Regiones y Desarrollo Sustentable
(2023) XXIII: 44
ISSN electrónico: 2594-1429
ISSN impreso: 1665-9511

Regiones y Desarrollo Sustentable

Artículo original Acceso abierto

Climate change and agriculture in Region of Cuitzeo, Michoacan, Mexico
Cambio climático y agricultura en la Región de Cuitzeo, Michoacán, México

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Fecha de recepción:
08-junio-2023
Fecha de aceptación:
18-septiembre-2023

Abstract

It is estimated that, in forty years, 10 billion inhabitants will be looking to satisfy their food needs. However, climate change will affect the production of some agricultural foods, which presents a challenge for humanity. It is necessary to generate information on the probable effects on some agricultural crops, especially those sensitive to extreme weather conditions like the winter crops, such as wheat, barley and oats, which need a cold season to bloom. This work aims to analyze the behavior of traditional non-technified agri-food production in the Cuitzeo Region (CR) under Climate Change (CC) conditions. The CC signal is obtained by supporting the Mann-Kendall coefficient (MK). It is linked to analyzing the agri-food production behavior in the region using the Coefficient of Variation (CV). The results show the presence of CC in the region, and it was observed that the municipalities with greater exposure to CC had reduced production growth rates with significant differences between irrigation and rainfed.
keywords: climate change, agricultural production, region of Cuitzeo, agri-food production.

Resumen

Se estima que, en cuarenta años, 10 mil millones de habitantes estarán buscando satisfacer sus necesidades alimenticias. No obstante, la producción agrícola se verá afectada por el cambio climático, lo cual representa un desafío para la humanidad. Es necesario generar información sobre los efectos probables y la producción agrícola. El objetivo de este artículo es analizar el comportamiento de la producción agroalimentaria en la Región de Cuitzeo (RC) bajo condiciones de Cambio Climático (CC). Para ello, se obtiene la señal de CC con ayuda del coeficiente de Mann-Kendall (MK) y se vincula con el análisis del comportamiento productivo agroalimentario en la región empleando el Coeficiente de Variación (VC). Los resultados muestran presencia del CC en la región, y se observa que los municipios con mayor exposición al CC redujeron las tasas de crecimiento de la producción con diferencias significativas entre riego y temporal.
Palabras clave: cambio climático, producción agrícola, región de Cuitzeo, producción de alimentos.

Introduction

Some of the climate change effects are increasing thaws, floods, droughts, and fires that have caused concern due increases on intensity and frequency in recent years (Intergovernmental Panel on Climate Change [IPCC], 2021a; 2021b). These phenomena contribute to generate situations that leads to increases vulnerability and risks, in ecosystems, society and economic growth itself (Kiley, 2021), with effects on health and productivity, which highly probability, will lead to economies contracting in the coming years (Stern, 2016; Weitzman, 2014).

In addition, the global change causes as uncertain and unpredictable socio-environments (Nigthtingale, Gonda & Eriksen, 2021) as important challenges in several aspects, such as producing food for a growing population that exceeds seven billion inhabitants and is expected to reach 10 billion in 40 years more approximately (WorldoMeters [WM], 2022), considering that a large part of the current agri-food production methods are one of the most important causes of environmental damage. Proof of this is that natural resources have been deteriorated, particularly those related with food production like water, soil, air and biodiversity (pollinators example) (Palacios & Moreno, 2022). The challenge is to rescue and reproduce food production methods that are respectful of the earth's regenerative capacity, which is reduced every year largely due to the current hegemonic agricultural practices. Finally, it is also necessary to point out that the well-being of nearly 3 billion people in the world, who are engaged in agriculture, is in a situation of vulnerability (Houtart, 2014).

According to the 2019 issue of the annual publication Panorama Agroalimentario (Secretaría de Agricultura y Desarrollo Rural [SADER], 2019), Mexico is among the world's leading fruit and vegetable producers and the world's leading corn importer. This information shows that agriculture in this country has different nuances that range from high-productivity regions to depressed areas where producers lack the resources to lead a decent life (Chong et al., 2015; Aguilar & Colín, 2022; Appendini, García & De la Tejera, 2003). Therefore, agriculture is still a strategic sector regarding social and food security (Borg, 2014).

To what extent does Climate Change (CC) pose a threat and affect crops patterns to Cuitzeo Region (CR) agriculture? The aim is to identify production contrasts occurring within the region between agricultural production and CC.

This work provides evidence of the CC situation in Michoacan's CR and its relationship with agricultural production. The information will help to confirm: the presence, direction, and intensity of CC at the regional level and to contribute to designing policies that could seek solutions, prevision and improvements regional scale.

Once the signal of CC was identified, a database with information from of Agri-Food Information System of Consultation (SIACON) (Gobierno de México, 2021) was constructed. It includes the main crops as of 2019 according to the value of production for the municipality in CR, and each of these shows' information on the type of crops for the 2003-2019 period. Based on tabulated information, the coefficient of variation was estimated using yield-per-hectare data, production growth rate and yield growth rate.

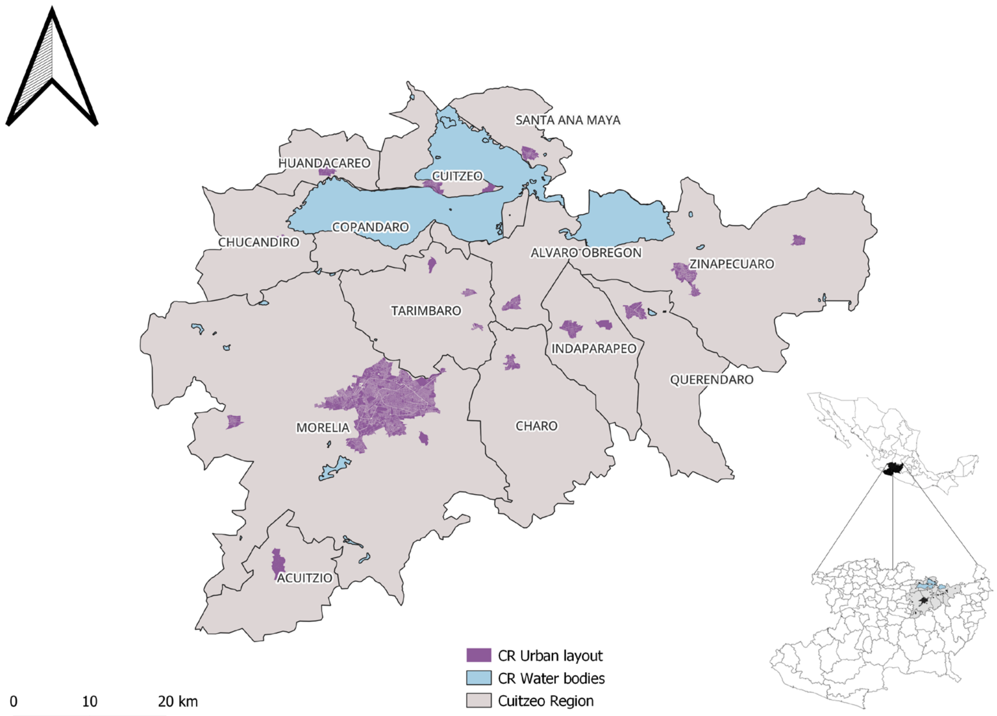
Characterization of the Cuitzeo Region (CR), Michoacan

The study region was delimited because it constitutes the basin of Lake Cuitzeo, in the part administratively corresponding to the state of Michoacán. The characteristics of this endorheic basin allow particular aspects to be considered a study region. As established in the planning law of the state of Michoacan. It is pertinent to use this regionalization since it is still current in the administrative planning of the government of Michoacan and uses water resources and other geographical and economic characteristics as integrating factors. Based on the first data obtained on the primary agricultural products, the municipality of Morelia was observed to produce the most significant amount of rainfed corn during the 2003-2019 period, with 366,848.92 tons (Gobierno de México, 2019). It makes the entire region the fourth largest producer in Michoacán. According to the area planted, corn is the most important crop, representing about 75% of the total, higher than the national percentage (33.76%).

For this research, CR is identified as a functional physical space in terms of public administration and hydrological basin of Lake Cuitzeo and comprising the municipalities of Acuitzio, Álvaro Obregón, Copándaro, Cuitzeo, Charo, Chucándiro, Huandacareo, Indaparapeo, Morelia, Queréndaro, Santa Ana Maya, Tarímbaro and Zinapécuaro (Catálogo Electrónico de la Legislación del Estado de Michoacán [CELEM], 2004) (Figure 1).

Figure 1

Cuitzeo Region, Michoacan



Source: Authors' design based on Instituto Nacional de Estadística y Geografía (INEGI, 2015). *Software* QGis3.6.3.

The Cuitzeo Lake basin is in the Transverse Volcanic System between 19º 30': 20º 05' north and 100º 35': 101º 30' west. It has an altitude of 1,800 meters and occupies an area of 3,944.865 km2, representing about 7% of the state surface (Filini, 2013). CR is the state's most populated region, with 1,173,150 inhabitants (Instituto de Planeación del Estado de Michoacán de Ocampo [IPLAEM], (2020). Its population's main economic activity is commerce, especially in the municipalities of Morelia and Cuitzeo, and there are most urbanized municipalities in the region. However, the manufacturing industry stands out in the municipalities surrounding the capital city, Charo and Indaparapeo.

Most CR municipalities have a medium degree of marginalization except for Cuitzeo, for which a "Low" marginalization index is estimated, and Morelia, with a "Very low" indicator (IPLAEM, 2020). The conditions are reflected in CR's migratory features. Except for Morelia, which has "High attraction" conditions, all municipalities have some degree of migratory expulsion (IPLAEM, 2020).

Materials and methods

The National Climatological Database (CLICOM System) (CLICOM, 2020) was used to identify CR's weather observation in Meteorological Stations (MS). This system uses a database from surface weather observation MS in Mexico, developed by the National Meteorological Service (Spanish acronym: SMN). This information was accessed through a tool developed by the Center for Scientific Research and Higher Education of Ensenada, Baja California (Spanish acronym: CICESE). This tool allows us to identify the crucial and geographic location and the estimated number of years of information available at a specific MS.

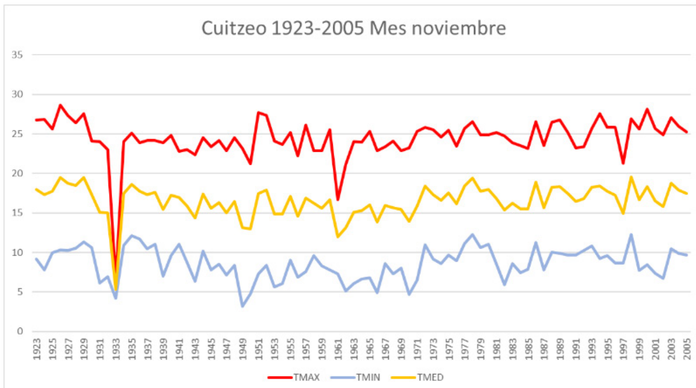
Based on this exploration, 25 weather observation MS were identified in CR. Once the vital and geographical reference information was obtained, the daily information for each selected MS was downloaded from SMN's website. Since all available data are in .txt format, they had to be migrated and debugged into Microsoft Excel to validate that daily information was available for a minimum of 25 years (Ortega, Ortiz & Ortega, 2018). For the variables of Rainfall (mm), Evaporation (mm), Maximum Temperature (0C), and Minimum Temperature (0C), 18 MS met the criterion.

Once the information was in Microsoft Excel, the daily data were grouped into monthly information, and a first data cleaning was performed. Some data entry errors were identified, such as decimal points, misplaced signals, or text that altered numerical data; these were the most recurrent cases identified during the processing stage. Subsequently, the information from each weather observation in MS was migrated to a specialized Clic-MD program developed by Bautista et al. (2011).

First, the missing information gaps were filled by calculating an average with data covering five previous and five subsequent years (Bautista, Pacheco y Bautista-Herrera, 2016). A second visual review was carried out based on that information. By plotting the Tmax, Tmed, and Tmin information, the behavior of data for each monthly period per MS was observed, which allowed to identify extreme peaks that would bias the results (see Figure 2). Despite having the first data review in the initial draft, detecting such anomalies was impossible, given the amount of information handled per MS.

Figure 2

Examples of data anomalies during visual inspection



Source: Authors' own design (2021).

Based on this situation, daily information was reviewed to locate any number or signal, possibly altering the monthly average. Likewise, the information on the geographically closest MS was reviewed to rule out the same situation if no apparent error was found in the draft. It implied conducting some research on meteorological news that reported any phenomenon that could be displayed in the data. The information was kept only if such documentary evidence was found; otherwise, complete days and months with anomalies were eliminated, and the information was recaptured using the Clic-MD program.

After the visual review, non-parametric normalization tests were applied to the data for monthly periods to rule out abrupt variations in the series' mean. The Geary coefficient, the Shapiro-Wilk test, the sequence test, the Bartlett test, and the Pettit test were applied to the program used (Bautista, Pacheco y Bautista-Herrera, 2016). To continue the analysis, the data for each month under testing had to pass at least one test.

The data were also subjected to homogenization tests. This procedure is applied to meteorological variables to ensure their oscillations respond to exclusively climatic factors. It is achieved by isolating the information from any bias caused by equipment (MS), human, or other errors. Homogeneous series are those whose variations respond to climatic causes, and non-homogeneous series contain jumps in the mean caused by non-climate-related aspects (Bautista, Pacheco y Bautista-Herrera, 2016). The tests applied by the software were Buishad's, Herlmert's, Von Neuman's, Anderson's, Spearman's, and Kolmorogov-Smirnov's. The data had to demonstrate homogeneity in at least one to continue the analysis.

The MK correlation coefficient was used to detect signals and trends of CC. It is among the non-parametric statistical tests because it uses freely distributed (Gómez, Danglot-Banck y Vega-Franco, 2003) or non-normal data (Bautista et al., 2011). This tool helps identify a data series's nonlinear change trends for equal time intervals.

The test compares the most recent data with the previous ones; the closer to 1 indicates that the most recent data concentration is more significant; if the value is -1 means the opposite. The score of the data series in the MK statistics is compared with a critical value to check for any trend (Bautista et al., 2011). The MK analysis was performed according to the following:

1. Data pairs n (*x1*, *y1*), (*x2*, *y2*) ... (*xn*, *yn*) are indexed according to the magnitude of the *x* value, so $x1 \leq x2 \leq \ldots xn$ and *yi* is the value of the dependent variable corresponding to *xi*.
2. When examining all *n* (*n*-1 pairs)/2 ordered *yi* values. Being P the number of cases in $yi > yj$ ($i > j$) and being M the number of cases in $yi < yj$ ($i > j$).
3. To define test statistics S = P-M.
4. For $n > 10$, the test is performed using a normal approximation. The standardized Z test statistic is calculated as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var\ (S)}} & S < 0 \end{cases} \qquad (1)$$

$$Var\ (S) = n(n-1)\ (2n + 5)\ /18 \qquad (2)$$

The null hypothesis is rejected at the significance point α if |Z|>Z (1-α)/2, where Z (1-α)/2 is the value of the standard normal distribution with a probability of exceeding of α/2. Then if α= 0.05, the null hypothesis is rejected due to |Z| > 1.96. The correlation coefficient τ of MK is defined as:

$$t = \frac{S}{\frac{n\,(n-1)}{2}} \qquad (3)$$

The reading of the indicator is similar to other correlation coefficients; the signal refers to the type of relationship (positive or negative), and the absolute value refers to the degree of the relationship. Since the test is used on rows of data, it can be applied even if some data are missing. This facilitates its application in terms of weather; when this situation arises, a correction is made in the variance formula (*S*), and the missing values are grouped using the following formula (Bautista et al., 2011):

$$Var\ (S) = \frac{n(n-1)(2n+5) - ?_{i=1}^{n} t_i\ \ i(i-1)(2i+)}{18} \qquad (4)$$

Where:

it is the number of links of extension *i*.

The test cannot be applied when there are multiple rejection thresholds for the null hypothesis in the data set; the values cannot be classified ambiguously (Hirsch et al., 1993; in Bautista et al., 2011). In this case, the MK test particularities are:

- The test does not consider the data magnitude.
- It is less sensitive to extreme data.
- It does not consider the time variation in the data, so it is impossible to obtain the magnitude of the trend.
- Data should be free of seasonality.

A non-trend result does not mean a stable data series; it means a trend has not been detected through this test. A decreasing or increasing trend result in the MK test is a more decisive conclusion than a no trend. The less data available, the less reliable the MK test result is. If $Z > 1.96$, there is statistical significance for the data series, i.e., a trend. A positive Z value indicates an upward trend; a negative value indicates a downward trend in the data series (Hirsch et al., 1993; Bautista et al., 2011).

The Agri-food Information System for Consultation (SIACON-NG) was used to analyze agricultural production in CR. According to it, the crops with the highest production value as of 2019 were chosen with information for at least five consecutive years in 2003-2019; that was the only information available in said system.

Based on the selection of crops by the municipality, a database was integrated to calculate Pearson's Variation Coefficient (VC) using the yield (tons/ha) for 2003-2019 as a reference. This indicator measures the percentage of variations of a variable concerning its mean (Vargas, 1995). Then it is possible to assume that variations in crop yields may be associated, among other factors, with climate change. Therefore, a municipality with a high variation is in a situation of greater vulnerability than another with a low coefficient.

In addition to the VC, production and yield growth rates were estimated for the abovementioned period. Based on the information obtained, an analysis of variance tests was performed (Serrano, 2003) to identify significant differences in variable behavior.

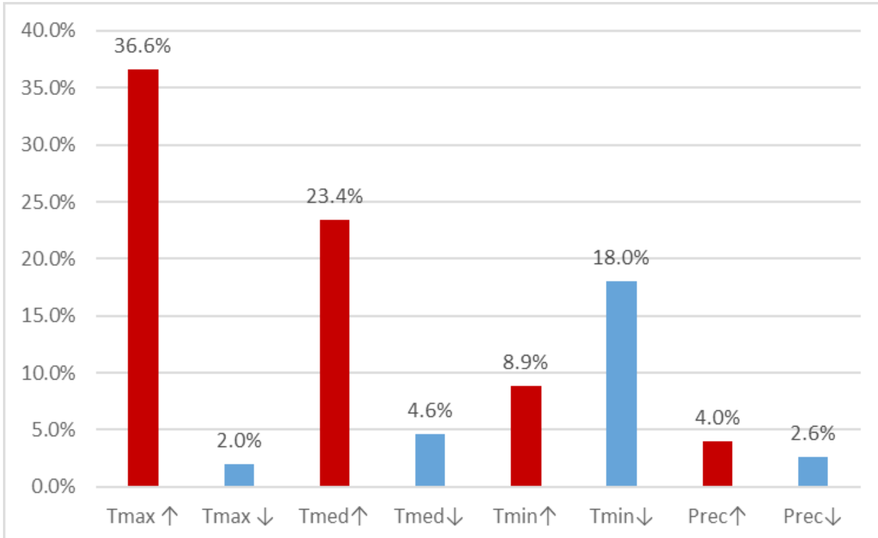
Results and discussion

Climate Change trends in Cuitzeo's region and its agricultural production

Notably, some CC trend was observed in the 18 observations MS reviewed. The results of this analysis indicate the identification of a trend, so the direction (increase or decrease) and the number of months occurring such trend for Maximum Temperature (Tmax), Average Temperature (Tmed), Minimum Temperature (Tmin) and Rainfall (Precip), were added up. There are 12 months for each of the four variables mentioned above, so there are 48 months in which a CC trend can be observed.
An increasing Tmax was the most frequent trend, with 128 cases representing 36.6% of the total number of months (350) when it happened. Then, an increasing Tmed (23.4%) and decreasing Tmin (18%) followed (Figure 3).

Figure 3

Percentage of CC trends identified in CR



Source: Authors' design (2021).

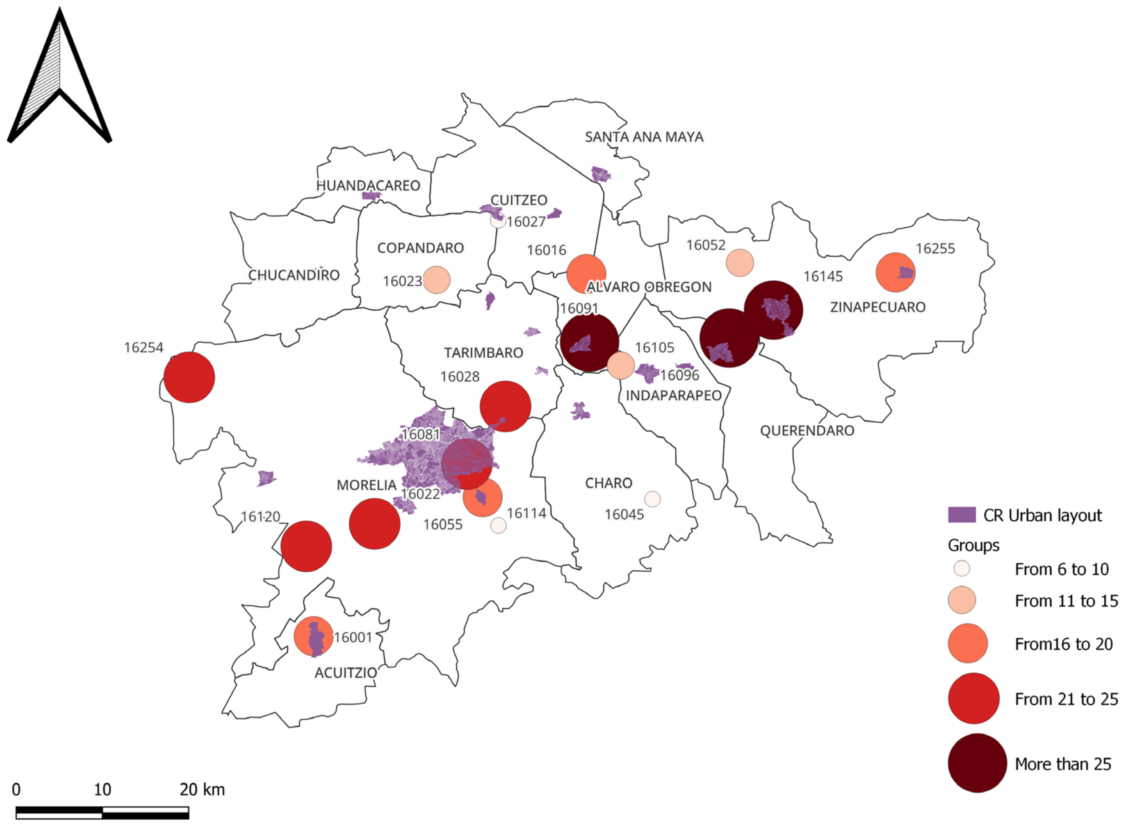
In the case of this study, MS 16096 "Presa Malpais" showed the most CC trends in 34 months; MS 16027 "Cuitzeo" and 16114 "San Miguel del Monte" showed minor CC trends (6 months).

The following map (Figure 4) contains the selected weather observation MS and a color gradient that displays the MS grouped in five sets ranging from 6 to 10 months of observed trend to more than 25 months of CC trend. It is worth mentioning that the most significant number of MS (10) present trends between 16 and 25 months.

As mentioned above, the signal of CC represents a trend of increase or decrease, so the georeferencing of results on the four variables indicates that changes do not occur homogeneously or in the same direction. The results are then integrated by variables (Tmax). They are highlighted in blue if the identified trend in that MS is a decrease, in white if no trend has been detected, and in red if the trend is upward (Figure 5).

Figure 5

Number of months with observed CC trend per MS

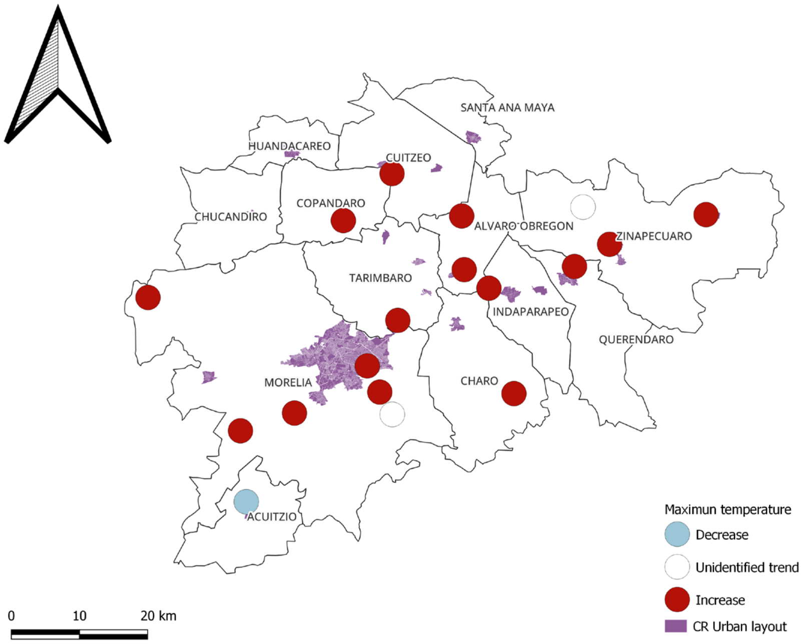


Source: Authors' design (2021).

When results are presented this way, it is clear that most cases show an increase in the case of Tmax. Only MS 16001 "Acuitzio" registered a decrease in temperature, and MS 16114 "San Miguel del Monte" and 16052 "Huingo" did not show a trend. As for Tmin, most cases show a decreasing trend, but 5 MS showed an increasing trend. The case of rainfall is noteworthy; out of the 13 MS with a trend, 8 showed increasing changes; the remaining five showed a decreasing movement. In this case, no trend was detected in five MS.

Figure 5a

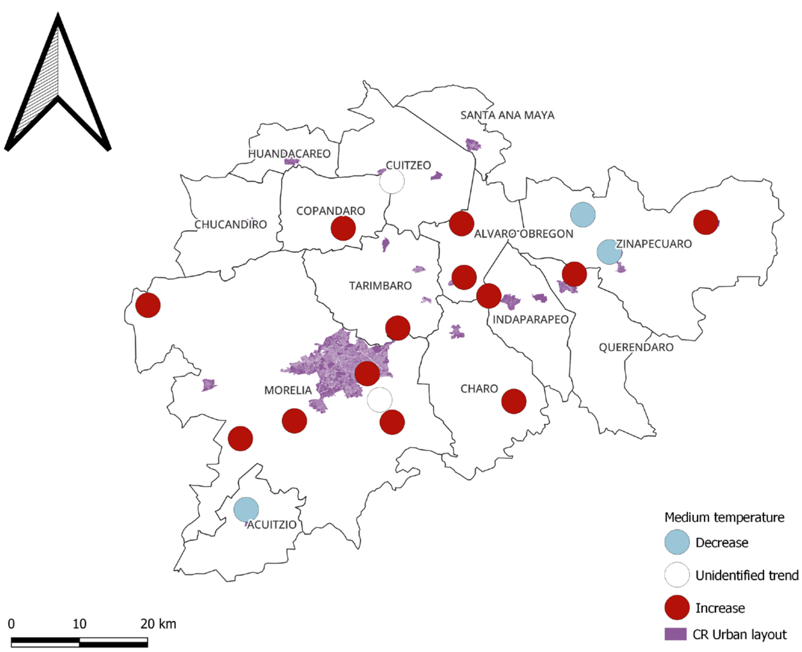
Trends observed by variable (CR)



Source: Authors' design (2021).

Figure 5b

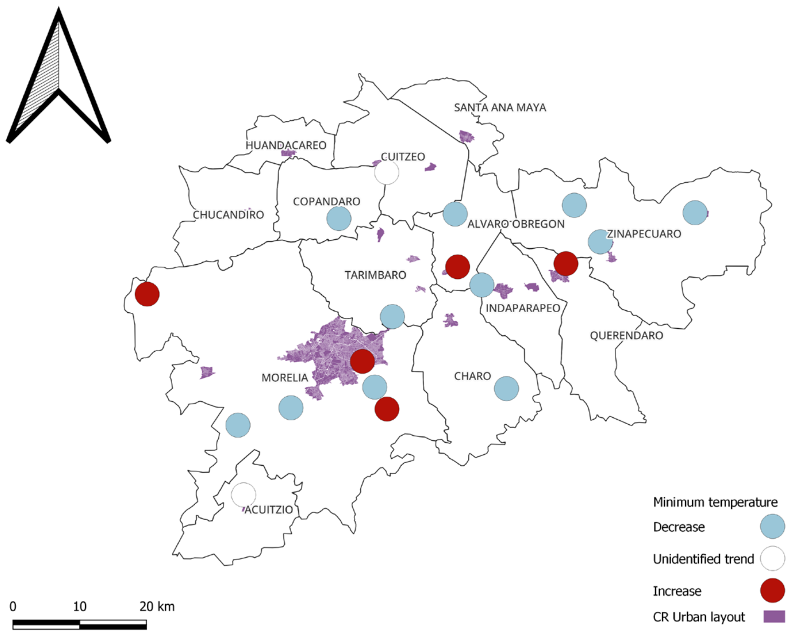
Trends observed by variable (CR)



Source: Authors' design (2021).

Figure 5c

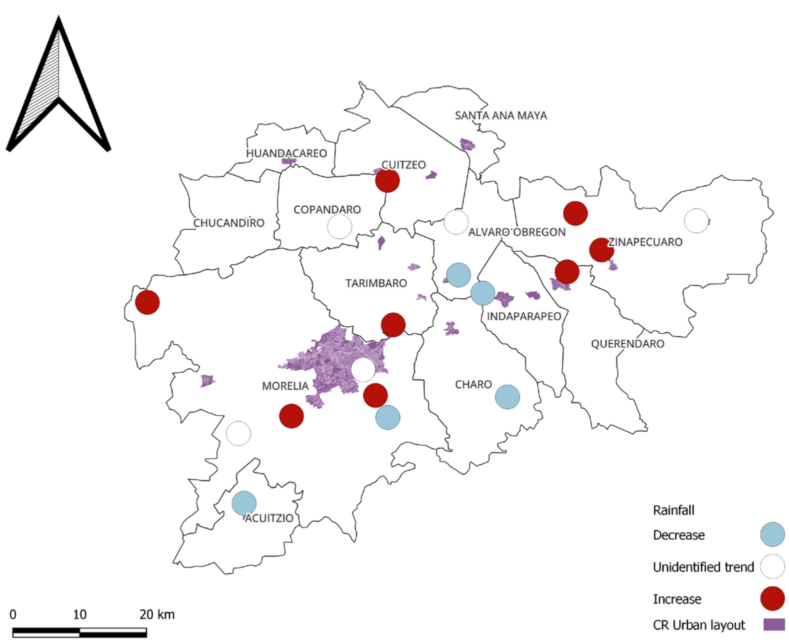
Trends observed by variable (CR)



Source: Authors' design (2021).

Figure 5d

Trends observed by variable (CR)



Source: Authors' design (2021).

As noted above, the upward trend in Tmax is the most common in the CR. Only Acuitzio (16001) had a downward trend, and San Miguel del Monte (16114) and Huingo (16052) had no such trend identified. The rest of the MS show an upward Tmax trend in at least one of their months. It shows evidence that the region is warming up. It has repercussions in productive terms for the primary sector and the rest of the economy.

The case of Tmed is very similar to that of Tmax; most MS register a Tmax increase in at least one month. Acuitzio (16001), Huingo (16052), and Zinapécuaro (16145) show a decrease in this variable; Cuitzeo (16027) and Jesús del Monte (16055) show no trend.

Regarding Tmin, the general trend identified is downward; however, MS Teremendo (16254), Morelia (16081), San Miguel del Monte (16114), Álvaro Obregón (16091), and Presa el Malpais (16096) show increases. No trends were observed for Cuitzeo (16027) and Acuitzio (16001) MS.

Rainfall is the most heterogeneously distributed, as no trend is identified in five MS: Copándaro (16023), Carrillo Puerto (16016), Ucareo (16255), Morelia (16081), and Santiago Undameo (16120); other MS located in the central and southern zone of CR register decreases: Acuitzio (16001), San Miguel del Monte (16114), El Temazcal (16045), Quirio (16105), and Álvaro Obregón (16091) —the remaining 8 MS recorded rainfall increases in some of their months.

The crop selection procedure in CR resulted in 47 irrigated and rainfed crops. This information also shows that all crops grown in each municipality add up to 203, of which 142 are irrigated, and 61 are rainfed (Table 1).

Table 1

Main agricultural products of CR, Michoacán

		# of municipalities producing it				# of municipalities producing it	
	Crop	**Irrigated**	**Rainfed**		**Crop**	**Irrigated**	**Rainfed**
1	Agave		1	25	Chickpea grain	5	
2	Avocado	7	5	26	Guava	1	
3	Green alfalfa	11		27	Broad bean		1
4	Green fodder oat	13	6	28	Jicama	1	
5	Beets	1		29	Lettuce	3	
6	Broccoli	1		30	Lentil	1	1
7	Zucchini	4		31	Hominy	13	13
8	Sweet potato	1		32	Apple	1	
9	Barley grain	1		33	Nopal cactus	1	1
10	Onion	7	1	34	Cloud flower-Gypsophilia (bunch)	2	
11	Pea	1		35	Pastures and meadows	1	2
12	Dry peppers	1		36	Cucumber	2	
13	Green peppers	4		37	Pear		1
14	Cilantro	1		38	Radish	1	
15	Plum	1	1	39	Hominy seed	1	
16	Cabbage	2		40	Grain sorghum	11	12
17	Cauliflower	2		41	Red tomato	6	
18	Peach	3	1	42	Green tomato	4	2
19	Ebo (Janamargo or Vetch)	6	2	43	Clover	1	
20	Bean pods	1		44	Wheat kernel	10	2
21	Corncob	1		45	Prickly pear (cactus fruit)		1
22	Spinach	1		46	Carrot	1	
23	Strawberry	2		47	Marigold (Zempoalxochitl flower) (bunch)	2	
24	Beans	2	8		**Grand total**	**142**	**61**

Source: Authors' design based on SIACON (Gobierno de México, 2021).

The main results of this calculation show that five rainfed and five irrigated crops have the highest production growth rate. Sorghum, a rainfed grain from the municipality of Tarímbaro, has a growth rate of 345%. Also, in the same municipality, irrigated spinach holds the most significant yield variation (Table 2).

Table 2

Crops with the highest production growth rate and yield variation (VC)

Municipality	Crop	Watering System	Production growth rate	Municipality	Crop	Watering System	Yield VC
Tarímbaro	Grain sorghum	Rainfed	345 %	Tarímbaro	Spinach	Irrigated	136 %
Morelia	Lentil	Irrigated	282 %	Huandacareo	Beans	Rainfed	88 %
Indaparapeo	Hominy	Rainfed	186 %	Charo	Beans	Rainfed	85 %
Santa Ana Maya	Grain sorghum	Rainfed	184 %	Indaparapeo	Beans	Rainfed	80 %
Copándaro	Hominy	Rainfed	173%	Tarímbaro	Cilantro	Irrigated	73 %
Queréndaro	Barley grain	Irrigated	163 %	Cuitzeo	Beans	Rainfed	61 %
Queréndaro	Grain sorghum	Irrigated	150 %	Santa Ana Maya	Hominy	Rainfed	59 %
Tarímbaro	Chickpea grain	Irrigated	146 %	Copándaro	Beans	Rainfed	58 %
Cuitzeo	Onion	Irrigated	142 %	Cuitzeo	Green peppers	Irrigated	57 %
Cuitzeo	Hominy	Rainfed	140%	Morelia	Wheat kernel	Rainfed	57 %

Source: Authors' design based on SIACON (Gobierno de México, 2021).

According to the descriptive results, the mean coefficient of variation was higher in rainfed crops, with an average variation of 35%. In comparison, irrigated crops registered a mean variation of 23% for the period analyzed. An analysis of variance test was applied using the t-test, accepting the alternative hypothesis about the difference of means ($p \geq 0.05$).

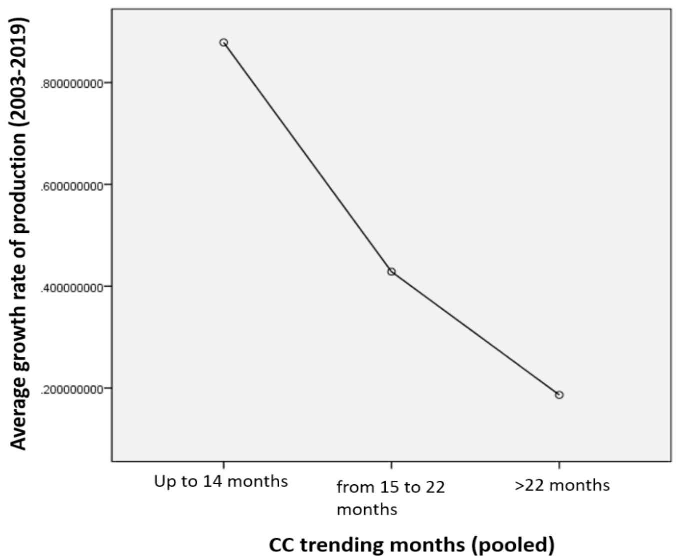
In the production growth rate, the mean for irrigated crops is 36% and 50% for rainfed crops. However, these differences were not significant by analysis of variance, which shows the heterogeneity of crop production growth within CR.

Similarly, an analysis of variance was conducted to contrast the growth rate of crop yields with their watering system, i.e., irrigated or rainfed. The yield growth rate for irrigated crops is 6% and 19% for rainfed crops; the differences are statistically significant ($p \geq 0.05$).

As for the signal of CC, once the results were obtained on the number of months identified in each MS, these were averaged to obtain one data per municipality and grouped in a new variable of three groups: up to 14 months, from 15 to 22 months, and >22 months. Results from the analysis of variance show statistically significant evidence ($p \geq 0.05$) that there are mean differences between said groups and the production growth rate. In the case of irrigated crops, this difference was observed between the first two groups; in the rainfed crops, it was observed between all three groups (Figure 6).

Figure 6

Production growth rate and months of CC trend



Source: Authors' own design (2021).

Finally, analyses of variance were performed between these variables and CC trend observations, which suggested the existence of statistical significance ($p \geq 0.05$) between the number of months of CC trend and production rate growth rate. In other words, a negative relationship was found, indicating that the lower the number of months of CC trend (less exposure to the phenomenon), the higher the growth rate of crops.

Discussion

We assumed in this paper that the CC phenomenon is present in Michoacán's CR, so we considered as an intervening variable. It is essential because it is a global problem. However, its effects are heterogeneous (Borg, 2014) in place and direction.

In this vein, this research provides evidence that CC happens heterogeneously within the region. The main results of the climate analysis are consistent with Ortega, Ortiz & Ortega (2018), who found through the same methodology that Tmax in Michoacán's Tierra Caliente Region is increasing while Tmin is decreasing in most months of the year. These results are also consistent with Hernández & Valdez (2004), who forecast that the country's climate will be drier and warmer.

In addition, the analysis of variance for the growth rate of the main CR crops shows that the greater the exposure to CC (CC trend months identified by MS), the lower the growth rate of irrigated and rainfed crops. This idea concurs with Conde, Ferrer y Araujo (2004). They mention that Mexico's agriculture is vulnerable to the CC phenomenon. Based on climate models, the Intergovernmental Panel on Climate Change (IPCC, 2014) states that agriculture in Latin America and the Caribbean (LAC) is prone to decrease food production and quality, and prices will rise due to extreme climate factors.

The ecological (Altieri & Nicholls, 2010), economical, productive (Van Der Ploeg, 2013), and cultural (Rosas, 2009) importance of small-scale or peasant agriculture is associated with rainfed crops because of its production characteristics (Uzcanga et al., 2015b; Uzcanga et al., 2015a; Damian et al., 2014). In this sense, the analysis of production and yields of the main CR crops during the 2003-2019 period displays contrasting results. On the one hand, rainfed agriculture shows the most significant variation (35%) during the period concerning irrigated agriculture (23%); therefore, it is more vulnerable. In the case of CR, however, the yield growth rate is higher in rainfed crops (19%) than in irrigated crops (6%), and rainfed crop production is higher than irrigated.

These ideas demonstrate that even in the CC context, small-scale production generates the most food (Van Der Ploeg, 2013) under increasingly severe conditions. This kind of production faces such changes with resistance and apparent naivety (Altieri & Nicholls, 2010) and develops complex adaptation processes (Smit & Skinner, 2002; Adger et al., 2007), but it essentially constitutes a healthy alternative to territorial occupation (Gómez-Olivier, 1995) and social functioning.

Conclusions

The approach of this research is based on the observation of such contrasts in food production in Michoacan. It induced a review of the main crop in the diet of a significant part of the Mexican population: corn. This crop is produced in the entire national territory, and its production guides the results of the country's food and regional policies.

This research provides evidence of the CC situation in Michoacan's CR and its relationship with agricultural production in this part of the state. The methodological tool allows that, with periodically updated information, such as that provided by the Agricultural Census Framework, regions can be diagnosed in Michoacan and throughout the country regarding vulnerability and municipal adaptive capacities. Among the adaptations required according to the specific environment of each region are those of analyzing and improving climate monitoring, expanding the number of weather stations, implementing data quality controls, and making them public and accessible.

According to a review and analysis of climatological information, there is evidence of the presence of the CC signal and trends in CR; at least six months were identified in the 18 MS reviewed.

However, such evidence has a heterogeneous behavior in the region; CC can vary according to the number of months that show a trend, and this number varies from 6 in Cuitzeo MS to 34 in "Presa Malpais" MS. These are indeed trends, and encouraging this behavior implies substantial changes in production (meanly agriculture) and in the use of natural resources.

So, the conclusion is that CR is warming; however, it has been mentioned in previous lines that the signal of CC is differentiated; the conclusive data obtained shows that Tmax in 15 of all 18 MS reviewed has an increasing trend. On the other hand, Tmin in 11 MS confirms cooling, i.e., a trend toward extreme temperatures.

As for rainfall, no conclusive behavior is observed. However, according to the georeferencing of weather observation MS, those in the upper part of the Cuitzeo basin (Acuitzio, San Miguel del Monte, and Temazcal) show a decreasing trend in some months.

The possible implications of the CC signal in CR are an increase in variance coefficient higher in rainfed crops, with 35%, while irrigated crops registered 23% for the period analyzed. An analysis of variance test was applied using the t-test, accepting the alternative hypothesis about the difference of means ($p \geq 0.05$).

For the production growth rate, the mean for irrigated crops is 36% and 50% for rainfed crops. However, these differences were not significant by analysis of variance, which shows the heterogeneity of crop production growth within CR. Similarly, the variance coefficient was carried out to contrast the growth rate of crop yields with their watering system, i.e., irrigated or rainfed. The yield growth rate for irrigated crops is 6% and 19% for rainfed crops; the differences are statistically significant ($p \geq 0.05$).

The analysis of variances allows assuming a behavior change in rainfed and irrigated crops concerning their VC. It indicates that crops with a more significant percentage of variation in their yields are more vulnerable; it is the case of rainfed crops with an average variation of 35% for the period under study.

There is also evidence that the rate of yield growth in rainfed crops is higher (19%) than that of irrigated crops (6%) for the period with available data. Finally, the contrast between the number of months of CC exposure (grouped in 3) and the yield growth rate showed statistical significance. It proves that those crops grown in areas with less exposure to CC trends (up to 14/48 months) have a higher yield growth rate than those grown in areas with a higher number of months with CC trends.

Due to the important challenge represented by CC, it is suggested to explore alternative approaches such as the circular economy in agriculture, both to reduce emissions, for soil carbon sequestration and reduction of vulnerability as regeneration agriculture. Such approaches have already been proposed for livestock, so this trend may yield proposals for regeneration alternatives (Villavicencio, Salazar & Meléndez, 2023).

Regarding the limitations inherent to the method, there are those that the indicators obtained are subject to the quality of the data, the survey methodology, and the speed of its update. So, our recommendation to minimize these limitations is to conduct a field approach to contrast the expected versus the observed. In this sense, we consider pertinent to develop lines of research that consider the following:

- Include study variables such as the producer's motivation for adaptation to CC.
- Evaluation of regional agri-food systems post-pandemic.
- Identification of community adaptive capacities and their determinants.
- Participatory action research in the development of regional productive projects.
- Longitudinal research of implementation and monitoring of regional agroecological projects.
- Study of societal interfaces for agricultural producers.
- Mechanisms that determine commodity prices in CR.

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