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Article

Global warming effect on alfalfa production in Mexico

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Abstract:

Alfalfa is the main forage crop in Mexico in terms of sown surface area, with 583,561 ha, representing 57.1 % of total forage, while forage crops of maize, oats and sorghum account for 42.9 %. The aim of this study was to estimate the impact of global warming as a result of climate change, under the basis of future climate scenarios over alfalfa production in potential irrigation areas of Mexico. Anomalies of temperature and precipitation for the 2021-2080 period were estimated through an ensemble of 11 general circulation models. Potential surface areas for alfalfa production were determined by considering reference climate and future climate projections focused on two Representative Concentration Pathways (RCP) of greenhouse gases (GHG), Results suggest an increasing temperature and its influence upon the reduction of areas with a high productive potential, as progress is made towards the future, with a reduction of 24.7% in 2070 in the RCP 4.5 with respect to the reference climate. Similar results, but with greater decrease of surface areas with productive potential —a situation that becomes even worse with time—, were estimated under the basis of the RCP 8.5. A differential effect was estimated depending on the harvesting region. Given its high water demand, alfalfa may be replaced by other crops with lower water requirements, such as maize. These results could be used in the design of strategies to adapt the crop to the effects of climate change in alfalfa producing areas.

Key words: *Medicago sativa*, Climate change, Productive potential, RCP, Mexico.

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Introduction

Under irrigation conditions, alfalfa is the main forage crop in Mexico in terms of land planted, with 583,561 ha (2006-2015), amounting to 57.1 %, while maize, oats and sorghum forage crops make up the remaining 42.9 %(1). This crop demands great water consumption(2), with water requirements ranging between 1,200 and 1,800 mm, approximately, per year(3,4,5) which makes it dependent on the availability of irrigation water. In addition to the vulnerability to weather conditions, the influence of climate change on the performance and production of this legume is uncertain in the future.

Currently, climate change causes changes in climatic patterns and, therefore, in the climate related to the management of agricultural activities. The increase in temperature, caused by the increase in the atmospheric concentration of greenhouse gases (GHG)(6), leads to the desiccation of many regions due to the increase in evaporation(7) and the modification of rainfall patterns(8).

The effects of climate change in the future are estimated using climate scenarios, which are representations of the future climate consistent with the assumptions about future emissions of greenhouse gases and other pollutants and, with the understanding that the effect of increasing atmospheric concentrations of these gases in the global climate serve as the basis for taking adaptation and emission reduction actions(9,10). It is important to recognize that there is uncertainty in the results of these scenarios. The general circulation models allow to project the future climate, but there is no single model that is the most convenient; therefore, ensembles of several models are used to reduce uncertainty(11).

Recent studies have shown that the temperature in the agricultural surface areas of Mexico has increased markedly since 1990(12,13). This increase in temperature brings about modifications in agroclimatic variables such as the accumulation of cold hours in the winter period(14). As in other countries, in Mexico there is a concern about climate change and its possible impacts on the primary productive sector.

On the other hand, as a result of the increase in GHGs in the atmosphere, the increase in temperature can have both positive and negative effects on crop production. An increase in temperature accelerates the process of maturity of the crops, reduces the duration of the leaf surface area and, thus, the total water requirement until the maturity of the crop(15,16).

Various studies have been developed to identify surface areas where crop production could be carried out with the greatest probability of success and profitability. These surface areas are also called surface areas with productive potential(17-20). However, the effect of climate change on crops in surface areas with productive potential has been little studied.

Changes in climate patterns have profound effects on plant growth and productivity in the short term(21). In Mexico, studies have been carried out on the theme of climate change and its impact on agriculture, but few have analyzed in detail the effects on product systems in particular, which limits the design of crop adaptation strategies to climate change(22).

Alfalfa is a species that has a wide range of adaptability. The belief is that depending on the environment where it develops, climate change can influence it positively or negatively. Several studies have demonstrated the great variability of alfalfa's response to climate change(23-27).

Alfalfa is a crop with intensive water demand. Its profitability depends largely on the availability of water and its costs. It is possible to obtain greater alfalfa production by increasing irrigation in the growth period(2). Water deficiency affects plant growth and climate change is expected to increase water stress in crops in some parts of the United States of America(6). Large reductions in alfalfa cultivation surface area in the northern plains in the United States of America have been observed due to the expansion of more profitable crops such as maize and soybeans, as well as the decrease in irrigation water(28).

The aim of this study was to estimate the impact of global warming as an effect of climate change on future climate scenarios on potential surface areas of irrigation alfalfa in Mexico.

Material and methods

An ensemble model was integrated from the value of the median of 11 general circulation models (MCG) reduced in scale and calibrated (29) and belonging to CMIP5 (Coupled Model Intercomparison Project Phase 5) reported in the 5th IPCC delivery: (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, MIROC-ESM, MIROC5, MRI-CGCM3, NorESM1-M), which were obtained from the information of the data portal of Global Change of World Clim.

The ensemble was generated considering two representative routes of concentration (RCP) of greenhouse gases, that is, for this purpose an intermediate emission RCP (4.5) was used consistently with a future with relatively ambitious emission reductions, and a high emission RCP (8.5), consistently with a future without policy changes to reduce emissions(10).

The monthly values of the ensemble of the 11 models of the maximum temperature, minimum temperature and precipitation variables of the years 2021 to 2080, for the scenarios 2021-2040, 2041-2060 and 2061-2080, hereinafter referred to as climates for the years 2030, 2050 and 2070, respectively, were used. The base or reference climate based on the same variables from the 1961-2010 period of the INIFAP climate information system(30) was considered. Thematic raster images were generated with a resolution of 30” arc, corresponding to the monthly values of the three variables of the base climate and the scenarios.

In studies related to agriculture, including that of productive potential, it is convenient to use a good resolution for the application of the results of the MCGs with scale reduction. Therefore, the INIFAP climate information system uses a resolution of 90 m, so that the results of the productive potential have sufficient detail to be applied in the decision making of long-term plans.

The second part of the study consisted of the estimation of the productive potential, which is based on the agroecological requirements of the plant species(31). The surface areas with productive potential for alfalfa cultivation under irrigation conditions were obtained. Potential surface areas were estimated for the base climate and the three climate scenarios in RCP 4.5 and 8.5. The surface areas with productive potential were calculated based on temperature and precipitation information from INIFAP, land use information series 5, and the edaphological cartography scale 1: 250,000 from INEGI. For this purpose, the geographic information systems IDRISI Selva and ArcGis Ver. 10.1 were utilized.

Finally, according to the results obtained, some adaptation actions are proposed for alfalfa cultivation in the face of climate change scenarios.

Results and discussion

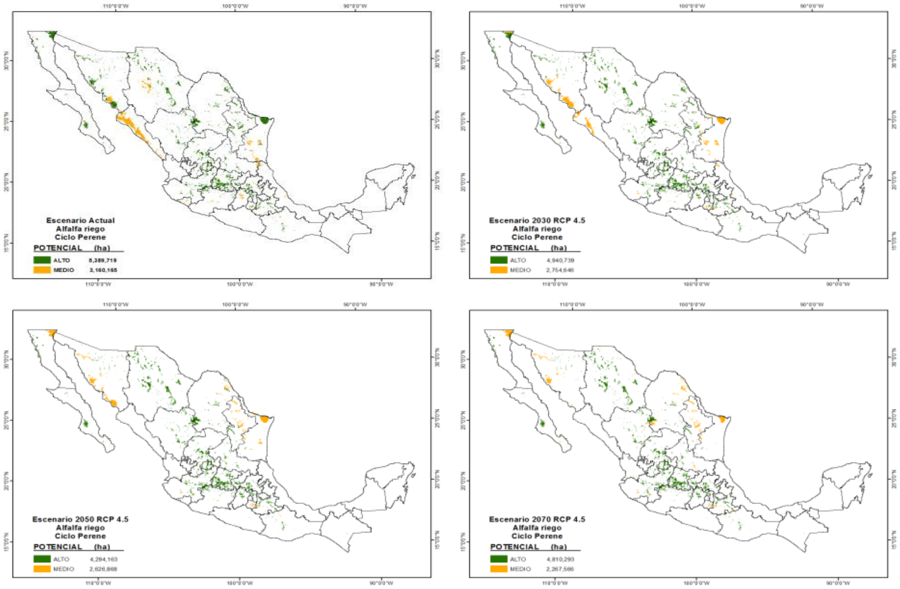
Table 1 shows the surface areas with alfalfa production potential under irrigation conditions, in current climatic conditions and for climates 2030, 2050 and 2070, in two representative routes of concentration of greenhouse gases. The potential surface area obtained is independent of the current use of agricultural land, i.e. it does not necessarily imply that surface area is available for sowing alfalfa under irrigation conditions.

Table 1: Surface area with high and medium production potential of irrigation alfalfa as a perennial crop under current climatic conditions and in the 2030, 2050 and 2070 climate scenarios in RCP 4.5 and 8.5

RCP	Climate scenario	Productive potential	
		High	Medium
4.5	Current	5’389,719	3’160,165
	2030	4’940,739	2’754,646
	2050	4’294,163	2’626,868
	2070	4’058,779	2’267,566
8.5	2030	4’735,023	2’586,661
	2050	4’006,668	2’079,239
	2070	3’126,862	1’962,538

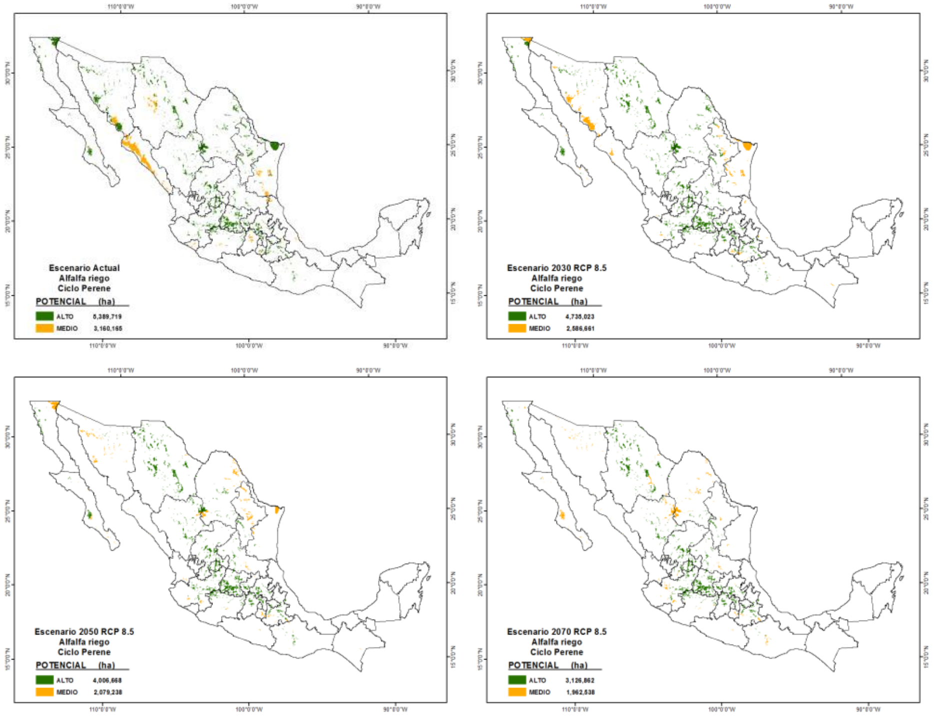
This Table shows how the surface area of high potential for alfalfa irrigation decreases as progress is made towards the future in the years 2030, 2050 and 2070 in the RCP 4.5, with respect to the average or current climatic conditions, from 5’389,719 ha in the current climate at 4’058,779 ha in the year 2070. Similarly, the average productive potential decreases towards the future, from 3,160,165 ha in the current scenario to 2,267,566 ha in the year 2070 (Figure 1).

Figure 1: Productive potential of irrigated alfalfa for the current average climatic conditions and the projected for 2030, 2050 and 2070 by the RCP 4.5



A similar behavior occurs in RCP 8.5, except that the decrease in surfaces is greater compared to the current scenario, with the higher productive potential diminishing from 5’389,719 to 3’126,862 ha, a reduction of 42.0 % of the surface area, and the mean potential cutting back its surface area from 3’160,165 to 1’962,538 ha, i.e. 37.9 %, in the year 2070 (Figure 2).

Figure 2: Productive potential of irrigated alfalfa for the current average climatic conditions and the projected for 2030, 2050 and 2070 by the RCP 8.5



The reduction of the surface area with high and medium productive potential may be basically due to the increase in the annual mean temperature in the different climatic scenarios, for a rise in the temperature can reduce the production of alfalfa, as has been found in other studies in Mexico in the warm environments where this species is grown(32). This is shown in Table 2, where the average temperature of the current scenario in high potential areas is 19.9 °C, while in the first two climates of RCP 4.5 it is 20.9 and 21.9 ° C —i.e. there is an estimated increment of 1.0 and 2.0 ° C—, respectively. The increase in the third climate may be 2.5 °C with respect to the reference climate, which can result in less than optimal conditions for the development of alfalfa.

Table 2: Temperature and annual mean precipitation in the highly productive potential areas of irrigation alfalfa, based on the current potential surface area in the different RCP and scenarios

RCP	**Scenario**	**Temperature (°C)**		**Precipitation**	
		Mean	**DEA**	**Mean (mm)**	**DCS (%)**
4.5	Current	19.9		436.6	
	2030	20.9	1.0	425.8	2.5
	2050	21.9	2.0	414.9	5.0
	2070	22.4	2.5	413.8	5.2
8.5	2030	21.2	1.3	416.3	4.7
	2050	22.5	2.6	395.9	9.3
	2070	23.7	3.8	383.4	12.2

DCS=Difference in relation to the current scenario.

Figure 3A shows the surface area with highly productive potential for the different climatic scenarios, in some of the main alfalfa producing states in the country. The possible effect of climate change is not the same in the different regions of the country for the production of alfalfa irrigation, as has been reported by other authors(26), according to whom the yield varied by municipality from -10 to 14% in scenarios B1 and A2 in the state of California, USA. In general, and at the country level, the trend is towards less surface area with a high potential. However, in current temperate regions the surface with potential may increase in the future, as in the case of the state of Chihuahua State, similarly to the results obtained in other studies(27), while in other states, such as Guanajuato and Hidalgo, it will remain stable, similarly to what occurred in another study in California, USA, where the yield remained unchanged until 2050 in scenarios B1 and A2(24). On the other hand, in the states with a warm climate, the surface areas with high productive potential have a tendency to decrease significantly, as in the states of Baja California and Sonora and at the La Laguna region of the states of Coahuila and Durango, similarly to what was found with high temperatures without any yield increase(25). In the average potential there is a differentiated trend between the states, but, in general, where the surface area with high potential decreases, the medium potential increases, since that surface area will pass from high to medium potential. In Sonora State, the mean potential increases first and then decrease (Figure 3B). A similar trend has been found in the surface areas producing maize(22) and beans(13) in Mexico. In RCP 8.5 (Figure 4A and 4B), a similar behavior is observed in the high potential areas, but the tendency to decrease in the yield is more noticeable.

Figure 3: Surface area of high (A) and medium (B) productive potential of perennial cycle irrigation alfalfa in the mean climatic conditions and climates of RCP 4.5, in different states of the country

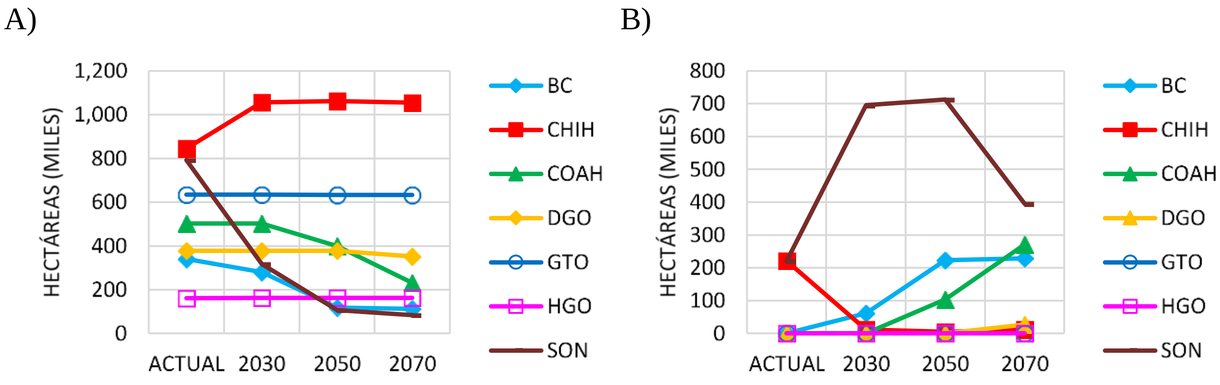
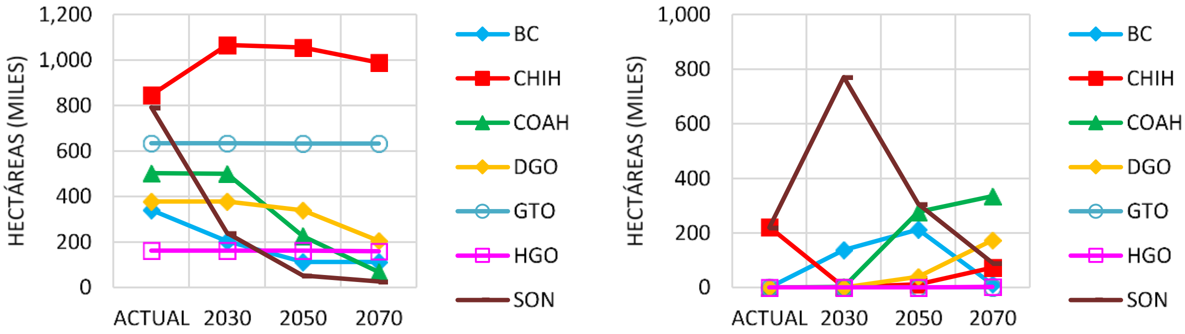


Figure 4: Surface area of high (A) and medium (B) productive potential of perennial cycle irrigation alfalfa in the average climatic conditions and climates of RCP 8.5, in different states of the country



In the short term (2030), only in the hottest region where alfalfa is grown (i.e. the states of Baja California and Sonora) will the area with high productive potential decrease by 17.8 and 60.0 % in RCP 4.5, respectively, and 40.1 and 69.7 % in RCP 8.5, respectively (Figures 3 and 4).

Although the estimation of the surface areas with potential for alfalfa production does not consider precipitation, these potential areas may be affected by the low availability of irrigation water, either dam or pumping water from aquifers. Precipitation in future climate scenarios with respect to the current climate will suffer a reduction (Table 3). In areas of high potential in RCP 4.5, there is a reduction of 22.8 mm by 2070, while in RCP 8.5 there is a greater reduction in precipitation of up to 53.2 mm in 2070 in areas of high potential and 59.8 mm in those of medium potential.

Table 3: Sown area and water balance for alfalfa production in the main alfalfa producing states in Mexico

State	**SS (ha)**	**AP (mm)**	**WR (mm)**	**PP SS**	**RH SS**	**Deficit SS**	**%WR AP**
				(million m^3)			
Chihuahua	77,144	410	1,473	316.1	1,136.3	820.2	27.8
Baja California	29,388	103	1,822	30.3	535.5	505.2	5.7
Sonora	29,038	276	1,636	80.3	475.1	394.8	16.9
Durango	28,267	274	1,601	77.6	452.6	375.0	17.1
Guanajuato	52,397	620	1,333	324.8	698.6	373.8	46.5
Coahuila	21,308	251	1,566	53.4	333.7	280.3	16.0
Hidalgo	47,686	537	1,054	255.9	502.5	246.6	50.9
San Luis Potosí	13,809	394	1,345	54.4	185.7	131.3	29.3
Zacatecas	11,104	414	1,205	46.0	133.8	87.8	34.4
Jalisco	9,680	612	1,450	59.2	140.3	81.1	42.2
Puebla	18,205	701	1,100	127.7	200.3	72.7	63.7
Querétaro	8,108	545	1,182	44.2	95.8	51.6	46.1
Aguascalientes	6,339	493	1,205	31.2	76.4	45.2	40.9
México	8,247	691	1,019	57.0	84.0	27.0	67.8

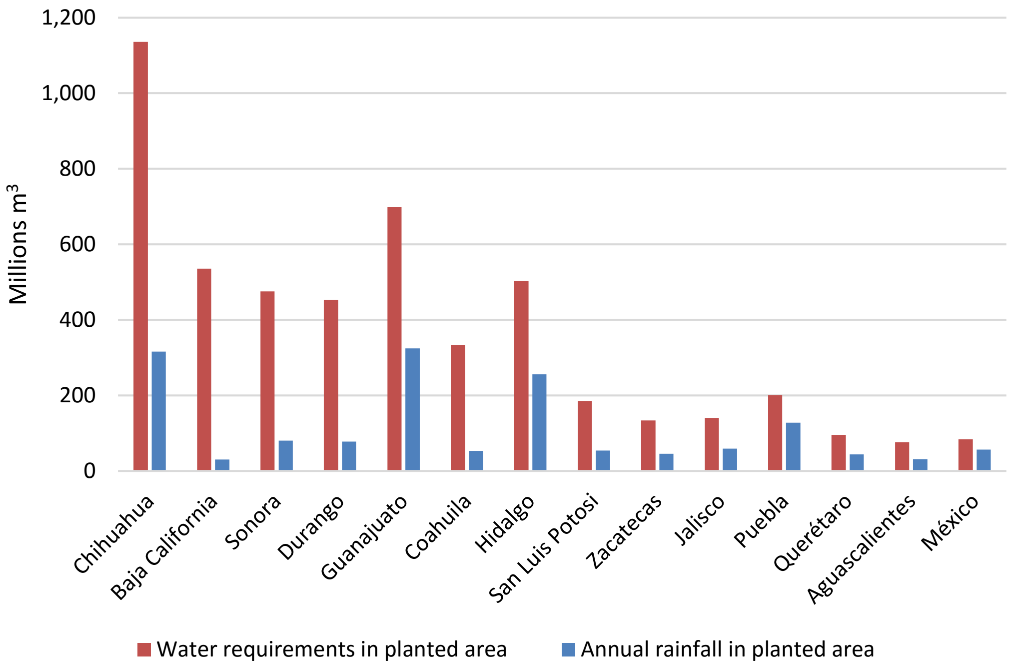
SS=Sown surface area, AP= annual precipitation, WR= alfalfa's water requirements.

%WR AP= percentage of water requirement covered by precipitation.

Alfalfa cultivation is very demanding of water(2). Table 3 shows the consumptive use or water requirement in each of the main alfalfa producing states, which ranges between 1,019 in the state of Mexico and 1,822 in the state of Baja California. The water requirements of the entire area were estimated based on this datum and the average sown area (2006-2015. On the other hand, the average volume of water contributed by precipitation on the same sown area by state was also estimated. The water deficit in the planted area was calculated based on these data.

Table 3 also shows that the water deficit in the area sown with alfalfa varies greatly between one state and another, ranging between 27.0 and 820.2 million m^3, corresponding to an average deficit of 63.9% with respect to the water requirement. This deficit is greatest in the northern state of the country, because the sown area there is greater, and the precipitation is lower. Those states are Chihuahua, Baja California and Sonora (Figure 5), i.e., in the states in the center of the country with a greater precipitation, the water deficit is lower.

Figure 5: Water requirements in the area sown with alfalfa in each state and the volume contributed by precipitation on the same surface area



The decrease in rainfall and the increase in temperature in future years may cause higher levels of evapotranspiration, due to which the crops will suffer more due to the lack of moisture in their water balance (6.22). Alfalfa crops demand much more water —an average of 1,350 mm per year— than other forage crops such as maize, which has a water demand of 550 mm throughout the cycle. In the above conditions, it is expected that in the years to come, the cultivation of alfalfa will gradually be replaced by other less water-demanding crops, as is happening in the plains of the northern United States of America, alfalfa is being replaced to a large extent by other crops, such as corn and soybeans, which require less water for irrigation(28).

The results obtained could be used in the planning or in the design of strategies to face climate change in alfalfa producing areas, such as the search for new varieties of alfalfa that adapt to higher temperature conditions and are tolerant to low humidity conditions.

Conclusions and implications

Global warming as an effect of climate change in the 21st century, can have a negative effect upon the viability of alfalfa cultivation in agricultural irrigation surface areas of Mexico, since the surface area with a high potential for this species is expected to decline steadily between 2030 and 2070, in both the RCP 4.5 and RCP 8.5 scenarios. However, if greenhouse gas emission patterns evolve towards RCP 8.5, the feasibility of alfalfa cultivation may be more strongly affected, since the reduction of high potential surface area would be greater than in the RCP 4.5 scenario. The most negative scenario is foreseen for the year 2070 in RCP 8.5, where the reduction of the high potential surface area may reach 42 %. As we move from a nationwide view to a state-based perspective, a differentiated effect of climate change is to be expected; the states where the potential surface area for alfalfa cultivation could be most negatively affected in the future are Baja California, Sonora and the La Laguna region in Coahuila and Durango; while other states in the center of the country, such as Guanajuato and Hidalgo, may experience virtually no negative effects; while an increase in the potential surface area for alfalfa cultivation may even be expected in Chihuahua. Alfalfa, a species with very high demand of water, is grown in irrigation conditions with an average deficit of 63.9 % with respect to the water requirement of the planted surface area. A mean reduction in precipitation of 7.2 % is expected to occur by 2050; therefore, the deficit of available water may increase, leading to the replacement in the near future of alfalfa by other less water-demanding crops like maize. The results of this study can serve as a basis for the design of strategies to face climate change in those areas of Mexico where irrigation alfalfa is produced, including the generation of new varieties that adapt to higher temperature and evapotranspiration or the design of a new composition of forage cropping patterns in the country's irrigation areas.

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