Article

# Network flow optimization in the formulation of an investment project in Tecamachalco, Puebla

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## Abstract

Using linear programming, a network flow model was formulated to optimize the use of the land of small producers in the area of the Tecamachalco Valley, Puebla, Mexico. The optimal crop pattern was estimated in order to increase net profits over a production horizon and obtain financial indicators such as NPV, IRR and B/C R. These values were compared with the traditional methodology of project evaluation. The production horizon was five years for five horticultural crops: onion, tomato, bell pepper, cucumber and zucchini. The results indicated that the optimal crop pattern was to produce tomato in spring-summer (s-s) and bell pepper in autumn-winter (a-w). A NPV of $295 229.84 pesos, an IRR of 68.64% and a B/C ratio of 1.52 were obtained. The net profit of the production plan was $7 422 367.00 pesos, being between 15 and 45% higher with respect to the individual production of each crop. For the selected crops, profits of $6 254 668.49 and $6 339 146.18 pesos were calculated for tomatoes and bell peppers, respectively.

**Keywords:** linear programming, network flow, optimization, projects, vegetables.

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# Introduction

Agriculture in Mexico, as in most developing economies, is an important source of jobs and income. Thirteen-point three percent of the population participates in primary activities, who represent 7.1 million economically active people (INEGI, 2018). In 2019 in the agricultural sector, 20 664 554.08 ha were allocated for agricultural production activities, 68% of this area was distributed in production units with supply of irrigation water 4 175 356.45 ha and rainfed 9 833 626.38 ha (SIAP, 2019). As for the value of production, the main crop is grain corn, which generates a value of $106 245 747.07 pesos, in an area of 7 157 586.88 ha.

In contrast to the value of all horticultural production, which generates an income of $89 269 654.01 pesos, in an area of 524 984.14 ha, horticultural production represents 7.3% of the cultivated area and generates 84% of the value of production, with respect to the cultivation of grain corn (SIAP, 2019). Horticultural production under protected agriculture represents 0.5% of all national production, and has a production value of $26 852 081.78 pesos, which means 6% of the national total (SIAP, 2019). The states of Sinaloa, San Luis Potosí, Jalisco, Sonora and Coahuila represent more than 50% of the value of total protected agriculture production. Puebla ranks within the top ten states that contribute the most to the total value of production in this same area, with a participation in its production of $906 857.92 pesos and that represents 4.6% (SIAP, 2019).

Among the main horticultural products under protected agriculture with respect to the value of production, tomato, onion, husk tomato and zucchini stand out; together they add up to 46.7% of the total value of the production of the state of Puebla (SIAP, 2019). In 2010, the horticultural area sown in Puebla was 51 243.8 ha, of which a production of 662 873.88 t was obtained, with a total value of $2 014 126.32 pesos, for 2017 the area increased to 62 159 ha and 1 073 449.62 t were produced, with a total value of $4 157 965.34 pesos (SIAP, 2019).

In the country there are 4 069 938 production units, of which 69% are made up of five or less ha, which contribute 39% of production, also generate 63% of jobs in the agricultural sector considering family labor, as well as hired labor (INEGI, 2018). Credit in the agricultural sector has suffered variations over the years, in 1994 there was a portfolio of $ 154 340.3 million pesos, which fell until 2006 reaching only $17 503.5 million pesos and having an increase to $20 425 million in 2009 and a stabilization that has been maintained since 2009 (Reyes and Reyes, 2018).

At the national level, only 6% of producers have access to institutional credit, about 70% of rural economic production units are of subsistence and self-consumption (CONEVAL, 2018), as access to tools to formulate projects is limited, it makes it impossible for the producer to access sufficient resources and preferential rates that allow them to make the leap to competitive production units (Fundar, 2014). Currently, the prevailing methodology for the formulation and evaluation of projects, established by ECLAC; in the ‘manual on economic development projects’, it contemplates the criteria of engineering or technical studies, investment of budget of income, expenses, financing and organization of the company (Pérez, 2000).

Farmers must make complex production and marketing decisions throughout the year, what crops to produce, how much land to rent, labor to employ and the optimal time to do it, production can be organized with the use of LP (Kaiser and Messer, 2011). Gittinger (1982); Alvarado (2009); Render *et al*. (2012) mention that LP is a mathematical method that allows analyzing and choosing the best way to distribute limited resources to maximize the profits of the company.

The objective of the present research was to optimize the combination of horticultural crops to improve the financial indicators used in the evaluation and formulation of investment projects, maximizing the net income of production, under a scenario of temporality in land use, compared to the traditional methodology. As a hypothesis, it was established that it is possible to determine in one hectare of soil the succession of horticultural crops that maximizes the net benefits, optimizing the results that would be obtained with the traditional methodology for the formulation of investment projects.

## Materials and methods

The research was conducted with information on the state of Puebla. It is in the central region of Mexico, has an area of 34 251 $km^2$, composed of 217 municipalities and 6 500 localities. Of the total, 6 200 are rural with a total area of 3 391 900 ha, of these 1 048 999 ha are for agricultural use (898 875 rainfed ha and 150 124 irrigated ha) (INEGI, 2019). In particular, information on the region of the Tecamachalco Valley was used, because producers are gradually adopting horticultural crops of high sowing density, production and value, information on the production cycles 2018-2019, to make a five-year projection.

In 2018, the cultivated area was 18 819.9 ha, with a production of 441 267.58 t and a production value of $1 942 453.74 pesos, compared to the rest of the municipalities with a cultivated area of 40 902.93 ha (SIAP, 2019). A LP model in the form of a network flow, proposed by Bazaraa *et al*. (2010), was used. One hectare was established as the land area with potential to be sown, and it was proposed to sow 5 crops: onion (ce), tomato (ji), cucumber (pe), bell pepper (mo) and zucchini (ca).

A planning period of 10 agricultural cycles (spring-summer (ss 01) and autumn-winter (aw 02)) was considered, represented as t= 1, 2, 3,…10. Crop succession needs depend only on the types of crops that are sown and are given in the form of sequences, so that two crops cannot be produced on the same land or in the same cycle. The model was built as follows: Maximize $(Z)=\sum_{i=1}^{N=165}TI_i^{t-1}*x_i^{t-1}-\sum_{i=1}^{N=150}\{c_i^{t-1}*x_i^{t-1}+la_i^{t-1}*x_i^{t-1}+wa_i^{t-1}*x_i^{t-1}\}$ 1). Where: i= horticultural crop, onion (ce), tomato (ji), cucumber (pe), bell pepper (mo) and zucchini (ca); t-1= succession of crops in cycles; $TI_i^{t-1}$= total income from the production of crop i in cycle t-1 (ss, aw); $x_i^{t-1}$= variable of land use decision (1 ha) of crop i, in cycle t-1 (ss, aw); $c_i^{t-1}$, $la_i^{t-1}$ and $wa_i^{t-1}$= costs of production, labor and water extraction (variable costs); N= 165: it represents the number of crop income activities and N= 150: it represents the number of crop cost activities.

Subject to: $\sum_{j=1}^{N} x_j^{t} = -1$ 2), restriction of maximum limit of availability of land to be sown for the preceding crop “j” at the beginning of the project in cycle t. $\sum_{i=1}^{N} x_i^{t-2} = 1$ 3), restriction of land requirement for crop i at the end of the period in cycle t-2. $\sum_{i=1}^{N} x_i^{t-2} - \sum_{j=1}^{N} x_j^{t-1} \leq 0$ 4), restriction of limit that represents the way in which the land available for preceding crop j at the beginning of cycle t-1 is distributed to the successor crop i in cycle t-2. $x_{i,j} \geq 0$, for all i, j 5).

## Restriction of non-negativity

Transfer restrictions provide the means by which the product obtained in one activity can be transferred within the model to other activities. $\sum_{i=1}^{N} c_i^{t-1} * x_i^{t-1} \leq 1$ 6). it transfers the costs (c) of production of crop i in cycle t-1 for the use of land for cultivation. $\sum_{i=1}^{N} la_i^{t-1} * x_i^{t-1} \leq 1$ 7), it transfers the labor (la) costs of crop i in cycle t-1 for the use of land for cultivation. $\sum_{i=1}^{N} wa_i^{t-1} * x_i^{t-1} \leq 1$ 8), it transfers the costs of kW for water (wa) extraction to crop i in cycle t-1 for the use of land for cultivation. The distribution of available land between the cycles can be seen in (Table 1).

**Table 1. Horticultural production schedule for the ss and aw cycles.**

| Month/activities | ce01 | ji01 | mo01 | pe01 | ca01 | ce02 | ji02 | mo02 | pe02 | ca02 |
|---|---|---|---|---|---|---|---|---|---|---|
| December | 0 | 0 | 0 | 0 | 1[¤] | 0 | 0 | 0 | 0 | 0 |
| January | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| February | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| March | 1 | 0 | 0 | 0 | 1[ǂ] | 0 | 0 | 0 | 0 | 0 |
| April | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mayo | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| June | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| July | 1[§] | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| August | 0 | 1 | 1[¥] | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| September | 0 | 1 | 0 | 1[†] | 0 | 1 | 0 | 0 | 0 | 1 |
| October | 0 | 1[¶] | 0 | 0 | 0 | 1 | 0 | 0 | 1[◊◊] | 1[ǂǂ] |
| November | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| January | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| February | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 1[§§] | 1 | 1[¥¥] | 1[††] | 0 |
| April | 0 | 0 | 0 | 0 | 0 | 0 | 1[¶¶] | 0 | 0 | 0 |

Information from INIFAP’s technology development and transfer centers. ce= onion, ji= tomato; mo= bell pepper; pe= cucumber; ca= zucchini; 01= period 1 ss cycle, 02= period 2 aw cycle, [§]1= end of production of ce01 July 4; [¶]1= end of production of ji01 October 12; [¥]1= end of production of mo01 August 23; [†]1= end of production of pe01 September 27; [¤]1= start of production December 16 and [ǂ]1= end of production March 15 of ca01; [§§]1= end of production of ce02 March 4; [¶¶]1= end of production of ji02 April 14; [¥¥]1= end of production of mo02 March 25; [◊◊]1= start of production October 16 and [††]1= end of production March 15 of pe02; [ǂǂ]1= end of production of ca02 October 29.

To avoid overlaps between crops, a time space of 15 days was established to give continuity to the production of a second crop. In the case of available agricultural labor, the information from the report on the National Survey of Agricultural Day Laborers (SEDESOL, 2011) was taken as the basis. The minimum wage of $123.22 pesos per day for workers in Mexico, excluding the northern zone bordering the United States of America, was considered as the salary of workers (CONASAMI, 2020). To determine the coefficient of water costs, the cost of extraction by pumping was calculated, for that the power required by the equipment was obtained, in watts (W): $P_e=\frac{Q*H*\gamma}{\eta_e}$ (9). Where:($\eta_e$) is the technical information of the various pump manufacturers in the country, the efficiency has a value of 82%, (CONUEE, 2011).

In the Tecamachalco Valley, the wells have an average instantaneous expenditure of 23 L $s^{-1}$ (Q), a specific water weight of 9.81 N $m^{-3}$ ($\gamma$) and a total pumping equipment load of 91.4 m (H), (CRETEALC-Mexico, 2011). As a result, the pumping equipment delivers a power ($P_e$) of 25 150 watts (w)= 25.15 kW. Table 2 shows the calculations of kWh (kilowatt-hour) necessary for the pumping of water required by crop and the cost of electrical energy, starting from: kWh= kW*t 10).

**Table 2. Water extraction costs based on the information on water requirement 2018.**

| | | Onion | Tomato | Bell pepper | Cucumber | Zucchini |
|---|---|---|---|---|---|---|
| Volume of water required (l) | | 7 600 000 | 5 908 000 | 4 432 000 | 6 000 000 | 3 650 000 |
| Extraction time (h) | | 91.78 | 71.35 | 53.52 | 72.46 | 44.08 |
| Kwh | | 8 310.27 | 6 460.14 | 4 846.20 | 6 560.74 | 3 991.11 |
| RABT fee | $2.50 | $20 813.00 | $16 189.53 | $12 156.29 | $16 440.92 | $10 019.4 |

Preparation with data from CFE, RABT (agricultural irrigation in low voltage) fee 2018.

The objective function consisted of 315 decision variables, 165 of sales and 150 of production costs. Two hundred two restrictions are included: 2 of land resource, 50 of alternation of crops in ten cycles, and 150 of resource transfer (50 of yields, 50 of number of daily wages and 50 of energy required for water extraction). The succession of possible crops to be sown, according to the production schedule, is expressed in a network flow model $b_{t-1}$. The b represents the amount of land allowed to produce in a previous cycle t-1.

The crops ce, ji, pe, mo and ca represent the nodes of supply and demand of land, 01 and 02 represent the production cycles ss and aw, respectively, the lines that connect the nodes represent the possible direction of production from the beginning to the end of the production horizon (Figure 1).

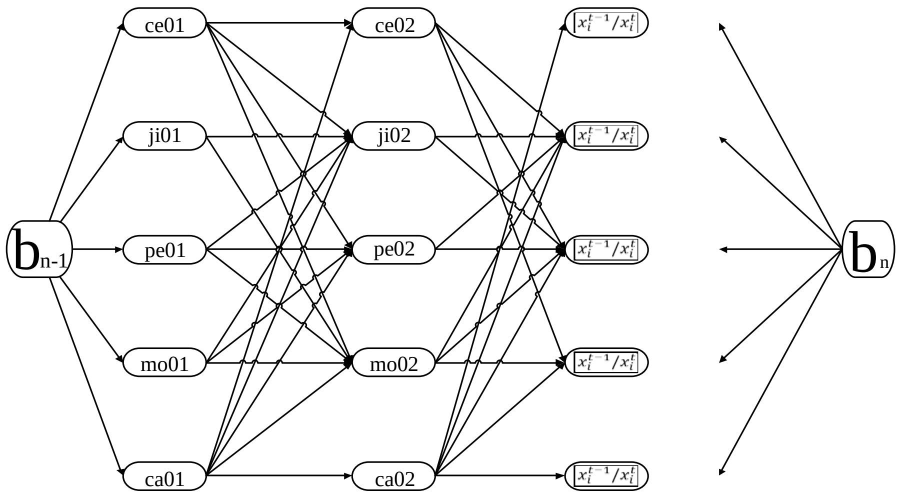


**Figure 1. Graphical representation of the network flow for the proposed horticultural crops.** Preparation based on the models of LP in network (Bazaraa *et al*., 2010).

## Results

The cash flow projection of the sequencing of optimal crops of the obtained model was analyzed, as well as the financial indicators of the project. Below is the LP model of network flow, which was run with Solver® Lindo®.

Objective function MAX Z= 718447.60ca0111 + 1000645.18pe0111 + 1000645.18pe0112 + 1000645.18pe0113 + 1000645.18pe0114 + 1648876.11mo0111 + 1648876.11mo0112 + 1648876.11mo0113 + 1648876.11mo0114 + 1648876.11mo0115 + 1225449.92ji0111 + 1225449.92ji0112 + 1225449.92ji0113 + 1225449.92ji0114 + 1225449.92ji0115 + 729757.00ce0111 + 598803.56ca0211 + 598803.56ca0212 + 564685.51pe0211 + 564685.51pe0212 + 564685.51pe0213 + 564685.51pe0214 + 786622.69mo0211 + 786622.69mo0212 + 786622.69mo0213 + 786622.69mo0214 + 786622.69mo0215 + 1148579.52ji0211 + 1148579.52ji0212 + 1148579.52ji0213 + 1148579.52ji0214 + 1148579.52ji0215 + 63,307.42ce0211 + 631307.42ce0212 + 718447.60ca0121 + 1000645.18pe0121 + 1000645.18pe0122 + 1000645.18pe0123 + 1000645.18pe0124 + 1648876.11mo0121 + 1648876.11mo0122 + 1648876.11mo0123 + 1648876.11mo0124 + 1648876.11mo0125 + 1225449.92ji0121 + 1225449.92ji0122 + 1225449.92ji0123 + 1225449.92ji0124 + 1225449.92ji0125 + 729757.00ce0121 + 598803.56ca0221 + 598803.56ca0222 + 564685.51pe0221 + 564685.51pe0222 + 564685.51pe0223 + 564685.51pe0224 + 786622.69mo0221 + 786622.69mo0222 + 786622.69mo0223 + 786622.69mo0224 + 786622.69mo0225 + 1148579.52ji0221 + 1148579.52ji0222 + 1148579.52ji0223 + 1148579.52ji0224 + 1148579.52ji0225 + 63,307.42ce0221 + 631307.42ce0222 + … + 598803.56ca0251 + 598803.56ca0252 + 564685.51pe0251 + 564685.51pe0252 + 564685.51pe0253 + 564685.51pe0254 + 786622.69mo0251 + 786622.69mo0252 + 786622.69mo0253 + 786622.69mo0254 + 786622.69mo0255 + 1148579.52ji0251 + 1148579.52ji0252 + 1148579.52ji0253 + 1148579.52ji0254 + 1148579.52ji0255 + 63307.42ce0251 + 631307.42ce0252 – 254525.85C0111 - 273148.60C0112 - 607723.83C113 - 620681.02C0114 - 334164.54 C0115 - … - 254525.85C0151 -

273148.60C0152 - 607723.83C153 - 620681.02C0154 - 334164.54 C0155 - 123.22MO0112 - 123.22MO0113 - 123.22MO0114 - 123.22MO0115 - … - 123.22MO0251 - 123.22MO0152 - 123.22MO0153 - 123.22MO0154 - 123.22MO0155 - 2.5AG0111 - 2.5AG0112 - 2.5AG113 - 2.5AG0114 - 2.5AG0115 - … - 2.5AG0251 - 2.5AG0152 - 2.5AG0153 - 2.5AG0154 - 2.5AG0155.

**Initial land availability restrictions**

ca0111 + pe0111 + pe0112 + pe0113 + pe0114 + mo0111 + mo0112 + mo0113 + mo0114 + mo0115 + ji0111 + ji0112 + ji0113 + ji0114 + ji0115 + ce0111= -1.

**Land use restrictions**

ca0251 + ca0252 + pe0251 + pe0252 + pe0253 + pe0254 + mo0251 + mo0252 + mo0253 + mo0254 + mo0255 + ji0251 + ji0252 + ji0253 + ji0254 + ji0255 + ce0251 + ce0252= 1. The way of organizing the model coincides with what was proposed by Detlefsen and Leck (2004) in using crop rotation through network modeling with periods of up to four cycles in the problem. The Table 3 shows the crops selected for the ss and aw cycles.

**Table 3. Selection of activities and reduced cost of the crops of two periods (2019 and 2024).**

| Year 5 a-w cycle (2024) | | | Year 1 a-w cycle (2019) | | |
|---|---|---|---|---|---|
| Activity | Area to be sown (ha) | Reduced cost | Activity | Area to be sown (ha) | Reduced cost |
| ca02 | 0 | $3 119 861.00 | ca02 | 0 | $0.00 |
| | 0 | $3 038 886.00 | | 0 | $0.00 |
| pe02 | 0 | $3 192 334.00 | pe02 | 0 | $2 164 099.0 |
| | 0 | $225 892.90 | | 0 | $0.00 |
| | 0 | $775 888.90 | | 0 | $0.00 |
| | 0 | $3 111 359.00 | | 0 | $2 164 099.00 |
| mo02 | 0 | $3 294 525.00 | mo02 | 0 | $2 164 099.00 |
| | 0 | $785 383.00 | | 0 | $0.00 |
| | 0 | $328 083.60 | | 0 | $0.00 |
| | 0 | $878 079.70 | | 0 | $0.00 |
| | 0 | $3 213 549.00 | | 0 | $2 164 099.00 |
| ji02 | 0 | $2 966 441.00 | ji02 | 0 | $2 164 099.00 |
| | 0 | $457 299.40 | | 0 | $0.00 |
| | 1 | $0.00 | | 1 | $0.00 |
| | 0 | $549 996.00 | | 0 | $0.0 |
| | 0 | $2 885 466.00 | | 0 | $2 164 099.0 |
| ce02 | 0 | $3 179 642.00 | ce02 | 0 | $0.00 |
| | 0 | $3 098 667.00 | | 0 | $0.00 |
| ca01 | 0 | $0.00 | ca01 | 0 | $0.00 |

Preparation with data from 2018 (projection 2019 and 2024).

If it were decided to produce ca02, as a result of sowing ce01 in the previous cycle, the information in Table 3 describes the value of the function in a reduction of $3 119 861.00 pesos. If it is decided to produce pe02, as a result of sowing ca01 in the previous cycle, the same table describes the value of the function a reduction by $3 111 359.00 pesos. In the case of ji02, it has a value of zero and is therefore an activity that was selected as a result of producing mo01 in the previous cycle.

The results are consistent with those obtained by Alvarado (2009), who proposed a model with six vegetables, and in his final results, only three crops were selected, because the program avoided the overlapping of crops, like this study. In Table 4, the shadow price represents how much the current value of the objective function will improve if the associated restriction is ‘relaxed’ by one unit.

**Table 4. Level of use of the land resource, shadow price and slack values of the study period.**

| No. | Row | Shadow price | Slack | No. | Row | Shadow price | Slack |
|---|---|---|---|---|---|---|---|
| 1 | Demand for land | $6 413 045.00 | 0 | 31 | ji01 | $2 511 647.00 | 0 |
| 2 | Land availability | $1 009 322.00 | 0 | 30 | mo01 | $2 968 947.00 | 0 |
| 3 | ca02 | $ - | 1 | 32 | ce01 | $1 526 214.00 | 0 |
| 4 | pe02 | $ - | 1 | 33 | ca02 | $1 847 946.00 | 0 |
| 5 | mo02 | $ - | 0 | 34 | pe02 | $3 218 206.00 | 0 |
| 6 | ji02 | $ - | 1 | 35 | mo02 | $3 444 099.00 | 0 |
| 7 | ce02 | $ - | 1 | 36 | ji02 | $3 444 099.00 | 0 |
| 8 | ca01 | $ - | 0 | 37 | ce02 | $1 788 164.00 | 0 |
| 9 | pe01 | $ - | 0 | 38 | ca01 | $2 289 321.00 | 0 |
| 10 | mo01 | $ - | 0 | 39 | pe01 | $4 453 420.00 | 0 |
| 11 | ji01 | $ - | 0 | 40 | mo01 | $4 453 420.00 | 0 |
| 12 | ce01 | $ - | 0 | 41 | ji01 | $4 453 420.00 | 0 |
| 13 | ca02 | $321 731.50 | 0 | 42 | ce01 | $2 289 321.00 | 0 |
| 14 | pe02 | $249 258.90 | 0 | 43 | ca02 | $2 611 053.00 | 0 |
| 15 | mo02 | $147 068.20 | 0 | 44 | pe02 | $4 702 679.00 | 0 |
| 16 | ji02 | $475 151.80 | 0 | 45 | mo02 | $4 600 488.00 | 0 |
| 17 | ce02 | $261 950.50 | 0 | 46 | ji02 | $4 928 572.00 | 0 |
| 18 | ca01 | $763 107.00 | 0 | 47 | ce02 | $2 551 272.00 | 0 |
| 19 | pe01 | $1 006 950.00 | 0 | 48 | ca01 | $3 052 428.00 | 0 |
| 20 | mo01 | $1 484 473.00 | 0 | 49 | pe01 | $5 387 898.00 | 0 |
| 21 | ji01 | $1 484 473.00 | 0 | 50 | mo01 | $5 937 894.00 | 0 |
| 22 | ce01 | $763 107.00 | 0 | 51 | ji01 | $5 480 594.00 | 0 |
| 23 | ca02 | $1 084 838.00 | 0 | 52 | ce01 | $2 971 453.00 | 0 |
| 24 | pe02 | $1 733 732.00 | 0 | 53 | ca02 | $ - | 1 |

| No. | Row | Shadow price | Slack | No. | Row | Shadow price | Slack |
|---|---|---|---|---|---|---|---|
| 25 | mo02 | $1 631 542.00 | 0 | 54 | pe02 | $ - | 1 |
| 26 | ji02 | $1 959 625.00 | 0 | 55 | mo02 | $ - | 1 |
| 27 | ce02 | $1 025 057.00 | 0 | 56 | ji02 | $ - | 0 |
| 28 | ca01 | $1 526 214.00 | 0 | 57 | ce02 | $ - | 1 |
| 29 | pe01 | $2 968 947.00 | 0 | | | | |

Preparation with data from 2018.

The optimal crop plan is shown in Table 5, based on data from the 2018-2019 agricultural year.

**Table 5. Five-year financial projection of the optimal crop pattern (2019 to 2024).**

| Cycle | Activity | Area ha | Production (t) | Price $t^{-1}$ | Sales | Costs | Profit |
|---|---|---|---|---|---|---|---|
| SS | Bell pepper | 1 | 128.96 | 12 785 | 1 648 876 | -639 554 | 1 009 321 |
| AW | Tomato | 1 | 150.28 | 7 642 | 1 148 579 | -673 427 | 475 151 |
| SS | Bell pepper | 1 | 128.96 | 12 785 | 1 648 876 | -639 554 | 1 009 321 |
| AW | Tomato | 1 | 150.28 | 7 42 | 1 148 579 | -673 427 | 475 151 |
| SS | Bell pepper | 1 | 128.96 | 12 785 | 1 648 876 | -639 554 | 1 009 321 |
| AW | Tomato | 1 | 150.28 | 7 642 | 1 148 579 | -673 427 | 475 151 |
| SS | Bell pepper | 1 | 128.96 | 12 785 | 1 648 876 | -639 554 | 1 009 321 |
| AW | Tomato | 1 | 150.28 | 7 642 | 1 148 579 | -673 427 | 475 151 |
| SS | Bell pepper | 1 | 128.96 | 12 785 | 1 648 876 | -639 554 | 1 009 321 |
| AW | Tomato | 1 | 150.28 | 7 642 | 1 148 579 | -673 427 | 475 151 |
| | | Total | | | 13 987 278 | -6 564 911 | 7 422 367 |

Preparation with data from 2018-2019.

Mohamad and Said (2011) concluded that in a crop planning scheme using LP, promising results are obtained, even using a short planning period; which gives alternatives to producers to reduce agricultural risk. It was observed that the crop pattern maintains a stability in the production of bell pepper and tomato in the five years of the project, the composition in each cycle does not change. The composition of costs and profits is shown in Table 6.

**Table 6. Comparison of individual production of horticultural crops with the selection of LP, 2018-2019.**

| Crops | Yield | Costs ($) | Income ($) | Profits ($) |
|---|---|---|---|---|
| Onion | 67.75 | 3 515 945.80 | 7 563 155.23 | 4 047 209.43 |
| Tomato | 140.37 | 6 468 891.20 | 12 723 559.69 | 6 254 668.49 |
| Bell pepper | 105.1 | 6 234 747.40 | 12 573 893.58 | 6 339 146.18 |
| Cucumber | 108.18 | 2 41 839.40 | 8 498 133.51 | 5 556 294.11 |
| Zucchini | 72.11 | 2 658 814.00 | 7 540 856.93 | 4 882 042.93 |
| Tomato LPM | 150.28 | 3 367 138.52 | 5 742 897.60 | 2 375 759.08 |
| Bell pepper LPM | 128.96 | 3 197 772.60 | 8 244 380.56 | 5 046 607.96 |

Preparation with data from 2018-2019.

A financial projection of costs and benefits was made based on the results of the LP model (Table 7).

**Table 7. Financial projection for the mo01 and ji02 crops resulting from the model, year 2019-2024.**

| Concepts/year | Beginning | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| (+) sales | 0 | 2 797 455 | 2 797 455 | 2 797 455 | 2 797 455 | 2 797 455 |
| (+) salvage value | 0 | 0 | 0 | 0 | 0 | 766 681 |
| (=) total income | 0 | 2 797 455 | 2 797 455 | 2 797 455 | 2 797 455 | 3 564 137 |
| (=) total costs | 0 | 1 312 982 | 1 312 982 | 1 312 982 | 1 312 982 | 1 312 982 |
| Purchase of fixed assets | 1 504 108 | 0 | 0 | 0 | 0 | 0 |
| Purchase of deferred assets | 0 | 0 | 0 | 0 | 0 | 0 |
| Purchase of working capital | 499 704 | | | | | |
| (=) final balance | -2 003 812 | 1 484 473 | 1 484 473 | 1 484 473 | 1 484 473 | 2 251 155 |

Preparation with data from 2018.

From the financial projection of the joint cultivation of bell pepper (mo01) and tomato (ji02) resulting from the LP model, the cash flow projection was established (Table 8), where the variation of cash inflow and outflow over a period of five years is observed.

**Table 8. Cash flow for the mo01 and ji02 crops resulting from the model (2019-2024).**

| Year | Income | Costs | Cash flow | Rate $(1+T)*n^{-1}$ | Updated income | Updated expenses |
|---|---|---|---|---|---|---|
| 0 | 0 | 2 003 812.06 | -2 003,812.06 | 1 | 0 | 1 669 843.38 |
| 1 | 2 797 455.63 | 1 312 982.22 | 1 484 473.409 | 0.833 | 2 331 213.02 | 1 094 151.85 |
| 2 | 2 797 455.63 | 1 312 982.22 | 1 484 473.409 | 0.694 | 1 942 677.52 | 911 793.21 |
| 3 | 2 797 455.63 | 1 312 982.22 | 1 484 473.409 | 0.578 | 1 618 897.93 | 759 827.675 |
| 4 | 2 797 455.63 | 1 312 982.22 | 1 484 473.409 | 0.482 | 1 349 081.61 | 633 189.729 |
| 5 | 3 564 137.29 | 1 312 982.22 | 2 251 155.076 | 0.401 | 1 432 346.84 | 527 658.108 |
| Total | 14 753 959.8 | 8 568 723.17 | 6 185 236.653 | | 8 674 216.94 | 5 596 463.95 |

Preparation with results of the model.

With the information obtained and the tables of financial analysis, the comparison was made; in a productive horizon of 5 years (2019-2020 to 2023-2024), between horticultural crops ‘without’ and ‘with’ the use of LP, in terms of the analysis of profitability indicators. Like Forrester and Rodríguez (2018), the purpose of running optimization models is to develop crop rotation planning that specifies the amount to be sown, land use, time period and how each crop must be sown to meet market demand.

To obtain the profitability indicators, the formulas of Gittinger (1982), net present value (NPV), internal rate of return (IRR) and benefit/cost (B/C) ratio were used, being discounted at a rate of 20%. The situation ‘with’ the use of LP was obtained: NPV= $2 952 269.84; IRR= 68.64%; B/C Rat= 1.52. Using the same discount rate, the profitability indicators ‘without’ the use of LP of each of the horticultural crops considered in the study were obtained (Table 9).

**Table 9. Values of the profitability indicators of crops 'without' the use of LP 2019-2024.**

| Crops | NPV | IRR (%) | B/C R |
|---|---|---|---|
| Onion 01/02 | 469 776 | 30.1 | 1.12 |
| Tomato 01/02 | 1 542 449 | 48.73 | 1.26 |
| Bell pepper 01/02 | 1 637 316 | 51.02 | 1.29 |
| Cucumber 01/02 | 1 419 091 | 50.38 | 1.4 |
| Zucchini 01/02 | 995 712 | 40.87 | 1.3 |

Preparation with data from 2018.

The results show that the combination of mo01 and ji02 improves financial indicators compared to a scenario without the use of LP. This is consistent with Prisenk and Turk (2015), who suggest that, with the knowledge of the cultivated area and the rest of their results obtained from optimization, producers could analyze different scenarios in a context of risk management; that is, what cultivation strategies and land to use, how much other resources could be used (mechanical or manual labor, fertilizers), how much to harvest and sell of the crops. For their part, Jebelli *et al*. (2016) found that when vegetables and the combination of these with cereals are increased, the model exhibits reductions in net income; this may be because one or more of the constraints may not have been linked in the optimization process, implying an increase in scarce resources.

## Conclusions

Based on the information from the area of the Tecamachalco Valley, Puebla, the LP of the network flow type allowed optimizing the crop pattern. Also formulating a feasible investment project with better results when comparing it with the traditional methodology. In a period of 10 agricultural cycles, it was possible to determine an optimal production dynamic that generated a total net income of $7 422 367 pesos, growing bell pepper in the s-s cycles and tomato in the a-w cycles.

Compared to a monoculture production, as traditionally established in the formulation and evaluation of projects for the crops selected in this study, profits of $6 254 668.49 and $6 339 146.18 pesos were calculated for tomato and bell pepper, respectively. Compared to the $7 422 637 pesos of the combination of tomato and bell pepper resulting from the LP model.

## Cited literature

Alvarado, B. J. 2009. La programación lineal aplicación de las pequeñas y medianas empresas. Reflexiones. 88(1):89-105. https://www.redalyc.org/articulo.oa?id=72912559007.

Bazaraa, M. S.; Jarvis, J. J. and Sherali, H. D. 2010. Linear Programming and Network Flows. 4th (Ed). Editorial Hoboken, New Jersey: John Wiley y Sons, Inc. 748 p.

CONASAMI, 2020. Secretaria del Trabajo y Previsión social. https://www.gob.mx/cms/uploads/attachment/file/525061/Tabla_de_salarios_m_nmos_vigentes_apartir_del_01_de_enero_de_2020.pdf.

CONEVAL, 2018. Plan Nacional de Desarrollo 2013-2018. Ciudad de México: Consejo Nacional de Evaluación de la Política de Desarrollo Social.

CONUEE, 2011. Estudio de Sistemas de Bombeo Agropecuarios en México, México DF.

CRETEALC-México, 2011. Manejo del acuífero del valle de Tecamachalco, Puebla, México.

Detlefsen, N. K. and Leck, A. L. 2004. Modelling optimal crop sequences using network flows. Tjele, Denmark: University of Aarhus, Faculty of Agricultural Sciences, Department of Agroecology and Environment. 94(2):566-572.

Forrester, R. J. and Rodríguez, M. S. 2018. An integrer programming approach to crop rotation planning at an organic farm. The UMAP Journal. 38(4):5-25.

Fundar, 2014. Centro de Análisis e Investigación. Infografía: ¿Por qué es importante la pequeña agricultura? Subsidios al Campo en México. https://fundar.org.mx/porque-es-importante-la-pequena-agricultura/.

Gittinger, J. P. 1982. Análisis económico de proyectos agrícolas. Banco Mundial. Madrid, España. 323-442 pp.

Kaiser, H. M. and Messer, K. D. 2011. Mathematical Programming for Agricultural, Environmental, and Resource Economics. United States of America: John Wiley y Sons Inc. 151-155 pp.

Jebelli, J.; Paterson, B. and Abdelwahab, A. 2016. A linear programming model to optimize cropping pattern in small-scale irrigation schemes: an application to Mekabo Scheme in Tigray, Ethiopia. International Journal of Environmental and Agriculture Research. 2(8):24-34.

INEGI, 2018. Encuesta Nacional Agropecuaria 2017, CDMX: https://www.inegi.org.mx/contenidos/programas/ena/2017/doc/mini_ena17.pdf.

INEGI, 2019. Marco Geoestadístico. Available at: https://www.inegi.org.mx/temas/mg/.

Mohamad, N. H. and Said, F. K. 2011. A mathematical programming approach to crop mix problem. African Journal of Agricultural Research. 6(1):191-197.

Pérez, M. D. 2000. Formulación y evaluación de proyectos de inversión. 1ra. Ed. DICEA. Chapingo, Estado de México: 150 p.

Prisenk, J. and Turk, J. 2015. A multi-goal mathematical approach for the optimization of crop lanning on organic farms: a Slovenian case study. Pakistan Journal of Agricultural Sciences. 52(4):971-979.

Render, B. C.; Stair, R. M. y Hanna, M. E. 2012. Métodos cuantitativos para los negocios. 11va. Ed. México. Pearson Education. 429-457 pp.

Reyes, O. S. y Reyes, R. E. 2018. La historia del crédito agrícola en México. México, DF. Cámara de Diputados LXIII Legislatura. 341-344 pp.

SEDESOL, 2011. Secretaría de Desarrollo Social. Pobreza, migración y capacidades básicas en la población jornalera agrícola en México. Resultados de la Encuesta Nacional de Jornaleros Agrícolas 2009, México, DF.

SIAP, 2019. Sistema de Información Agroalimentaria de Consulta. Ciudad de México: SADER. https://nube.siap.gob.mx/gobmx_publicaciones_siap/pag/2019/Atlas-Agroalimentario-2019.