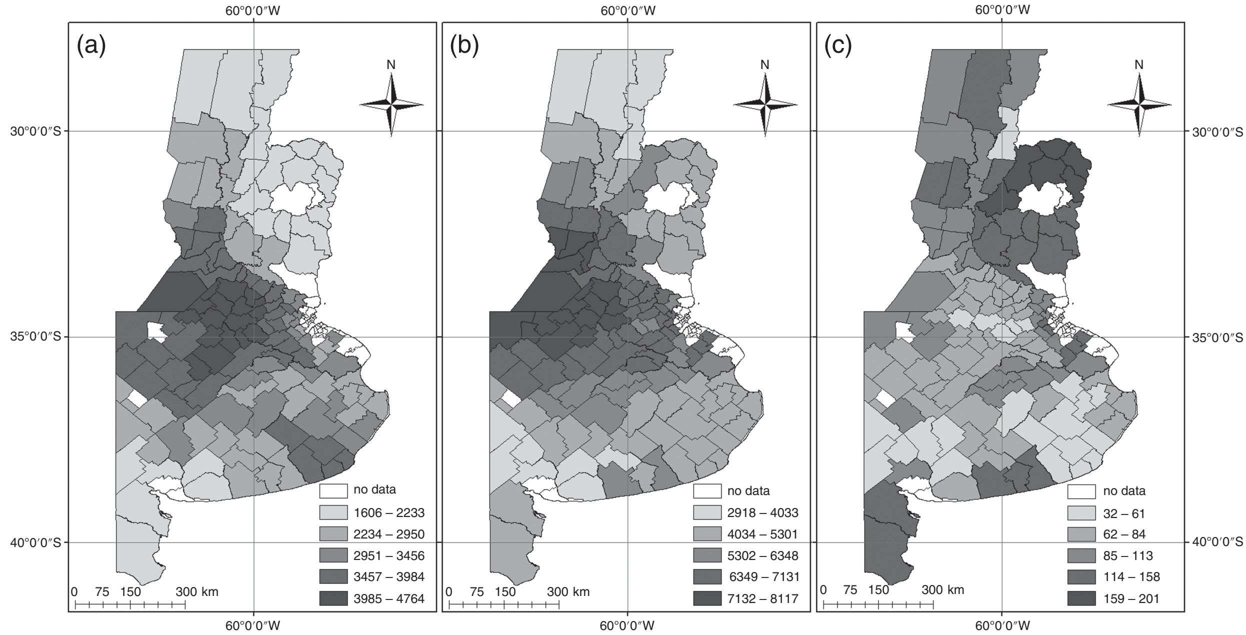

Figure 2. Average county corn yields for Pi (a) and Pii (b); (c) Percentage of corn yield increase between periods.

Table 3. Distribution of ENSO phases based on the JJA-ONI and NDJ-ONI.

JJA-ONI				NDJ-ONI		
El Niño	La Niña	Neutral		El Niño	La Niña	Neutral
1972	1973	1976	1993	1972	1973	1978
1982	1974	1977	1994	1976	1974	1980
1987	1975	1978	1995	1977	1975	1981
1991	1988	1979	1996	1979	1984	1983
1992	1998	1980	2001	1982	1988	1985
1997	1999	1981	2003	1986	1995	1989
2002	2000	1983	2005	1987	1998	1990
2004	2010	1984	2006	1991	1999	1992
2009		1985	2007	1994	2000	1993
		1986	2008	1997	2007	1996
		1989	2011	2002	2010	2001
		1990	2012	2004	2011	2003
				2006		2005
				2009		2008
						2012

while in Pii it explained between 26% and 50% of the dY variability in 34% of the counties.

Figure 4 shows the regression of dY against the JJA-ONI in Pii for three different counties (one county per province). If actual yield (Y) of a particular year equals Yt ($dY = 1$), data should match the dotted line. Years above (below) the dotted line represent observed yields higher (lower) than expected. Remarkably, with positive values of JJA-ONI (11 years), corn dY below 1 occurred in only 2 years in the counties of Castellanos and San Nicolas and in 4 years in Tala. On the other hand, with negative values of JJA-ONI (9 years), corn dY was higher than 1 in only one year in Tala. In Castellanos and San Nicolás, all the years with negative JJA-ONI presented corn dY close to or lower than 1. For both periods, correlations between the JJA and NDJ-ONIs and corn dY, and their significance are shown for each county in Figures 5 and 6. The number of counties showing significant correlations between both ONIs assessed and corn dY increased markedly from the first to the second period. The area with significant correlation in Pi was higher with JJA-ONI than with the NDJ one, while the opposite happened in Pii. Counties that most consistently presented a significant correlation in Pii were located in the southern and central part of SF, northern part of BA and in the entire province of ER. In northern BA, the counties with most significant correlations shifted eastward from Pi to Pii. The central region of SF and the entire province of ER showed a remarkable contrast between periods, from only a few counties in Pi to most of them in Pii presenting a significant correlation. The rest of the region under analysis did not present significant correlations for either period. Remarkably, most of the counties with a significant correlation in Pii were outside of the area with the highest yields, and most of them presented high yield increases between periods (Figures 2(b) and (c)).

Figure 7 shows the coefficient of variation (CV) of corn dY per county for both periods. In most cases, there was a decrease in CV between periods, suggesting a lower response of corn yields to climatic variability and hence a higher stability. For both periods, the most productive counties (Figure 2) were those with lower CV. Entre Ríos showed the highest variability in dY, whereas most counties from BA presented the lowest variability in both periods, in line with the results obtained using province average yields (Figure 1).

3.5. JJA-ONI spatial score

The effect of ENSO phase on corn dY is shown in Figure 8 as percentages of El Niño (La Niña) years with $dY > 1$

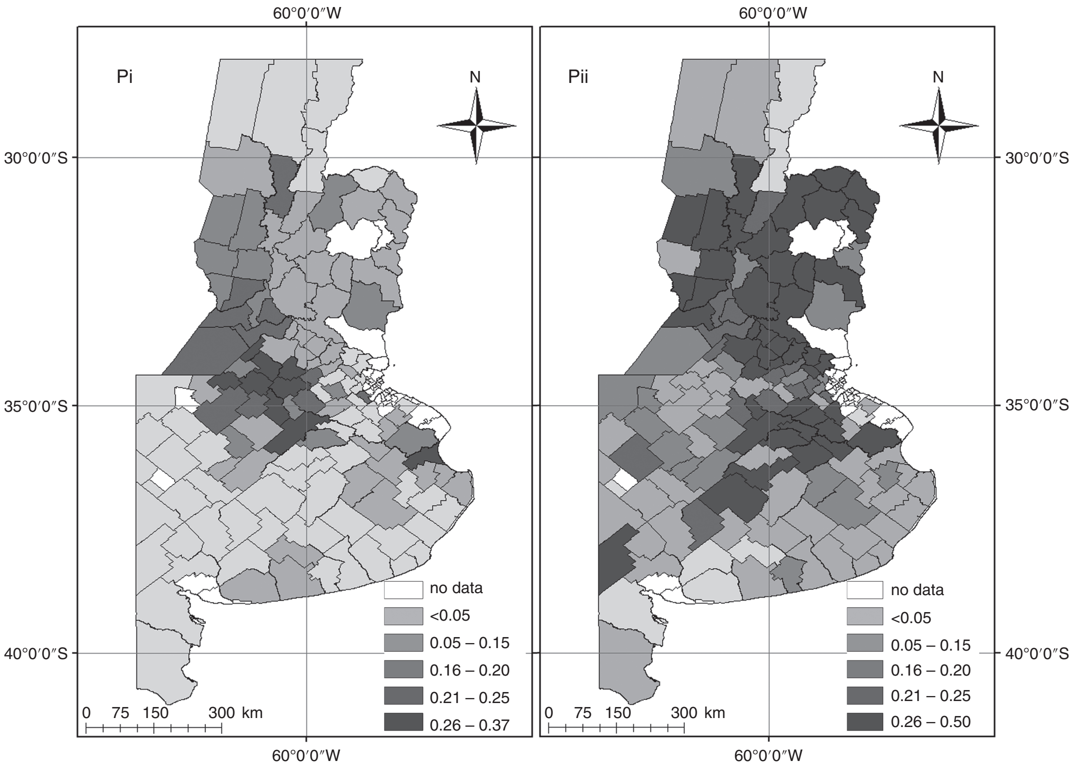

Figure 3. Determination coefficient (r^2) between corn dY and JJA-ONI.

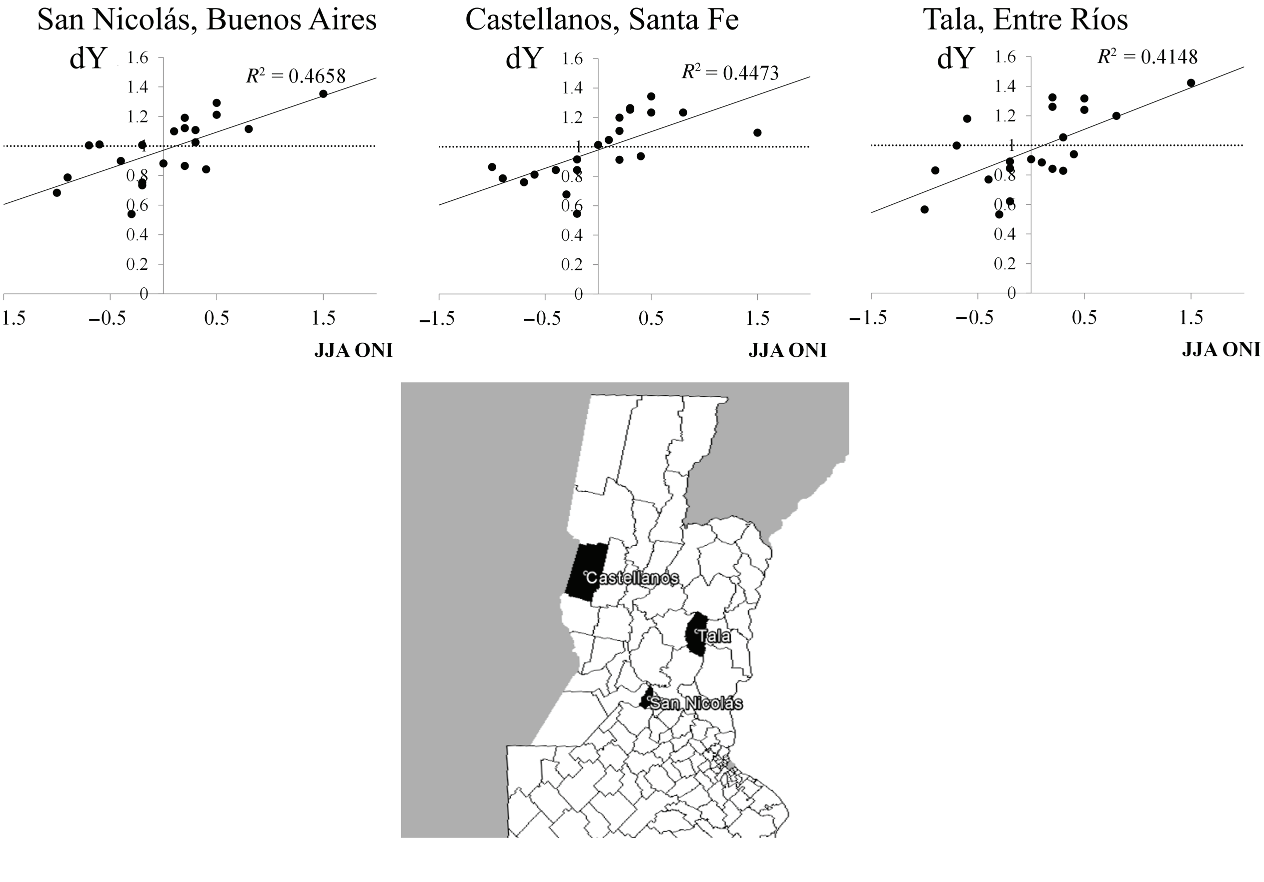

Figure 4. Linear regression and coefficient of determination between JJA-ONI and dY in three different counties for Pii.

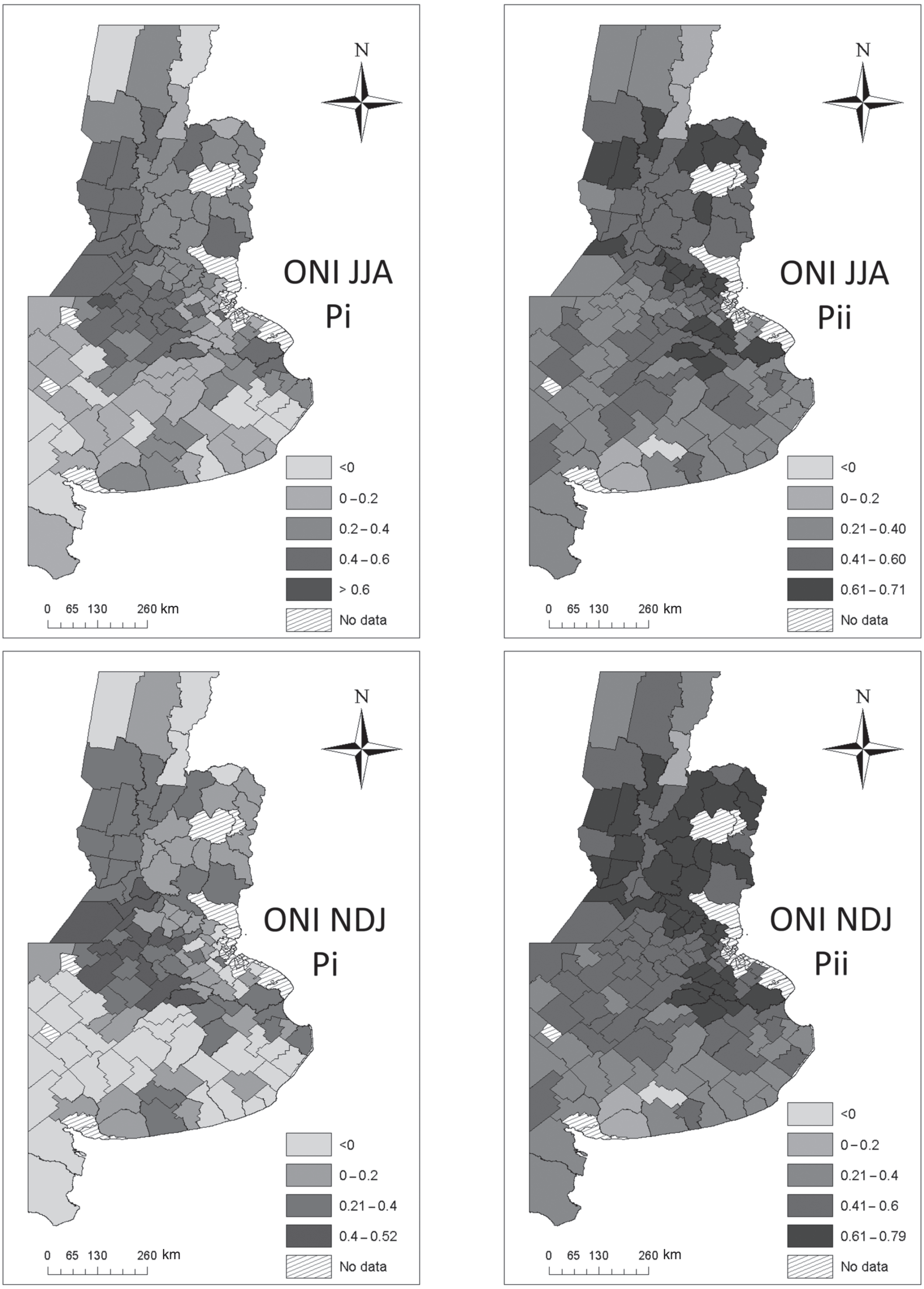

Figure 5. Pearson Coefficient (r) between HA and NDJ-ONIs and corn dY for Pi and Pii.

($dY < 1$). Remarkably, the dY in a vast region (which includes the highest yielding counties) was above 1 in more than half El Niño years for both periods regardless of the ONI considered. Specifically for Pii, the dY of many of these counties, as well as that of the southwest of ER, was above 1 in more than 76% of the years of that phase. In La Niña phase, almost all counties had a dY below 1 at least in 50% of the years both for Pi and Pii, also regardless of the ONI considered. The best scores were obtained in Pii and with the NDJ-ONI for both phases.

3.6. Correlation between JJA-ONI and NDJ detrended rainfall

Figure 9(a) shows the location of the CMS used in the study. The r^2 of JJA-ONI against the NDJ accumulated detrended rainfall for both periods is shown in Figure 9(b). Interestingly, there was a clear increase of r^2 from Pi to

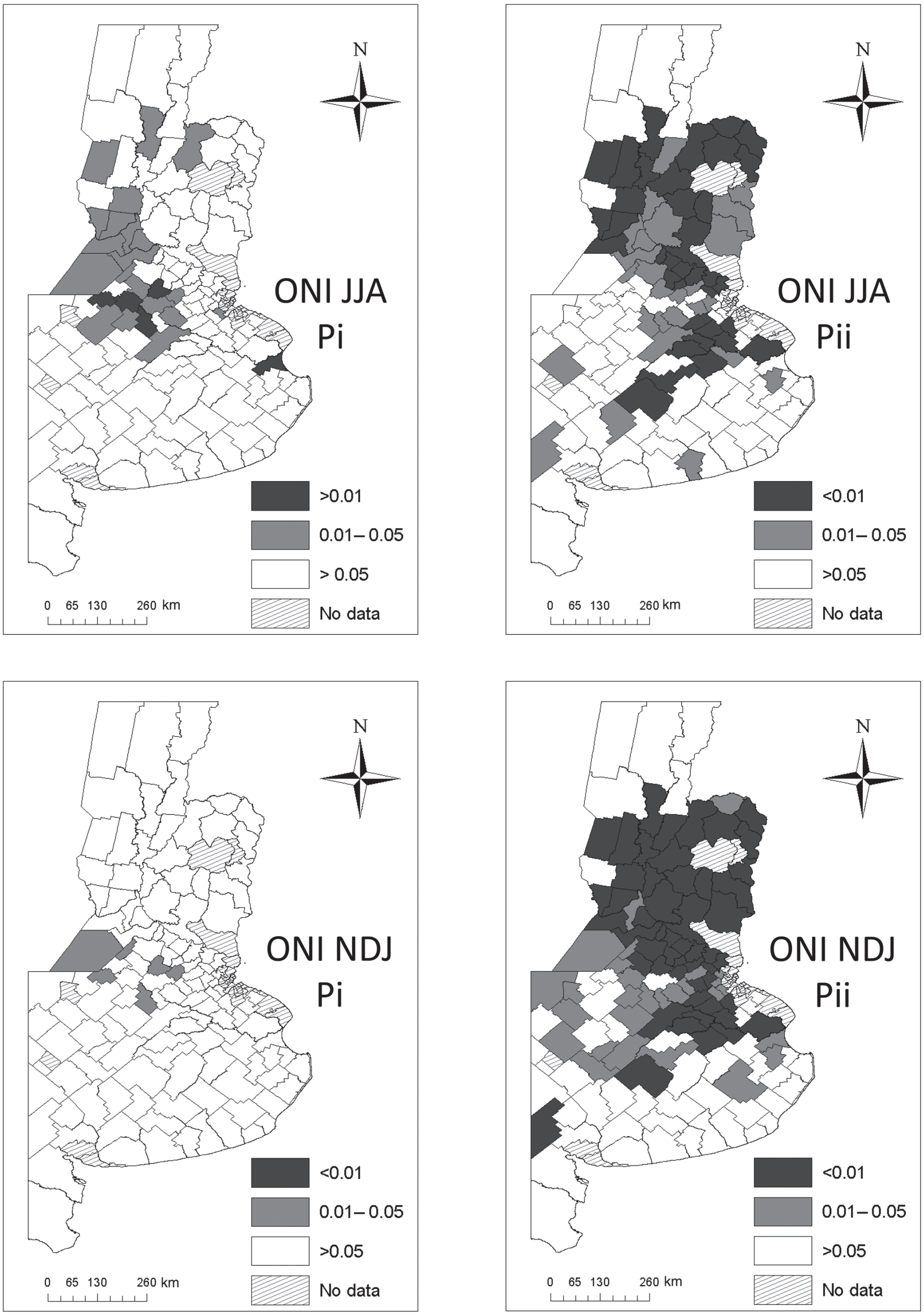

Figure 6. Counties with significant ($P < 0.05$ and $P < 0.01$) correlation between JJA and NDJ-ONIs and corn dY.

Pii in most of the CMS, in line with the increase found in the correlation between JJA-ONI and dY (Figure 5). The most striking result to emerge from the data was observed in three locations of ER (Paraná, Concepción and Concordia), where the JJA-ONI in Pii explained more than 50% of the NDJ accumulated rainfall variability.

Table 4 shows the correlation between the NDJ-ONI and NDJ detrended rainfall of the CMS analysed. Only in Bordenave, Balcarce, Pehuajó and 9 de Julio, neither of the periods presented significant correlations. In the rest of the stations, except in Ceres, the correlation increased from Pi to Pii being significant in Pii. Tandil had a negative (non-significant) correlation in Pi.

4. Discussion

The correlations between JJA-ONI and dY increased strongly from Pi to Pii in a wide region of the central part of Argentina. Two interacting factors could explain this behaviour, although others might be involved: (1)

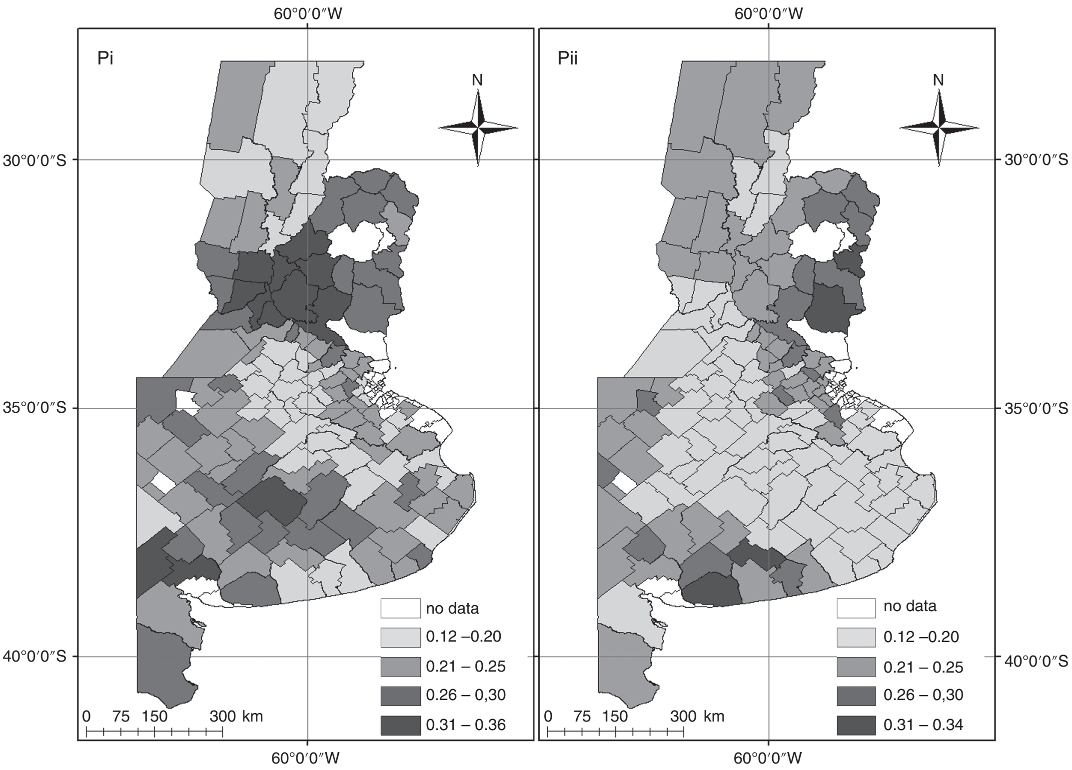

Figure 7. Coefficient of variation of corn dY.

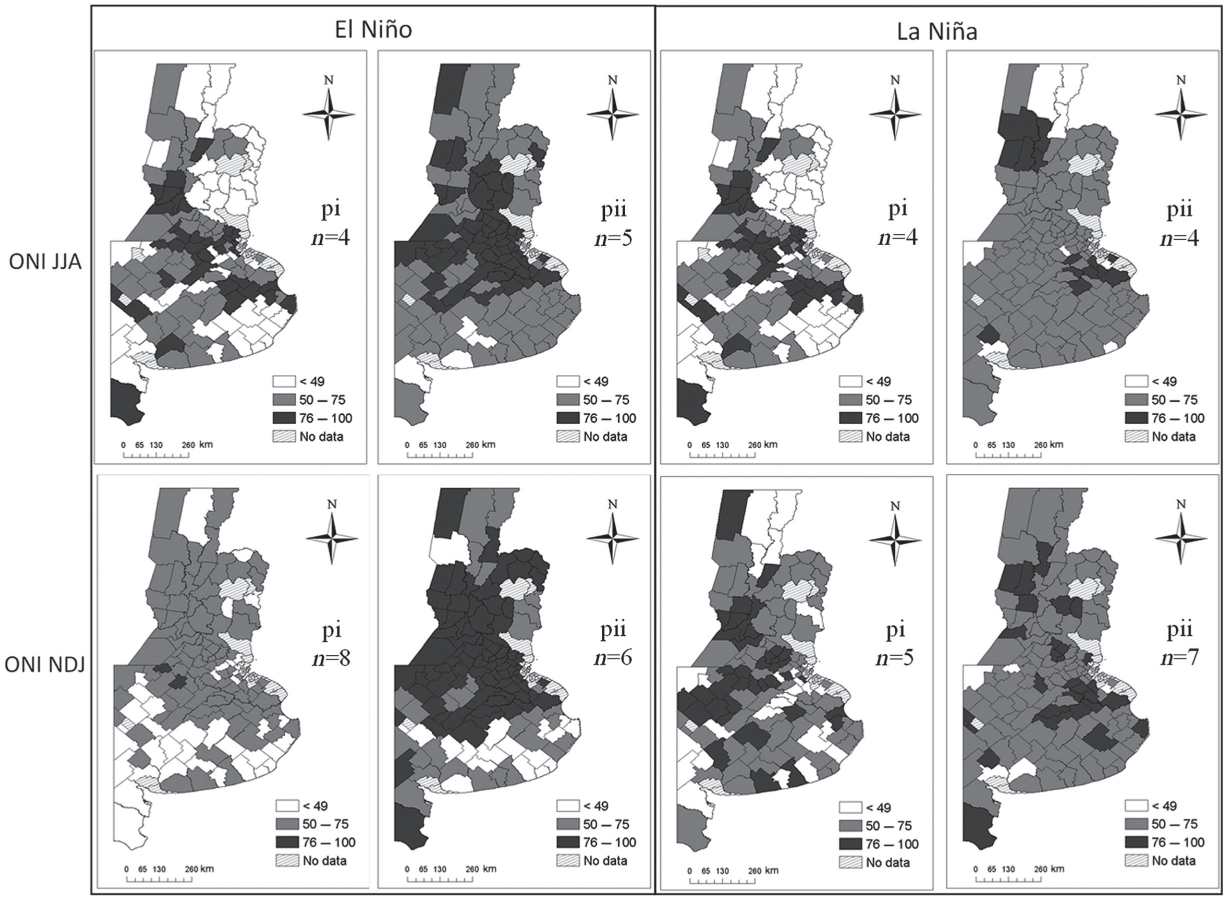

Figure 8. Percentage of El Niño (La Niña) years with corn dY above 1 (below 1) characterizing the phase with the JJA and NDJ-ONIs for Pi and Pii (n: number of years per phase).

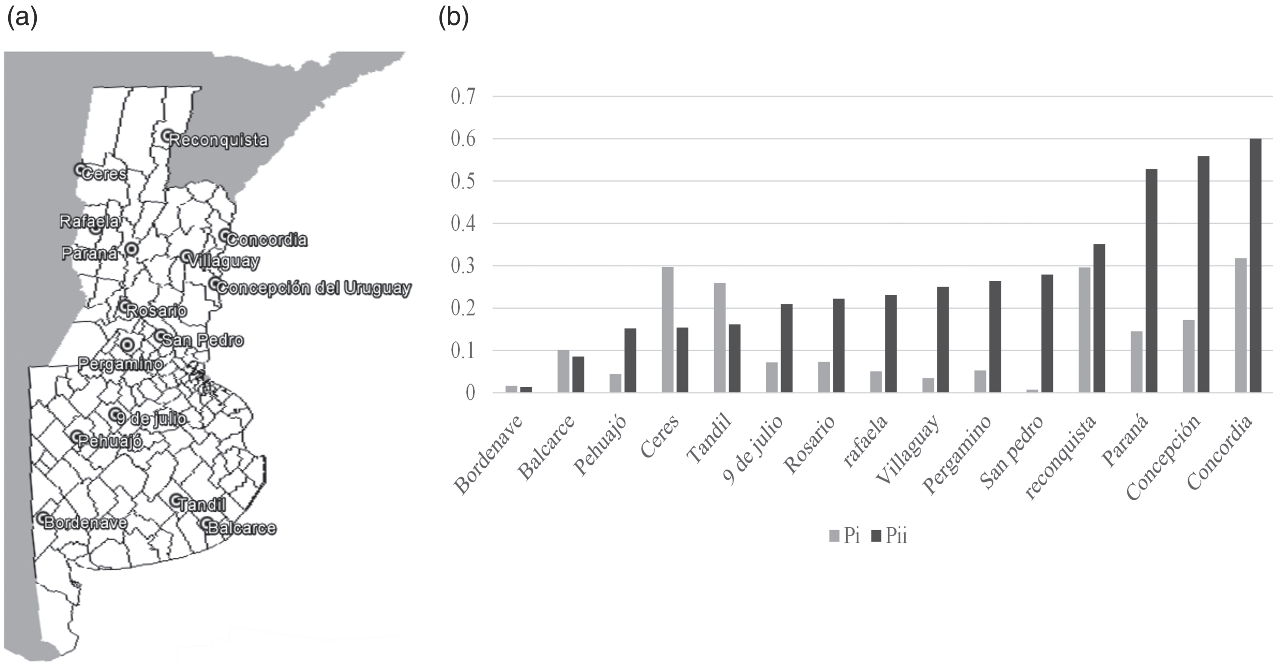

Figure 9. (a) Map of the three provinces showing the CMS analysed and (b) r^2 of NDJ precipitation and JJA-ONI of both periods.

Table 4. Correlation between the NDJ-ONI and NDJ rainfalls in the analysed CMS.

Location\period	Pi	Pii
Rafaela	0.29	0.46*
Reconquista	0.64**	0.68**
Paraná	0.36	0.82**
Concepción	0.32	0.77**
Pergamino	0.24	0.58**
Balcarce	0.22	0.24
San pedro	0.09	0.59**
Bordenave	0.32	0.08
Concordia	0.50*	0.83**
Ceres	0.46*	0.36
Rosario	0.27	0.58**
Tandil	−0.42	0.54*
Pehuajó	0.20	0.36
Villaguay	−0.27	0.57**
9 de julio	0.19	0.42

*Values represent significant correlations with $P < 0.05$. **Values represent significant correlations with $P < 0.01$.

increased correlations of JJA-ONI and summer rainfall for most of the region in Pii (Table 4); (2) higher responses of corn yields to good weather conditions in Pii associated to higher use of technological improvements that help overcome yield-limiting factors (such as low nitrogen availability or pest damage) when water is not limiting.

The phase of ENSO had different effects on corn dY over the region. As expected, El Niño (La Niña) phase resulted in higher (lower) corn dY. However, La Niña phase impacted over a wider region, which agrees with results reported by other authors (Ropelewski and Halpert, 1996).

The coefficient of determination (r^2) between the JJA-ONI and summer rainfall increased remarkably from Pi to Pii. In Pii, the JJA-ONI explained a high fraction of summer rainfall variability in many locations of central Argentina, explaining as much as 60% of its variability in Concordia. Few works have documented the temporal variations in the correlation between ENSO indexes and rainfall in different regions of the world. Janicot *et al.*(1996) reported increases in the correlation between the Southern Oscillation Index (SOI) and summer rainfall in Sahel. Other authors found gradual increases in sliding correlations on a 21-year moving window between sea surface temperature (SST) of El Niño 3.4 region and winter precipitations in northwest India (Yadav *et al.*, 2010). Aceituno *et al.* (1993) found oscillations in a 30-year sliding correlation in two locations in central and northeast Argentina, reporting a decrease until 1950 and a subsequent increase until 1970. Diaz *et al.*(2001) reported the variability in the correlation between ENSO and rainfall in many regions of the world.

We found statistically significant differences in yield trends between periods with a higher trend in Pii. The main reason of this increase could be a significant change in the level of imported inputs and technology applied in the agricultural sector. This is an example, sustained with statistically significant evidence, of how economic policies can have repercussions on agriculture. Similarly, Simonyan and Omolehin (2012) found a positive impact in the net income of farmers that were beneficiary of a stimulus programme aimed at investment on irrigation facilities in a state of Nigeria, compared to those not involved in the program.

Even though the ONI has been used in previous research for this region of Argentina, most of this research has focused on rainfall (Berri and Bertossa, 2004; Rivera and Penalba, 2014), and only one research has assessed its correlation with corn yields in clusters of counties (Fernández Long *et al.*, 2011). Iizumi *et al.* (2014) studied corn yield anomalies related to ENSO characterized by the ONI at a global scale, reporting significant positive impacts of El Niño phase and non-significant negative impacts of La Niña phase for the central region of Argentina. Travasso *et al.* (2009) assessed three indicators for corn, soybean and sunflower yield variability: the Southern Oscillation index (SOI), Sea Surface Temperatures from the Equatorial Pacific (SSTN3), and South Atlantic (SSTSA) Oceans. They found that SOI was the best indicator of corn yield variability. Our research is the first to report the performance of the ONI as an indicator of corn yield variability at a county scale in the central region of Argentina.

Wise use of reliable forecasts should lead to an increase in corn yields in both wet and dry seasons. Unfortunately, validated information regarding ENSO and its consequences in the region seems to be unfamiliar to stakeholders. Boulanger and Penalba (2010) interviewed seventeen agribusiness companies from Argentina about the use of forecasts for their decisions, finding that even though most of them recognized the influence of climate on their activities, they did not consider it when making their decisions. A field survey of about 200 farmers from the region revealed that even though most farmers know about ENSO, they did not consider it for management decisions. Furthermore, their knowledge about the regional variability of its effect on weather and crop production was incomplete (Letson *et al.*, 2001)

5. Conclusions

The JJA-ONI was shown to correlate well with corn dY, showing a significant correlation in many counties of the region analysed ($P < 0.01$). Compared to other indexes related to corn yield, this one has the clear advantage of being available soon enough to be considered for corn management decisions each year before the corn sowing season begins. Since corn production is highly dependent of rainfall during the corn critical period, which takes place sometime between November and January in the region analysed, our results provide valuable information that should be at least considered by farmers aiming to plant corn.

We found that in most of the assessed region, correlations between JJA-ONI and rainfalls have grown markedly from Pi to Pii. We believe that the variability of such correlation should be monitored frequently in order to report any significant change. Moreover, further research should be undertaken to assess its performance as a rainfall and yield predictor. Soil variability among counties is another variable to consider when studying corn yield variability.

Among the summer crops, corn is the most risky option from a profitability perspective because it is the most expensive to plant. Corn yield was noticeably lower and more variable in ER than in BA and SF. We attributed this higher variability to the poor soils of the central and northern part of ER. Thus, crop production in general, and of corn in particular, poses higher risks in ER, hence conditioning technology adoption.

This research found vital evidence regarding corn yield and summer rainfall correlations with ENSO for a wide and highly productive area of Argentina. Properly used, this information could help reduce corn yield losses during dry seasons or allow exploiting yield potential during wet seasons. It is crucial to note that the JJA-ONI is available well in advance to be considered by corn growers for their main management decisions such as: (1) surface allocated to this crop or displacement by species more efficient in water use; (2) dose of fertilizers; (3) planting dates; (4) plant densities and (5) choice of hybrids of high potential yield or stability. Even though JJA-ONI was chosen for the analysis, subsequent ONIs (July–August–September; August–September–October) present better correlations with summer rainfalls and with dY. Therefore, the ONI should be monitored along the corn-growing season in addition to being considered for management decisions (e.g. nitrogen fertilization or insect and diseases management).

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