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Impact valuation of droughts in soybean and maize production: the case of Argentina

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Abstract

Purpose – In Argentina, soy and maize represent 28% of the total country exports, affecting the balance of payments, international reserves accumulation and sovereign credit risk. In the past 10 years, three extreme and moderate droughts have affected the agricultural areas, causing significant losses in soybean and maize production. This study aims to estimate the economic impact generated by different drought levels for soy and maize production areas through a financial perspective that allows the estimation of the cash flow and income losses.

JEL classification – Q1, Q14

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Design/methodology/approach – By analyzing the extreme deviations in yields during dry periods, the losses generated by droughts were valuated among 183 departments nationwide.

Findings – The aggregated results indicated a total loss of US$24.170m, representing 57.45% of the international reserves of the Argentinean Central Bank in 2021. This estimate shows the magnitude of the climate impact on the Argentinean economy, indicating that severe droughts have macroeconomic impacts, with the external sector as the main transmission channel in an economy with historic restrictions on the balance of payments, international reserve accumulation and sovereign credit risk.

Originality/value – This study analyses the macroeconomic impact of drought on Argentinean soybean and maize production.

Keywords Soy, Maize, Drought, Palmer Drought Severity Index, Climate change, Economic impact

Paper type Research paper

Introduction

The growth and development dynamics of many Latin American countries are linked to the exportation of natural resources. International commodity price volatility and world demand affect the domestic macroeconomy through at least three transmission channels:

(1) international reserve generation;

(2) internal economic activity; and

(3) public sector revenues, given the bias of taxation toward natural resources (United Nations Economic Commission for Latin America and the Caribbean, 2021).

Falls in international commodity prices amplify the volatility of the growth rate, reduce long-term growth and increase the risk of generating a crisis in the balance of payments (Bravo-Ortega and De Gregorio, 2007; Briguglio *et al.*, 2008; Canuto and Cavallari, 2012; Céspedes and Velasco, 2012; Ffrench-Davis, 2005; Frankel, 2011; Gala, 2008; Guillaumont, 2009; Montalbano, 2011; Ocampo, 2007; Rodrik, 2008; Seth and Ragab, 2012).

In the case of Argentina, the agricultural sector had a high incidence in the net exports and domestic economic activity: primary products and agricultural produce represented 60% of the total country exports in 2009–2018, whereas agroindustry accounted for at least 12.8% of the gross domestic product (GDP). If the entire agroindustry supply chain (transport, commerce and services) will be considered, the GDP incidence will be considerably higher (Massot *et al.*, 2016).

Soy and maize have the highest incidence of total exports. Argentina is the third biggest soybean producer in the world and the top exporter of soybean mill and oil. These three products account for 23% of the total country exports. As for maize, although far below 5% of the total exports, there has been an increase in its production in recent years. In addition, together, soy and maize represent 28% of the total country exports, representing an annual flow of US$24.253m (60% of the 2021 Argentinean international reserves).

Climate affects directly agricultural production, and one consequence of climate change is the increase of climate variability (Barros *et al.*, 2015; Intergovernmental Panel on Climate Change, 2012; Magrin *et al.*, 2014; United Nations International Strategy for Disaster Reduction, 2013; World Meteorological Organization, 2014). In the case of Argentina, extreme precipitation events, such as extreme rainfall are expected to increase in frequency and intensity (World Bank, 2021). Also, the country is overall expected to experience increased temperatures which will likely exacerbate existing tensions for water in the agricultural sector (World Bank, 2021). More specifically, in the studied agricultural area, the Copernicus Database (2022), which provides projections of various climate variables from many models in the framework of the sixth phase of the Coupled Model Intercomparison Project developed to support the 6th Assessment Report of the Intergovernmental Panel on Climate Change, shows an 65% increase in the frequency of extreme low rainfall levels for the next 20 years, considering the average of 130 climate models of the five shared socioeconomic pathways scenarios.

This change in the dynamics of rainfall and temperature may affect the growth structure of countries dependent on agricultural export commodities. Water shortages directly affect soy and maize production in Argentina, especially during the growth period in January and February. Low rainfall levels and low hydraulic reserves generate significant production losses. In the past 20 years, three extreme droughts (2008, 2011 and 2017) and seven moderate droughts (2003, 2005, 2007, 2010, 2012, 2013 and 2015) have affected agricultural areas, causing significant losses in soybean and maize production.

Despite the fact that several studies have been conducted on the impact of climate change on Argentinean agriculture (Murgida *et al.*, 2014; De Zarate *et al.*, 2014; United Nations Economic Commission for Latin America and the Caribbean, 2014, 2018) and the impact of climate variability (Bert *et al.*, 2006; Hansen *et al.*, 2004; Heinzenknecht, 2011; Letson *et al.*, 2005; Letson *et al.*, 2009; Lozanoff and Cap, 2002; Magrin *et al.*, 2014; Podestá *et al.*, 2002; Podestá *et al.*, 2013; Rajagopalan *et al.*, 2009), none of them have estimated the total monetary losses incurred by all agricultural areas during droughts.

In addition, despite the economic incidence of soy and maize, there are no available macro models for estimating the impact of droughts on agricultural areas from a financial perspective. Thus, the present study was conducted to develop a model capable of providing an estimate of monetary losses generated by different drought levels for soybean and maize production areas with a financial perspective that allows the estimation of the cash flow of profits and losses.

The aim of this paper is to take the first step toward a climate risk management process. Integrated risk management traditionally lists four or five steps: identification, evaluation, monitoring and mitigation or adaptation. In the case studied, climate risk factors have already been identified for soybean production. However, the following steps have not yet been analyzed. Therefore, the main contribution of this paper will be to relate climate models to impact evaluation, providing the estimates necessary for mitigation or adaptation strategies, contributing to a data-driven policy action framework. The estimation of losses during droughts is the first step in determining the scale of impact necessary to design investment vehicles for financing adaptation strategies in the context of climate change, such as irrigation, index-based insurance and fiscal aids. Moreover, in the case of Argentina, it provides insights into the quantification of macroeconomic risk (Seth and Ragab, 2012), fiscal risks for budgetary planning (World Bank, 2017; International Monetary Fund, 2016) and sovereign debt sustainability (Pinzón *et al.*, 2020).

This paper is structured as follows. Section 1 presents a literature review related to climate impact modeling on crops. Section 2 presents the materials and methods developed to assess the case studied. Section 3 analyses the study results. Finally, Section 4 presents some concluding remarks.

Literature review

Several methods for determining the economic impact of climatic events in the agricultural sector can be found in the literature. Following Giannakopoulos *et al.* (2009) and Roudier *et al.* (2011), three main approaches can be summarized: crop simulation models, Ricardian analysis and statistical modeling.

Crop simulation models study the relationship between harvestable land, existing technology and climate conditions. The primary objective is to design a harvesting strategy (Motha, 2011). According to Motha (2011), crop growth simulation models study the various parameters of a crop to predict what may happen over time when a climatic event occurs or when the cropping strategy is modified. These models are widely used but require much data to implement. To carry them out, the Decision Support System for Agrotechnology Transfer software is used (Jones *et al.*, 2003). In Argentina, Aramburu Merlos *et al.* (2015) used a crop simulation model to analyze how wheat, maize and soybean production would have varied by simulating different water availability scenarios. They concluded that the yield gap is larger in wet years and that water is not used optimally. These models are thus designed to analyze improved harvesting strategies at local levels and require extensive data sets; they are not originally designed for economic valuation, which will be discussed in this article.

The Ricardian approach was developed to study long-term adaptation to climate impacts on agriculture (Mendelsohn *et al.*, 1994; via Bozzola *et al.*, 2017). This approach measures how climate events or other factors can influence the value of land (Vanschoenwinkel *et al.*, 2016) or benefit farmers (Deschenes and Greenstone, 2007; Roudier *et al.*, 2011). Seo and Mendelsohn (2007) used it to determine how technological or socioeconomic variables, in addition to climate, influence the value of land. Deschenes and Greenstone (2007) used the Ricardian approach to study the economic impact of climate change on the main crops produced by the USA. López and Hernandez (2016) reported the main criticisms that the approach had received :

- that it is a long-term model that does not provide much information on how it is performed (Reilly, 1999); and
- that it is a method of static comparison and assumes that the best conditions are adjusted during their estimation (Mendelsohn, 2009).

Regarding statistical modeling, unlike the Ricardian models that explain the impact of climate on the price of land, this approach tries to explain the impact of climate on production, changes in crop yields or sectorial GDP. Thomasz *et al.* (2017) divided statistical modeling into three subcategories: the macroeconomic, structural and empirical time series variability approaches.

The macroeconomic approach (Inter-American Development Bank–United Nations Economic Commission for Latin America and the Caribbean–National Planning Department, 2014) is based on information from national accounts and estimates the impact of climate on each sector of activity in terms of GDP. Based on a stochastic general equilibrium model, the climate variable is incorporated into different scenarios provided by the Intergovernmental Panel on Climate Change to see how it affects the productivity of each sector (Inter-American Development Bank–United Nations Economic Commission for Latin America and the Caribbean–National Planning Department, 2014). Ferreira-Filho (2021) implemented this approach through a computable general equilibrium model for two different climatic scenarios in Brazil. The results showed how three climate shock scenarios could affect the economy. The main results were that in the intermediate carbon emissions scenario, there is a major loss of arable area and climate shocks affect more vulnerable regions that are more dependent on agriculture. In Argentina, Corfield *et al.* (2020) used a vector autoregressive model to estimate impulse–response functions relating aggregated variables, such as consumption, exports, investment, agricultural GDP, total GDP and exchange rate, to changes in precipitation levels. The results showed that the first five variables responded positively to a precipitation shock, whereas the exchange rate responded negatively, generating an appreciation of the local currency. The strength of the macroeconomic approach lies in its flexibility in analyzing how each sector of the economy varies, but it does not allow for the analysis of more specific climate events or the impact of climate on particular crops.

On the other hand, the structural approach constructs more specific statistical models that estimate changes in yields due to several factors, such as technology, soil quality and any climate event (Chimeli *et al.*, 2008; Lobell and Burke, 2010; Paltasingh *et al.*, 2012; Rahman *et al.*, 2005). These models can be tailored to the scenario under study at a particular point in time (Georgopoulou *et al.*, 2017). The approach estimates yield sensitivity using different methods (commonly least squares) on cross-sectional data for different areas. The model is generally set with the crop yield in each region for a particular time as the dependent variable (Lobell and Burke, 2010; Paltasingh *et al.*, 2012). The independent variables are all those that influence crop yield: climatic, technological or socioeconomic variables. The main advantage of the approach is its ability to analyze cases with enough precision to estimate the sensitivity of yields to specific climatic variables, isolating it from the effects of other variables. This model, although enabling a very comprehensive analysis, is based on assumptions that are susceptible to change over time, and its use requires much data.

Despite the advantages of the structural approach, it requires a large data set to estimate the regression parameters and does not provide a direct estimate of losses due to climate events or a counterfactual scenario for comparison purposes, which is necessary for economic valuations. In addition, it does not consider adaptative behavior, which can be critical in the context of climate change.

Given the limitations of the macroeconomic and structural approaches, the empirical time series variability approach has emerged. It assumes that agricultural production shows two dynamics over time:

(1) a trend, which is mainly explained by technological improvement; and

(2) deviation from the trend, which is explained by exogenous shocks that affect the crop, with climate as the main stressor.

Tannura *et al.* (2008) analyzed this approach by applying it to soybean and corn production in the USA and verified that yields tend to show increases over time, known as trend yields. The study concluded that the potential impact of climate on farms is quite remarkable as predictions based on the perception of an increase in technology can be poor; that is, unfavorable weather conditions can lead to unexplained drops in production despite the increase in technology (Tannura *et al.*, 2008). In Argentina, Heinzenknecht (2011) applied the variability approach by obtaining the trend through an ordinary least squares model to determine the probability of low, normal or high yields during El Niño and La Niña for locations with rainfall data in Argentina. After the trend was obtained, the percentage difference with the observed values was calculated, the deviations were classified into the three categories (low, normal or high yields), and each case was related to the climatic phenomenon of El Niño or La Niña or to neither of them. Finally, the Food and Agriculture Organization of the United Nations (2017) calculated the economic impacts of adverse weather events on agriculture by calculating the long-term trend yields to compare them with the actual production in the years with natural disasters (drought, flood, tropical storm, earthquake or volcanic eruption). Finally, the losses were multiplied by the prices to estimate the monetary values and obtain the economic impacts. The study (conducted for countries in Africa, Asia, Latin America and Eastern Europe) concluded that agriculture and livestock absorb 22% of the economic impacts of natural hazards and that climate change-related natural disasters, such as droughts, account for 25% of the damage and losses in the agricultural sector.

The main components of all the aforementioned approaches are summarized in Table 1.

Table 1.
Summary of impact models

Approach	Independent variable	Main use or result	Scale
Crop simulation	Yield simulation	Farming strategies to optimize yields	Farm level
Ricardian	Impact on land value	Land value pricing, sensibility to each component	Department/county level
Statistical			
Macroeconomic	Impact on gross domestic product or other macro variables	Aggregate effect of climate over macro variables	Unscaled, macrofinance level
Structural	Impact on yields, sensibility analysis	Sensibility of each component	Department or county level
Empirical time series variability	Yield deviations	Detrended event analysis; provision of the difference by year	National/regional/ department/county level

Source: Authors' elaboration from the literature review

Unlike most of the studies with Argentina as the setting, which analyzed the impact of climate on crop yields and quantities in particular cases (specific departments with enough data, experimental farms or simulations for specific areas), the objective of the present study is to provide an overall economic estimate of losses for the total soybean and maize productive area, analyzing not specific cases but the total agricultural territory. Considering the extension and diversity of the productive area and the data limitation for the application of crop simulation or Ricardian analysis, the most appropriate approach is empirical variability analysis. It can be easily used for all production areas with limited information, provides valuation of the monetary flow based on observed cases, allows comparisons over time and between countries (Food and Agriculture Organization of the United Nations, 2017) and extrapolates future valuations. It can also be applied to other crops.

Materials and methods

Materials

The study area included 183 agricultural departments from the top five agricultural provinces in Argentina: Buenos Aires, Chaco, Córdoba, Entre Ríos and Santa Fe (Figure 1). These provinces covered a geographical area with 15 million hectares devoted to soybean production and 7 million hectares devoted to maize production, accounting for 90% of all the areas devoted to the production of the two crops. The remaining 10% was not taken into consideration because it comprises recently developed agricultural areas with an insufficient history for performing a robust statistical analysis.

The data below were systematized at the departmental level.

- Crop data: data on the soybean and maize sown areas, harvest areas, production and yields collected from 1969/1970 to 2019/2020 from the Secretaría de Agroindustria de Argentina (2021).
- Price data: data on the international prices of soybean and maize collected from the Chicago Board of Trade. The first future contract value was selected from the "*t*" moment of the total contract available; the values were scaled in US$/*t*, and the information source was the primary commodity price of the International Monetary Fund.

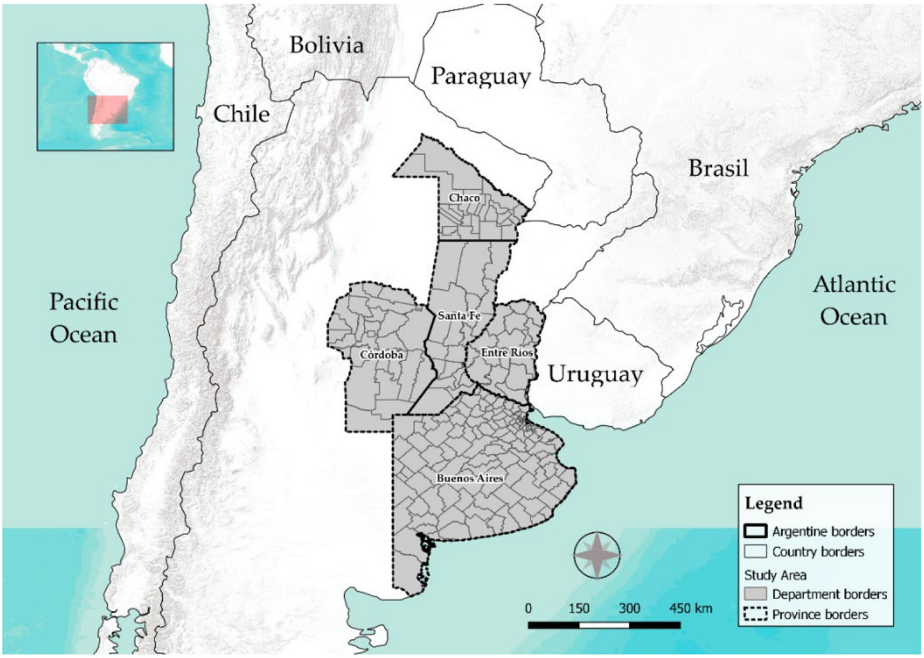


Figure 1. Study area

Source: Authors' elaboration

- Macroeconomic data: data of international reserves and exports, trade balance and balance of payments were taken from the open-access primary sources of the Central Bank of Argentina and the Ministry of Economy (2021).
- Climate data: data taken from the Palmer Drought Severity Index (PDSI), which measures the soil moisture deficiency through three variables: potential evapotranspiration, monthly precipitation and useful soil water content. Primary data source: Centro de Relevamiento y Evaluación de Recursos Agrícolas y Naturales, Universidad Nacional de Córdoba (www.crean.unc.edu.ar); secondary source: weekly agricultural outlook of the Buenos Aires Grain Exchange (2021), which presents the detailed evolution of the sown areas, harvest areas and yields, together with the climate evolution during the entire production cycle.

Figure 2 presents the historic data about the yields, production, sown areas and international prices of soybean and maize for all the studied areas. The method discussed in the next section was used to analyze these variables for each of the 183 departments in the sample.

Methods

Soybean yield variability over time reflects the incidence of several factors that can be classified into two main categories:

(1) technological variables, such as soil quality, seed genetics and producer-level management techniques; and

(2) climatic variables, such as average and maximum temperature and accumulated rainfall.

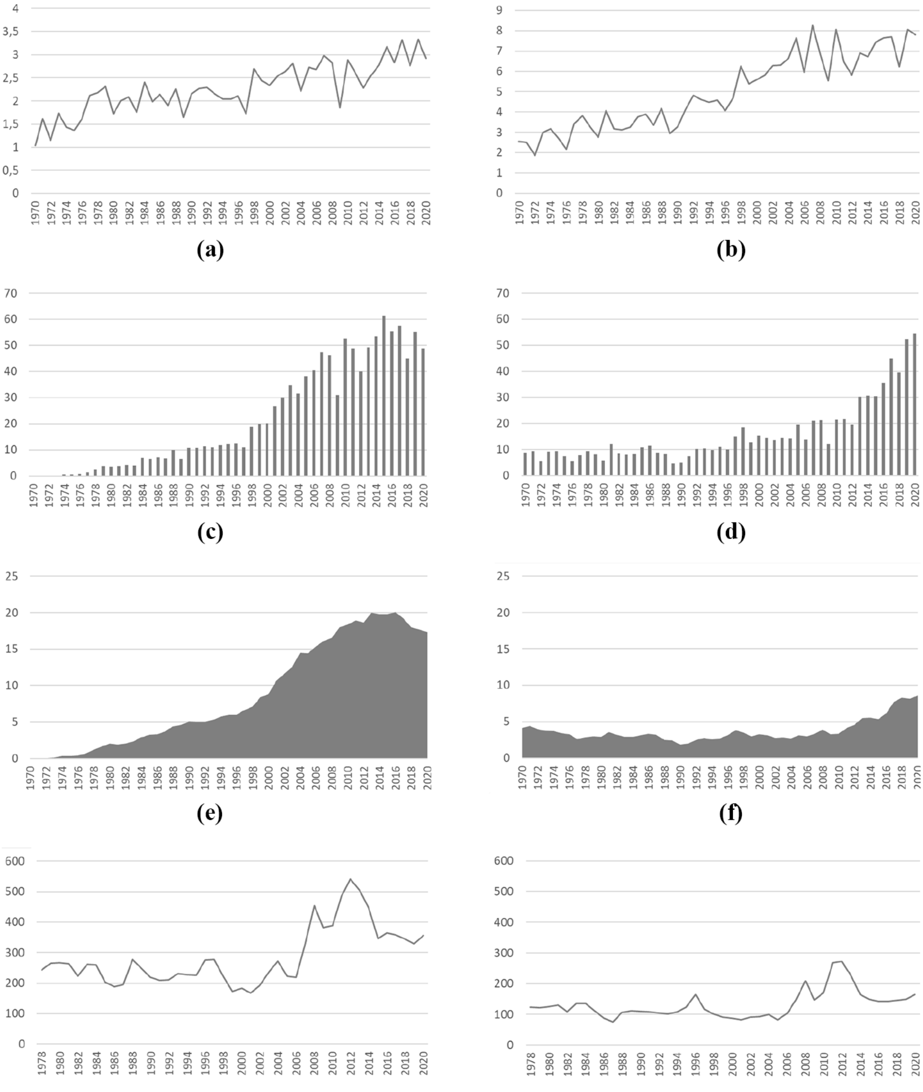


Figure 2.
Historic evolution of yields, production, implanted area and international price for soybean and maize

Notes: (a) Soybean yield (t/ha); (b) maize yield (t/ha); (c) soybean production in million tons; (d) maize production in million tons; (e) soybean area in million hectares; (f) maize area in million hectares; (g) soybean price in USD per ton; (h) maize price in USD per ton
Source: Authors' elaboration of information from the Ministry of Agriculture, Livestock, and Fisheries of the Government of Argentina (2021)

While technology generates a long-term increase in yields (the trend), climate generates fluctuations in the short-term or current yield (deviations from the trend).

The baseline from which deviations were measured was estimated using a linear trend model of crop yields. The linear model was chosen instead of the logarithmic one because, according to Irwin and Good (2015), a logarithmic estimate could expand the range of the deviation of the yields in tons over time, a situation that could not be verified empirically. Furthermore, the percentage change in returns decreases as time passes, a property that is correctly reflected in the linear trend model. The latter is historically consistent with the average soybean yields in the USA (Irwin and Good, 2015; Tannura *et al.*, 2008), with similar production strategies as in the case of Argentina. Second, Thomasz *et al.* (2015) empirically verified that the linear model was able to identify all the cases of droughts with an impact on soybean production in Argentina during the period from 1990 to 2016, while the logarithmic model omitted two cases.

In addition, the linear trend is empirically related to the continuous positive impact of technology on crop yields (Tannura *et al.*, 2008; Irwin and Good, 2015). This allows the building of a detrended yield series, with the variability mostly explained by climate conditions but also by other exogenous factors, such as plagues. Considering that deviations from the trend cannot be completely explained by climate conditions, only extreme cases have been studied. In an investigated case (Tannura *et al.*, 2008; Thomasz *et al.*, 2017), over the empirical bases, a threshold of one standard deviation was set empirically, considering the observed distribution of yields.

The next step is to set an attribution criterion to relate cases exceeding one standard deviation with climate data. Two conditions must be met simultaneously:

(1) the observed yield must be below one standard deviation from the linear trend; and

(2) there must be a drought process in the departments studied defined by the PDSI value.

Drought processes are classified into moderate, severe and extreme according to the PDSI values. The volume of loss is estimated as the difference between the linear trend value and the observed production only for cases that meet the two aforementioned conditions.

Area loss is also considered. The aforementioned case study showed that area loss is by far less variable than yield; thus, deviations from the mean can lead to overestimation or underestimation. Therefore, the absolute difference from the median is used instead in the cases selected in the previous step.

Finally, the total loss is converted into a monetary value by means of the soybean and maize international prices, considering that Argentina is price-acceptant and that much of the production of both crops is export-oriented. In Rondinone and Thomasz (2016), it was found that the main factors influencing international soybean prices are the USA's stock levels relative to global demand, the prevailing interest rate and the value of the US$ relative to other major currencies. Although Argentina is a key global producer of soybeans, its production level does not appear to have a significant impact on these international prices, except when US stock levels are low, and event in this cases it can be considered a price taker (Thomasz *et al.*, 2021; Thomasz *et al.*, 2017). Therefore, it is reasonable to assume that using Chicago Board Futures prices is a viable approach for forecasting and analyzing international soybean prices.

Formalization

The current yield was calculated as $Y_t = \frac{Q_t}{A_t}$, where Q_t is the soybean quantity in tons per department in year t and A_t is the area harvest in year t in hectares. From the current yield series, a linear model is estimated, with β_0 as the intercept and β_1 as the trend. From the estimated parameters, the yearly estimated yield is as follows:

$$\hat{Y}_t = \beta_0 + \beta_1 * t. \tag{1}$$

Detrended yield $\tilde{Y}_t$ is calculated as the difference between observed yield Y_t and estimated yield $\hat{Y}_t$, as follows:

$$\tilde{Y}_t = Y_t - \hat{Y}_t. \tag{2}$$

The detrended series is centered at zero, with positive and negative values. The variability of this detrended series is taken into consideration as a proxy for climate impacts. For better visualization and comparison among the departments, the series is scaled into the following index number:

$$Index(\tilde{Y}_t) = 1 + \left(\frac{\tilde{Y}_t}{\hat{Y}_t}\right). \tag{3}$$

A dichotomic function was set to identify the cases below the one standard deviation threshold, as follows:

$$f(Index(\tilde{Y}_t)) = \begin{cases} 1 & if\ Index(\tilde{Y}_t) < 100\% - \sigma Index(\tilde{Y}_t) \\ 0 & if\ Index(\tilde{Y}_t) > 100\% - \sigma Index(\tilde{Y}_t) \end{cases}. \tag{4}$$

Where σ is the standard deviation of the yields index.

The values of $Index(\tilde{Y}_t) < 100\% - \sigma Index(\tilde{Y}_t)$ represent the potential cases of yields affected by climate shocks. These cases are contrasted with the PDSI values and double-checked with precipitation data and the weekly agricultural outlook from the Buenos Aires Grain Exchange as a secondary source.

Estimated trended production level $\hat{Q}_t$ is defined as follows:

$$\hat{Q}_t = \hat{Y}_t * AS_t, \tag{5}$$

where $\hat{Y}_t$ is the estimated yield from equation (1) and AS_t is the sown area of period t.

With $\hat{Q}_t$, the value of estimated production $\hat{V}_t$ is calculated as follows:

$$\hat{V}_t = P_t^i * \hat{Q}_t, \tag{6}$$

where P_t is the international crop price in year t. With the same price, the observed production value is calculated as follows:

$$V_t = P_t^i * Q_t. \tag{7}$$

The loss value (VLt) is estimated as the difference between the observed and tendential production values, as follows:

$$\text{VLt} = P_t^i * Q_t - P_t^i * \hat{Q}_t$$

or

$$\text{VLt} = (Q_t - \hat{Q}_t) * P_t^i. \tag{8}$$

Besides extreme deviations in yields, area loss is taken into account to valuate total loss. As area loss is relatively stable across the sample and results only from extreme climate events, its average value is not a reasonable reference. Therefore, its median value is taken as a reference, as follows:

$$\text{Area} \quad H_t\%S_t = \frac{Area\ \ harvest_t}{Area\ \ sown_t} \text{ and} \tag{9}$$

$$\text{Median}(\text{Area} \quad H_t\%S_t]\ {}_{t=1}^{t=n}). \tag{10}$$

Area loss cases are selected by means of the following dichotomic function:

$$Cases\ \ area\ \ loss_t = \begin{cases} 1 & if\ \ Area\ H_t\%S_t < \ Median\ \ (\text{Area} \quad H_t\%S_t)]\ {}_{t=1}^{t=n} \\ 0 & if\ \ Area\ H_t\%S_t > Median\ \ (\text{Area} \quad H_t\%S_t)]\ {}_{t=1}^{t=n} \end{cases}. \tag{11}$$

In all, the total production quantity loss (TQL_t) decrease in yields and areas is as follows:

$$TQL_t = \left(Q_t - \ \hat{Q}_t\right) * [Median\ \ (Area\ \ C_t\%S_t) - (Area\ \ C_t\%S_t)] * AreaS_t * \hat{R_t}. \tag{12}$$

Finally, the total value loss estimate in dollars (TVL_t) is as follows:

$$TVL_t = TQL_t * P_t^i. \tag{13}$$

Results

The proposed method was applied to each of the 183 departments in the sample, and 183 different estimates for soybean and 183 for maize were obtained. The estimated parameters of the lineal trend of the yields for each department are presented in the supplementary file.

The study results show a high concentration of extreme deviations in yields during the 2008/2009, 2011/2012 and 2017/2018 campaigns in almost all the geographical areas analyzed, and in the regional concentrations in particular provinces and years, such as in the cases of Chaco and Entre Ríos in 2003/2004, Córdoba in 2010/2011 and Entre Ríos and Santa Fe in 2015/2016. The results shown in Table 2 are summarized as follows:

- only the estimates from the year 2000 were presented because of their economic relevance; and
- extreme cases of deviation of yield were aggregated per province and reported as the percentage of total cases.

As for the attribution of the extreme deviations in yields to climate events, 100% of the cases were related to adverse climate conditions according to the PDSI values (Appendix). A total of 98% of the cases were coincident with droughts (from mild to severe), and 2% of the cases were related to extreme hydric excess. The main result shows that the method for identifying the impacts of all the drought levels in both crops was robust but can identify only extreme hydric excesses.

Table 3 summarizes the affected years, provinces and crops and characterizes the drought level according to the PDSI value (Appendix). As has been mentioned, only in the 2015/2016 events were the negative extreme deviations in yields related to flooding.

Table 2. Departments with extreme negative deviations in yields in percentage of total departments per province

Year	Buenos Aires		Chaco		Córdoba		Entre Ríos		Santa Fe	
	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)	Soybean (%)	Maize (%)
2000/2001	4	1	0	0	0	0	0	0	0	11
2001/2002	0	2	0	0	0	0	0	0	0	5
2002/2003	4	1	0	0	4	0	0	0	0	5
2003/2004	1	0	52	0	26	9	35	0	11	0
2004/2005	0	0	24	0	4	0	0	0	5	0
2005/2006	1	4	0	0	0	4	18	12	11	16
2006/2007	1	3	0	0	0	0	0	0	0	0
2007/2008	6	1	0	0	0	9	0	0	16	21
2008/2009	86	83	80	96	35	22	94	76	74	37
2009/2010	4	5	4	0	4	4	0	0	0	0
2010/2011	6	1	0	0	9	35	0	0	0	11
2011/2012	8	37	92	8	48	30	0	0	42	21
2012/2013	1	0	44	72	17	17	0	0	0	11
2013/2014	11	17	0	0	0	0	0	0	5	0
2014/2015	0	0	12	0	0	0	0	0	0	0
2015/2016	1	1	8	0	0	0	59	0	47	0
2016/2017	2	1	0	0	0	4	0	0	0	0
2017/2018	49	29	0	0	13	30	94	29	89	42

Source: Authors' elaboration

Year	Provinces affected	Crop	Drought level according to the PDSI
2003/2004	Chaco, Entre Ríos, Córdoba and Santa Fe	Soybean and maize in Cordoba and soybean in the rest of the provinces	Severe in north and south Cordoba and Santa Fe; moderate in central Cordoba and Santa Fe and in Entre Rios
2005/2006	Santa Fe and Entre Ríos	Soybean and maize	Moderate
2007/2008	Buenos Aires and Santa Fe	Soybean and maize	Moderate
2008/2009	All the study areas	Soybean and maize	Extreme
2010/2011	Córdoba	Soybean and maize	Severe in the northern and southern parts of the province and moderate in the center
2011/2012	Buenos Aires, Chaco, Córdoba and Santa Fe	Soybean and maize	Extreme in some cases; moderate in the rest of the provinces
2012/2013	Chaco and Córdoba	Soybean and maize	Extreme in Chaco and Cordoba; moderate in most of the other provinces; severe in the north
2013/2014	Buenos Aires	Soybean and maize	Extreme to severe in the west-central region of the province
2015/2016	Entre Ríos and Santa Fe	Soybean	Hydric excess
2017/2018	Buenos Aires, Entre Ríos, Córdoba and Santa Fe	Soybean and maize	Extreme; moderate in some areas

Source: Authors' elaboration

Table 3. Summary of areas and crops affected and drought levels

However, considering that the method identifies only cases of extensive flooding, with only one record in the analyzed history, the case was excluded from the economic valuation. Unlike droughts, flooding has local impacts that cannot be captured at the departmental scale used in this study. The 2015/2016 case was analyzed by Ravelo *et al.* (2016).

With the confirmation that all the negative extreme deviations of yields and area losses could be attributed to droughts, economic impact valuation is reported herein. Figures 3 and 4 report the departments that were economically affected by the droughts. The graph sets summarize the value of losses per crop and province.

While the severe and extreme droughts in 2008/2009, 2011/2012 and 2017/2018 generated direct losses of US$5,000–6,000m each year for the entire region, the moderate droughts in 2010/2011, 2012/2013 and 2013/2014 generated direct losses of US$600–800m for the entire region, valuated in the current US$ for each year (Table 4).

The quantification of the losses relative to the production baseline showed that severe to extreme droughts generated losses of up to 35.4% in 2008/2009, 28.1% in 2017/2018 and 18.4% in 2011/2012. The different impact levels were explained by the severity and extensiveness of the droughts across the studied areas. The milder drought events generated relative losses of up to 6.2% in 2003/2004 and at least 1.3% in 2007/2008. A comparison of the relative losses of soybean and maize production shows a different level of impact between the crops: the losses of maize production can double the losses of soybean production. Considering the highest severity event, the relative losses of soybean production were 33.2% of the baseline production, while those of maize production were 50.8%. The difference is attributed to the higher resistance of soybean to climate variability than maize. The aforementioned results are summarized in Table 5.

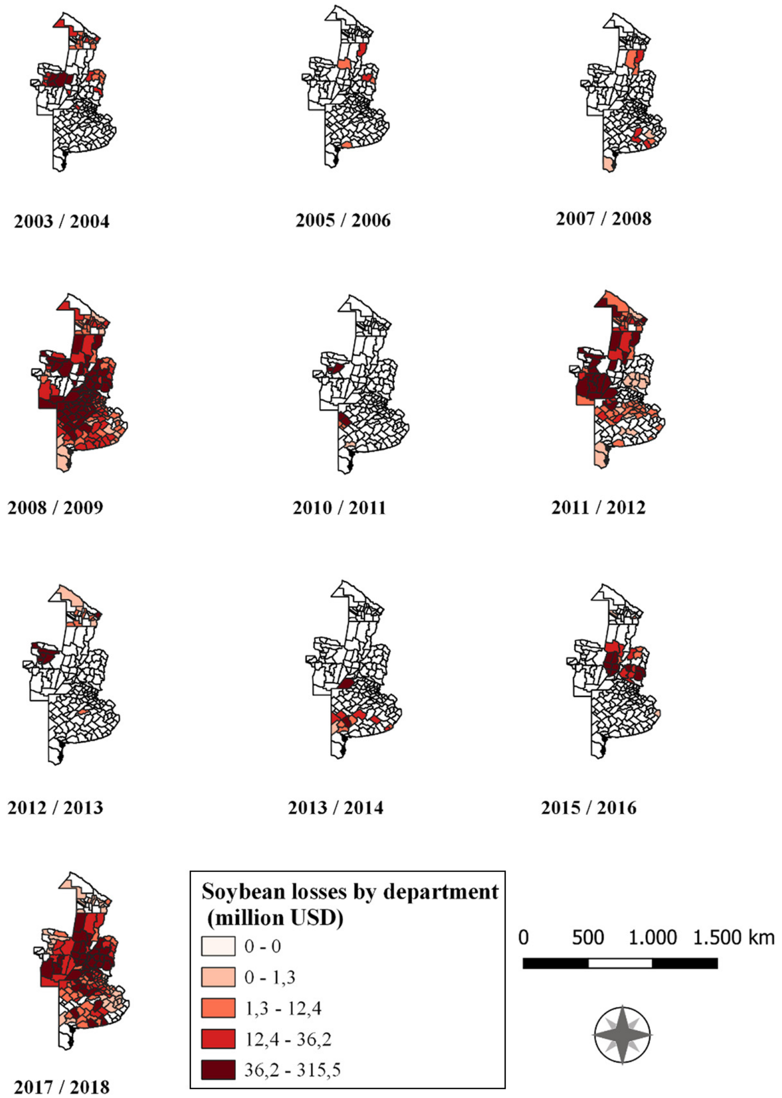
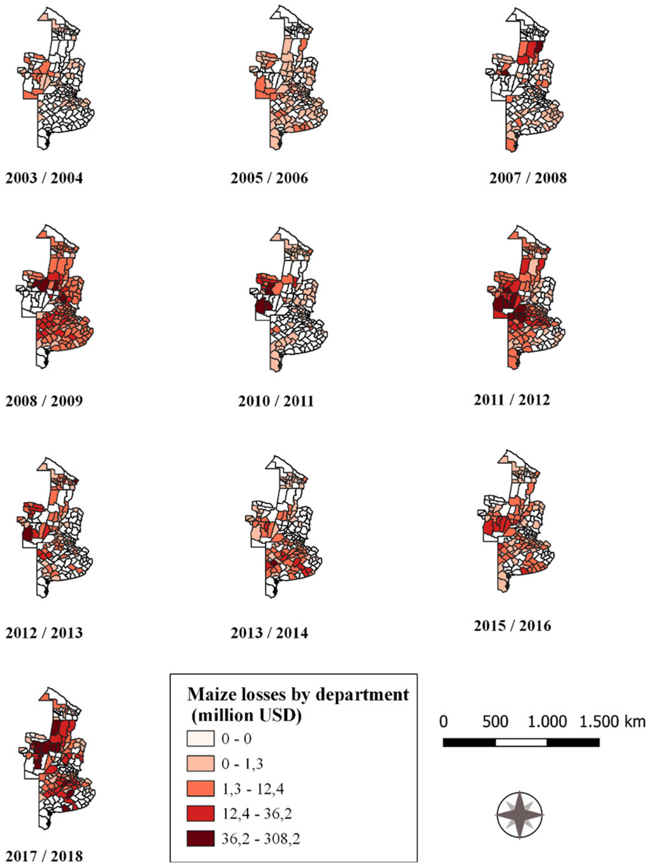


Figure 3. Departments with soybean losses

Source: Authors' elaboration

Losses can also be quantified relative to exports and trade balance, considering that maize and, especially, soybeans are export oriented. The losses generated by the three major droughts (2009, 2012 and 2018) were 11.2%, 6.6% and 9.9% of the total country exports in each year, respectively. In addition, they represented 37%, 44% and 159% of the balance of trade in those years. Even in the case of the moderate drought in 2013, the losses represented 63.5% of the trade balance. In 2018, the negative balance of US$3.823m could have been a surplus of US$2.269m in the context of the baseline scenario (Table 6).



Source: Authors' elaboration

Figure 4. Departments with maize losses

To estimate the global value of the loss updated to 2021, either inflation or the time value of money can be considered. The total value in dollars in 2021 considering the US inflation rate was US$24.170m, whereas the value in 2021 considering the opportunity cost of the treasury bills was US$26.948m (Table 7).

Both of the aforementioned valuations are representative of different approaches. Despite inflation adjustment being the standard method, the opportunity cost of the time value of money in treasury bills makes sense in a macro-financial system such as that in Argentina, where international reserves and public borrowing are dependent on agricultural exports. However, to be conservative, the lowest value was used for the following estimates: a total loss of US$24.170m was generated in nine events spanning 17 years: nine milled events with an average loss of US$692m and three severe–extreme events with an average loss of US $6.672m (Table 8).

Finally, the total loss estimated represented 57.45% of the international reserves of the Argentinean Central Bank in 2021. This last estimate reveals the magnitude of the impact of climate risk and, eventually, climate change on the Argentinean economy,

Table 4.
Total revenue losses by province in current million US$ by drought event

Year	Buenos Aires		Chaco		Córdoba		Entre Ríos		Santa Fe		Total		
	Soybean	Maize	Soybean	Maize	Soybean	Maize	Soybean	Maize	Soybean	Maize	**Soybean**	**Maize**	**Total**
2003/2004	15.9	2.0	125.8	0.3	317.6	25.2	51.2	0.6	80.0	4.5	*590.6*	*32.6*	*623.2*
2005/2006	4.8	38.1	–	0.2	–	37.0	25.8	3.6	24.8	12.3	*55.5*	*91.3*	*146.8*
2007/2008	56.4	22.1	–	–	–	50.3	–	8.1	45.4	102.0	*101.8*	*182.5*	*284.3*
2008/2009	2,879.8	598.2	252.6	48.4	614.8	131.9	679.7	177.0	730.4	130.4	*5,157.2*	*1,085.9*	*6,243.1*
2010/2011	179.0	11.8	–	10.6	154.6	281.0	–	4.1	–	19.9	*333.6*	*327.5*	*661.1*
2011/2012	340.8	990.0	559.5	77.8	1,731.7	807.2	2.6	3.3	582.4	186.1	*3,217.0*	*2,064.4*	*5,281.4*
2012/2013	8.8	138.3	121.6	101.7	351.7	218.0	–	1.0	–	24.0	*482.1*	*483.1*	*965.2*
2013/2014	188.3	335.2	–	5.9	–	41.8	–	0.1	176.4	20.2	*364.7*	*403.2*	*767.9*
2017/2018	1,239.4	608.1	5.7	16.4	710.4	1,061.0	790.4	96.1	1,156.5	408.0	*3,902.5*	*2,189.7*	*6,092.2*

Source: Authors' elaboration

Table 5. Total losses in current million US$ and relative losses as percentage of baseline production

Year	Loss		Baseline production		Relative loss		Loss	Baseline production	Relative loss
	Soybean	Maize	Soybean	Maize	Soybean (%)	Maize (%)	Total	Total	Total (%)
2003/2004	590.6	32.6	8,852.4	1,175.84	6.7	2.8	623.2	10,028.24	6.2
2005/2006	55.5	91.3	7,511.3	1,364.14	0.7	6.7	146.8	8,875.45	1.7
2007/2008	101.8	182.5	17,268.1	4,046.89	0.6	4.5	284.3	21,315.04	1.3
2008/2009	5,157.2	1,085.9	15,518.7	2,136.76	33.2	50.8	6,243.1	17,655.43	35.4
2010/2011	333.6	327.5	21,210.2	5,713.64	1.6	5.7	661.1	26,923.86	2.5
2011/2012	3,217.0	2,064.4	22,844.6	5,890.68	14.1	35.0	5,281.4	28,735.30	18.4
2012/2013	482.1	483.1	23,879.8	6,198.98	2.0	7.8	965.2	30,078.74	3.2
2013/2014	364.7	403.2	21,384.1	4,324.88	1.7	9.3	767.9	25,709.01	3.0
2017/2018	3,902.5	2,189.7	15,415.1	6,282.91	25.3	34.9	6,092.2	21,698.04	28.1

Source: Authors' elaboration

indicating that climate events have macroeconomic impacts on the economy, especially in the external sector and international reserves. How this translates to growth, exchange rate volatility and domestic inflation dynamics is an open field for future research.

Table 6. Estimated losses in million US$ and foreign trade indicators

Year	Total exports	Trade balance	Total loss	Loss in % of exports	Loss in % of trade balance	Loss-free trade balance
2004	34,576	12,130	623	1.8	5.1	12,754
2006	46,546	12,393	147	0.3	1.2	12,539
2008	70,019	12,556	284	0.4	2.3	12,841
2009	55,672	16,886	6,243	11.2	37.0	23,129
2011	82,981	9,020	661	0.8	7.3	9,682
2012	79,982	12,008	5,281	6.6	44.0	17,290
2013	75,963	1,521	965	1.3	63.5	2,486
2014	68,405	2,670	768	1.1	28.8	3,438
2018	61,620	−3,823	6,092	9.9	159.4	2,269

Source: Authors' elaboration based on data from the Ministry of Economy (2021)

Table 7. Current and adjusted estimated losses in million US$

Year	Current US$	2021 USD (US inflation)	2021 US$ (US Treasury bills)
2003/2004	623.2	876.7	1,013.1
2005/2006	146.8	194.5	225.4
2007/2008	284.3	354.9	412.2
2008/2009	6,243.1	7,507.3	8,798.0
2010/2011	661.1	784.6	879.8
2011/2012	5,281.4	6,077.8	6,831.0
2012/2013	965.2	1,088.1	1,213.2
2013/2014	767.9	853.2	938.0
2017/2018	6,092.2	6,432.9	6,637.7
TOTAL 2021		24,170.4	26,948.7

Source: Authors' elaboration

Table 8. Total loss in million US$ in 2021 from drought events

Concept	Total loss	No. of events	Average loss
(1) Severe–extreme drought events	20,018.0	3	6,672.6
(2) Moderate drought events	4,152.3	6	692.0
(3) Total loss	24,170.4	9	
(4) International reserves	42,066		
Reative loss $^{(3)}/_{(4)}$	57.45%		

Source: Authors' elaboration

Conclusion

This work proposed a method of identifying and valuating the soybean and maize production losses generated by droughts at the departmental level in Argentina. The method was shown to have 98% accuracy in identifying extreme deviations in yields related to different drought levels. The remaining 2% accuracy pertained to cases related to massive flooding, which were registered in only one year during the series studied. Therefore, the proposed method is considered robust enough to estimate the losses generated by extreme, severe and, in some cases, moderate droughts. The impact of milder events may be underestimated because the approach does not consider yield decreases that do not exceed the one standard deviation threshold, which may also be related to water shortages. Therefore, the estimates presented in this work must be considered minimal values.

The drought impact evaluation model estimated a total loss of US$24.1071m in soybean and maize production, representing 57.45% of the Argentinean Central Bank's international reserves in 2021. Up to 83% of the total loss (US$20.018m) was generated by the three severe–extreme drought events in 2009, 2012 and 2018 and the rest (US$4.152m) was generated by the six moderate drought events. The relative loss from severe events scaled up to 35.4% of the baseline production in 2009, representing 11.2% of the total country exports that year.

The main finding of the present study is that extensive and severe droughts have macroeconomic impacts, with the external sector as the main transmission channel in an economy with historic restrictions on the balance of payments, international reserve accumulation and sovereign credit risk.

Despite the fact that drought events are not new in Argentina's agricultural history, the current scale (17 million hectares planted) and value (given the higher commodity prices) generate losses much higher in value than those in the past, within the context of export dependence on agricultural products. As it was mention the methods section, this is exacerbated by the fact that Argentina is a price taker in the soybean and maize markets, therefore there is no tradeoff between quantity and price. The context of climate change raises the question of whether drought events will increase in frequency or intensity in the next 20 years. In Argentina, three extreme and six moderate drought events have been registered in the past 20 years. As mentioned in the introduction, rainfall projections suggest a future increase of frequency for these events in the next 20 years; therefore, management and adaptation constitute the only strategy to reduce the economic and social impact.

The economic impact model also allows future production to be projected. This makes it possible to estimate the income generated by the crop export sector in different climate scenarios, thus making the model a potential tool for macro fiscal planning. The multi-scalar profile of the model, which starts from the estimation at the departmental level and can be added homogeneously at the provincial and national levels, allows the model to provide relevant data for adaptation measures at both the local and macroeconomic levels. The development of financial and fiscal vehicles, from hedging tools at the microeconomic scale to stabilization funds at the macroeconomic scale, are strategies that require climatic economic impact as an input from a financial perspective. The model proposed in this work, even though it was used to valuate past events to determine the macroeconomic significance of the problem for Argentina, can also be used to calibrate future projections of cash flows and income losses.

The future lines of research at the modeling level are the identification of milder drought events and of the losses generated by flooding, which were excluded from the analysis in the present study. Further research should also incorporate the analysis of production cost at the department level, to analyze the impact of over the farmers' profits. At the application level, future research must determine the avoidable loss and estimate the proportion of the impact that can be prevented by adaptation measures.

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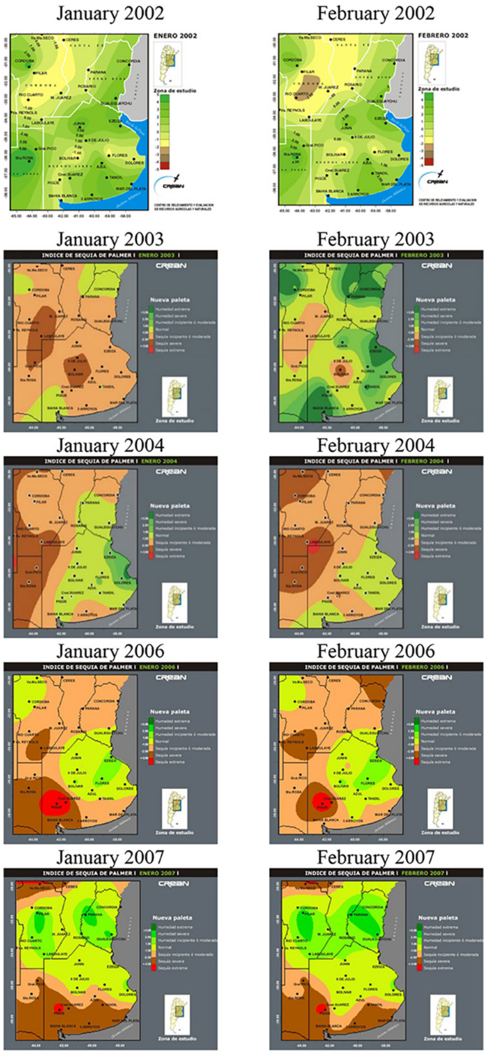
Appendix



(*continued*)

Figure A1.
Palmer Drought Severity Index

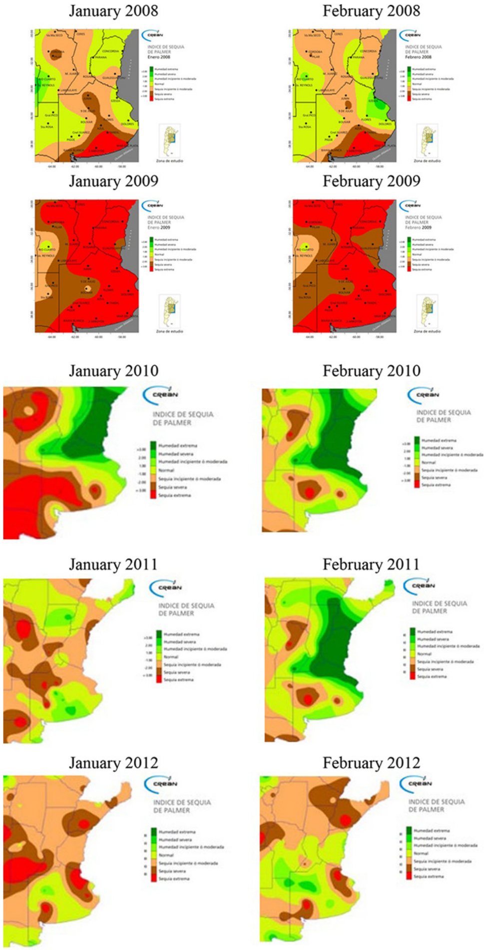
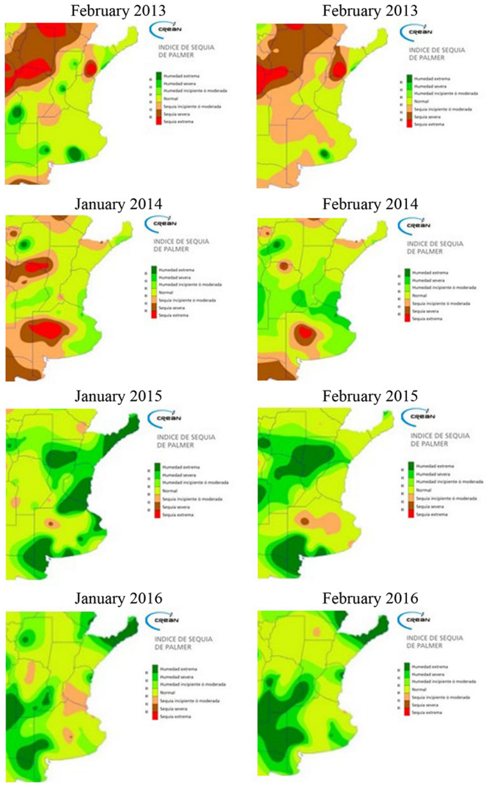


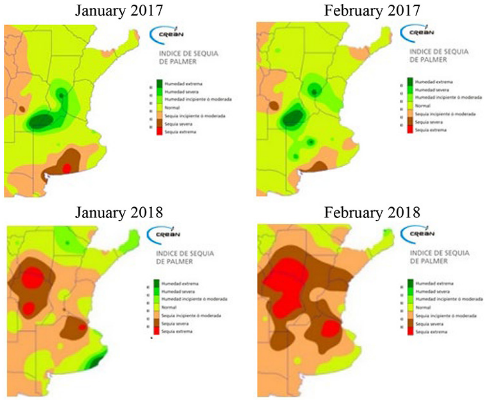
Figure A1.

(*continued*)



(*continued*)

Figure A1.



Source: Centro de Relevamiento y Evaluación de Recursos Agrícolas y Naturales, Universidad Nacional de Córdoba (www.crean.unc.edu.ar)

Figure A1.

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