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Suitable Crops for the Municipality of El Llano, Aguascalientes, Mexico. Semi-arid Region with Overexploitation of Aquifers

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Abstract

The overexploitation of water sources together with the lack of rain due to climate change that causes problems in the recharge of aquifers, this has led to the analysis of possible crops suitable for the current situation to ensure food self-sustainability in the future. Using a system of linear equations in an optimization model, emphasizing the water requirements to ensure the total development of the crop with new technologies, as well as the restriction to the availability of water for agricultural use in the region, feasible and substitutes crops were found. These crops maximize the value of production from the producer's point of view and cross-price elasticities of supply. This tool will support decision-making in strategic planning in agribusiness and government policies.

Keywords: semi-arid; overexploitation of aquifers; planning; crops

Abbreviations

x_{it}: Production volume of crop *i* in year *t*. Unit: Tons.

a_{it}: Coefficient of crop *i* in relation to its yield in year *t*.

b_{it}: Coefficient of crop *i* in relation to its water requirement in year *t*.

P_{it}: Price per produced volume unit of crop *i* in year *t*.

AP: African or oil palm.

Apple: Apple.

A-W: Autumn-Winter.

Beans: Beans.

B: Broccoli.

BS: Butternut squash.

cm: Centimeter.

CP: Camedor palm.

C: Coriander.

Corn: Corn.

Date: Date.
DCh: Dried chili.
FMG: Forage maize in green.
FTG: Forage triticale in green.
G: Garlic.
GC: Grain corn.
Grape: Grape.
GA: Green alfalfa.
GCh: Green chile.
GFO: Green fodder oats.
GT: Green tomato.
HP: Heel palm.
Km^2: Square kilometer.
L: Lettuce.
m.a.s.l.: Meters above sea level.
NA: Not available.
Nut: Nut.
OF: Objective function. Units: Mexican Peso [Mx$].
Onion: Onion.
OP: Ornamental palm.
PM: Pastures and meadows.
Pea: Pea.
Prnn: Perennials.
P: Pistachio.
RT: Red tomato (tomato).
S-S: Spring-Summer.

Introduction

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, the need for more drastic decisions became evident (Adams et al. 1990).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 (Abrol & Ingram 1996, Boko & Niang 2007, Kumar et al. 2019).

In the state of Aguascalientes, the increase in temperature was calculated at 0.77°C (Ledesma et al. 2021) increasing the evaporation of surface water. Although forage crops resist around 40°C, the heat-humidity balance was affected during their development. Consequently, groundwater extraction increased. Eighty percent of the original vegetation cover of the state was modified due to human settlements with agricultural and livestock activities, largely causing around 90% of soil erosion and groundwater scarcity (Siqueiros et al. 2016). Consequently, it is essential to improve the yields of irrigated agriculture and the management of water resources.

Some proposals from international organizations to meet the food needs of the future establish response capacity as a requirement: build a response system to the spread of risks, modify traditional and current practices, create species resistant to environmental stress, promote cooperation between governments and finance projects at the local level that solve specific problems (Kumat et al. 2019, Olowa et al. 2011). Therefore, it was chosen to solve the problem at the regional level (municipality) based on the disaggregation of data.

The study region is located between 22°04' and 21°47' latitude, -102°11' and -102°50' longitude and from 1980 to 2505 m.a.s.l., with an area of 456,727 Km^2. The soils are particularly shallow with a layer thickness of 20-50 cm, poor in organic matter and nutrients and with a medium texture and sandy crumb material. The types of soil that it presents are feozem, lithosol, planosol, regosol and rendzina The vegetation has been adapted for irrigation agriculture (El Llano and Soyatal localities) and rainfed agriculture (El llano, Soyatal and Juan el Grande), which correspond to desert plains with a rocky floor, hills with ravines, moderate slopes with volcanic relief, low elevations and typical plateau. Semi-dry and semi-warm climate with an average temperature of 16.9°C, maximum temperature of 25.4°C and minimum of 8.3°C. Annual rainfall of 400 to 600 mm and average rainfall of 481mm. Rains occur annually in a total of approximately 53 days, hailstorms fluctuate from 1 to 2 days a year and from 245 to 275 days without frost. The crops are exposed to the irregular distribution of rains, frequent frosts, wide thermal oscillations, droughts in short periods and wind (SEDESOL 2012, H. Ayuntamiento 2017). So alternative crop options are limited. The disposal of water for surface agricultural use has varied from 2003 to 2021 from 49.8 to 10.8% and the underground from 50.2 to 80.2%, respectively (UAM 2019).

Most models focus on 1) crop yields and their relationship with climatic variables and 2) crop development with moisture-heat balance using the modified Penman-Monteith method (FAO 1990, Steduto et al 2012).

Prakash (2011) built an autoregressive model based on time series relating changes in crop yields to changes in climatic variables. His model presented low correlation between the variables and some of them were not statistically significant, which is natural since the rain cycles are irregular and are mainly linked to the ranges of temperature, humidity, atmospheric pressure, altitude and latitude (Maharjan & Joshi 2013).Even so, Prakash found interesting results, especially for rice cultivation, which was favored by climate change, since it increased the availability of water in Nepal. This type of model is complementary to the Penman-Monteith method to find the response of crops to water stress. Ledesma et al. 2021 adapted these methodologies to assess the impact of climate change on crops in the state of Aguascalientes and its municipalities. Because rainfed crops are the most affected, their study focused on them.

For irrigated crops, water stress is minimal if they have enough water to cover the demand of the plant. The present study proposes another methodology that analyzes historical crops restricted to the availability of necessary and sufficient water for the complete development of the plant.

In Mexico there are National Plans, among them, the Water Plan and the Agricultural Plan. The first monitors the recharge and exploitation of aquifers while the second provides fertilizers by type of crop and region, crop intentions based on weather forecasts, yield measurement and production prices, among other variables and parameters.

A general optimization model was formulated and the cross elasticities of supply prices were calculated. This was to take into account both the feasibility of the crop and its competitive advantage.

Fertilizers are basic, composed of potassium, sulfides, nitrates and some metals, suitable for crops in the area. Therefore, the model focused on the requirements and availability of water, yields and production value, both for crops registered as substitutes or complementary.

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.

The following section specifies the official free open access data sources and software that can be used via predefined subroutines called "utilities". The structure, variables and parameters of the model are described in the Methodology section. In the results and analysis section, the concentrated results of both model and elasticities are presented in tables, specifying which crops are feasible and competitive. Finally, the conclusions of the work and the references to consult.

Materials and Methods

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 (SIAP 2020a,2020b,2021,2022). Data from surface and underground sources according to the Public Registry of Water Rights (REPDA in Spanish) were used (UAM 2019). 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.

Lineal Programming Model. 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

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

Restricted to

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

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

$$x_{it} | Ejx_{it} \leq historical\ maximum\ level\ without\ loss_i$$

$$x_{it} \left| Ej_{x_{it}} \right. \geq 0$$

Results and Discussion

Cross elasticities of supply prices are shown in tables 1 to 5 and the concentrate of the results of the optimization model in tables 6 to 15.

The advantage of the model applied in this work is that it takes into account both aspects related to the total development of the crop through yields (yields are a function of damaged areas) and the market through prices and production volumes. As mentioned, irrigated crops have almost no disaster, so only the lack of water would cause the moisture-heat imbalance during plant development. No crop from 2003 to 2021 presented this situation. To ensure that the affected area was null, that is, the planted area is equal to the harvested area, the water sources were overexploited. So for future plantings, other crops must be adapted, others must be stopped, or designated areas must be reduced.

A-W	G	GFO	B	Onion	Pea	L	FTG	PM
G	NA	NA	NA	NA	NA	NA	NA	NA
GFO	0	0.8157	0	0.0840	0	0.3816	0.5308	0.5765
B	NA	NA	NA	NA	NA	NA	NA	NA
Onion	NA	NA	NA	NA	NA	NA	NA	NA
Pea	NA	NA	NA	NA	NA	NA	NA	NA
L	0	2.5412	0	0.2617	0	1.1888	1.6537	1.7962
FTG	NA	NA	NA	NA	NA	NA	NA	NA
PM	0	3.3351	0	0.3435	0	1.5602	2.1703	2.3573

Table 1: Cross supply price elasticities. Autumn-Winter Crops (A-W). Own elaboration.

S-S	GFO	B	BS	Onion	Pea	DCh	GCh	C
GFO	2.4198	0	1.0543	2.1374	1.8897	2.4198	0	1.0543
B	NA	NA	NA	NA	NA	NA	NA	NA
BS	6.2146	0	2.7078	5.4892	4.8532	6.2146	0	2.7078
Onion	1.9133	0	0.8336	1.6899	1.4941	1.9133	0	0.8336
Pea	10.6057	0	4.6210	9.3678	8.2823	10.6057	0	4.6210
DCh	2.1674	0	0.9444	1.9144	1.6926	2.1674	0	0.9444
GCh	2.3309	0	1.0156	2.0589	1.8203	2.3309	0	1.0156
C	NA	NA	NA	NA	NA	NA	NA	NA
Corn	NA	NA	NA	NA	NA	NA	NA	NA
Beans	1.0119	0	0.4409	0.8938	0.7902	1.0119	0	0.4409
L	NA	NA	NA	NA	NA	NA	NA	NA
FMG	1.4370	0	0.6261	1.2692	1.1222	1.4370	0	0.6261
GC	1.1445	0	0.4987	1.0109	0.8938	1.1445	0	0.4987
RT	1.2179	0	0.5306	1.0757	0.9511	1.2179	0	0.5306
GT	1.0951	0	0.4771	0.9673	0.8552	1.0951	0	0.4771

Table 2: Cross supply price elasticities. Spring-Summer Crops (S-S). Own elaboration.

S-S	Corn	Beans	L	FMG	GC	RT	GT
GFO	0	0.9424	1.2882	6.0673	5.0753	0	0.9424
B	NA	NA	NA	NA	NA	NA	NA
BS	0	2.4203	3.3082	15.5821	13.0344	0	2.4203
Onion	0	0.7451	1.0185	4.7971	4.0128	0	0.7451
Pea	0	4.1304	5.6458	26.5919	22.2441	0	4.1304
DCh	0	0.8441	1.1538	5.4344	4.5459	0	0.8441
GCh	0	0.9078	1.2408	5.8444	4.8888	0	0.9078
C	NA	NA	NA	NA	NA	NA	NA
Corn	NA	NA	NA	NA	NA	NA	NA
Beans	0	0.3941	0.5387	2.5371	2.1223	0	0.3941
L	NA	NA	NA	NA	NA	NA	NA
FMG	0	0.5596	0.7649	3.6029	3.0139	0	0.5596
GC	0	0.4457	0.6092	2.8696	2.4004	0	0.4457

RT	0	0.4743	0.6483	3.0536	2.5543	0	0.4743
GT	0	0.4265	0.5829	2.7457	2.2968	0	0.4265

Table 3: Cross supply price elasticities. Spring-Summer Crops (S-S). Table 2 *continued*. Own elaboration.

Prnn	***GA***	***Apple***	***Nut***	***P***	***Grape***	***PM***
GA	1.0139	1.5136	0.9662	NA	5.1207	8.4087
Apple	0.4584	0.6843	0.4369	NA	2.3152	3.8018
Nut	0.6326	0.9445	0.6029	NA	3.1953	5.2470
P	NA	NA	NA	NA	NA	NA
Grape	0.2381	0.3555	0.2269	NA	1.2026	1.9748
PM	0.9159	1.3674	0.8729	NA	4.6260	7.5964
Date	0.6417	0.9580	0.6115	NA	3.2409	5.3218
AP	0.5661	0.8451	0.5395	NA	2.8591	4.6948
CP	0.5629	0.8404	0.5365	NA	2.8431	4.6686
OP	0.1576	0.2353	0.1502	NA	0.7961	1.3073
HP	0.4526	0.6757	0.4314	NA	2.2861	3.7540

Table 4: Cross supply price elasticities. Perennial Crops (Prnn). Own elaboration.

Prnn	***Date***	***AP***	***CP***	***OP***	***HP***
GA	9.5026	5.8268	2.8785	8.0207	3.7407
Apple	4.2963	2.6344	1.3014	3.6263	1.6912
Nut	5.9296	3.6359	1.7962	5.0049	2.3342
P	NA	NA	NA	NA	NA
Grape	2.2317	1.3684	0.6760	1.8837	0.8785
PM	8.5846	5.2639	2.6004	7.2459	3.3793
Date	6.0141	3.6877	1.8218	5.0762	2.3674
AP	5.3056	3.2533	1.6072	4.4782	2.0885
CP	5.2760	3.2351	1.5982	4.4532	2.0769
OP	1.4773	0.9059	0.4475	1.2470	0.5816
HP	4.2424	2.6013	1.2851	3.5808	1.6700

Table 5: Cross supply price elasticities. Perennial Crops (Prnn). Table 4 *continued*. Own elaboration.

The best replacement option for green alfalfa are pastures and meadows, but they are not feasible, so the only option is strict control of water supply through optimal technology under scenario *E1*. Your second best option would be to replace it with date palms, feasible with elasticity of 0.6417 under scenarios *E1* and *E2*.

Spring-Summer rainfed green fodder oats is not feasible in both scenarios, while Autumn-Winter oats is (tables 6 to 15). The latter can be substituted for lettuce with an elasticity of 2.5412 in scenario *E1*. This same case occurs for green forage triticale and pastures and meadows with elasticities of 1.6537 and 1.7962, respectively (Table 1). Now, taking into account the value of production, forage oats is the one that has had it for the last 8 years, being surpassed in some years by forage triticale and pastures and meadows. Consequently, it is preferable to continue growing fodder oats with strict control of the water supply as the only crop in the Autumn-Winter season, rotating plots so that the soils recover.

2003	***Original***	***E1***	***E2***	***2004***	***Original***	***E1***	***E2***
OF	26439629.6	281453147.5	228128379.3	***OF***	33391135.2	316436245	257078913
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	2535	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	142	142	0	L	0	0	0
FTG	0	0	0	FTG	0	0	0
PM	2680	0	0	PM	1125	0	0
S-S				***S-S***			
GFO	575	0	0	GFO	1139	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	0	0	0	Onion	42	51	51
Pea	0	0	0	Pea	0	0	0
DCh	40	149	0	DCh	18	149	149
GCh	350	822	822	GCh	304	822	822
C	0	0	0	C	0	0	0
Corn	15	0	0	Corn	0	0	0
Beans	59	142	142	Beans	142	142	142
L	0	0	0	L	0	0	0
FMG	25860	27453	0	FMG	28535	28535	0
GC	1062	1560	0	GC	755	1560	0
RT	0	0	0	RT	0	0	0
GT	45	245	245	GT	122	245	245
Prnn				***Prnn***			
GA	24057	0	0	GA	27396	0	0
Apple	0	0	0	Apple	0	0	0
Nut	2	4	0	Nut	2	4	0
P	0	0	0	P	0	0	0
Grape	1498	3125	0	Grape	3125	3125	0
PM	506	0	0	PM	354	1	0
Date		8656	8656	Date		8656	8656
AP		207835	139220	AP		207835	130121
CP		0	0	CP		0	0
OP		6630	0	OP		6630	0
HP		197	197	HP		197	197

Table 6: Reported data and scenario results E1 and E2. OF and x_{ij}. 2003-2004. Own elaboration.

2005	***Original***	***E1***	***E2***	***2006***	***Original***	***E1***	***E2***
OF	29709498.9	314454486	256022849	***OF***	34027229.5	333634802	270078928
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	1242	0	0	GFO	740	0	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	0	0	0	FTG	0	0	0
PM	1385	0	0	PM	1050	0	0
S-S				***S-S***			
GFO	1375	1560	0	GFO	506	1560	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	10	51	0	Onion	30	51	51
Pea	0	0	0	Pea	0	0	0
DCh	149	149	0	DCh	9	149	0
GCh	86	822	822	GCh	822	822	822
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	92	142	142	Beans	48	142	142
L	0	0	0	L	0	0	0
FMG	24130	27999	0	FMG	20910	27104	0
GC	659	1560	0	GC	596	1560	0
RT	75	451	451	RT	0	0	0
GT	0	0	0	GT	18	245	245
Prnn				***Prnn***			
GA	26185	0	0	GA	27007	0	0
Apple	0	0	0	Apple	0	0	0
Nut	2	4	0	Nut	2	4	0
P	0	0	0	P	0	0	0
Grape	1065	3125	0	Grape	1152	3125	0
PM	366	0	0	PM	459	534	0
Date		8656	8656	Date		8656	8656
AP		207835	141091	AP		207835	141080
CP		0	0	CP		0	0
OP		0	0	OP		0	0
HP		197	197	HP		197	197

Table 7: Reported data and scenario results E1 and E2. OF and x_{ij}. 2005-2006. Own elaboration.

2007	***Original***	***E1***	***E2***	***2008***	***Original***	***E1***	***E2***
OF	36418584.7	440586726.1	352458435	***OF***	25330994.5	485471506	388630172.4
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	1100	0	0	GFO	1512	0	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	8	8	8	Pea	0	0	0
L	0	0	0	L	120	142	0
FTG	330	2449	0	FTG	390	2449	0
PM	570	0	0	PM	2391	0	0
S-S				***S-S***			
GFO	300	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	30	51	0	Onion	0	0	0
Pea	8	30	30	Pea	0	0	0
DCh	86	149	0	DCh	27	149	0
GCh	0	0	0	GCh	0	0	0
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	67	142	142	Beans	0	0	0
L	0	0	0	L	0	0	0
FMG	25650	0	0	FMG	16320	28270	0
GC	1481	1560	0	GC	1108	1560	0
RT	90	451	0	RT	0	0	0
GT	245	245	0	GT	0	0	0
Prnn				***Prnn***			
GA	23009	15924	0	GA	23785	0	0
Apple	20	30	0	Apple	27	30	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	1641	3125	0	Grape	873	3125	0
PM	408	0	0	PM	423	0	0
Date		8656	8656	Date		8656	8656
AP		207835	143238	AP		207835	143929
CP		0	0	CP		0	0
OP		0	0	OP		0	0
HP		197	0	HP		197	0

Table 8: Reported data and scenario results E1 and E2. OF and x^{ij}. 2007-2008. Own elaboration.

2009	***Original***	***E1***	***E2***	***2010***	***Original***	***E1***	***E2***
OF	31782275.6	554980777.6	433757419.6	**OF**	31366109.2	599066270	477152290
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	132	9411	0	GFO	9411	796	0
B	0	0	0	B	72	72	0
Onion	60	80	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	20	142	0
FTG	0	0	0	FTG	0	0	0
PM	1239	0	0	PM	600	0	0
S-S				***S-S***			
GFO	505	0	0	GFO	1560	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	0	0	0	Onion	30	51	0
Pea	0	0	0	Pea	0	0	0
DCh	30	149	0	DCh	20	149	0
GCh	224	822	822	GCh	165	822	822
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	94	142	142	Beans	62	142	142
L	0	0	0	L	0	0	0
FMG	18750	18789	0	FMG	18030	28535	0
GC	1348	1560	0	GC	924	1560	0
RT	45	451	451	RT	60	451	451
GT	131	245	0	GT	18	245	0
Prnn				***Prnn***			
GA	20684	0	0	GA	16818	0	0
Apple	30	30	0	Apple	28	30	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	873	3125	0	Grape	1360	3125	0
PM	238	0	0	PM	534	0	0
Date		8656	8656	Date		8656	8656
AP		207835	141091	AP		207835	141091
CP		0	0	CP		0	0
OP		0	0	OP		0	0
HP		197	197	HP		197	197

Table 9: Reported data and scenario results E1 and E2. OF and x_{ij}. 2009-2010. Own elaboration.

2011	***Original***	***E1***	***E2***	***2012***	***Original***	***E1***	***E2***
OF	39885596.9	666493154.7	516115428.3	***OF***	45123252.9	712777203	662810198
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	3319	0	0	GFO	6945	9411	0
B	0	0	0	B	0	0	0
Onion	80	80	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	0	0	0	FTG	1084	2449	0
PM	255	0	0	PM	843	2680	0
S-S				***S-S***			
GFO	0	0	0	GFO	0	0	0
B	0	0	0	B	140	140	140
BS	0	0	0	BS	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
DCh	78	149	0	DCh	0	0	0
GCh	120	822	822	GCh	0	0	0
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	63	142	142	Beans	71	142	142
L	0	0	0	L	0	0	0
FMG	16305	28535	0	FMG	16978	28535	0
GC	1414	1560	0	GC	999	1560	1560
RT	0	0	0	RT	0	0	0
GT	95	245	245	GT	0	0	0
Prnn				***Prnn***			
GA	20661	583	0	GA	20710	14138	0
Apple	27	30	0	Apple	30	30	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	751	3125	0	Grape	1051	3125	817
PM	497	0	0	PM	499	534	0
Date		8656	8656	Date		8656	8656
AP		207835	141314	AP		207835	207835
CP		0	0	CP		0	0
OP		0	0	OP		0	0
HP		197	197	HP		0	0

Table 10: Reported data and scenario results E1 and E2. OF and x_{ij}. 2011-2012. Own elaboration.

2013	***Original***	***E1***	***E2***	***2014***	***Original***	***E1***	***E2***
OF	42836265.3	616351625.8	570448755.5	**OF**	43137587	633625744	591682624.8
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	80	80	80	G	0	0	0
GFO	2295	9411	0	GFO	4776	9411	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	2449	2449	0	FTG	1790	2449	0
PM	416	2680	0	PM	848	2680	0
S-S				***S-S***			
GFO	0	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	17	51	51	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
DCh	0	0	0	DCh	0	0	0
GCh	70	822	822	GCh	8	822	822
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	79	142	142	Beans	32	142	142
L	78	78	78	L	0	0	0
FMG	20940	28535	0	FMG	20637	28535	0
GC	1461	1560	1560	GC	1474	1560	1560
RT	24	451	451	RT	0	0	0
GT	16	245	0	GT	0	0	0
Prnn				***Prnn***			
GA	22115	13783	0	GA	29504	14045	0
Apple	13	30	0	Apple	12	30	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	1245	3125	499	Grape	1226	3125	757
PM	189	534	0	PM	166	534	0
Date		8656	8656	Date		8656	8656
AP		207835	207835	AP		207835	207835
CP		0	0	CP		0	0
OP		0	0	OP		0	0
HP		197	197	HP		197	197

Table 11: Reported data and scenario results E1 and E2. OF and x_{ij}. 2013-2014. Own elaboration.

2015	***Original***	***E1***	***E2***	***2016***	***Original***	***E1***	***E2***
OF	41476993.1	701260467	658356738	***OF***	44691966.8	754220612	692677149.4
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	3099	9411	0	GFO	2814	9411	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	1189	2449	0	FTG	1120	2449	0
PM	639	2680	0	PM	1143	2680	0
S-S				***S-S***			
GFO	0	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
DCh	0	0	0	DCh	0	0	0
GCh	0	0	0	GCh	0	0	0
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	15	142	142	Beans	22	142	142
L	0	0	0	L	0	0	0
FMG	19136	28535	0	FMG	21168	28535	0
GC	1122	1560	1560	GC	1474	1560	1560
RT	0	0	0	RT	0	0	0
GT	0	0	0	GT	0	0	0
Prnn				***Prnn***			
GA	29890	14173	0	GA	32161	32161	0
Apple	12	30	0	Apple	12	30	0
Nut	3	4	0	Nut	4	4	0
P	0	0	0	P	0	0	0
Grape	1201	3125	918	Grape	1008	3125	918
PM	165	534	0	PM	161	534	0
Date		8656	8656	Date		8656	8656
AP		207835	207835	AP		207835	207835
CP		0	0	CP		268152	0
OP		0	0	OP		6630	0
HP		197	197	HP		197	197

Table 12: Reported data and scenario results E1 and E2. OF and x_{ij}. 2015-2016. Own elaboration.

2017	***Original***	***E1***	***E2***	***2018***	***Original***	***E1***	***E2***
OF	40319308.6	843137253.7	776179342	***OF***	46011024.4	867415540.1	770246158.3
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	2914	9411	0	GFO	2990	9411	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	1133	2449	0	FTG	1225	2449	0
PM	1908	2680	0	PM	2061	2680	0
S-S				***S-S***			
GFO	0	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	15	28	28
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	30	30	30
DCh	0	0	0	DCh	0	0	0
GCh	0	0	0	GCh	0	0	0
C	0	0	0	C	22	22	0
Corn	0	0	0	Corn	0	0	0
Beans	6	142	142	Beans	0	0	0
L	0	0	0	L	0	0	0
FMG	19902	28535	0	FMG	21204	28535	0
GC	1284	1560	1560	GC	1537	1560	0
RT	0	0	0	RT	451	451	451
GT	0	0	0	GT	73	245	0
Prnn				***Prnn***			
GA	27404	32161	0	GA	29690	32161	0
Apple	14	30	0	Apple	12	30	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	394	3125	918	Grape	126	3125	1757
PM	157	534	0	PM	162	534	0
Date		8656	8656	Date		8656	8656
AP		207835	207835	AP		207835	207835
CP		268152	0	CP		1122124	0
OP		6630	0	OP		6630	0
HP		197	197	HP		197	197

Table 13: Reported data and scenario results E1 and E2. OF and x_{ij}. 2017-2018. Own elaboration.

2019	***Original***	***E1***	***E2***	***2020***	***Original***	***E1***	***E2***
OF	41198518.6	867030133	771123902.4	***OF***	42013201	890625287	793108250.6
A-W	***Original***	***E1***	***E2***	***A-W***	***Original***	***E1***	***E2***
G	0	0	0	G	0	0	0
GFO	2904	9411	0	GFO	8130	9411	0
B	0	0	0	B	0	0	0
Onion	0	0	0	Onion	0	0	0
Pea	0	0	0	Pea	0	0	0
L	0	0	0	L	0	0	0
FTG	1028	2449	0	FTG	0	0	0
PM	1869	2680	0	PM	0	0	0
S-S				***S-S***			
GFO	0	0	0	GFO	0	0	0
B	0	0	0	B	0	0	0
BS	0	0	0	BS	18	28	0
Onion	0	0	0	Onion	39	51	0
Pea	0	0	0	Pea	0	0	0
DCh	0	0	0	DCh	0	0	0
GCh	0	0	0	GCh	31	822	822
C	0	0	0	C	0	0	0
Corn	0	0	0	Corn	0	0	0
Beans	0	0	0	Beans	0	0	0
L	0	0	0	L	0	0	0
FMG	23007	28535	0	FMG	22977	28535	0
GC	1510	1560	0	GC	1470	1560	0
RT	248	451	451	RT	21	451	451
GT	0	0	0	GT	19	245	245
Prnn				***Prnn***			
GA	21832	32161	0	GA	22891	32161	0
Apple	0	0	0	Apple	0	0	0
Nut	3	4	0	Nut	3	4	0
P	0	0	0	P	0	0	0
Grape	127	3125	1783	Grape	15	3125	3125
PM	0	0	0	PM	0	0	0
Date		8656	8656	Date		8656	8656
AP		207835	207835	AP		207835	196344
CP		1122124	0	CP		1122124	0
OP		6630	0	OP		6630	0
HP		197	197	HP		197	197

Table 14: Reported data and scenario results E1 and E2. OF and x_{ij}. 2019-2020. Own elaboration.

2021	***Original***	***E1***	***E2***				
OF	38901583.9	890364019	793567122				
A-W	***Original***	***E1***	***E2***	***S-S***	***Original***	***E1***	***E2***
G	0	0	0	Beans	0	0	0
GFO	3344	9411	0	L	0	0	0
B	0	0	0	FMG	22753	28535	0
Onion	0	0	0	GC	1560	1560	0
Pea	0	0	0	RT	30	451	451
L	0	0	0	GT	29	245	245
FTG	0	0	0	***Prnn***			
PM	0	0	0	GA	22109	32161	0
S-S				Apple	0	0	0
GFO	0	0	0	Nut	3	4	0
B	0	0	0	P	0	0	0
BS	28	28	0	Grape	44	3125	3125
Onion	51	51	0	PM	0	0	0
Pea	0	0	0	Date		8656	8656
DCh	0	0	0	AP		207835	196344
GCh	14	822	822	CP		1122124	0
C	0	0	0	OP		6630	0
Corn	0	0	0	HP		197	197

Table 15: Reported data and scenario results E1 and E2. OF and x_{ij}. 2021. Own elaboration.

In the case of Spring-Summer crops, green forage maize and grain maize have the highest value. The first is feasible in scenario *E1* and the second in both. In addition, forage corn can be a substitute for forage oats with an elasticity of 1.4370.

On the other hand, dry chili was replaced by green chili since it is feasible in both scenarios and its production value is higher on average during the study period. Elasticities 4.3475 and 5.9787, respectively. Thus, the green chili has been preferred to the dry one. Similarly, between the red tomato (2.7457) and green tomato (2.5543), the green tomato has been preferred in recent years over the red one, see tables 2, 3, 6-15.

Onion has more production value than peas and peas than lettuce. In general, onions and lettuce are feasible in both scenarios while peas are feasible only in scenario *E1*. The onion can substitute peas with an elasticity of 9.3678, and the bean for peas (4.1304). Beans are feasible and their production value is slightly below that of fodder oats, see tables 3, 6-15.

Finally, in scenario *E2*, perennial crops: green alfalfa, pistachio, pastures and meadows are not feasible. They can be replaced by apple, walnut and palm trees (mainly date). In the case of green alfalfa, with walnut (0.6326) and date palm (0.6417). Pistachio with dates (5.3218) and apple (5.2470). There were not enough data for the complete evaluation of pistachio, see tables 4, 5. 6-15. As the crop with the highest production value is alfalfa, to conserve it in the future, action must be taken under scenario E1. Likewise, for pastures and meadows. The grape is feasible in both scenarios with the third place in production value. Their best substitutes are pastures and meadows, but they are not recommended due to what has already been mentioned, see tables 4-15.

This model makes it possible to compare substitute or complementary crops, as well as to control production volumes with water availability restrictions and better yields given the characteristics of the soil. By knowing the production volumes, the hectares to be planted can be associated and a strategic planning of land use can be made.

Conclusion

The research provided a useful tool for strategic planning regarding agricultural use in the region. The research can be adapted and re-scaled to other regions. In addition, other scenarios can be defined by setting the predominant conditioning variable, which in this case was the availability of water. Substitute or complementary crops were consistently tested.

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