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ECONOMIC IMPACT OF FOUR FRUIT TREES IN THREE MUNICIPALITIES OF THE LAXAXALPAN BASIN, PUEBLA, MEXICO IN THE PERIOD 2003 - 2022

Georgel Moctezuma López
Master of Science, Colegio de Postgraduados, Mexico / Agricultural Economics Branch Centro Nacional de Investigación Disciplinaria en Conservación y Mejoramiento de Ecosistemas Forestales del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Mexico

Francisco Moreno Sanchez
Master of Science, Universidad Nacional Autónoma de México / Branch of Soil Sciences; Centro Nacional de Investigación Disciplinaria en Conservación y Mejoramiento de Ecosistemas Forestales del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (National Center for Disciplinary Research in Conservation and Improvement of Forest Ecosystems of the National Institute of Forestry, Agriculture and Livestock Research)

Efraín Velasco Bautista
D. in Science from the Colegio de Postgraduados, Mexico / Statistical Sciences Centro Nacional de Investigación Disciplinaria en Conservación y Mejoramiento de Ecosistemas Forestales of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Abstract: This article deals with the evolution and modification of land use change in one of the most important watersheds in the country, which in addition to generating electricity by means of a hydraulic infrastructure work for a territorial surface of central Mexico, and how anthropogenic activities modify land use change within the watershed through agriculture and livestock raising. The methodology used was worked in two phases: the first one on land use change using series III to VII provided by INEGI in a time span from 2002 to 2022 and with data processing using ArcMap 10.8.1 within the Laxaxalpan river basin and in particular in three municipalities of the state of Puebla: Ciconcuatla, Chignahuapan and Zacatlán and with the evolution in planted surfaces of four fruit trees: avocado, blueberry, cherry coffee and apple, the first two of recent introduction and the others that are of traditional type in diverse areas of the mentioned municipalities. The second phase was documentary type with information from SIAP for planted areas and production value and from CONAPO for population growth in the study sites. The sum of the four fruit trees in the planted area had a small growth of 0.9 %, but in the value of production at market prices its growth rate was 7.71 % and in both cases the blueberry was the one with the best indicators with 6.12 % and 9.66 % respectively and for the last year of the data, the contribution of the fruit trees to the economy of the region was 136.7 million Mexican pesos.
Keywords: planted area, average annual growth rate, land use, value of production.

INTRODUCTION

The National Strategy for Sustainable Forest Management to Increase Production and Productivity (ENAIPROS) implemented by CONAFOR (2013), gathers the experiences of all the participating agents and proposes to continue with the actions that have allowed the maintenance of timber production areas, strengthening silvicultural techniques applied in forest management to achieve maximum productivity in each of the intervened sites, incorporating better management practices to conserve the biodiversity of the areas under silvicultural intervention. In the state of Puebla, the region known as "Chignahuapan-Zacatlán" was chosen as an area for reactivating silviculture because this part of the state is home to more than half of the area under forest management and annual harvest volumes, as well as to almost 50% of the forest industry.

At the beginning and before human intervention, the hydrographic systems were in a state of natural equilibrium and today the watersheds are increasingly threatened and affected by anthropogenic modifications in land cover and changes in land use (Moreira *et al*., 2020). The protection of watersheds as an objective within territorial and environmental planning and management is recognized by several authors, such as D'Agostini and Schilindwein (1998), Cecilio and Reis (2006), Drake and Hogan (2013) and Bothelo and Silva (2014) for zoning studies, environmental analysis and pollution, water quality and development planning where they seek to contribute to the theoretical, methodological and practical conceptualization of what a watershed is, its importance for society and its main functions that emanate from it.

The Laxaxalpan river basin has a strong interdependence with the Necaxa river basin, due to the existence of a hydraulic infrastructure work that has an aqueduct that

collects runoff water from several tributaries through tunnels and canals that transports this water to the Nexapa dam, which is inserted in the Necaxa river basin where, by means of hydroelectric energy, electricity is generated and distributed to a large area in the center of the country and the study area is located mainly in the state of Puebla and in bordering areas of the states of Veracruz, Tlaxcala and Hidalgo (UACH 2024), Tlaxcala and Hidalgo (UACH 2024).

METHODOLOGY

The methodological process used was divided into two phases:

I) The analysis of land use and vegetation cover changes can be a tool that can give us a general idea of the impacts of national strategies on natural resources. For this study, series III to VII were used, covering a time span from 2002 to 2022 (previous series were not considered because of changes in the legend and method of integration, which would lead to errors in the quantification of areas). For the comparison of the use of areas, the vectorial information of the mentioned series was downloaded from the INEGI web page and processed with ArcMap 10.8.1, in the Geomatics laboratory of the National Center for Disciplinary Research in Conservation and Improvement of Forest Ecosystems (CENID COMEF), belonging to the National Institute of Forestry, Agriculture and Livestock Research (INIFAP).

II) The five-stage documentary type:

First: selection of the topic to be studied, for the socioeconomic research the one that deals with the evolution of the planted surface of four fruit species: avocado, blueberry, cherry coffee and apple, in the Laxaxalpan basin and in three municipalities of the state of Puebla that were selected because they have statistical data: Choconautla, Chignahuapan and Zacatlan.

Second: gathering information from secondary documentary sources, the main idea was to compile statistics with the purpose of quantifying, ordering and classifying them in order to measure and assess the importance of the subject. We resorted to the search and precise location of documents kept in information centers, libraries, reference centers, databases, as well as articles and summaries of proceedings of seminars and national and international congresses, among others. During this phase, an Excel database was designed and elaborated, which was fed with the information generated by the Agrifood and Fisheries Information System (SIAP) of the Ministry of Agriculture and Rural Development (SADER) in its various documents published periodically, which were used to organize the documentary sequence. The study period was delimited according to the national accounts published by the aforementioned source during the period of 20 years 2003 - 2022 and the base year that served as a basis was 2018, to use constant prices with which the data can be comparable when analyzing the value of production of perennial fruit trees.

Third: elaboration of the research plan, with the purpose of ordering and exercising thought and understanding, as well as that the concepts have a logical and systematic structure for hierarchizing, the indicators of planted area (in hectares) and production value (in Mexican pesos) were chosen, in addition to data on the economically active population (men, women, employed and unemployed) were considered.

Fourth: organization of the information that was collected, which was done by indexing the content and secondary sources of information, for which it was segmented by fruit species in surface area and by value of production and visualize the contribution of each of them to the local economy, which would allow a better understanding of the subject.

Fifth: selection of the statistical indicator, it was considered that the mathematical formula that best reflects the annual growths is the average annual growth rate because it is supposed to be the one that best reflects the growths of an activity in a medium and long term period, its mathematical expression is:

$$SSS = ((Vf / Vi) \wedge (1 / n) - 1) * 100.$$

Where Vf means the final value at the end of the period; Vi corresponds to the initial value of the period and n represents the number of years considered in the analysis. Likewise, the growth of a specific year was taken into account, which was compared with its immediate previous one, to facilitate and identify the sizes of positive and negative increases that result throughout the period (Addin Technology, 2018). Likewise, a trend line was included to have a better understanding of the evolution of the indicators.

Therefore, the objective of the research was to determine the increases in the plantations of the four fruit trees in the three municipalities, as well as the economic value they contribute to the regional economy through their average annual growth rates, as well as that of the total population and the economically active population within the study area.

RESULTS AND DISCUSSION

Figure 1 shows the hydrological basin of Laxaxalpan where the municipalities that were considered as case studies are identified: Chiconcuautla, Zacatlán and Chignahuapan, which cover the southern, central and north--central zone of the basin, which are located between the geographical coordinates of latitude 19^0 40' 00¨ and 20^0 10' 00¨ North and latitude 98^0 20' 00¨ and 97^0 30' 00¨ West. The total number of municipalities including the three that served as case study were 31, distributed as follows in four states: 6 in the state of Veracruz de Ignacio de la Llave, 1 in Hidalgo, 1 in Tlaxcala and 23 in Puebla de Zaragoza.

At a general level, we can observe an interesting dynamic of land use and vegetation coverage of forest vegetation cover in its various classes, which went from 37.12% in 2002 to 41.02% in 2022, which meant an increase in forest cover of 6,293.9 ha, while agriculture had a decrease of 3.75%, equivalent to 6,003 ha. Human settlements had an increase of 0.51% or 1,152 ha. Pastures went from 5.61% to 4.79%, that is, their coverage decreased by 1,501 ha.

However, this dynamic does not have a linear behavior, but is due to social and economic changes by period, as shown in Figure 2, for example, the behavior of agriculture, pastures and human settlements.

In general, the increase in population is always associated with agriculture and livestock (represented by pastures), but this is not the case in the basin.

The variable that was selected to visualize the economic behavior in the 20 years covered by the period of analysis was the evolution of the planted surface of selected fruit species, Table 1 shows the evolution of the planted surface of each of the selected fruit species in the three selected municipalities of the state of Puebla.

The table above shows that the largest contribution to the planted area is apple, traditional in this region of Mexico, followed in order of importance by cherry coffee and with a marginal participation of avocado, with the largest planted area in 2022. Figure 2 shows the behavior of the four fruit plantations in the basin.

Figure 2 shows that the best curve that explains the behavior of the area planted with fruit trees is a polynomial curve whose formula is $y = 187416x^2 - 15.495x + 3348.6$, and with an $R^2 = 0.6514$, which is considered a medium correlation. Apple remained for nine years (2005/13) without variation in its planted area and then with a slight decrease, while cherry coffee, practically remained constant from the beginning of the analysis

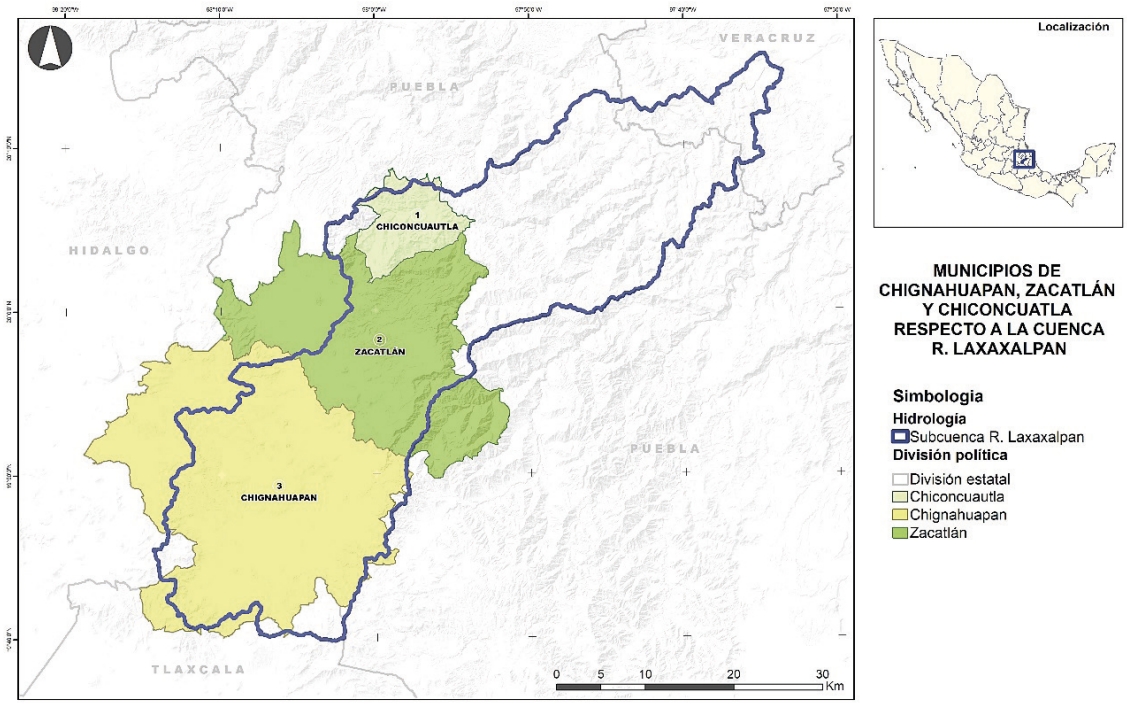


Figure 1. Laxaxalpan Watershed
Source: INEGI.
Prepared by the Cenid - Comef Geomatics Laboratory. INIFAP

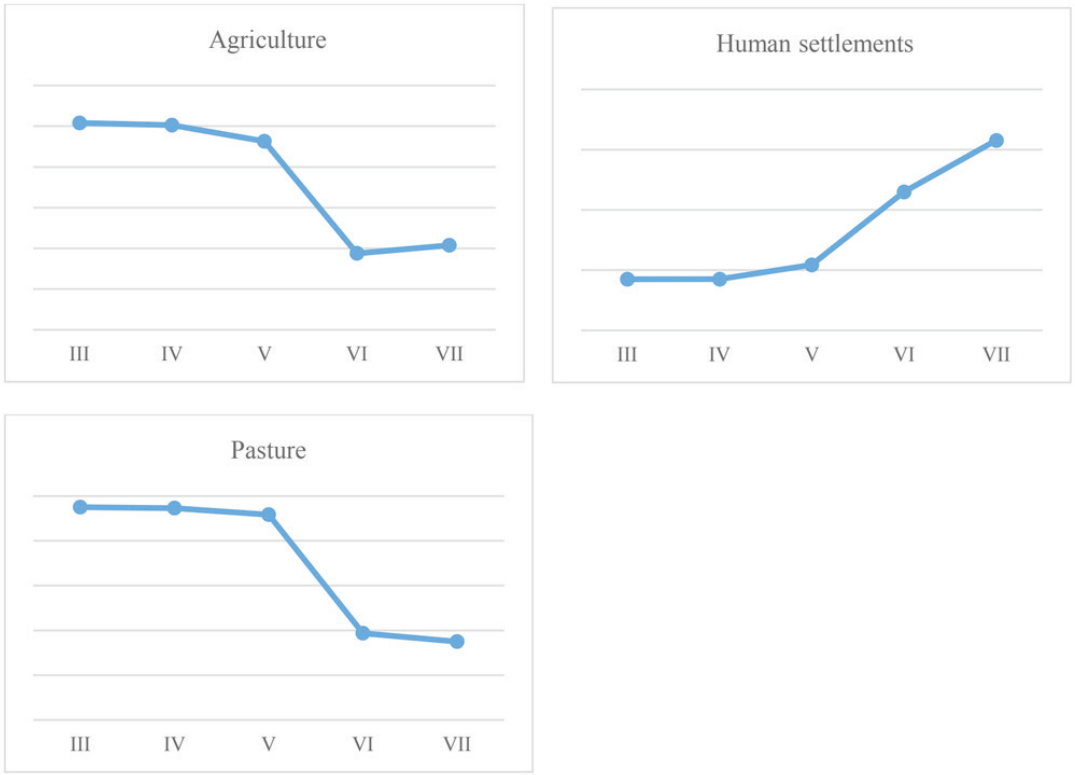
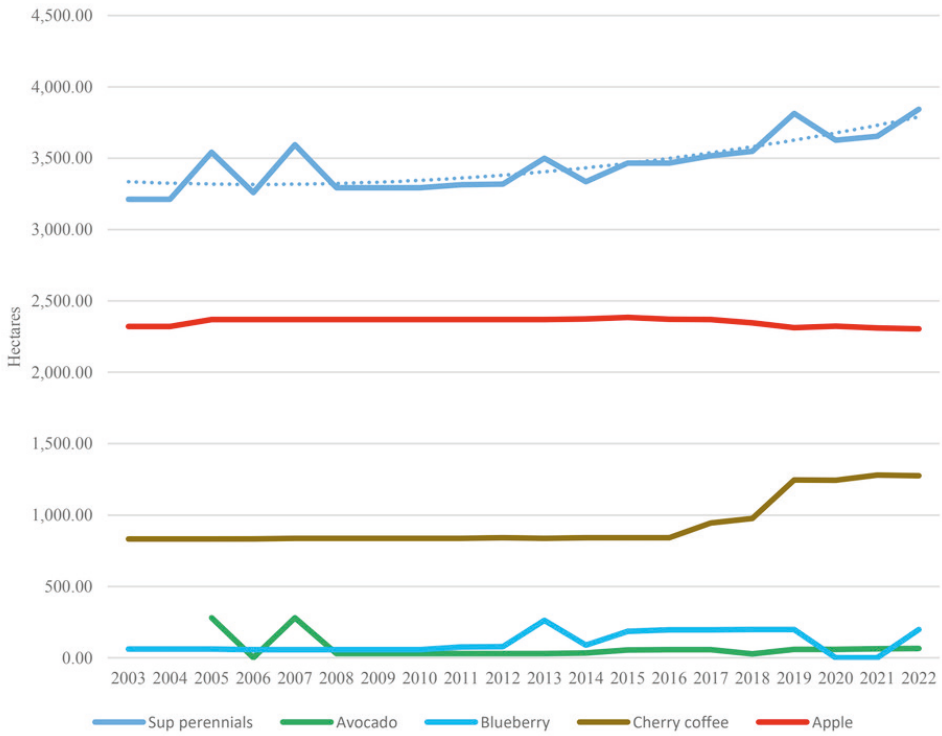


Figure 2. Evolution of agriculture, human settlements and rangelands from 2002 to 2022.
Own elaboration of the Geomatics Laboratory



Behavior and trend of planted areas in hectares of perennial fruit trees in three municipalities of Puebla in the Laxaxalpan watershed.

Source. Prepared by the authors with data from SIAP. SADER's Agrifood and Fisheries Information System.

Year	Avocado	Blueberry	Cherry coffee	Apple	Perennials
2003	0	60.00	832.15	2,320.00	**3,212.15**
2004	0	60.00	832.15	2,320.00	3,212.15
2005	280.00	60.00	832.15	2,370.00	**3,542.15**
2006	0.60	56.00	833.50	2,370.00	**3,260.10**
2007	280.00	56.00	836.32	2,370.00	**3,593.92**
2008	30.00	56.00	837.15	2,370.00	**3,293.15**
2009	30.00	56.00	837.15	2,370.00	**3,293.15**
2010	30.00	56.00	837.15	2,370.00	**3,293.15**
2011	30.00	76.00	837.15	2,370.00	**3,313.15**
2012	30.00	78.00	841.15	2,370.00	**3,319.15**
2013	30.00	262.00	837.14	2,370.00	**3,499.14**
2014	34.00	89.00	840.00	2,373.00	3.336.00
2015	54.00	186.00	840.00	2,384.00	**3,465.50**
2016	56.30	56.30	840.00	2,371.70	**3,466.00**
2017	56.50	196.00	944.00	2,369.20	**3,516.00**
2018	28.10	196.30	975.00	2,345.70	**3,547.10**
2019	58.55	198.30	1,245.00	2,311.80	**3,813.85**
2020	58.00	0.00	1,243.10	2,324.00	**3,625.10**
2021	63.00	0.00	1,278.87	2.310.41	**3,653.10**
2022	63.35	197.00	1,276.20	2,304.77	**3,842.82**

Table 1. Evolution of the planted area (hectares) of the four perennial fruit trees in the period 2003 - 2022.
Source: SIAP. Agrifood and Fisheries Information System.

period until 2016 (15 years) and from then on, it had a positive growth, Finally, blueberry (SIAP, 2024) remained constant until 2010 (8 years) and began its growth phase, with a couple of years (2020/21) in which no data were reported.

The second variable was the value of production expressed in Mexican pesos of the four fruit species mentioned above. This valuation was quantified at current (market) and constant (real) prices, which are shown in Table 2, which shows the evolution of their contribution to the regional economy.

Year	Current prices $	Constant prices $
2003	24,465,900.00	11,278,779.90
2004	25,097,200.00	12,523,502.80
2005	37,608,499.25	19,857,287.60
2006	32,206,988.79	18,068,120.71
2007	28,315,341.00	16,904,258.58
2008	41,734,655.40	26,376,302.21
2009	39,593,735.00	26,369,427.51
2010	38,795,530.00	26,952,893.35
2011	38,021,688.60	27,907,919.43
2012	51,065,233.60	39,167,034.17
2013	68,320,782.88	53,290,210.65
2014	55,157,034.01	44,952,982.72
2015	68,264,722.78	57,410,631.86
2016	58,261,484.85	51,969,244.49
2017	52,267,773.83	49,706,652.91
2018	72,752,183.83	72,752,183.83
2019	82,762,941.71	86,321,748.20
2020	60,399,245.58	66,016,375.42
2021	58,603,403.75	65,295,912.46
2022	108,136,480.00	131,710,232.64

Table 2. Evolution of production value (Mexican pesos) at current (market) prices and constant (real) prices of fruit trees in the period 2003 - 2022.

Source: SIAP. Agrifood and Fisheries Information System.

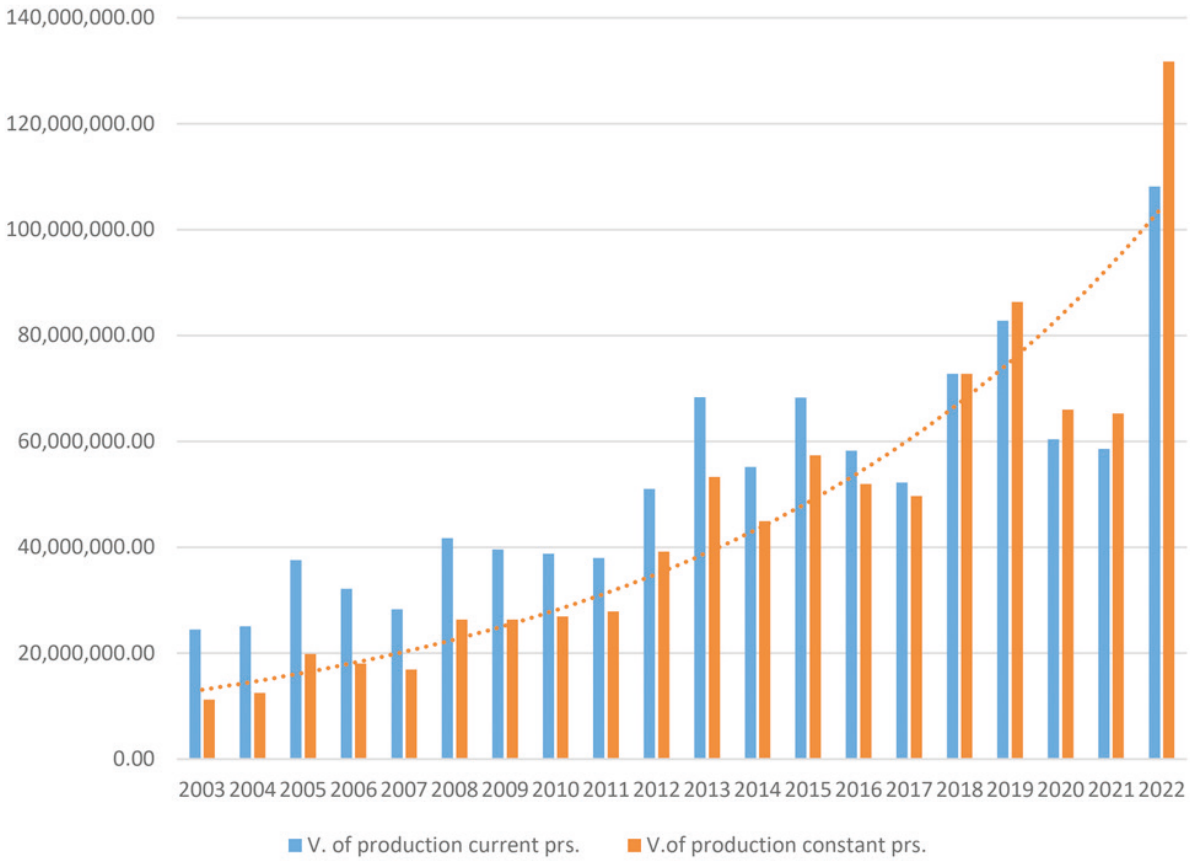
The differences in value are due to the updating factor used by INEGI and Banco de México in which the values of the base year (2018) are equal for both types of valuation and are set as 1.0 and from the first year (2003) to the base year, the updating factors are < 1.0 and from the 2019/22 period the factors are > 1.0, with this consideration the behavior of its evolution is shown in Figure 3.

Figure 3 shows how in 2018 (base year) the two bars are identical and in the years 2008/11 the value of production at current prices has a significant drop and also in the three-year period 2019/21 this value falls sharply, possibly due to the effect of Covid 19 and in the last year of the data series, the value of production has a significant rebound, as for the trend in the value of production at constant prices, the best fitting curve was an exponential type with the formula $y = 1E + 07e^{0.1091x}$ and with an $R^2 = 0.9292$ which is considered highly correlated and therefore very acceptable.

Figure 4 a and b shows, in the last year of the data series (2022), the planted area (ha) and its production value (Mexican $).

Figure 4 a and b above shows that in the first case, the apple, a traditional fruit of the region, with 60% of the planted area, contributes half of the value to the economy of the area, while, in contrast, the blueberry, a fruit recently incorporated to the regional production and with only 5% of the planted area, contributes almost a quarter of the economic value and the cherry coffee, also a traditional product, with a third of the planted area, has a slightly lower contribution (one percentage point) than the blueberry, Finally, although aguate is also a recent introduction to the basin, its participation in terms of surface area and value is considered marginal.

Average annual growth rates (cagr %). In order to know the growth (positive or negative) during the 20 years of study of the planted area of each fruit species and the global area, as well as by six-year periods, Table 3 shows the values of the ccawt.



Behavior and trend of production value at current and constant prices in Mexican pesos of fruit trees in three municipalities of Puebla in the Laxaxalpan watershed.

Source. Prepared by the authors with data from SIAP. SADER's Agrifood and Fisheries Information System.

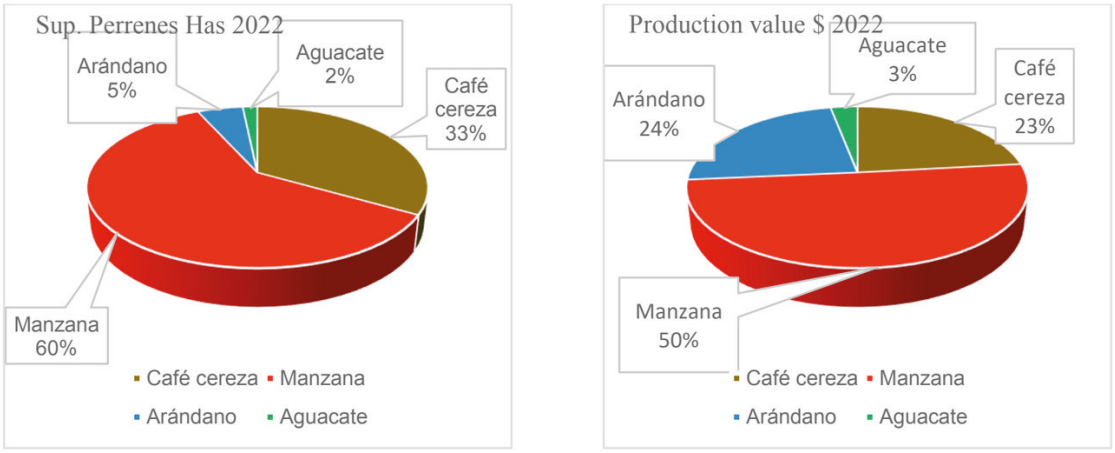


Figure 4 a and b. Planted area (ha) and production value ($) of fruit trees in the year 2022 in three municipalities of Puebla in the Laxaxalpan watershed.

Source. Prepared by the authors with data from SIAP. SADER's Agrifood and Fisheries Information System.

Period	Avocado	Blueberry	Cherry coffee	Apple	Total fruit trees
2003-2006*	-95.37	-1.71	0.04	0.53	0.37
2007-2012	-31.08	5.68	0.10	0.00	-1.32
2013-2018	-1.08	-4.54	2.57	-0.17	0.23
2019-2022*	2.78	-0.19	0.62	-0.08	0.19
2003-2022	**-7.77**	**6.12**	**2.16**	**0.03**	**0.90**

Average annual growth rates (%) of the planted area of each of the fruit trees and of the total.

* The first and fourth six-year periods are four years due to data availability and are not comparable, only the second and third are comparable and can be inferred as the total period.

Source: Own elaboration.

The above table shows that the planted area during the 20 years of analysis had an increase of almost one percentage point and from which it can be seen that the blueberry was the fruit tree with the best growth indicator since it exceeded six points, mainly due to the demand for this product, as well as the increase in its price; the opposite case was that of the avocado that despite being a raw material for export to the United States of America with a strong demand, its cultivation shows variations in its production very pronounced downward. In the case of cherry coffee, its growth in planted areas was of little more than two points, and for apples, its planted area remained practically constant throughout the period and its growth is almost nil.

In the same way as for the planted area of fruit trees, Table 4 shows the growth in the value of production, which are exemplified using current (or market) values.

Period	Avocado	Blueberry	Cherry coffee	Apple	Total fruit trees
2003-2006*	N/A	31.42	7.62	3.58	7.11
2007-2012	-37.38	7.42	12.04	12.75	10.33
2013-2018	0.09	18.59	2.80	-2.42	1.05
2019-2022*	11.97	5.23	12.25	3.53	6.91
2003-2022	**1.32****	9.66	9.17	5.68	7.71

Average annual growth rates (%) of the production value of each of the fruit trees and of the total.

* The first and fourth six-year periods are of four years due to data availability and are not comparable, only the second and third are comparable and can be inferred as the total period. ** For statistical purposes, the first year was eliminated as it corresponds only to the value of a little more than half a hectare, which is not significant.

Source: Own elaboration.

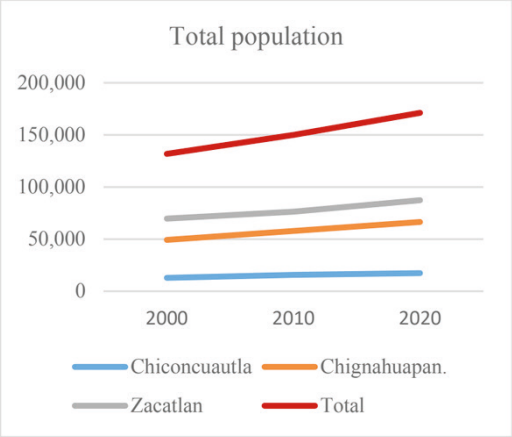
The above table shows the variations in the growth of the value of production taken at market prices, where the best performer was the blueberry, with just over nine percentage points and two thirds of a point more. Next in order of importance was the cherry coffee fruit, characteristic of the region, with a very similar growth, also of nine points but with a little less than two hundredths of a point. The apple, which characterizes the municipality of Zacatlan, had the lowest growth in production value with five percentage points and just over two-thirds of a hundredths of a point and even in the period from 2013 to 218 its production value had a negative growth rate of just under two and a half points. Avocado is not considered significant within the value of production since during the first four years its production value was practically nil and the total of the four perennial fruit trees reached a growth rate in the 20 years of analysis of just under eight percentage points, due to the increases in market prices of each of the fruit trees.

Total Population (TP) and Economically Active Population (EAP). In the three municipalities of the state of Puebla that were selected and according to CONAPO censuses (2000 - 2010 - 2020), the data are shown in Table 5.

Total Pop.	2000	2010	2020	ADP	2000	2010	2020
Chiconcuautla	12,855	15,767	17,382	Chiconcuautla	3,613	5,381	9,359
Chignahuapan	49,266	57,909	66,464	Chignahuapan	14,451	21,160	32,426
Zacatlan	69,698	76,296	87,361	Zacatlan	21,388	28,589	44,607
Total	131,819	149,972	171,207	Total	39,452	55,130	86,392

Table 5 Total population and Economically Active Population in the municipalities of Chiconcuatla, Chignahuapan and Zacatlan in the State of Puebla

Source: Census of the National Population Commission (CONAPO) 2000, 2010 and 2020.



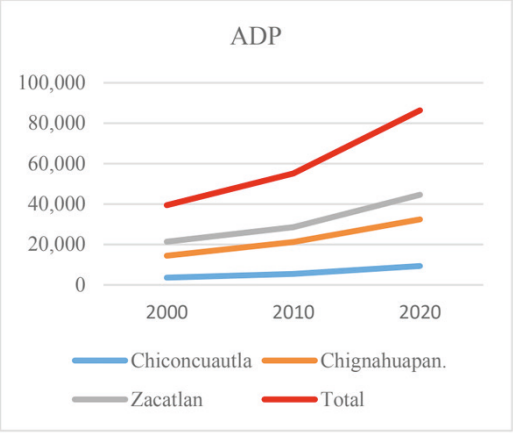


Figure 5 - a and b. Total Population and Economically Active Population (2000 - 2010 - 2020) in three Puebla municipalities of the Laxaxalpan watershed.

Source. Censuses of the National Population Commission (CONAPO) 2000, 2010 and 2020.

From the previous table, it can be observed that the most populated municipality was Zacatlán, where for the year 2020, both the total population and the economically active population represented practically the same: 51.03 % for the total population and 51.63 % for the economically active population. In the case of the municipality of Chignahuapan, the total population represents 38.82 %, the economically active population was 37.53 % and for Chiconcuautla the proportions were 10.16 % and 10.83 % respectively, from which it is inferred that the lower the total population, the economically active population decreases in a high proportion.

Figure 5 a and b, shows the evolution of the data series (2000 - 2010 - 2020), in the total population and the economically active population of the selected municipalities of the Laxaxalpan watershed.

In the first case, Figure 5 a and b above shows a parallelism between the three municipalities in terms of their behavior and growth trends. For the year 2020 there is a considerable percentage increase in the economically active population with a more pronounced positive slope.

According to Figueroa *et al*, (2011) in a study on the San Cristobal de las Casas watershed, Chiapas, Mexico, found that the predominant land use was rainfed agriculture, followed in order of importance by oak and pine forests, this type of vegetation indicated that the main habitat of the watershed is forestry, however, the anthropogenic impact is reflected by the presence of extensive areas dedicated to rainfed agriculture near medium and small towns in Chiapas. On the other hand, Mendoza *et al.* (2002) report that in the closed basin of Lake Cuitzeo, Michoacán, Mexico, they found that

the change in vegetation cover and land use was agricultural crops, followed by forests and dense vegetation. Moreira *et al*. (2020) found in their study of the hydrographic basin of the Lajeado Amarelo stream in Tres Lagoas, state of Mato Grosso do Sul, Brazil, that pastures are the land use and land cover class that occupies the greatest extension in the hydrographic basin with 62 02 %, this component being the most relevant for land management.

CONCLUSIONS

The sum of the planted area of the four fruit trees during the analysis period showed a positive but moderate slope, and only reached one tenth of a percentage point less. The fruit tree with the highest growth was the blueberry with a growth rate in the period of just over six percentage points, mainly due to the international demand for this product. The opposite was the case with avocado, which, in addition, it is worth mentioning that its surface area data began two years after the period of analysis and from the beginning of its planting, presented strong reductions in its surface area, which were replaced with plantings of blueberry and the decline in avocado surfaces was almost eight percentage points. Cherry coffee, a traditional crop in the study area, achieved a positive but modest growth of just over two percentage points, and apple, the fruit that identifies the municipality of Zacatlan, had a practically constant trend (an increase of three hundredths) throughout the analysis horizon.

The value of production is influenced by market prices, which in general are on the rise, and therefore the growth rates are higher, since while the increase in the sum total of the four perennial fruit trees barely reached nine tenths of a percentage point, the value of production of the same fruit trees was slightly less than eight points, so the ratio is 8.57 times, which is influenced by the market prices of agricultural products.

The blueberry is the fruit that stands out in the growth of its production value, since this fruit reached almost 10 points of annual growth rate, mainly due to the world demand for this type of product.

For avocado, its participation in the value of production is tangential because during the first three years of the analysis period, the data source does not report areas and in the fourth year only half a hectare is recorded, which is not significant for the value of production and it is not until the last year of the period (2022) that its value begins to be significant.

In the case of cherry coffee, its trend showed ups and downs throughout the period (eleven increases and nine decreases) due to international fluctuations in the price of agricultural raw materials, including coffee.

The apple, a raw material that identifies the population, has a practically captive demand with the soft drinks and liquor companies in the region, which, despite the fact that its production has remained practically constant during the period of analysis, its monetary value is the one that contributes the most to the regional economy.

When comparing the planted areas of fruit trees *versus* their production value, apples, although they contribute 60% of the area, contribute half of that value to the regional economy and the opposite was the case with blueberry plantations, The opposite was the case with blueberry plantations, which with only five percent of the area, contribute almost one fifth of the region's cash flow, cherry coffee, with a third of the area, contributes a little less than a quarter of the regional production value, and avocado maintains a similar relationship in its low participation in area and production value.

In relation to the Total Population and the Economically Active Population and with the data available for 2020, the largest population (Zacatlan) has the highest proportion of EAP with a little more than half and vice versa with

the smallest (Chiconcuautla), where its EAP barely exceeds 10%.

Blueberry plantations have been carried out on agricultural surfaces that were previously covered by mesophyll forest and this has allowed the secondary vegetation of the aforementioned forest to be reestablished.

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