**Archives of Business Research – Vol. 10, No. 9**
**Publication Date:** September 25, 2022
**DOI**:10.14738/abr.109.13135.
Ledesma-Carrion, D. E. (2022). Analysis of Irrigated Crops in Regions with Overexploited Water Sources: Case Aguascalientes, Ags, Mexico. Archives of Business Research, 10(9). 142-156.

# Analysis of Irrigated Crops in Regions with Overexploited Water Sources: Case Aguascalientes, Ags, Mexico

**Dora Elena Ledesma-Carrión**
Dirección General de Integración, Análisis e Investigación
Instituto Nacional de Estadística y Geografía), Mexico City, Mexico

**ABSTRACT**

**There are few crop options for arid and semi-arid soils with annual rainfall of less than five hundred millimeters. Irrigated crops are supplied by rivers, dams, and aquifers. Due to climate change, rainfall has significantly changed its start of the season, frequency, and intensity. This causes problems in the recharge of aquifers and intensive extraction of water, putting the availability of the liquid in check to ensure the total development of the crop. What are the crops that should be replaced by more suitable ones? Which plants should no longer be cultivated? To answer these questions, optimization techniques and cross elasticities were applied, maximizing the value of production subject to the minimum water requirements that ensure the total development of the crop. Some perennial crops showed that they could be replaced, and other seasonal ones should not be cultivated in the coming years. The study was done at the regional level given the access to public and free information.**

**Keywords:** Region, Overexploitation, Temporary and Perennial Irrigation Crops.

## ABBREVIATIONS

| | |
|---|---|
| AP | African or oil palm |
| Apple | Apple |
| A-W | Autumn Winter |
| B | Broccoli |
| Beans | Beans |
| BS | Butternut squash |
| Cbb | Cabbage (cabbage) |
| Ccb | Cucumber |
| Chia | Chia |
| Clt | Cilantro |
| cm | Centimeter |
| Corn | Corn |
| CP | Camedor palm |
| Crr | Carrot |
| Date | Date |
| E1 | Scenario 1 |
| E2 | Scenario 2 |
| Egg | Eggplant |
| FMG | Forage maize in green |

FPP Forage prickly pear
FSG Forage sorghum in green
FTG Forage triticale in green
G Garlic
GA Green lucerne
GC Grain corn
GCh Green chile
GFB Green feed barley
GFO Green fodder oats
GFR Green fodder rye
Grape Grape
Grn Pomegrenate
GS Grain sorghum
GT Green tomato
Guava Guava
HP Heel palm
$Km^2$ Square Kilometer
L Lettuce
m.a.s.l. Meters above sea level
mm Millimeter
Npl Nopalitos
Nut Nut
Onion Onion
OP Ornamental palm
P Potato
Peach Peach
PM Pastures and meadows
Prnn Perennials
Pst Pistachio
Quince Quince
RT Red tomato (tomato)
S-S Spring Summer
Stb Strawberry

## INTRODUCTION

Due to climate change, the effects of changes in rainfall patterns and temperature ranges have been affecting the development of rainfed crops. Lately, irrigated crops have also experienced the unavailability of water.

When analyzing the decisions made from 2003 to 2021 in terms of planting and consumptive use of water for irrigation, Is it feasible to continue with traditional crops or try others, given the overexploitation of aquifers and the effects of climate change? What other crops could be an alternative?

There are methodologies to resolve these doubts, such as optimization techniques, establishing scenarios with an emphasis on restrictions on water consumption and cross elasticities. Adjusting production volumes by maximizing production values subject to water availability

and consumption during crop development. Seasonal and perennial crops were analyzed, the latter being feasible for substitution. The procedure can be replicated to other regions.

Municipality of Aguascalientes is located at latitude 22°N and altitude 1987 m.a.s.l. Territorial extension of 1178.1 $Km^2$.

Soil and climate: Semi-arid. Temperate semi-dry and semi-warm semi-dry with an average temperature of 17.6 °C and an average annual rainfall of 500 mm.

The objective of the study is to find a tool that, based on past decisions regarding irrigated crops, determines the appropriate crops given the water requirements during the development of the plant and the availability of water, whether of surface or underground origin, depending on the characteristics of the region.

## BACKGROUND

Early experiences in mitigating climate change, with the use of yield enhancement factors, proved that these are not enough. African farmers adopted to improve their yields: improved seeds, specific fertilizers and innovative irrigation and sanitation techniques, depending on the crop. Even so, for medium-term changes in precipitation patterns and daily temperature ranges, it showed the need to make more drastic decisions [1] to ensure feeding. Since 1990, papers have been published that have exposed the devastating effect of changes in rainfall patterns: intensive concentration in one month, change in frequency and intensity, and temporary offset [1, 2, 3, 4]. There is general agreement that global warming will be greatest at latitudes between tropics and poles. Models based on various methodologies (time series, econometric and multiregressive) predicted that the effects of global warming would cause increases in daily temperature ranges and changes in duration of seasons, according to latitude and altitude, [5, 6]. Prakash formulated a model for traditional crops in Nepal, based on crop response to water stress, which linearly relates changes in crop yields and changes in temperatures and rainfall. Their results indicated that the temperature increase of 0.7 °C favored rice cultivation over potato, wheat, and corn, due to the increased availability of water in historically frozen areas. In the state of Aguascalientes, the increase in temperature was calculated at 0.77 °C [7], which increases the evaporation of surface water.

Siqueiros *et al*. (2016) reported that 80% of the original vegetation cover of the state has been modified due to human settlements with agricultural and livestock activities, causing, to a large extent, around 90% of soil erosion and groundwater scarcity. Surface water evaporates on average 70%.

Since the beginning of the 21st century, Olson *et al*. (2007) analyzed the state of agriculture and water resources for irrigation in Mexico and specified that there were very few alternatives to irrigated agriculture, because the level of rainfall only allowed the production of low value rainfed crops or did not allow rainfed agriculture at all. For this reason, fodder crops were preferred to boost livestock in semi-arid areas. With the Free Trade Agreement (NAFTA), policies to support the competitiveness of agricultural production encouraged the degradation of water resources. Consequently, it was essential to improve the yields of irrigated agriculture and the management of water resources by increasing water use concessions (REPDA 2022, Table 1), currently reaching the overexploitation of aquifers.

Some proposals from international organizations to meet the food needs of the future establish response capacity as a requirement: build a system to respond to the spread of risks, modify traditional and current practices, create species resistant to environmental stress, foster cooperation between governments ( at all levels) and finance projects at the local level that solve specific problems [4, 9]. Therefore, it was chosen to solve the problem at the regional level based on the disaggregation of data. Complementary methodologies were used here to find the most suitable traditional and alternative crops in the region given the future scenario of global warming.

Irrigation district 001 is in the Aguascalientes Valley (85.4%), Chicalote Valley (10.6%) and El Llano (4.0%) aquifers, water concessions for use are registered in the Public Registry of Water Rights (REPDA in Spanish). Changes in water withdrawals for agricultural use from 2003 to 2021 have slightly changed, 0, 0.3 and -0.3%, respectively. The hydrological basins that feed the tributaries where water is extracted for agricultural use are the Ajojucar and El Niagara Dams, and the Lerma Toluca, San Pedro, and Verde Grande Rivers, which in 2003 contributed 0.184, 0.149, 0.261, 0.051 and 99.355%. And for 2021: 0.106, 1.617, 0.151, 0.029 and 98.096%, respectively [10].

Crops have specific coefficients associated with the heat-humidity balance or evapotranspiration necessary for their development [7, 11, 12, 13]. From the REPDA, the water concessions for agricultural use are of the surface and underground type. To date, 31.255227 (42%) and 44.03180329 (58%) $hm^3$ are extracted, respectively [10], the values from 2003 to 2021 appear in Table 1.

**Table 1. Volumes of water withdrawals for agricultural use from 2003 to 2021 [$hm^3$]**

| Year | Underground | Superficial |
|---|---|---|
| 2003 | 37896608.9 | 26101967 |
| 2004 | 38519608.9 | 27156563 |
| 2005 | 38531608.9 | 27224563 |
| 2006 | 38763608.9 | 27290563 |
| 2007 | 38805608.9 | 27290563 |
| 2008 | 38891408.9 | 27290563 |
| 2009 | 39279060.1 | 27303563 |
| 2010 | 39413460.1 | 27303563 |
| 2011 | 39456660.1 | 27853563 |
| 2012 | 39551859.3 | 28355431 |
| 2013 | 41077491.8 | 28511397 |
| 2014 | 41545491.8 | 28585397 |
| 2015 | 41766491.8 | 28613099 |
| 2016 | 41881491.8 | 28613099 |
| 2017 | 41971491.8 | 28613099 |
| 2018 | 43543907.3 | 31184403 |
| 2019 | 44031803.3 | 31255227 |
| 2020 | 44031803.3 | 31255227 |
| 2021 | 44031803.3 | 31255227 |

The following section presents information on the subject, in section 3 the methodologies, and in sections 4 and 5 the results and analysis. And the conclusions in section 6.

## METHODOLOGIES

### Cross price elasticities of supply

Equation 1 expresses the relationship between the demand for one good and the prices of another, that is, the cross price elasticity. When it is positive, the good is a substitute and when it is negative, the good is complementary. Thus, $x^i$ is the quantity of crop *i* and $p^j$ the price of crop *j*.

$$\frac{\Delta x^i}{x^i} = \frac{\Delta p^j}{p^j} \quad (1)$$

### Linear programming model

A model with a linear structure was formulated from the producer's point of view. The objective function maximizes the value of production, subject to restrictions on water requirements for agricultural use, which ensure the complete development of the crop given the availability of the resource, and the best yields, including improvement factors such as the use of improved or native seed, health, fertilizers, mechanization, and modernization of irrigation. In general, claims are not reported in irrigated crops. The model allows finding the feasible production volumes that satisfy the stated conditions. Data from surface and underground sources according to the Public Registry of Water Rights (REPDA in Spanish) were used. Two scenarios were considered: *E1*, minimum water requirements with optimal water saving technology, fertilizers, labor, and capital necessary for the development of crop i in year t. *E2*, maximum water requirements with irrigation technology and the rest unchanged.

Let:

$x_{it}$ is the production volume of crop *i* in year *t*.

$a_{it}$ the coefficient of crop *i* in relation to its yield in year *t*.

$b_{it}$ the coefficient of crop *i* in relation to its water requirement in year *t*.

$p_{it}$ is the price per produced volume unit of crop *i* in year *t*.

Objective Function:

$$Max_x\left\{\sum_{i=1}^{41} p_{it}x_{it}\left|Ej_{x_{it}}\right.\right\}, i = irrigation\ crops, t = 2003, \ldots, 2020; j = 1,2 \quad (2)$$

restricted to:

$$\sum_{i=1}^{41} a_{it}x_{it}\left|Ej_{x_{it}} \leq historical\ maximum\ yields\ in\ the\ region \text{ without } loss\right. \quad (3)$$

$$\sum_{i=1}^{41} b_{it}x_{it}\left|Ej_{x_{it}} \leq available\ water\ in\ year\ t\right. \quad (4)$$

$$x_{it}\left|Ej_{x_{it}} \leq historical\ maximum\ level\ without\ \ loss_i\right. \quad (5)$$

$$x_{it}\left|Ej_{x_{it}} \geq 0\right. \quad (6)$$

## RESULTS

### Elasticities and linear programming model

Tables 2 to 7 show the cross supply price elasticities between the different crops, for seasonal and perennial, equation 1. Tables 8 to 10 show the results obtained from solving the model expressed by equations 2 to 6.

Table 2 is associated with the autumn-winter season crops.

Tables 3, 4 and 5 present the results for spring-summer seasonal crops.
And tables 6 and 7 correspond to perennial crops.
Tables 8 to 10 show the results for all crop types from 2003 to 2021.

**Table 2. Cross supply price elasticities. Autumn-Winter Crops (A-W). Own elaboration**

| A-W | G | GFO | B | GFB | Onion | GFR | Chia | L | FTG | PM |
|---|---|---|---|---|---|---|---|---|---|---|
| **G** | 1.4475 | 1.0397 | 1.7211 | 2.7548 | 0 | 0 | 0 | NA | 3.6714 | 1.0898 |
| **GFO** | 1.5083 | 1.0834 | 1.7935 | 2.8706 | 0 | 0 | 0 | NA | 3.8256 | 1.1356 |
| **B** | 5.2111 | 3.7430 | 6.1963 | 9.9177 | 0 | 0 | 0 | NA | 13.2173 | 3.9235 |
| **GFB** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Onion** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **GFR** | 0.7660 | 0.5502 | 0.9109 | 1.4579 | 0 | 0 | 0 | NA | 1.9430 | 0.5768 |
| **Chia** | 0.7074 | 0.5081 | 0.8411 | 1.3463 | 0 | 0 | 0 | NA | 1.7941 | 0.5326 |
| **L** | 0.8981 | 0.6451 | 1.0679 | 1.7093 | 0 | 0 | 0 | NA | 2.2780 | 0.6762 |
| **FTG** | 0.8524 | 0.6123 | 1.0136 | 1.6224 | 0 | 0 | 0 | NA | 2.1621 | 0.6418 |
| **PM** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

**Table 3. Cross supply price elasticities. Spring-Summer Crops (S-S). Own elaboration**

| S-S | GFO | Egg | B | BS | Onion | GCh | Clt | Cbb | Clf | Corn |
|---|---|---|---|---|---|---|---|---|---|---|
| **GFO** | 3.1985 | 0 | 5.3904 | 2.4102 | 2.2367 | 3.0967 | 1.8854 | 0 | 1.4470 | 0.1655 |
| **Egg** | 1.2801 | 0 | 2.1574 | 0.9647 | 0.8952 | 1.2394 | 0.7546 | 0 | 0.5792 | 0.0662 |
| **B** | 1.9263 | 0 | 3.2464 | 1.4516 | 1.3471 | 1.8650 | 1.1355 | 0 | 0.8715 | 0.0997 |
| **BS** | 1.8998 | 0 | 3.2017 | 1.4316 | 1.3286 | 1.8394 | 1.1198 | 0 | 0.8595 | 0.0983 |
| **Onion** | 1.8285 | 0 | 3.0815 | 1.3779 | 1.2787 | 1.7703 | 1.0778 | 0 | 0.8272 | 0.0946 |
| **GCh** | 1.3855 | 0 | 2.3349 | 1.0440 | 0.9689 | 1.3414 | 0.8167 | 0 | 0.6268 | 0.0717 |
| **Clt** | 1.1912 | 0 | 2.0076 | 0.8977 | 0.8331 | 1.1534 | 0.7022 | 0 | 0.5389 | 0.0616 |
| **Cbb** | 1.2801 | 0 | 2.1574 | 0.9647 | 0.8952 | 1.2394 | 0.7546 | 0 | 0.5792 | 0.0662 |
| **Clf** | 1.5669 | 0 | 2.6407 | 1.1807 | 1.0958 | 1.5171 | 0.9236 | 0 | 0.7089 | 0.0811 |
| **Corn** | 1.2972 | 0 | 2.1862 | 0.9775 | 0.9072 | 1.2560 | 0.7647 | 0 | 0.5869 | 0.0671 |
| **Stb** | 7.2338 | 0 | 12.1911 | 5.4511 | 5.0587 | 7.0037 | 4.2640 | 0 | 3.2726 | 0.3743 |
| **Beans** | 1.2103 | 0 | 2.0398 | 0.9121 | 0.8464 | 1.1719 | 0.7134 | 0 | 0.5476 | 0.0626 |
| **L** | 1.5362 | 0 | 2.5889 | 1.1576 | 1.0743 | 1.4873 | 0.9055 | 0 | 0.6950 | 0.0795 |
| **FMG** | 2.6265 | 0 | 4.4264 | 1.9792 | 1.8367 | 2.5430 | 1.5482 | 0 | 1.1882 | 0.1359 |
| **GC** | 3.5029 | 0 | 5.9035 | 2.6396 | 2.4497 | 3.3915 | 2.0648 | 0 | 1.5848 | 0.1813 |
| **P** | 1.4224 | 0 | 2.3971 | 1.0718 | 0.9947 | 1.3772 | 0.8384 | 0 | 0.6435 | 0.0736 |
| **Ccb** | 1.8836 | 0 | 3.1745 | 1.4194 | 1.3173 | 1.8237 | 1.1103 | 0 | 0.8522 | 0.0975 |
| **FSG** | 3.0660 | 0 | 5.1671 | 2.3104 | 2.1441 | 2.9685 | 1.8073 | 0 | 1.3871 | 0.1587 |
| **GS** | 1.2801 | 0 | 2.1574 | 0.9647 | 0.8952 | 1.2394 | 0.7546 | 0 | 0.5792 | 0.0662 |
| **RT** | 0.9881 | 0 | 1.6652 | 0.7446 | 0.6910 | 0.9566 | 0.5824 | 0 | 0.4470 | 0.0511 |
| **GT** | 2.2378 | 0 | 3.7714 | 1.6863 | 1.5650 | 2.1667 | 1.3191 | 0 | 1.0124 | 0.1158 |
| **FTG** | 1.9809 | 0 | 3.3384 | 1.4927 | 1.3853 | 1.9179 | 1.1677 | 0 | 0.8962 | 0.1025 |
| **Crr** | 38.3702 | 0 | 64.6655 | 28.9142 | 26.8331 | 37.1501 | 22.6177 | 0 | 17.3591 | 1.9856 |

**Table 4. Cross supply price elasticities. Spring-Summer Crops (S-S). Own elaboration. Continuation of table 3**

| S-S | Stb | Beans | L | FMG | GC | P | Ccb | FSG | GS | RT |
|---|---|---|---|---|---|---|---|---|---|---|
| **GFO** | 0.5949 | 2.1090 | 1.6629 | 0.5665 | 2.3521 | 2.0258 | 2.1536 | 1.5676 | 0 | 3.8975 |
| **Egg** | 0.2381 | 0.8441 | 0.6656 | 0.2267 | 0.9414 | 0.8108 | 0.8620 | 0.6274 | 0 | 1.5599 |
| **B** | 0.3583 | 1.2701 | 1.0015 | 0.3412 | 1.4165 | 1.2201 | 1.2970 | 0.9441 | 0 | 2.3473 |
| **BS** | 0.3533 | 1.2527 | 0.9877 | 0.3365 | 1.3971 | 1.2033 | 1.2792 | 0.9311 | 0 | 2.3150 |
| **Onion** | 0.3401 | 1.2056 | 0.9506 | 0.3238 | 1.3446 | 1.1581 | 1.2312 | 0.8961 | 0 | 2.2281 |
| **GCh** | 0.2577 | 0.9135 | 0.7203 | 0.2454 | 1.0188 | 0.8775 | 0.9329 | 0.6790 | 0 | 1.6883 |
| **Clt** | 0.2216 | 0.7855 | 0.6193 | 0.2110 | 0.8760 | 0.7545 | 0.8021 | 0.5838 | 0 | 1.4516 |
| **Cbb** | 0.2381 | 0.8441 | 0.6656 | 0.2267 | 0.9414 | 0.8108 | 0.8620 | 0.6274 | 0 | 1.5599 |
| **Clf** | 0.2914 | 1.0332 | 0.8146 | 0.2775 | 1.1523 | 0.9924 | 1.0550 | 0.7679 | 0 | 1.9094 |
| **Corn** | 0.2413 | 0.8553 | 0.6744 | 0.2297 | 0.9539 | 0.8216 | 0.8734 | 0.6358 | 0 | 1.5807 |
| **Stb** | 1.3454 | 4.7697 | 3.7609 | 1.2812 | 5.3195 | 4.5817 | 4.8706 | 3.5453 | 0 | 8.8148 |
| **Beans** | 0.2251 | 0.7981 | 0.6293 | 0.2144 | 0.8901 | 0.7666 | 0.8150 | 0.5932 | 0 | 1.4749 |
| **L** | 0.2857 | 1.0129 | 0.7987 | 0.2721 | 1.1297 | 0.9730 | 1.0343 | 0.7529 | 0 | 1.8719 |
| **FMG** | 0.4885 | 1.7318 | 1.3655 | 0.4652 | 1.9315 | 1.6635 | 1.7685 | 1.2873 | 0 | 3.2005 |
| **GC** | 0.6515 | 2.3097 | 1.8212 | 0.6204 | 2.5760 | 2.2187 | 2.3586 | 1.7168 | 0 | 4.2685 |
| **P** | 0.2646 | 0.9379 | 0.7395 | 0.2519 | 1.0460 | 0.9009 | 0.9577 | 0.6971 | 0 | 1.7333 |
| **Ccb** | 0.3503 | 1.2420 | 0.9793 | 0.3336 | 1.3852 | 1.1931 | 1.2683 | 0.9232 | 0 | 2.2953 |
| **FSG** | 0.5702 | 2.0216 | 1.5940 | 0.5430 | 2.2547 | 1.9419 | 2.0644 | 1.5027 | 0 | 3.7361 |
| **GS** | 0.2381 | 0.8441 | 0.6656 | 0.2267 | 0.9414 | 0.8108 | 0.8620 | 0.6274 | 0 | 1.5599 |
| **RT** | 0.1838 | 0.6515 | 0.5137 | 0.1750 | 0.7266 | 0.6258 | 0.6653 | 0.4843 | 0 | 1.2040 |
| **GT** | 0.4162 | 1.4756 | 1.1635 | 0.3963 | 1.6457 | 1.4174 | 1.5068 | 1.0968 | 0 | 2.7270 |
| **FTG** | 0.3684 | 1.3061 | 1.0299 | 0.3508 | 1.4567 | 1.2546 | 1.3338 | 0.9708 | 0 | 2.4138 |
| **Crr** | 7.1365 | 25.3002 | 19.9491 | 6.7957 | 28.2166 | 24.3027 | 25.8355 | 18.8055 | 0 | 46.7566 |

**Table 5. Cross supply price elasticities. Spring-Summer Crops (S-S). Own elaboration. Continuation of table 4**

| S-S | GT | FTG | Crr | S-S | GT | FTG | Crr | S-S | GT | FTG | Crr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **GFO** | 4.3794 | 1.8700 | 0.5789 | **Stb** | 9.9046 | 4.2292 | 1.3093 | **GT** | 3.0641 | 1.3083 | 0.4050 |
| **Egg** | 1.7528 | 0.7484 | 0.2317 | **Beans** | 1.6572 | 0.7076 | 0.2191 | **FTG** | 2.7123 | 1.1581 | 0.3585 |
| **B** | 2.6375 | 1.1262 | 0.3486 | **L** | 2.1034 | 0.8981 | 0.2780 | **Crr** | 52.5375 | 22.4329 | 6.9448 |
| **BS** | 2.6012 | 1.1107 | 0.3439 | **FMG** | 3.5962 | 1.5355 | 0.4754 | | | | |
| **Onion** | 2.5036 | 1.0690 | 0.3309 | **GC** | 4.7963 | 2.0480 | 0.6340 | | | | |
| **GCh** | 1.8970 | 0.8100 | 0.2508 | **P** | 1.9476 | 0.8316 | 0.2574 | | | | |
| **Clt** | 1.6311 | 0.6965 | 0.2156 | **Ccb** | 2.5791 | 1.1013 | 0.3409 | | | | |
| **Cbb** | 1.7528 | 0.7484 | 0.2317 | **FSG** | 4.1980 | 1.7925 | 0.5549 | | | | |
| **Clf** | 2.1454 | 0.9161 | 0.2836 | **GS** | 1.7528 | 0.7484 | 0.2317 | | | | |
| **Corn** | 1.7762 | 0.7584 | 0.2348 | **RT** | 1.3529 | 0.5777 | 0.1788 | | | | |

**Table 6. Cross supply price elasticities. Perennials Crops (Prnn). Own elaboration**

| Prnn | GA | Peach | Grn | Guava | Apple | Quince | FPP | Npl | Nut | Pst |
|---|---|---|---|---|---|---|---|---|---|---|
| **GA** | 0.6180 | 2.8462 | 0.8653 | NA | NA | 1.5754 | 0.1627 | 2.0728 | 3.0061 | NA |
| **Peach** | 0.6440 | 2.9658 | 0.9016 | NA | NA | 1.6416 | 0.1695 | 2.1599 | 3.1324 | NA |
| **Grn** | 2.2250 | 10.2467 | 3.1150 | NA | NA | 5.6715 | 0.5857 | 7.4625 | 10.8224 | NA |
| **Guava** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Apple** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Quince** | 0.3271 | 1.5063 | 0.4579 | NA | NA | 0.8337 | 0.0861 | 1.0970 | 1.5909 | NA |
| **FPP** | 0.3020 | 1.3909 | 0.4228 | NA | NA | 0.7699 | 0.0795 | 1.0130 | 1.4691 | NA |
| **Npl** | 0.3835 | 1.7660 | 0.5369 | NA | NA | 0.9775 | 0.1009 | 1.2861 | 1.8652 | NA |
| **Nut** | 0.3640 | 1.6762 | 0.5096 | NA | NA | 0.9278 | 0.0958 | 1.2207 | 1.7704 | NA |
| **Pst** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Grape** | 0.3345 | 1.5404 | 0.4683 | NA | NA | 0.8526 | 0.0880 | 1.1218 | 1.6269 | NA |
| **PM** | 0.3129 | 1.4410 | 0.4381 | NA | NA | 0.7976 | 0.0824 | 1.0494 | 1.5219 | NA |
| **Date** | 0.4881 | 2.2478 | 0.6833 | NA | NA | 1.2441 | 0.1285 | 1.6370 | 2.3740 | NA |
| **AP** | 0.4245 | 1.9551 | 0.5943 | NA | NA | 1.0821 | 0.1117 | 1.4238 | 2.0649 | NA |
| **CP** | 0.4249 | 1.9569 | 0.5949 | NA | NA | 1.0831 | 0.1119 | 1.4252 | 2.0669 | NA |
| **OP** | 0.1114 | 0.5132 | 0.1560 | NA | NA | 0.2840 | 0.0293 | 0.3737 | 0.5420 | NA |
| **HP** | 0.2975 | 1.3699 | 0.4164 | NA | NA | 0.7582 | 0.0783 | 0.9976 | 1.4468 | NA |

**Table 7. Cross supply price elasticities. Perennials Crops (Prnn). Own elaboration. Continuation of table 6**

| Prnn | Grape | PM | Date | AP | CP | OP | HP |
|---|---|---|---|---|---|---|---|
| **GA** | 2.6571 | 0.5334 | 0 | 0 | NA | 0 | 0 |
| **Peach** | 2.7687 | 0.5559 | 0 | 0 | NA | 0 | 0 |
| **Grn** | 9.5657 | 1.9205 | 0 | 0 | NA | 0 | 0 |
| **Guava** | NA | NA | NA | NA | NA | NA | NA |
| **Apple** | NA | NA | NA | NA | NA | NA | NA |
| **Quince** | 1.4062 | 0.2823 | 0 | 0 | NA | 0 | 0 |
| **FPP** | 1.2985 | 0.2607 | 0 | 0 | NA | 0 | 0 |
| **Npl** | 1.6486 | 0.3310 | 0 | 0 | NA | 0 | 0 |
| **Nut** | 1.5648 | 0.3142 | 0 | 0 | NA | 0 | 0 |
| **Pst** | NA | NA | NA | NA | NA | NA | NA |
| **Grape** | 1.4380 | 0.2887 | 0 | 0 | NA | 0 | 0 |
| **PM** | 1.3452 | 0.2701 | 0 | 0 | NA | 0 | 0 |
| **Date** | 2.0984 | 0.4213 | 0 | 0 | NA | 0 | 0 |
| **AP** | 1.8252 | 0.3664 | 0 | 0 | NA | 0 | 0 |
| **CP** | 1.8269 | 0.3668 | 0 | 0 | NA | 0 | 0 |
| **OP** | 0.4791 | 0.0962 | 0 | 0 | NA | 0 | 0 |
| **HP** | 1.2788 | 0.2567 | 0 | 0 | NA | 0 | 0 |

**Table 8. Results of the optimization model 2003 to 2010. E1 and E2 Scenarios 1 and 2. 1: feasible with increased production volume, -1: feasible with decreased production volume, i: feasible, x: not feasible**

| Year | 2003 | | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-W | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 |
| G | | | | | | | | | | | | | | | | |
| GFO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B | | | | | x | x | | | | | | | | | | |
| GFB | X | X | | | | | | | | | | | | | | |
| Onion | | | | | | | | | | | | | | | | |
| GFR | i | i | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Chia | | | | | | | | | | | | | | | | |
| L | | | | | | | | | | | | | | | | |
| FTG | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PM | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| S-S | | | | | | | | | | | | | | | | |
| GFO | | | x | x | | | | | x | x | | | | | | |
| Egg | | | | | | | | | | | | | | | | |
| B | 1 | 1 | 1 | 1 | 1 | 1 | i | i | 1 | 1 | 1 | 1 | | | | |
| BS | | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Onion | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 |
| GCh | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Clt | | | | | | | | | | | | | | | | |
| Cbb | | | | | | | | | | | | | | | | |
| Clf | 1 | 1 | i | i | 1 | 1 | 1 | 1 | | | | | | | | |
| Corn | | | i | i | 1 | 1 | i | i | i | i | | | | | | |
| Stb | | | | | | | | | | | | | | | | |
| Beans | 1 | 1 | i | i | 1 | 1 | | | | | | | 1 | 1 | 1 | 1 |
| L | | | 1 | 1 | | | | | | | | | | | | |
| FMG | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 |
| GC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P | | | | | 1 | 1 | | | | | | | 1 | 1 | | |
| Ccb | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 |
| FSG | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| GS | i | i | | | | | | | | | | | | | | |
| RT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| GT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FTG | | | | | | | | | | | | | | | | |
| Crr | | | | | | | | | | | | | | | | |
| PRNN | | | | | | | | | x | x | | | | | | |
| GA | | | | | x | x | x | x | 1 | 1 | x | x | x | x | x | x |
| Peach | 1 | 1 | 1 | 1 | i | i | i | i | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Grn | | | | | | | | | | | | | | | | |
| Guava | | | | | | | | | | | | | | | | |
| Apple | | | | | | | | | | | | | | | | |
| Quince | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | i | i | 1 | 1 | i | i |
| FPP | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | i | i |
| Npl | 1 | 1 | 1 | 1 | i | i | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Nut | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Pst | | | | | | | | | | | | | | | | |
| Grape | 1 | 1 | x | 1 | | | | | | | | | | | | |
| PM | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Date | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| AP | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CP | | | | | | | | | | | | | | | | |
| OP | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| HP | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 9. Results of the optimization model 2011 to 2018. E1 and E2 Scenarios 1 and 2. 1: feasible with increased production volume, -1: feasible with decreased production volume, i: feasible, x: not feasible**

| Year | 2011 | | 2012 | | 2013 | | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-W | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 | E1 | E2 |
| G | | | x | x | x | x | | | | | | | | | | |
| GFO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B | | | | | | | | | | | | | | | 1 | 1 |
| GFB | | | x | x | | | x | x | x | x | x | x | x | x | x | x |
| Onion | | | | | | | | | x | x | | | | | | |
| GFR | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Chia | | | | | | | | | | | | | x | x | | |
| L | | | | | | | | | | | | | | | | |
| FTG | 1 | 1 | i | i | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| PM | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| S-S | | | | | | | | | | | | | | | | |
| GFO | | | x | x | | | x | x | x | x | x | x | x | x | 1 | x |
| Egg | | | | | | | | | i | i | | | | | | |
| B | | | | | | | | | | | | | | | | |
| BS | | | | | i | i | | | | | | | | | | |
| Onion | 1 | 1 | i | i | 1 | 1 | 1 | 1 | | | | | | | | |
| GCh | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | i | i |
| Clt | 1 | 1 | i | i | 1 | 1 | 1 | 1 | | | | | | | | |
| Cbb | | | | | | | | | i | i | | | | | | |
| Clf | | | | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | | | | |
| Stb | | | | | | | | | | | | | | | 1 | 1 |
| Beans | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| L | | | | | | | i | i | | | 1 | 1 | | | | |
| FMG | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 | 1 | -1 |
| GC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | i | i |
| P | i | i | | | | | | | | | | | | | | |
| Ccb | 1 | 1 | i | i | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| FSG | x | x | x | x | x | x | x | x | x | x | x | x | x | x | -1 | x |
| GS | | | | | | | | | | | | | | | | |
| RT | 1 | 1 | 1 | 1 | | | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 |
| GT | 1 | 1 | 1 | 1 | 1 | 1 | | | | | 1 | 1 | i | i | 1 | 1 |
| FTG | | | | | | | 1 | x | | | | | 1 | x | 1 | x |
| Crr | | | | | | | | | | | | | | | | |
| PRNN | | | | | | | | | | | | | | | | |
| GA | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Peach | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Grn | | | | | | | | | | | | | | | i | x |
| Guava | | | | | | | | | | | | | | | | |
| Apple | | | | | | | | | | | | | | | | |
| Quince | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FPP | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| Npl | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Nut | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Pst | | | | | | | | | | | | | | | | |
| Grape | | | | | | | | | | | | | 1 | 1 | 1 | 1 |
| PM | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Date | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| AP | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CP | | | | | | | | | | | | | | | | |
| OP | | | | | | | | | | | | | | | | |
| HP | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 10. Results of the optimization model 2019 to 2021. E1 and E2 Scenarios 1 and 2. 1: feasible with increased production volume, -1: feasible with decreased production volume, i: feasible, x: not feasible**

| Year | 2019 | | 2020 | | 2021 | | Year | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-W | E1 | E2 | E1 | E2 | E1 | E2 | PRNN | E1 | E2 | E1 | E2 | E1 | E2 |
| G | | | | | | | GA | x | x | x | x | x | x |
| GFO | 1 | 1 | 1 | 1 | 1 | 1 | Peach | 1 | 1 | 1 | 1 | 1 | 1 |
| B | 1 | 1 | 1 | 1 | i | i | Grn | i | x | 1 | x | 1 | x |
| GFB | x | x | | | | | Guava | | | | | | |
| Onion | | | | | | | Apple | | | | | | |
| GFR | 1 | 1 | | | | | Quince | 1 | 1 | | | | |
| Chia | | | | | | | FPP | | | | | | |
| L | | | | | | | Npl | 1 | 1 | 1 | 1 | 1 | 1 |
| FTG | 1 | 1 | 1 | 1 | 1 | 1 | Nut | 1 | 1 | 1 | 1 | i | i |
| PM | x | x | | | | | Pst | | | | | | |
| S-S | | | | | | | Grape | 1 | 1 | 1 | 1 | i | i |
| GFO | 1 | x | 1 | x | i | x | PM | x | x | | | | |
| Egg | | | | | | | Date | 1 | 1 | 1 | 1 | 1 | 1 |
| B | 1 | 1 | 1 | 1 | 1 | 1 | AP | 1 | 1 | 1 | 1 | 1 | 1 |
| BS | | | | | | | CP | | | | | | |
| Onion | | | | | | | OP | | | | | | |
| GCh | 1 | 1 | 1 | 1 | | | HP | 1 | 1 | 1 | 1 | 1 | 1 |
| Clt | | | | | | | | | | | | | |
| Cbb | | | | | | | | | | | | | |
| Clf | | | | | | | | | | | | | |
| Corn | | | | | | | | | | | | | |
| Stb | 1 | 1 | i | i | 1 | 1 | | | | | | | |
| Beans | | | | | | | | | | | | | |
| L | | | | | | | | | | | | | |
| FMG | 1 | -1 | 1 | -1 | 1 | -1 | | | | | | | |
| GC | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| P | | | | | | | | | | | | | |
| Ccb | | | | | | | | | | | | | |
| FSG | -1 | x | 1 | x | 1 | x | | | | | | | |
| GS | | | | | | | | | | | | | |
| RT | i | i | 1 | 1 | 1 | 1 | | | | | | | |
| GT | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| FTG | i | x | | | | | | | | | | | |
| Crr | 1 | 1 | 1 | 1 | i | i | | | | | | | |

## ANALYSIS

From tables 2 to 7, the crops that have an advantage over the others according to their type are: From autumn-winter, broccoli over the other crops of the season. Followed by green fodder oats.

From spring-summer: Carrots are the ideal substitute crops for any other followed by strawberries.

And for perennials: pomegranate is the substitute crop. Followed by palm trees.

From tables 8 to 10, the feasible or non-feasible crops were found according to the scenario. They are grouped according to the type of crop:

**Feasible crops**
W-A: Forage oats in green, Forage rye in green, Forage triticale in green.
S-S: Broccoli, Zucchini, Onion, Green Chile, Coriander, Cabbage, Cauliflower, Corn, Strawberry, Bean, Lettuce, Grain Corn, Potato, Cucumber, Red Tomato, Green Tomato, Carrot.
Perennials: Peach, Quince, Forage Nopal, Nopalitos, Walnut, Grape, Date, African or oil palm, Ornamental palm, Taco palm.

**Non-feasible crops**
A-W: Garlic, green barley, onion, chia, lettuce, pastures and meadows.
S-S: Green fodder oats, green fodder sorghum.
Perennes: Green lucerne, pastures and meadows.

**Feasible crops in E1 and non-feasible in E2**
S-S: Forage triticale in green and pomegranate.

*Feasible crop with increase in production volume in E1 and decrease in E2*
S-S: Forage maize in green.

Taking both results into account, broccoli is not feasible, so the second best substitute is green forage oats for autumn-winter crops. Similarly, carrot is feasible and predominant substitute crop in spring-summer. And finally, the pomegranate is not feasible unless it is produced under the strict *E1* scenario (the least amount of water that ensures the complete development of the crop) to be a substitute. The cultivation of palm trees is convenient, mainly date palms, followed by the African, camedor, taco and ornamental.

## CONCLUSION

The appropriate crops, both seasonal and perennial, were found to be applied in the following years according to the future availability of water for agricultural use in the region. The two applied techniques complement each other adequately and provide a solution to the given problem.

## References

Adams R., Rosenzweig C., Peart R. (1990), *Global climate change and US agriculture*, Nature, 345, 219–224 (1990), USA. https://doi.org/10.1038/345219a0.

Abrol Y.P. e Ingram K.T. (1996); *Effects of higher day and night temperatures on growth and yields of some crop plants*; Ed. Bazzaz F., Sombroek W., Book Global climate change and agricultural production: direct and indirect effects of changing hydrological, pedological and plant physiological processes; Wiley, West Sussex, pps.123–140.

Boko M., Niang I. (2007), *Africa. Climate change 2007: impacts, adaptation and vulnerability*. Parry M.L., Canziani O.F., Palutikof J.P., Linden P.J., Hanson C.E. (eds) Contribution of working Group II to the fourth assessment report of the intergovernmental panel on climate change, pp 433–467. Cambridge University Press, Cambridge, UK.

Kumar Singh, Anwesha Borthakur, Arif Ahamad, Gaurav Kumar, Pardeep Singh (2019), *Climate Change and Agricultural Ecosystems*, Charper 1 - Agriculture in the Era of Climate Change: Consequences and Effects; Ed. Krishna Kumar Choudhary and Ajay Kumar and Amit Kishore Singh; Book, Woodhead Publishing, pps. 1 – 23. ISBN 978-0-12-816483-9, https://doi.org/10.1016/B978-0-12-816483-9.00001-3.

Prakash Niraj (2011), *Effect of Climate Variables on Yield of Major Food-Crops in Nepal: A Time-Series Analysis*, Journal of Contemporary India Studies: Space and Society. Vol. 1, 2011, pp. 19-26, consultaed 9/02/2020: https://ir.lib.hiroshima-u.ac.jp/en/list/HU_journals/hindas/--/1/item/31425.

Maharjan K.L. y Joshi N.P. (2013), *Climate Change, Agriculture and Rural Livelihoods in Developing Countries*, Advances in Asian Human-Environmental Research, pp. 1-10. Springer Japan 2013, DOI 10.1007/978-4-431-54343-5_1.

Ledesma-Carrión, D. E., A. Pérez-Hernández & L. Hernández-Hernández (2021). *Effect of Geo-Climatic Variables on the Yield of the Main Spring-Summer Seasonal Crops of the State of Aguascalientes*, Realidad, Revista Internacional de Estadística y Geografía, Vol. 12, Núm. 3, año 2021: pp. 62-65. ISBN: ISSN 2007-2961. México.

Siqueiros-Delgado M.E., Rodríguez-Avalos J.A., Martínez-Ramírez J. & Sierra-Muñoz J.C. (2016), *Situación actual de la vegetación del estado de Aguascalientes, México*, Botanical Sciences 94 (3): 455-470, DOI: 10.17129/botsci.466, México.

Olowa O.W., Olowa O.A. & Leal-Filho W. (2011), *Links Between Capacity and Action in Response to Global Climate Change: A Climate Response Shift at the Local Level*, Book Experiences of Climate Change Adaptation in Africa, Climate Change Management, Springer, pp. 3636-3645, ISSN 1610-2010 e-ISSN 1610-2002 ISBN 978-3-642-22314-3 e-ISBN 978-3-642-22315-0. DOI: 10.1007/978-3-642-22315-0.

UAM (2019), *Agua para todos, ¿Quién controla el agua en tu Estado?*, Propuesta de proyecto de dictamen y articulado ley general de aguas, México, 2019, consulted 28/06/2022: ¿QUIÉNES CONTROLAN EL AGUA EN TU ESTADO? (aguaparatodos.org.mx).

Food and Agriculture Organization of the United Nations (FAO) (1990), *Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos*, Estudio FAO riego y drenaje. 56, ISSN 0254-5293.

Stedito, P., T. C. Hsiao, E. Fereres & D. Raes. *Crop yield response to water* (2012), Irrigation and drainage paper 66. Rome, Food and Agriculture Organization of the United Nations, pp. 1-501, ISSN 0254-5284. ISBN 978-92-5-107274-5.

SIAP (2020), Servicios de información agroalimentaria y pesquera (open data and documents), Open data, Agrifood and Fisheries Information Service, consulted 8/02/2020: https://www.gob.mx/siap/acciones-y-programas/informacion-geoespacial-32571 https://www.gob.mx/siap/prensa/aptitud-agroclimatica-de-mexico?idiom=es
https://www.gob.mx/cms/uploads/attachment/file/92738/Cuadros_tabulares_2014.compressed.pdf
https://www.gob.mx/siap/documentos/tecnificaciondasd