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Investigation note

Exploratory study of the change occurred in five ecophysiological variables of corn (stages V8-R1) in Serdán, Puebla

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Abstract

For Mexico, precipitation and maximum and minimum temperatures are climatic variables of interest since most of its agricultural area is under rainfed conditions, a situation that makes the country vulnerable to climate change. The study of climate change is carried out at different scales, with those carried out in regional weather stations currently standing out. The present study was conducted in the Serdán Valley, in the state of Puebla, where the great agrodiversity of crops (28) that existed in the 40s has decreased at present to only six, for climatic and economic reasons, having little diversity of varieties, the producer depends mainly on corn, the most adapted to the current climatic changes that occur in the valley. The general objective was: to evaluate the local changes in temperature and precipitation in two different research periods and their current influence on five ecophysiological variables of the corn crop in the 60 days of greatest growth dynamics. The bibliographic review and statistical analysis of the climatic changes that occurred in the local weather stations and their influence on the ecophysiological variables selected for the study allowed us to conclude that the research carried out in the two research periods (1975-1981, 2010-2018) was conducted under different climatic conditions of rainfall and temperatures, but that the current adaptation of landrace corn and cultivation practices have resulted in better yields.

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Mexico's great diversity of climates is due to its large land surface and latitude that receives high solar radiation throughout the year and its great orographic diversity and reliefs (Conde *et al*., 2016). These factors make the study and change of climate in the country to be carried out at different scales, such as synoptic or cyclonic, at mesoscales, large regions based on precipitation statistics for social and economic purposes, bioclimatic regions, up to microregions, or local (Chávez *et al*., 2014; Murray 2021). The agricultural area of the country is 22.2 million hectares, mainly rainfed with 73.4%, the area depends on rainfall, so precipitation and maximum and minimum temperatures are climatic variables of interest.

In the country, the increase in average annual temperatures averages 0.3 degrees Celsius (°C) per decade since 1950, but with a notable increase of 0.72 °C in the last decade (Chávez *et al*., 2014). Beginning in the late 1980s, average annual precipitation began to decline. In the present decade (20s), the decrease in rainfall is higher in the center and coasts of the Gulf of Mexico, the problems of water deficit occur mainly in the north and center of the country, generating pressure on water resources due to less rainfall, and increases in temperatures and evaporation, which have affected biodiversity, biological life, productive sectors, affecting the population economically (Méndez *et al*., 2008; Martínez and Patiño, 2012).

Recently in the state of Puebla, it was identified that since 2013, the eight warmest continuous years have been recorded with an increase in the average temperature of 1.2 °C. The annual precipitation of the state averaged 1 270 mm, presenting in the period 1985-2020 decreases of 1.7 mm year^{-1}, which accelerated from 2004, the highest decrease in rainfall occurred in 2019 with a reduction of 366.9 mm (Gobierno del Estado de Puebla, 2022).

The study valley (2022) comprised the municipalities of Tlachichuca, San Juan Atenco, and Chalchicumula de Sesma (Serdán), with a height ranging from 2 440 to 2 560 masl, they have regosol soils of sandy texture (70 to 92% sand), deep (> 2 m) without defined horizons, with 5 to 6 compact layers of 0.1 to 0.25 m thick each which hinder the penetration of the roots of the crops and of the rain. Local farming systems are rainfed (94%). Concerning 1974, the rains have moved to April; in the present decade, the precipitation decreased from June to September by approximately 40%.

This paper aims to: Evaluate local changes in temperature and precipitation in two different research periods and their current influence on five ecophysiological variables of the corn crop in the 60 days of greatest growth dynamics. The weather station of Cd. Serdán was used as a climatic reference source, and the climate stations of Tlachichuca, Coyotepec (municipality of San Juan Atenco) were used as complementary support due to inconsistencies or periods of years of missing data.

Two research cycles or periods were defined, cycle A) was from 1975 to 1981 with 24 experiments, and period B) covered the years from 2010 to 2018 with 16 experiments. The months of July (Jul.) and August (Aug.) were included because they coincide with the vegetative stages of corn V8 to R1 (stem elongation to tassel emergence), a period that coincides with rains, droughts, and high temperatures, and occasionally low temperatures.

The climatic variables considered were precipitation (mm), maximum and minimum temperatures in degrees Celsius (°C). The daily heat units (DHUs) for the selected 60-day period were estimated in each research period. The average daily temperature and the minimum base value at which corn can grow in the area (6 °C) were determined based on the experiments of the first cycle (A) of research.

A previous exploratory analysis of the weather stations of Serdán, Coyotepec, and Tlachichuca showed consistent periods of drought in July and August. Therefore, we proceeded to perform the statistical analysis of the climatic and ecophysiological variables (DHUs and ADO) employing t-tests with the InfoStat V2 program; the mean, standard deviation, coefficient of variation, correlation, asymmetry values, and kurtosis of the variables studied were obtained as supporting statistics.

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The precipitation of July (B) averages 98.2 mm, representing a 20.4% reduction in precipitation, equivalent to -25.2 mm of rainfall compared to the average of July of period A. For August, the average monthly rainfall was 94.5 mm in period B, with a 15.6% reduction in rainfall compared to cycle A (Table 1).

Table 1. Statistical analysis of t-tests for precipitation in the periods studied (A: 1975-1981, B: 2010-2018), in Serdán, Puebla.

Period	Average monthly precipitation				July		August	
	July (mm)	Valor de t	August (mm)	Valor de t	CV	Kurtosis	CV	Kurtosis
A	123.43	8.64	110.14	8.33	176.1	5.37	146.6	15.74
B	98.2	8.12	94.5	6	194.8	13.32	177.7	45.36
	p< 0.0001		*p*< 0.0001					
	Units in which the variables increase or decrease							
	-25.43		-15.74					

Data generated with information from the Puebla National Water Commission.

The historical data of the period 2010-2018 indicate that in 55% of the years studied, they were below the average of the calculated monthly precipitation, in addition, in 25% of the years of the period, the sum of the precipitation of July and August presented reductions in the rainfall of 40% on average. The days with rain have also changed, in period A the average number of days with rain in both months was 12, these have decreased in cycle B to 10 for July and 9 rainy days for August. According to Martínez and Patiño (2012), the increase in precipitation intensity, even with the reduction of rainfall in period B studied, is a growing and frequent trend in different parts of the world.

In Table 2, the period 2010-2018 was statistically significant due to the increase in maximum and minimum temperatures, also accompanied by a reduction in precipitation, compared to period A (Table 1). This indicates that the moisture deficit will be higher due to the possible increase in the crop's evapotranspiration, so this aspect should be studied in subsequent studies, as it follows the national trend, identified by Murray (2021).

Table 2. Statistical analysis of t-tests for maximum and minimum temperatures in the periods studied (A: 1975-1981; B: 2010-2018) in Serdán, Puebla.

Period	Maximum temperatures (°C)				Minimum temperatures (°C)			
	July	T-value	August	T-value	July	T-value	August	T-value
A	21.03	100.6	22.02	116.43	6.96	55.78	7.18	68.7
B	22.89	151.9	22.9	156.2	8.49	78	8.49	88.87
	p< 0.0001		*p*< 0.0001		*p*< 0.0001		*p*< 0.0001	
	Units in which the variables increase or decrease							
	+1.86		+0.88		+1.53		+1.31	

Data generated with information from the Puebla National Water Commission.

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The minimum temperatures of period B presented increases in their average temperatures, significantly different compared to period A, July (B) was the month with the highest increase in its average temperature, with an increase of +1.53 °C, compared to cycle A (Table 2). The correlation of precipitation and maximum temperatures in August for both periods was negative, -0.642 (period A) and -0.643 (period B), clearly indicating an inverse relationship between both variables.

The exploration of the data from the Serdán weather station indicated that the presence of frosts went from 7.14 events (cycle A) to only 0.55 in July in period B, in August the average frost events went from 3.6 to only 0.22 in August in period B.

A favorable effect of the increase in the minimum temperature of period B is that they are accompanied by a reduction in the number of frosts in stages V10 to R2 of corn, a period that, for productive reasons, is of interest to the producer and the state of Puebla. In this regard, Velasco *et al*. (2015) point out that, from the eighties of the twentieth century, frosts in the region presented a growing trend that threatens crops and producers in the area; therefore, these results should be confirmed in subsequent studies for all months of the active cycle of the crop in Serdán (March to October).

The trend of increasing local average temperatures in the two months in period B is consistent with international and national studies. Murray (2021) analyzed the climatological information of the Mexican Republic from 1951 to 2017, identifying that average temperatures increased by +0.96 °C on average, even with a notable decrease in average temperature in the period 1951-1980, indicating that the largest increases in temperatures in Mexico have occurred in the last 40 years, mainly from 2012 to date. For Serdán, the average temperatures have increased in period B by +1.69 °C for July and by +1.09 °C for August, above the estimated average value (for the months of July to November) of +0.53 °C identified by Murray (2021) in his study.

The thermal oscillations (ADO) for the months and periods studied are within the average oscillation range (ranges from 10 to 18 °C). The statistical analysis of the tests of the thermal oscillations of July and August shows significant differences between the months and periods studied (Table 3).

Table 3. Statistical analysis of the t-tests for the temperature oscillations that occurred in the valley in the periods studied (A: 1975-1981; B: 2010-2018), in Serdán, Puebla.

Period	Months and statistical values obtained ADO						
	Month	Mean	SD	LI	UL	T	*p value*
A	July	14.5	2.62	14.85	14.85	81.52	0.0001
B	July	14.41	3.51	14.82	14.82	68.6	
	Difference	0.09					
A	August	14.84	2.67	14.49	15.2	82.2	0.0001
B	August	14.43	3.17	14.05	14.8	76.06	
			Difference	-0.41			

Data generated with information from the Puebla National Water Commission.

According to Table 3, the highest values of thermal oscillation occurred in cycle A, for July, they were 22 °C, for August, the values of the thermal oscillation were 18 °C (with temperature ranges from 4 to 22 °C). The thermal oscillation in the two months of period B decreased, with average values of 0.09 °C for July and 0.41 °C for August.

The data from the three stations studied, mainly from Serdán, indicated that the minimum temperatures below 6 °C had favorable changes in period B. In summary, in cycle A, the total accumulated days below the minimum required for the crop was 77 days (34% of the total days of the period), while cycle B accumulated only 10 days without appropriate temperatures for corn

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(10/279). The maximum temperatures of the Serdán station did not exceed 30 °C in the periods studied.

Table 4 shows the statistically significant differences in the means of the daily heat units (DHUs) of July and August (*p*> 0.001) favorable for period B, for both months of the study period. For period B, the daily mean of the DHUs of the study months was +8.4 units. With a total of +80.9 DHUs gained in period B, so it is estimated that the crop cycle in the period 2010-2018 tends to decrease by 9.6 days when considering the two months. It is still necessary to discern the climatic and physiological changes that can occur in corn from March to June (emergence and vegetative growth), and from September to October (stages R2 to senescence).

Table 4. Statistical analysis of t-tests for heat units for the periods studied (A: 1975-1981; B: 2010-2018), in Serdán, Puebla.

Period	Month and statistical values obtained DHUs						
Month	**Mean**	**SD**	**LI**	**UL**	**T**	***pvalue***	
A	July	8.21	2.2	7.91	8.5	55.15	0.0001
B	July	9.69	1.31	9.54	9.84	123.8	
	Difference	1.48					
A	August	8.6	1.81	8.36	8.84	70.27	0.0001
B	August	9.73	1.32	9.57	9.88	122.89	
	Difference	-0.41					

Data generated with information from the Puebla National Water Commission.

For period B, the daily mean of the DHUs of the study months was +8.4 units. With a total of +80.9 DHUs gained in period B, so it is estimated that the crop cycle in the period 2010-2018 tends to decrease by 9.6 days. This alters in different directions the mechanisms of adaptation and the length of the phenological stages of corn, so the study must be extended to its entire cycle.

Possible impacts on corn due to local climate changes

According to what was recorded by Zarazúa *et al*. (2011) in their agroclimatic study of corn for the Ciénega de Chapala. The increase in the daily heat units (DHUs) for the Serdán area can have a positive effect by shortening the crop cycle of the landraces used as fewer days are required to complete the DHUs needed to conclude the crop cycle.

The consistent reduction of rainfall in period B in July and October in the area during stages V10 to R1-R2 is accompanied by an increase in maximum temperatures (Tables 1 and 2), in addition to high solar radiation that is received in summer in the area (6.6 to 6.4 to kW h m^{-2}, for July and August), so an increase in days with water stress is expected.

Water stress negatively affects physiological processes such as cell growth, protein synthesis, stomatal closure, assimilation of carbon dioxide (CO_2), and respiration, among other elements (Ahumada *et al*., 2014). For Ibarra *et al*. (2020), prolonged droughts affect growth, development and production are reduced in the corn plant as a consequence of the impact of drought on physiological and biochemical processes.

Bänziger *et al*. (2012) point out that cell expansion is slowed down under conditions of mild or moderate water stress, as the period of stress and its intensity increase, there is less growth of leaf area and stigmas, stem elongation (lower height) and root growth (smaller exploration area) are also affected. With prolonged periods of drought, the plant may survive, but cell division is inhibited because the affected organs lack enough cells to expand.

Contreras and Díaz (2022) estimated the average yields per hectare under the environmental conditions of the period 1975-1981, obtaining an average of 3 200 to 3 800 kg, with a maximum

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of 4 500 kg. The adaptation carried out under the conditions of period B showed that the response of corn to nitrogen, phosphorus, and potassium is similar to period A since the available moisture of the cycle will condition the response to these nutrients. The adjustments of period B, of changing the sowing date, fractionating the fertilizer according to the available moisture, and incorporating rotations appropriate to the area, allowed average yields of corn grain of 4 400 kg ha^{-1}, with potentials of 6 250 kg ha^{-1}, the average yields were higher (4 800 kg ha^{-1}) when a cycle of grass-legume rotations was included.

Conclusions

The climatic changes that occurred in July and August between the periods 1975-1981 (A) and 2010-2018 (B) show that the climate conditions in July and August between both periods were different. The higher precipitation of period A allowed a better response of corn to fertilizer at that time.

The technical adjustments and management practices proposed to face a lower availability of rainfall and an increase in temperature have allowed average and potential yields of corn grain in cycle B to be higher than in the previous period.

There is evidence that must be studied to give better precision of the local adaptation of corn to conditions of water stress and increase in temperatures, such as the reduction of the crop cycle and the decrease in height and leaf area. Since they are factors that also affect the plant's response to the environment and the demand for nutrients.

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