Article

Impact of climate change on agriculture in Irrigation District 005 Chihuahua, Mexico

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Abstract

The sector most economically affected by climate change is expected to be agriculture, being affected by the decline in economic income. The objective of the research was to know the impact of climate change on agriculture in Irrigation District 005, located in the state of Chihuahua, through the application of surveys in 2020. Chi-square tests were performed, of the respondents, 40% [X^2(138.32) p< 0.001] has more than 20 ha, 65% grows mainly pecan tree (*Carya illinoinensis*), 97.89% [X^2(187.17) p< 0.001] has heard of climate change and 44.09% [X^2(155.33) p< 0.001] defines it as pronounced climatic variation between seasons. The multiple correspondence analysis estimated that the variables that presented greater inertia for the first dimension were: zero tillage (M1), change of type of crop (M3), water collection techniques (M4), others (M5) and percentage of contribution (cmedidas), for the second dimension, those that presented greater inertia were: those who have suffered economic losses (peconomicas), most affected period (periodo), cause of the impact (causa), percentage of economic losses (pp). Two multinomial logistic regression models were run, the measures applied to reduce the effects of climate change were zero tillage and the use of organic products. The results obtained showed that as the age of the producers increases, the possibility that they know about climate change, its causes and choose to take out insurance decreases. Finally, more than one mitigation/adaptation measure needs to be applied to counteract climate change.

Keywords: adaptation, agriculture, climatology, mitigation.

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Introduction

Climate change is one of the problems of greatest interest to be addressed in the global agenda because its effects are reflected in all countries, either to a greater or lesser extent. Its causes can be natural or anthropogenic (Díaz, 2012). The sector most economically affected by climate change is expected to be agriculture, being affected by the decrease in economic income. This sector is a determinant for food security (López and Hernández, 2016), which occurs when everyone has permanent access to safe, nutritious food and in sufficient quantity to meet their nutritional requirements and food preferences, thus being able to lead an active and healthy life (FAO, 2019).

Agriculture is the main source of the economy in Irrigation District 005, so a reduction in the area of crops, due to the lack of water resources, would entail a socioeconomic impact (IMTA, 2013). On the other hand, climate change affects the growing degrees days, which refer to the indices used to estimate the development of plants, these have been used in numerous vegetable production systems to predict physiological maturity, harvest date and time of successive sowings (Hoyos *et al*., 2012).

There is a consensus on the part of the scientific community for the study of climate change around the social sciences, to describe how it is perceived by people (Vélez-Torres *et al*., 2016), since, by knowing the relationship that various variables have with respect to climate change, strategies that allow farmers to understand it and choose the option for mitigation/adaptation for the type of crop and region can be established.

Adaptation has been shown to be an effective option that can significantly reduce the economic and social costs implied by climate change (Galindo *et al*., 2014). In Mexico, the topic of the implementation of adaptation measures to climate change is new, so it is important to first consider the existing uncertainty in this regard, since the magnitude is not known and this makes it difficult to establish adaptation measures; secondly, the constant fluctuation of vulnerability to changes requires a constant evaluation of processes for their better understanding (INECC, 2018). The objective of this study was to know the impact of climate change on agriculture in Irrigation District 005 in relation to the impact of climate change on agriculture.

Materials and methods

Characteristics of the study area

The study area is located in Irrigation District 005, in the central-south region of the state of Chihuahua, Figure 1. At the coordinates 27° 31’ to 28° 35’ north latitude and 105° 45’ to 105° 00’ west longitude (CONAGUA, 2002). The average annual rainfall, in the irrigation area of the Irrigation District, is 334.1 mm (IMTA, 2013). The climate is very dry semi-warm BWh’ (h), dry semi-warm BSOh’ (h) and semidry temperate BS1k’ (h) with rains in summer, and average annual temperatures between 12 and 18 °C, average temperatures of the coldest month from -3 °C to 18 °C and a total annual rainfall of 300 to 500 mm (INEGI, 2005).

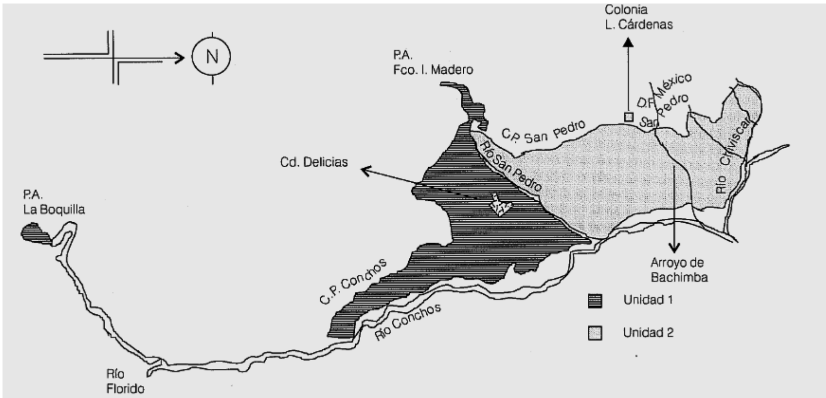

Figure 1. Location of the study area of Irrigation District 005 (1Velasco and Miranda, 1996).

Sampling

The applied sampling was simple random according to Otzen and Manterola (2017). The sample size was obtained using the formula proposed by Aguilar-Barojas (2005): $n=\frac{NZ^2pq}{d^2(N-1)+Z^2pq}=94.91=$ 95 (1). Where: p= probability of success= 0.5; N= total population= 8096 farmers (CONAGUA, 2018); q= probability of failure= 0.5; Z= confidence level= 1.96; d= sample error= 0.1.

Survey design and data collection

The survey was designed using the Kobotoolbox website(https://www.kobotoolbox.org/), because its interface is user-friendly and the data processing is functional, later we had contact with farmers in the study area, to whom the survey was applied.

Method

Thirty categorical variables were considered, which were analyzed using the R4 software; through Chi-square tests, through which the results obtained in each question of the survey were analyzed, for the measurement of the level of significance, a multiple correspondence analysis, in order to identify the relationship of the variables and multinomial logistic regression models of the variables of interest that presented more inertia in each dimension, in order to understand the relationship between variables and their categories.

Results

The characterization of the producers in the study area estimated that 91.58% [X^2(165.69) $p<$ 0.001] of the farmers surveyed are male and 8.42% correspond to the female gender, this result is similar to what is documented by SADER (2019), which mentions that in Mexico only 15% of the total producers nationwide are women. In addition, it was found that the age of the 49.47% [X^2(140.2) $p<$ 0.001] of respondents is between 41 and 60 years old, which is consistent with what was recorded in the study on the aging of the rural population in Mexico carried out by SAGARPA Y FAO (2014), which indicates that the average age of agricultural producers in Mexico is 54.6 years.

Regarding the characteristics of agricultural production, it was found that 40% [X^2(138.32) $p<$ 0.001] of respondents have more than 20 ha. In 65.26% [X^2(1 131.47) $p<$ 0.001] of the cases, walnut is the main crop (Table 1), which has as its attractiveness its high demand in the market, since 70% is destined for export to the United States of America (Retes *et al*., 2014). In turn, 78.95% [X^2(1 268.73) $p<$ 0.001] of the respondents mention that, of their main crop, they harvest less than 10 t ha^{-1}, 10.53% harvest between 10 and 20 t ha^{-1}, 5.26% mentioned harvests between 61 and 80 t ha^{-1}. In the case of alfalfa, it is below the state average, 47.5 t ha^{-1}. However, in Irrigation District 005 in the agricultural cycle of 2000, the yield was even lower than the average mentioned, reaching only 18.3 t ha^{-1} of dry forage and in 2012 it was 18.54 t ha^{-1} (Lara *et al*., 2014).

Table 1. Main crop of the farmers surveyed.1

Main crop	N	%	Chi-square	Sig
Alfalfa	20	(21.05)	131.47	***
Chili	5	(5.26)		
Corn	3	(3.16)		
Walnut	62	(65.26)		
Other	5	(5.26)		

NS= non-significant differences ($p>$ 0.05); *= significant differences at 5% ($p<$ 0.05); **= significant differences at 1% ($p<$ 0.01); ***= significant differences at 0.1% ($p<$ 0.001).

Regarding climate change, 97.89% [X^2(187.17) $p<$ 0.001] of respondents said they had heard about it; likewise, 44.09% [X^2(155.33) $p<$ 0.001] define it as a climatic variation (Table 2). This shows similarity with the opinion study carried out by SEMARNAT-INECC (2016), in which 89% of respondents said they had heard about climate change and 5 out of 10 Mexicans defined climate change as an alteration of the climate or the environment.

Table 2. Definition of climate change.

Definition	N	(%)	Chi-square	Sig
Temperature change	27	(29.03)	55.33	***
Change in hydrological cycles	3	(3.23)		
Consequence of pollution	4	(4.3)		
Other	18	(19.35)		
Climate variation	41	(44.09)		

NS= non-significant differences ($p>$ 0.05); *= significant differences at 5% ($p<$ .05); **= significant differences at 1% ($p<$ 0.01); ***= significant differences at 0.1% ($p<$ 0.001).

Eighty-seven point thirty-seven percent [X^2(153.06) $p<$ 0.001] of respondents claimed to know what the causes of climate change are, of these, 55.42% [X^2(195.77) $p<$ 0.001] identified pollution as the main cause (Table 3). This is consistent with a study developed by SEMARNAT-INE (2016), where it was found that more than 70% of respondents blamed human activity and air pollution for climate change.

Table 3. Causes of climate change.

Causes	n	(%)	Chi-square	Sig
Global warming	3	(3.61)	95.77	***
Pollution	46	(55.42)		
Greenhouse gases	7	(8.43)		
Other (human activity, burning of fuels)	13	(15.66)		
Overexploitation of resources	11	(13.25)		
Use of agrochemicals	3	(3.61)		

NS= non-significant differences (p> 0.05); *= significant differences at 5% (p< 0.05); **= significant differences at 1% (p< .01); ***= significant differences at 0.1% (p< 0.001).

On the other hand, 96.84% [X^2(183.38) p< 0.001] of respondents consider that the climate has changed; of these, 42.39% [X^2(129.87) p< 0.001] mention that it is notorious due to the climatic variation that exists in the region with respect to previous years. In this sense, it is reported that, regarding the phenomenon of climate change in Michoacán, according to what was documented by González *et al*. (2017), 90% of respondents said they perceived changes in the climate of the region, with the increase in temperature standing out. Also, of the respondents who believe that the climate has changed, 38.04% [X^2(118.52) p< 0.001] consider that the change occurred more than 15 years ago.

However, according to the ONU (2017), in the period 1880-2012 there was an increase in the average annual temperature of 0.85 °C. Subsequently, the IPCC (2013) for the period 2016-2035 predicted a likely change in the global average surface temperature, compared to 1986-2005, with a range of 0.3° to 0.7 °C. This is similar to the present study since 45.26% [X^2(1151.47(p< 0.001] of respondents consider that the situation that has occurred most frequently has been the increase in temperature (Table 4). This increase affects deciduous fruit trees, such as walnut, since they require accumulation of cold hours for their proper development (José *et al*., 2016).

Table 4. Climatological situation that has occurred more frequently.

Situation	n	(%)	Chi-square	Sig
Temperature increase	43	(45.26)	151.47	***
Temperature decrease	1	(1.05)		
Hail	4	(4.21)		
Frost	3	(3.16)		
Rains	1	(1.05)		
All mentioned	5	(5.26)		
Droughts	38	(40)		

NS= non-significant differences (p> 0.05); *= significant differences at 5% (p< 0.05); **= significant differences at 1% (p< 0.01); ***= significant differences at 0.1% (p< 0.001).

With respect to the impact on agriculture, 49.47% [X^2(1 133.97) p< 0.001] of respondents mentioned that the most affected crop has been walnut (Table 5). Fifty-two point seventeen percent [X^2(1 68.11) p< 0.001] said that the period in which their crop was perceived most affected was from 2016 to 2020. In this regard, the low temperatures that occurred at the end of December 2018 caused serious damage to vegetable crops in Sonora and Chihuahua (CONAGUA, 2019). While it is true that climatic variations have directly affected agriculture, the impact for each farmer is different due to the diversity and extent of crops in the region.

Table 5. Crops that have been most affected by climate change.

Crops	n	(%)	Chi-square	Sig
Alfalfa	10	(10.53)	133.97	***
Cotton	3	(3.16)		
Peanut	2	(2.11)		
Onion	2	(2.11)		
Chili	11	(11.58)		
Walnut	47	(49.47)		
Other (corn, quince, pistachio)	16	(16.84)		
Watermelon	4	(4.21)		

NS= non-significant differences ($p> 0.05$); *= significant differences at 5% ($p< .05$); **= significant differences at 1% ($p< 0.01$); ***= significant differences at 0.1% ($p< 0.001$).

Seventy-seven point eighty-nine percent [X^2(129.57) $p< 0.001$] of respondents state that climate change affected their crop yields. In the case of walnut, the lack of cold hours has resulted in reduced productions; according to this, Grageda *et al*. (2017) assert that the increase in temperature affects the development of deciduous fruit trees, such as pecan tree, which require an accumulation of cold to break the dormancy period. In addition, 35.62% [X^2(130.36) $p< 0.001$] of respondents said that the percentage of impact to the yield of their crops was between 21 and 40%. In relation to economic losses in crops as a result of climate change, 72.63% [X^2(119.46) $p< 0.001$] said they had suffered losses, while for 39.13% [X^2(131.8) $p< 0.001$] they were between 21 and 40%.

Of the respondents who suffered economic losses, only 40.58% answered how much the losses amounted to, agreeing that the impact in 25% of the cases [X^2(14.86) $p> 0.05$] was between $100 000.00 and $250 000.00, while another 25% had losses >$1 000 000.00 and <$100 000.00. Due to the failure of the producers to answer the question, the results were not significant. Nevertheless, climate change may eventually have negative effects on the agricultural economy (Ortiz and Ortega, 2018) and it is estimated that by 2055 in Latin America and Africa, corn production will suffer a reduction of 10%, which will be equivalent to losses of two billion dollars a year, mainly affecting small producers.

Notably, 39.13% [X^2(118.94) $p< 0.001$] of the respondents consider that the most affected period has been in the development of crops, this because changes in weather patterns affect the development and physiological processes, which makes it difficult to meet the water demand of crops in the region, since, under these conditions, demands increase (Ojeda *et al*., 2011). Thirty-six point twenty-three percent [X^2(143.51) $p< 0.001$] consider that the cause for which crops have been affected is mainly due to the increase in temperature (Table 6). It should be noted that the months of January 2016 and 2017 have been warmer since 1880, in this regard, in the region crops faced water stress due to lack of water and dehydration due to high temperatures (CONAGUA, 2019).

Table 6. Cause of the impact on crops.

Cause	N	(%)	Chi-square	Sig
Temperature increase	25	(36.23)	43.51	***
Temperature decrease	3	(4.35)		
Hail	15	(21.74)		
Frost	4	(5.8)		
Rains	1	(1.45)		
Other (pests, pollution, lack of access to water)	8	(11.59)		
Droughts	13	(18.84)		

NS= non-significant differences ($p > 0.05$); * = significant differences at 5% ($p < 0.05$); ** = significant differences at 1% ($p < 0.01$); *** = significant differences at 0.1% ($p < 0.001$).

As for measures against climate change, 48.42% [X^2(119.06) $p < 0.001$] of respondents have implemented some measure. Regarding the implementation of zero or conservation tillage, only 13.04% [X^2(125.13) $p < 0.001$] of the respondents have applied this measure, the change of type of crop has been applied by 17.39% [X^2(119.57) $p < 0.001$] and the implementation of water collection techniques has been applied by 21.74% [X^2(114.7) $p < 0.001$]. Additionally, 76.09% [X^2(112.52) $p < 0.001$] have implemented other measures, among which the use of organic products for crops stands out.

In addition, of the people who have implemented mitigation/adaptation measures against climate change, 58.7% [X^2(145.52) $p < 0.001$] consider that these measures have only contributed 0 to 20%, commenting that part of this is because not all farmers are applying the same measures and it is necessary to be consistent to see results. Although products such as organic fertilizers favor soil fertility and plant nutrition, their nourishment capacity compared to fertilizers is low, requiring large amounts for a more noticeable result (Álvarez-Solís *et al*., 2010).

In relation to whether farmers have any type of insurance to protect their crops in the event of a catastrophic weather event, only 20% [X^2(134.2) $p < 0.001$] have it. However, 55.56% [X^2(15.33) $p < 0.05$] of the respondents who have insurance did not know how to specify the name of the insurance but commented that its acquisition was a requirement to obtain a credit.

Multiple correspondence analysis

In this analysis, two dimensions were obtained as a result, which together explained 13.4% of the total inertia (Figure 2). The first dimension explained 7.6% of the total inertia, mainly related to the application of measures for mitigation and adaptation against climate change: zero tillage (M1), change of type of crop (M3), water collection techniques (M4), others (M5) and their percentage of contribution (cmedidas). In this sense, Galindo *et al*. (2014) mention that some adaptation measures reduce costs significantly depending on the type of crop/region. Better resource management brings with it lower costs, in turn, using fertilizers or irrigation different from the usual one results in positive effects.

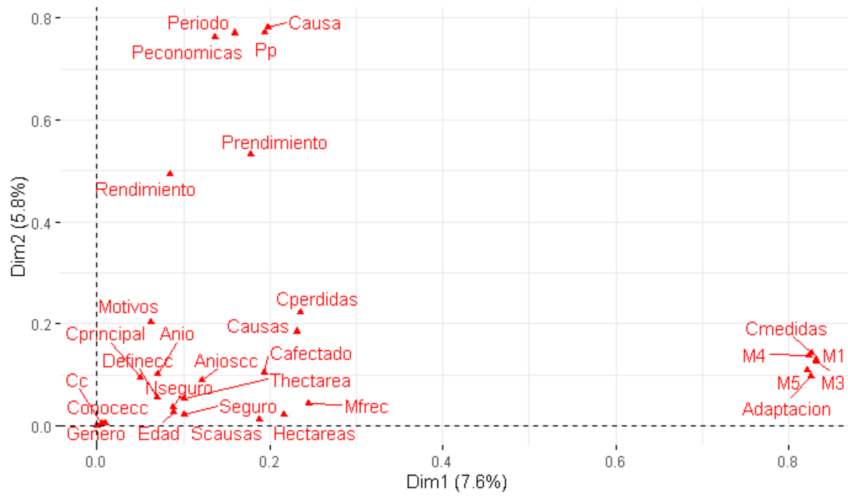

Figure 2. Measured dimensions of discrimination and correlation between variables.

The second dimension explains 5.8% of the total inertia and is mainly related to the variables of: you have suffered economic losses (peconomicas), most affected period (periodo), cause of the impact (causa), percentage of economic losses (Pp). Of the impact of climate change on the agricultural sector in Mexico the Centro de Estudios para el Desarrollo Rural Sustentable y la Soberanía Alimentaria (2019) states that agriculture can be affected, among other causes, by extreme weather events, also mentions that the increase in temperatures will affect the growth and development of some crops, especially because of the water requirements.

In Mexico, the rainfed agricultural areas will have to adapt to an increase in temperature and less amount of precipitation. This same situation is represented in this study, since the most affected crop has been walnut, which has a water demand with variable ranges of 1 170 and 1 310 mm per year in adult trees (INIFAP, 2010). Being in turn the main crop mentioned by the respondents, so the losses due to the lack of cold hours due to high temperatures could explain the relationship of the variables studied.

In this sense, climate change shows its negative effects on agricultural profits, and to face it, it is considered that the replacement of 10% of the area sown with more profitable alternative crops will demand less water and they may be more resistant to its effects (Tonconi, 2015).

Multinomial logistic regression

The first multinomial logistic regression model for the variables of interest was developed taking as a dependent variable 'percentage of contribution of the measures to mitigation and adaptation to climate change applied' (cmedidas) and as independent variables 'zero tillage'(M1), 'change of type of crop (M3), 'water collection techniques' (M4) and 'other measures' (M5), which were the ones that presented the most inertia for the first dimension of the multiple correspondence analysis and are correlated as shown in Figure 2. For the variable ‘percentage of contribution of the measures to mitigation and adaptation to climate change applied’, the level 0-20% was used a reference.

In this regard, for climate change issues, there is a lack of previous studies using this methodology, however, it has significant potential for agricultural studies related to climate variables. The result was significant (*p*= 0) when measuring the relative risk that the percentage of contribution to climate change mitigation/adaptation is 21-40%, implementing: zero tillage (β11), being $1.622824e^{+09}$ times more than when not implementing zero tillage, change of type of crop (β12) being $5.748581e^{-17}$ times less than when not implementing a change in the type of crop, water collection techniques (β13) being $9.302693e^{-10}$ times less than when not implementing water collection techniques and in the case of other measures (β14), being $1.686106e^{+16}$ times more than when not implementing other measures. The expression that documents the relationship of the measured variables was: $\ln(\frac{P(cmedidas= 21\text{-}40)}{P(cmedidas= 0\text{-}20)})$= β10+β11(M1= yes) +β12(M3= yes) + β13(M4= yes) + β14(M5= yes) + εij.

The result was significant (*p*= 0) when measuring the relative risk that the percentage of contribution to mitigation/adaptation to climate change is 41-60 (%), implementing: zero tillage (β21) being $2.799979e^{-14}$ times less than when not implementing zero tillage; change of type of crop β22) being $4.646137e^{-14}$ times less than when not implementing a change in the type of crop, water collection techniques (β23) being $5.305706e^{-07}$ times less than when not implementing water collection techniques and in the case of other measures (β24) being $2.064378e^{-07}$ times less risk than when not implementing other measures. The expression that documents the relationship of the measured variables was: $\ln(\frac{P(cmedidas= 41\text{-}60)}{P(cmedidas= 0\text{-}20)})$= β20+β21(M1= yes)+β22(M3= yes)+β23(M4= yes)+β24(M5=yes)+εij.

The result was significant (*p*= 0) when measuring the relative risk that the percentage of contribution to mitigation/adaptation to climate change is 61-80%, implementing zero tillage (β31), being $0.977972e^{-17}$ times less than when not implementing zero tillage; while the result was not significant when implementing the change of type of crop (*p*= 0.4338), water collection techniques (*p*= 0.6378) and other measures (*p*= 0.0488).

The expression that documents the relationship of the measured variables was $\ln(\frac{P(cmedidas= 61\text{-}80)}{P(cmedidas= 0\text{-}20)})$= β30 + β31(M1= yes) + β32(M3= yes) + β33(M4= yes) + β34(M5= yes)+εij. The result was significant (*p*= 0) when measuring the relative risk that the percentage of contribution to mitigation/adaptation to climate change is 81-100 (%), applying: zero tillage (β41) being $5.761973e^{-07}$ times less than when not implementing zero tillage, change of type of crop (β42) being $1.224252e^{-09}$ times less than when not implementing a change in the type of crop, water collection techniques (β43) it is $2.905795e^{-08}$ times less than when not implementing water collection techniques, other measures (β44) it is $1.184600e^{+05}$ times more than when not implementing other measures. The expression that documents the relationship of the measured variables was: $\ln(\frac{P(cmedidas= 81\text{-}100)}{P(cmedidas= 0\text{-}20)})$= β40 + β41(M1= yes) + β42(M3= yes) + β43(M4= yes) + β44(M5= yes)+εij.

The second multinomial logistic regression model was developed taking the variable ‘age’ (edad) as a dependent variable and as independent variables ‘knowledge of climate change’ (conocecc), ‘knowledge of the causes of climate change’ (scausas), insurance (seguro), which were chosen because, despite not being the ones that presented the greatest inertia for the second dimension of the multiple correspondence analysis, they showed significant results, which are decisive for the objective of the study (Figure 2). For the variable ‘age’ the level ‘20-40’ was used as a reference.

The results were not significant when analyzing the relative risk that farmers aged 41 to 60 know what climate change is (*p*= 0.9498), its causes (*p*= 0.09113) and have insurance (*p*= 0.9201). The expression that documents the relationship of the measured variables was: $\ln(\frac{P(Edad= 41\text{-}60)}{P(Edad= 20\text{-}40)})= \beta 10 + \beta 11(conocecc= yes) + \beta 12(scauses= yes) + \beta 13(seguro= yes) + \varepsilon ij$. The results were not significant when analyzing the relative risk that farmers aged 61 to 80 know what climate change is (*p*= 0.8579), its causes (*p*= 0.3976) and have insurance (*p*= 0.8621). The expression that documents the relationship of the measured variables was: $\ln(\frac{P(Edad= 61\text{-}80)}{P(Edad= 20\text{-}40)})= \beta 20 + \beta 21(conocecc= yes) + \beta\ 12(scausas= yes) + \beta\ 13(seguro= yes) + \varepsilon ij$.

Finally, the results were not significant when analyzing the relative risk that farmers over 80 years of age know what climate change is (*p*= 0.9825), its causes (*p*= 0.9446) and have insurance (*p*= 0.2775). The expression that documents the relationship of the measured variables was: $\ln(\frac{P(Edad= Mas\ de\ 80}{P(Edad= 20\text{-}40)})= \beta 30 + \beta 31(conocecc= yes) + \beta 32(scausas= yes) + 313(seguro= yes) + \varepsilon ij$.

Conclusions

Climate change has impacted agriculture in Irrigation District 005, with walnut being the most affected in cold hours and amount of water required, a situation that can be aggravated due to the increase in temperatures and decrease in precipitation due to droughts. A viable option for adaptation and mitigation to climate change in this area is the implementation of measures that together help reduce its effects, such as conservation tillage and other measures such as the use of organic products for application to the soil in cultivation areas and the conversion of crops with lower water demand.

One of the drawbacks is that as the age of producers increases, their knowledge of climate change, and its causes, decreases, so it is important that farmers have this knowledge, so they can decide what measures to implement in their crops. Another option is to take out insurance with a wide coverage that protects the crops in case of any catastrophic event that could occur; however, the experience of the producers is that, at present, taking out an insurance occurs as a requirement to obtain a credit, and not as a measure against climate change.

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