Article

Influence of ‘El Niño, Southern Oscillation’ on the yield of rainfed corn in Nayarit

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Abstract

In Mexico, the phenomenon of El Niño Southern Oscillation (ENSO) affects weather conditions and consequently on the behavior of crops, especially rainfed corn. For the rainfed corn-producing region in the state of Nayarit, there is no information available to measure this influence. The objective of this research was to know the impact of the ENSO phases on some meteorological variables during the vegetative cycle of corn and the degree of vulnerability on grain yield. A 15-year phenological database of evaluation records of commercial maize varieties were used. Quantifying the rainfall, wet days, potential evapotranspiration and degree days of development during the vegetative cycle of the crop, grouping the data by phase of the ENSO ‘El Niño’, ‘Neutral’ and ‘La Niña’. Joined with an analysis of yield and its vulnerability to climate variability. The influence on precipitation and air temperature (degree days of development) was widely identified, which are important for the development of maize in storm. In ‘Niña’ events, precipitation is 28.6% higher than in the ‘Niño’ phase, contrary to the degree days of development, where in the ‘Niño’ phase it accumulates 6.3% more than in ‘Neutral’ or ‘Niña’. This explains the yield of early varieties in the ‘Niño’ phase (greater than 8 t ha^{-1}) and makes it clear how the vulnerability of this crop can decrease if adequate seed is available for each phase of the ENSO.

Keywords: *Zea mays* L., climatic variability, ENSO.

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Introduction

In Mexico, the influence of the “El Niño Southern Oscillation” (ENSO) phenomenon on meteorological conditions governs the behavior of crops, especially corn. In rainfed areas with marginal production systems, yields will be compromised by interannual variations in precipitation resulting in years with contrasting yields (Vallejo-Nieto *et al*., 2011). These variations are usually modulated by synoptic-scale atmospheric events, as well as global teleconnections such as the ‘El Niño Southern Oscillation’ phenomenon. This phenomenon is characterized by the temperature anomaly on the surface of the equatorial Pacific Ocean in the region 3.4 of “El Niño” (Latif and Keenlyside, 2009; Maturana *et al*., 2004).

There are different models called ‘Indices’ that explain the behavior of the ENSO with a certain degree of precision. However, in North American countries the use of the ‘El Niño’ Oceanic Index (ONI) developed by the Center for Climate Prediction of the National Oceanic and Atmospheric Administration (NOAA) is recommended. The ONI is the quarterly moving average of the temperature anomaly on the surface of the equatorial Pacific Ocean (subregion 3.4) (Guevara-Diaz, 2008).

The use of indices that describe the ENSO phases and their interaction with precipitation has been widely documented, for example, in South America Pinilla and Pinzon (2012), Ramírez-Builes and Jaramillo-Robledo (2009) and Ruiz-Cabarcas and Pabon-Caicedo (2013) report a decrease in precipitation in the ‘El Niño’ phase and increases during the ‘La Niña’. For Salinger *et al*. (2000) ENSO is an important forcing of short-term climate variability and responsible for alterations in the ocean-atmosphere system, which have economic, social, environmental, political and academic implications, as detailed by Zebiak *et al*. (2014). Iizumi *et al*. (2014) highlight the importance of the ENSO study and its effect on crop yield, since in many regions of the world this relationship is uncertain.

De La Casa and Ovando (2006) found statistically positive anomalies in maize yield in the ‘El Niño’ phase and negative in ‘La Niña’, as did Monasterio *et al*. (2011) in Venezuela and Shuai *et al*. (2016) in China, report low yields in the ‘La Niña’ phase and high yields during ‘El Niño’ episodes. In contrast to what was reported by Moeletsi *et al*. (2011) where in South Africa the decline decreases in ‘El Niño’ years (droughts) and increases in the ‘La Niña’ phase (mainly due to increased precipitation). In Mexico the impacts of ENSO have been measured by different authors, highlighting the work of Adams *et al*. (2003) that in years with the ‘El Niño’ phase, a decrease in the established area of corn and an increase in the price in contrast to the ‘La Niña’ years where the price decreases due to an increase in production.

The above is closely related to the distribution of precipitation, this being confirmed by Mendez-Gonzalez *et al*. (2007); Pavia *et al*. (2006) where they demonstrated a significant relationship between the ENSO phases and monthly precipitation. In Nayarit, little more than 40 thousand ha of rainfed corn are cultivated, representing 1.9% of the national surface. While Santa Maria del Oro in Nayarit is important for being a region of corn evaluations by research centers, as well as for being one of the municipalities with the highest yields (5 t ha^{-1}) and having an established area of more than 2 thousand ha (SIAP, 2016).

Despite the relative importance of the crop for the region, the impact of ENSO on corn yield is unknown. Therefore, the objective of this work was to analyze the impact of the ENSO phases on some meteorological variables and on the yield of rainfed corn. The results can be useful in decision-making by producers and technicians for the selection of suitable maize varieties depending on the ENSO phase to prevail in subsequent cultivation cycles.

Materials and methods

Study zone

The experimental site represents the rainfed corn zone in Nayarit, Mexico. It was located near the town of San Jose de Mojarras, municipality of Santa Maria del Oro, at an altitude of 940 meters above sea level, with a strict temporary humidity regime with precipitation between June and October.

Phenological database

A database with 15 years of records was used, from the 1998-1999 to 2012-2013 cycle. This consisted of 344 records of commercial and regional varieties of corn, from which the sowing date (FS), flowering date (FF) and harvest date (FC) were obtained. To categorize the varieties according to their growth habit, the following criteria were used: early $\leq$ 57 days to flowering, intermediate > 57 and < 62 days to flowering and late $\geq$ 62 days to flowering.

Oceanic index of ‘El Niño’

ONI monthly data was obtained from the NOAA website (NOAA, 2017). The values were classified into three phases: warm or ‘El Niño’ (anomaly $\geq$ 0.5 ºC), cold or ‘La Niña’ (anomaly $\leq$ -0.5 ºC) and ‘Neutral’ with anomalies between -0.5 ºC and 0.5 ºC (Latif and Keenlyside, 2009).

Meteorological data

The National Meteorological Service database was available, Cerro Blanco station with code 18005 which is located at the coordinates of north latitude 21° 22’ 36” and west longitude 104° 37’ 06” at an altitude of 965 meters above sea level, the which was made up of daily records of maximum temperature (Tmax), minimum temperature (Tmin), mean temperature (Tmed= (Tmax+Tmin)/2) and precipitation. The daily solar radiation data was obtained from the project database ‘surface meteorology and solar energy’ (NASA, 2017).

Study variables

For the meteorological quantification, the period from FS to FC was considered. The variables were calculated as follows: precipitation (P)= amount of accumulated rainfall in the period. Humid days (DH)= represents the number of days with precipitation greater than 1 mm. Potential evapotranspiration (ET0 in mm day^{-1})= 0.0023 x Ra x (Tmax - Tmin)$^{0.5}$ x (Tmed + 17.78), where: Ra= solar radiation. Degrees day of development (GDD)= Tmed-Tb; where:

Tb= 10 °C. Yield (Ren)= Pc x Fs x Fh, where: Pc= field weight, as a function of direct grain weight (without ear weight or shelling factor) per plot as a function of the number of plants harvested with full competition. Fs (area factor)= kg $plot^{-1}$ in kg ha^{-1}: 10 000 m^2/area occupied by harvested plants. Fh= 100-Hg (14%)/86; where: Hg= percentage of moisture from grain to harvest.

Statistical analysis

An analysis of variance was used to identify possible differences by ENSO phase. When significant differences were present, a means comparison test (Tukey with an alpha at 0.05% confidence level) was performed using the Minitab statistical program (Minitab, 2010).

Results and discussion

Influence of ENSO on the meteorological variables evaluated

The effect of the phenomenon of 'El Niño Southern Oscillation' on the meteorological variables evaluated in the rainfed corn-producing region of Nayarit in the 15 cycles analyzed, showed relevant differences in the different phases. 'La Niña' was characterized by wetter conditions (P and DH) and a lower accumulation of heat (GDD), contrary to what happens in the 'El Niño' phase characterized by drier conditions (less rainfall) and greater accumulation of degree days of development.

The above coincides with what was found by Ruiz-Cabarcas and Pabon-Caicedo (2013), Pavia *et al*. (2006) and Moeletsi *et al*. (2011), where the ENSO phases contrast mainly in rainfall anomalies being positive for 'La Niña' and negative for 'El Niño'. In the analysis of the meteorological variables from FS to FC, distinguishing the ENSO phase, it was possible to identify how the P showed differences between phases, the 'La Niña' episodes being the ones with the highest accumulated quantity in the period (997 mm), which is equivalent 28.6% more than the 'El Niño' phase (712 mm).

Regarding DH, the years with the 'El Niño' phase presented the lowest accumulation of DH (50), while the years 'Neutral' and 'La Niña' accumulated 60 and 62 respectively (there being no statistical differences between these last two). The potential evapotranspiration did not show statistical differences ($p > 0.05$) between the three phases, with a fluctuation of only 21 mm between the extreme means. Finally, differences were identified in the cumulative GDD in 'El Niño' years of 6.3% greater than the 'Neutral' and 'La Niña' years, with the values fluctuating between 1 887 °C and 2015 °C. Ruiz-Corral *et al*. (1999), citing various authors, points out that corn thrives in multiple environmental conditions but said phenotypic plasticity is influenced by the growth habits of the crop, which is verified in the present work.

These results coincide with races of the early tropical group such as Conejo, Zapalote Chico, Raton and Nal-Tel, described by Ruiz-Corral *et al*. (2013). The foregoing allows us to glimpse the presence of said phenotypic plasticity in widely adapted maize, such as that existing in creole breeds, in contrast to the vulnerability of commercial maize to the specificity of its habit (improved genotypes) and the presence of an adaptation narrow both in environments where they are formed, developed and cultivated. Mercer and Perales (2010) conclude that landraces are better adapted to changing environmental conditions thanks to their greater genetic variation, which gives them the phenotypic plasticity of adapting to unfavorable environments (Table 1).

Table 1. Influence of ENSO on the weather from sowing to harvest.

Weather variable	ENSO phase		
	‘El Niño’	‘Neutro’	‘La Niña’
Precipitation	712.39 c	908.5 b	997.5 a
Humid days	50.38 b	60.69 a	62.4 a
Potential evapotranspiration	737.88 a	749.61 a	758.97 a
Development day grades	2015.8 a	1928.18 b	1887.8 b

Means with the same literal do not present significant differences. Tukey ($p \leq 0.05$).

ENSO phases and yield

The corn crop established under storm conditions is exposed to meteorological variations, so the yield is highly influenced. The results of this work show that the yield was sensitive to the environmental conditions established by the three phases of ENSO, which reinforces the importance and need to know the effect of ENSO on yields, as pointed out by Iizumi *et al*. (2014) and Zebiak *et al*. (2014). The grain yields above 8 t ha^{-1} were obtained by the early varieties within the ‘El Niño’ and ‘La Niña’ phases and in the intermediate varieties in the ‘El Niño’ phase. The lowest yield was obtained by the early and intermediate-cycle varieties in the ‘Neutral’ phase, while the late varieties registered the lowest yield in the ‘La Niña’ phase. Without considering the growth habit, the best yields were obtained in the ‘El Niño’ phase (< 8 t ha^{-1}), while the lowest yields (6.5 t ha^{-1}) were obtained in the ‘Neutral’ phase (Table 2).

Table 2. Influence of ENSO on the yield per vegetative cycle.

ENSO phase	Yield (t ha^{-1})		
	Early	Intermediate	Late
‘El Niño’	8.37 a	8.35 a	7.19 b
‘Neutro’	5.9 b	6.75 a	6.92 a
‘La Niña’	8.18 a	6.81 b	6.69 b

Means with the same literal in line do not present significant differences. Tukey ($p \leq 0.05$).

These results coincide with other studies around the world such as in Argentina (De La Casa and Ovando, 2006), in Venezuela (Monasterio *et al*., 2011) or in China (Shuai *et al*., 2016) where the conditions of the phase ‘El Niño’ were conducive to achieving high yields. Although Mendez-Gonzalez *et al*. (2007); Pavia *et al*. (2006); Llano and Vargas (2011) consider that the ‘El Niño’ phase is related to a deficit storm in terms of rainfall, it has been shown that for the study area the P during this phase is not a limiting factor above all for early varieties that reach their water requirements with greater efficiency in this phase (Álvarez-Bravo *et al*., 2014).

On average the early varieties reached 78.8% of the potential yield (9.5 t ha^{-1}) being the highest percentage. On the contrary, the late varieties expressed 73% of the potential yield. However, the late varieties are those that present the yields with the least variation according to the ENSO phase (70.4 to 75.8%). The greatest difference in yield was presented in early habit varieties during the 'Neutral' phase (37.9%).

The "El Niño" phase was the one that allowed the best expression of the potential yield between vegetative cycles (84% on average). In the 'Neutral' phase, the greatest difference was obtained between the observed yield and the potential (lower yield) with 69% on average (Figure 1). Due to the importance that corn production implies for Mexico, results such as those of this research contribute to the construction of a system that provides food security in the face of the fluctuating influence of the environment.

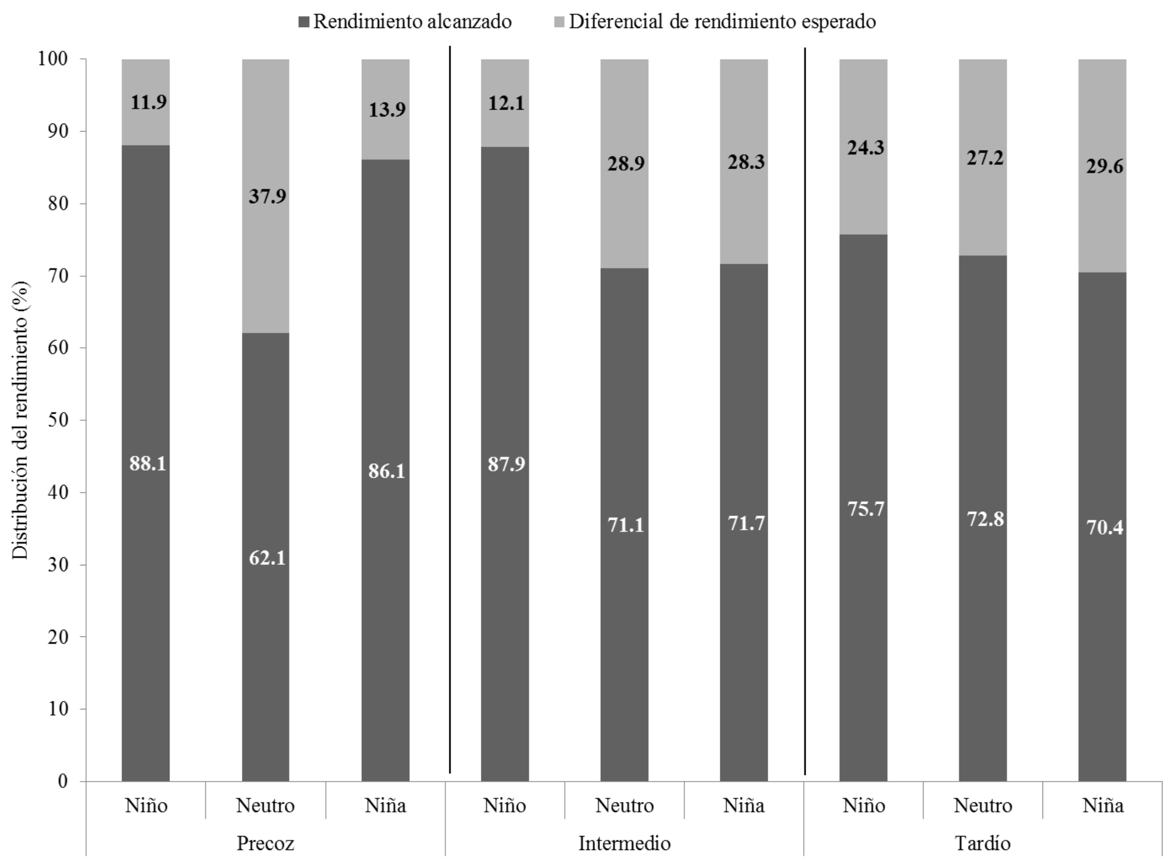

Figure 1. Yield distribution by vegetative cycle and ENSO phase.

The above reaffirms the conclusions of Bojorquez-Serrano *et al*. (2016) in the sense of improving the understanding of the dynamics of corn production to reduce the vulnerability of the productive sector. By classifying the yield of the different varieties according to their vegetative cycle and the effect that the different ENSO phases have on the meteorological variables, it will reduce the risk of low yields associated with climatic variability in the same way as Vallejo-Nieto *et al.* (2011); Ponvert-Delisles *et al*. (2007).

Conclusions

The phases of the 'El Niño Southern Oscillation' phenomenon affect some important meteorological variables for the production of rainfed corn in Nayarit. These phases have a deferred influence depending on the type of vegetative cycle of corn. The 'La Niña' events were characterized by humid conditions in contrast to the 'El Niño' phase. Corn yield is favored by a better distributed storm, between fewer wet days ('El Niño') than by a very rainy storm ('La Niña'), where the interval between wet days is shorter and therefore its distribution is not adequate. The early varieties are the least vulnerable to climate variability, particularly in the 'El Niño' phase. While the ENSO phase that most affects the loss of yield in the three vegetative cycles of corn is the 'Neutral' phase.

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