Article

Technical-economic study to identify areas with potential to produce pineapple in the humid tropics of Mexico

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Abstract

In order to identify the productive and economic potential of pineapple cultivation at the hydrological response unit, basin and state level, considering the yield and the cost-benefit ratio (RB/C), a technical-economic study was carried out, in the main producing states of the Humid Tropics of Mexico. To this end, the potential yield of total aerial biomass and pineapple fruit was simulated and mapped in nine states in the south-southeast of Mexico and the areas with the greatest potential for cultivation were identified. Likewise, the establishment, maintenance and income costs of the shade net technology package were estimated and the financial profitability of the crop was evaluated for each identified region. The results show that pineapple cultivation is profitable when more than 45.8 t ha^{-1} is produced. 596 666 ha were identified with the potential to produce pineapple, located in Campeche, Chiapas, Oaxaca, Puebla, Quintana Roo, Tabasco, Veracruz and Yucatán, being the state of Campeche the one that presented the highest yield (90 t ha^{-1}) and a RB/C of 1.88. It is concluded that pineapple production is profitable in those regions that present ideal agroecological conditions for its production.

Keywords: *Ananas comosus*, economic potential, humid tropics, productive potential.

Introduction

The Mexican tropics presents appropriate agroecological conditions for the development of tropical crops such as pineapple (*Ananas comosus*), a fruit that, due to its pleasant taste and aroma, as well as its content in vitamins A, B and C, is highly demanded in the various markets of the world (ASERCA, 2010), expresses its maximum growth potential in subtropical, hot and humid climates, therefore its production is mainly distributed between latitudes 30° latitude N and S (Malezieux *et al*., 2003). The second place in the world production of tropical fruit trees, only surpassed by mango (Uriza *et al*., 2018), although it is native to Brazil and Paraguay, especially in the Parana river basin (Coppens *et al*., 2011). Currently the main producing countries are Costa Rica, Brazil, the Philippines and Thailand (FAOESTAT, 2020).

In Mexico, pineapple in 2019 was produced in 14 states, although 80% of the production is concentrated in the Lower Papaloapan region, which includes seven municipalities in the state of Veracruz: Isla, Juan Rodríguez Clara, Jose Azuela, Chacaltianguis, Medellin, Alvarado and Tlalixcoyan and two municipalities in the state of Oaxaca: Loma Bonita and Tuxtepec (SIAP, 2020). Both the planted area and the pineapple production have increased from 13 938 ha and 376 150 t in 1980 to 44 182.9 ha and 1 041 161 t in 2019, which represents an average annual growth rate of 3% and 2.6% respectively (SIAP, 2020).

At a global level there is a trend to increase the demand for pineapple, with the expectation of achieving the per capita consumption currently in countries such as North America and the European Union (EU), which is 2 kg and 1.3 kg for Japan, the that allows us to glimpse the growth potential of production, its consumption and the international market (UNCTAD, 2016), which represents an area of opportunity for the Mexican pineapple, therefore it is urgent to locate new areas with potential, in such a way that producers and decision makers promote their production with criteria of productivity and profitability, integrated in a technical-economic study.

The technical-economic studies combine productivity and profitability indicators as joint criteria to characterize or support decision-making and have been applied to a wide variety of activities and production processes, such as the one carried out by Rodríguez *et al*. (2017) who estimated the technical-economic differential of the turkey production systems in the State of Mexico to determine if the technified systems obtain greater technical and economic efficiency than the semi-technical and backyard ones, which allowed recommending what decisions producers have to make of these last systems to achieve the efficiency of the technified ones.

The one carried out by Herrera and Andrade (2010) who estimated technical and economic indicators to make the decision to develop flat solar collectors (CSP) for hot water for domestic use that can be purchased by most of the population of the state of Oaxaca and where they recommended using financing of no more than two years to acquire the equipment and that the cost of the equipment is accessible to the majority of the population and thus contribute to improving the quality of life of the community in this area.

The technical study carried out contemplates the estimation of pineapple yield, which is done through the use of agroecological simulation models that are especially explicit (Gálvez *et al*., 2010), which allows identifying areas with potential for the establishment of commercial

plantations, such as the Soil and Water Assessment Tool (SWAT), which is a dynamic simulation mathematical model (Neitsch *et al.*, 2005), initially developed for hydrological modeling that allows to simulate the production of water and sediments in hydrographic basins, considering the effect that agronomic practices have on water quality due to the use of pesticides and fertilizers.

(Rivera *et al.*, 2012), thanks to an interface with GIS (ArcSWAT), it can be used to estimate yields of perennial crops using agroclimatic information (Inurreta *et al.*, 2013). Once information on yields is available, information on production costs and crop income is integrated to carry out the economic study estimating profitability indicators (Gittinger, 1982).

Carrying out an analysis of the technical and economic viability of an agricultural activity, generates information of great use for decision makers, as well as for producers, as Barrera *et al.* (2011) have done in a study on the profitability of vanilla, Espinosa *et al.* (2015) for the cultivation of cocoa, Espinosa *et al.* (2016) for the cultivation of coffee and Moctezuma *et al.* (2017) for the cultivation of rubber. Analyzes of this type are strengthened if combined with information from technological packages, agroclimatic data, market variables for inputs and the product.

Therefore, the objective of the study was to identify areas with productive and economic potential to establish pineapple plantations at the hydrological response unit (URH) level, basin and by state in the humid tropic region of Mexico.

Material and methods

Technical study

It was carried out estimating the potential yields of fresh pineapple in 48 hydrological basins, divided into 816 sub-basins and 7 154 hydrological response units (URH), covering an area of 50.7 million hectares, distributed in nine states of the Southern region. southeast of Mexico: Campeche, Chiapas, Guerrero, Oaxaca, Puebla, Quintana Roo, Tabasco, Veracruz and Yucatán, using the SWAT simulation model with its ArcSWAT extension within the ArcGIS 9.3 interface.

Because SWAT is a hydrological model that works at the basin level, it was necessary to condition the study area to perform the simulation at the URH level (Inurreta *et al.*, 2013), using topographic information from a digital elevation model (DEM) and a surface runoff map (Inurreta *et al.*, 2013). In each sub-basin, areas with the same slope interval, soil type and current land use, called URH's, were identified. The slope map is generated by SWAT from the DEM, instead the edaphological and current land use maps were taken from INEGI with a scale of 1:250 000 and entered into the system.

In the model, information on the climate, soil, physiology and management practices of pineapple was used to simulate the development of the crop, estimate its yield at the URH level and express the result cartographically. This model consists of eight components: a) climate;

b) hydrology; c) nutrients and pesticides in the soil; d) soil erosion; e) plant growth and soil cover; f) management practices; g) processes in the main drainage channel; and h) bodies (storage) of water.

The climatic information was extracted from a database of 1 145 stations from the SMN, which had complete climatic information for at least 10 years. With this information and using the climate generator of the EPIC model (Sharpley and Williams, 1990), the climatic statistics and later the daily data for the period 1912-2014 were generated.

The edaphological information to characterize the soil subclasses of the INEGI map was obtained from a report by this same INEGI with field data from 1 247 agrological wells. The missing information was generated from the following sources: the hydraulic properties and the soil erosion factor (Universal Soil Loss Equation), were calculated according to the texture according to Colin *et al.* (2013); Ramírez *et al.* (2009) and the albedo was calculated from the organic matter of the soil, applying a regression equation obtained from the original information of the SWAT with 202 soils with albedo and organic matter. The physiological parameters of the crop required by the model are presented in Table 1. The agronomic management was elaborated according to Rebolledo *et al.* (1998); Uriza (2011).

Table 1. Physiological parameters used to estimate the potential yield of pineapple.

Physiological parameter	Units	Value	Source
Optimal temperature	(°C)	35	Uriza *et al.* (2018)
Base temperature	(°C)	16	Uriza *et al.* (2018)
Leaf area index	$[m^2\ m^{-2}]$	8	Milis and Jones (1996)
Efficiency in use of radiation	$[(kg\ ha^{-1})\ (MJ\ m^{-2})^{-1}]$	35	Malezieux *et al.* (2003)
Harvest index	(dimensionless)	0.35	Arias and Toledo (2000)
Root depth	(m)	0.8	Gutiérrez (2001)
Minimum height above sea level	(m)	0	Uriza *et al.* (2018)
Maximum height above sea level	(m)	300	Uriza *et al.* (2018)

Economic study

The costs of pineapple production were estimated, applying a structured survey to producers in southern Veracruz, during the months of October and November 2016. The sample was determined through a sampling design of maximum variance proportions (Infante and Zárate, 1990).

$$n = \frac{N\ p\,(1 - q)}{(N - 1)\left(\dfrac{b}{Z_{1-a}}\right)^2 + p\,(1 - q)}$$

Where: n= sample size; N= size of the target population, 3 000 producers; β= precision in percentage at 70%; $Z_{1-\alpha}$= 95% reliability value.

The survey was designed to collect information on the establishment and maintenance costs of a pineapple ha with producers who apply the traditional technological packages, shade mesh and padding, based on this information, the total cost per pineapple ha for each package was estimated, applying the operational cost procedure proposed by Lopes and Dos Santos (2013), adding the cost of manual and mechanized labor, as well as the purchase of nutrition inputs, crop protection, pest and disease control, weed control and floral induction.

Identification of areas with productive and economic potential

With the estimated yields, a regional map was constructed, identifying five categories, area with less than 20, from 20 to 39.9, from 40 to 50.9, from 60 to 79.9, from 80 to 99.9 and more than 100 t ha^{-1}. Likewise, these yields made it possible to estimate the economic potential of a pineapple plantation, for which the long-term agricultural project evaluation methodology was applied (Gittinger, 1982), by estimating profitability indicators: benefit/cost (RB/C); net present value (NPV); internal rate of return (IRR); and at the URH level, whose mathematical expressions are presented below (Coss, 1984).

$$TIR=\sum_{t=1}^{n}\frac{FI-FC}{(1+i)^n}=0$$

$$R\,B/C=\frac{\sum_{t=1}^{n}\frac{FI}{(1+i)^n}}{\sum_{i=1}^{n}\frac{FC}{(1+i)^n}}$$

$$VAN=\sum_{t=1}^{n}\frac{FI-FC}{(1+i)^n}$$

Where: FC= the flow of production costs; FI= to income flow; i= at the update rate; and n= number of years of plantation. The FC and FI were estimated from the data obtained from the survey of pineapple producers for the technological packages of shade mesh and padding, considering the investment horizon of five years, which is the life period of the shade mesh, applying the following formulas.

$$FC=TCoE_1+\left(\sum_{i=1}^{n=5}CoFP + CoVP\right)$$

Where: TCoE= the total cost of establishing the plantation in year 0; CoFP= the fixed cost of production from year one to year five, calculated by the sum of the depreciation costs of the shade net and administration costs (3% of the income from pineapple sales); and CoVP= at the variable cost of production from year one to year five.

$$FI=\left(\sum_{i=2}^{n=5} Pxkg * RPxha\right)$$

Where: Pxkg= the average market price of pineapple; and RPxHa= the estimated pineapple yield. All monetary values of both input costs and pineapple prices were deflated with the national producer price index (INEGI, 2020).

Because the costs of establishment, production and income correspond to the life of the project, they were taken to present value applying a discount rate of 9.5%, proposed by the World Bank (WB), as the opportunity cost of capital for public investment projects for Mexico (Coppola *et al.*, 2014). The study of economic potential was complemented with a sensitivity analysis, considering the decrease in the price of pineapple of 10, 15, 20, 25, 30, 35, 40, 45 and 50% considering the great variability of the international price of pineapple, under the assumption that in the long term the national market price decreases as a consequence of this variability.

Results and discussion

Potential yield of pineapple crop

The area with potential to produce pineapple is presented in Figure 1, in four areas pineapple could be produced with a yield higher than the national average, which is 35.9 t ha^{-1} Veracruz, Tabasco, Chiapas and Campeche, a quantity slightly higher than the current area planted with pineapple, which is 44 182 ha (SIAP, 2020). Veracruz, Tabasco, Chiapas and Campeche, an amount slightly higher than the current area planted with pineapple, which is 44 182 ha (SIAP, 2020); however, the area with yields above 80 t ha^{-1} is 52 000 ha, located in the states of Veracruz, Tabasco, Chiapas and Campeche, an amount slightly higher than the current area planted with pineapple, which is 44 182 ha (SIAP, 2020).
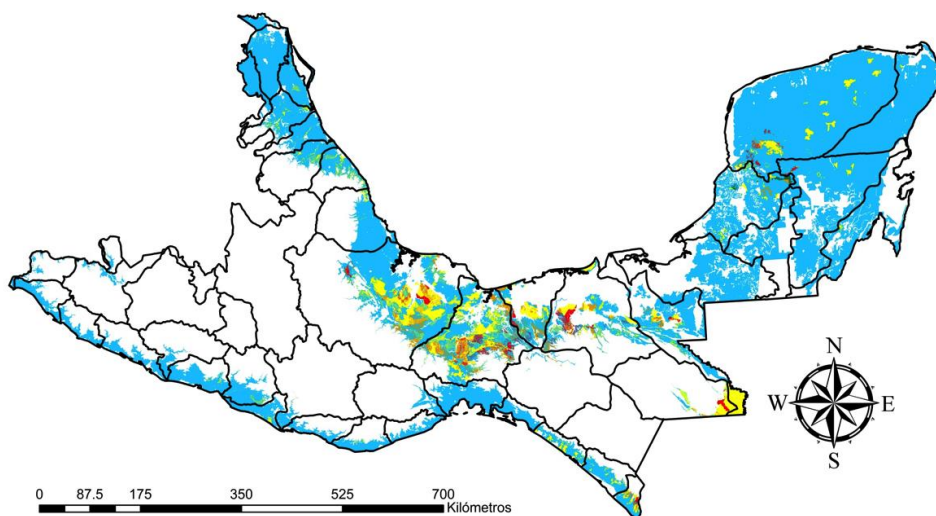

Figure 1. Area with potential to produce pineapple in the South-Southeast of Mexico.

The distribution of the area by yield level of fresh pineapple fruit and by state is presented in Table 2, where it can be seen that only 5% of the regional area can produce pineapple with yields greater than 20 t, Guerrero being Puebla and Quintana Roo are the states with the smallest area and Veracruz and Chiapas the largest; however, the state with the potential to produce more than 100 t ha^{-1} is Campeche, a situation that contrasts with today, where Veracruz is the largest producer, although with yields below 50 t ha^{-1} (SIAP, 2020).

Table 2. Distribution of the area (thousands of hectares) with potential to produce pineapple.

State	Pineapple yield (t)						Total area	
	< 20	20-39.9	40-59.9	60-79.9	80-99.9	>100	state	simulated
Campeche	2 530	81	19	22	6	25	5 053	2 683
Chiapas	889	393	25	88	16	0	7 353	1 411
Guerrero	973	4	0	0	0	0	6 388	977
Oaxaca	1 733	313	61	54	0	0	9 124	2 162
Puebla	141	11	0	2	0	0	3 410	154
Quintana Roo	3 453	23	0	0	0	0	4 875	3 476
Tabasco	606	140	37	17	4	0	2 479	804
Veracruz	3 597	713	151	128	1	0	7 132	4 589
Yucatán	3 337	112	2	10	0	0	3712	3 461
Total	17 259	1 790	296	322	27	25	50 713	19 718

Estimates made applying the SWAT model.

Worldwide, the highest pineapple yields are obtained by Indonesia and Costa Rica with an average of 123 and 76 t ha^{-1} respectively (FAOSTAT, 2020), values much higher than the national average, therefore, if Mexico wants to be competitive, it should obtain yields above 80 t ha^{-1}, according to the estimates made, this value is obtained at 52 000 ha, located in the states of Campeche, Chiapas, Tabasco and Veracruz (Table 3).

Table 3. Production costs of a pineapple hectare.

Stage	Concept	Unit	Quantity	Unit value ($)	Total ($)
Establishment	Mesh	Unit	1	68 200.00	68 200.00
	Chapeo	Service	1	1 042.90	1 042.90
	Fallow	Service	1	1 035.30	1 035.30
	Plow	Service	1	766.70	766.70
	Beds or grooves	Service	1	823.10	823.10
	Harrows	Service	2	847.40	1 694.80
	Subsoil	Service	1	850.00	850.00
	Seed	Plant	39 750	0.40	15 900.00
	Fertilizer	(kg)	1 482.9	8.40	12 456.40
	Plagicide	(kg)	18.3	209.60	3 835.70
	Herbicide	(kg)	6.7	356.10	2 385.90

Stage	Concept	Unit	Quantity	Unit value ($)	Total ($)
	Padded	Plastic	1	7 156.30	7 156.30
	Freight	Service	1	6 868.00	6 868.00
	Manual labor	Wages	94	191.00	17 954.00
	Subtotal				140 969.00
Maintenance	Fertilizer	Kg	957.8	12.30	11 736.40
	Plagicide	Lt	13.5	173.80	2 337.10
	Herbicide	Lt	4.6	329.30	1 500.00
	Floral Inductor	Kg	42.7	78.90	3 367.20
	Crop protection	Unit	1	1 746.00	1 746.00
	Harvest	Wages	22.0	223.00	4 906.00
	Manual labor	Wages	65.0	223.00	14 495.00
	Freight	Service	1.0	5 921.00	5 921.00
	Subtotal				46 008.80
	Total				186 977.80

The hydrological basin with the largest extension with pineapple yields greater than 20 t ha^{-1} is that of the Coatzacoalcos River, with an area of 638 339 ha located in the states of Veracruz, Oaxaca and Chiapas, it comprises 542 URH, followed in importance by the of Papaloapan river, with an area of 618 920 ha located in the states of Veracruz and Oaxaca, comprising 407 URH. The basin where yields greater than 100 t ha^{-1} can be obtained is that of Champoton river and another, in the states of Campeche and Yucatan, although pineapple is not currently produced in this basin.

The results presented show the usefulness of estimating the productive potential, a similar study was carried out in Argentina by Tacchini and Tacchini (2012), for cherry plantations (*Pronus avium*) than with the use of climatic variables similar to those used by SWAT It was possible to perform a probabilistic calculation to determine the potential to be reached in the production of cherries in the Mendoza region and under this scheme to estimate the income for the producer and Rivera *et al*. (2012), in the same way, worked on the potential yield of cassava (*Manihot esculenta* Crantz) in the state of Tabasco, using the variables: climate, soil, temperature, rainfall, altitude, photoperiod and period of growth, with which they were able to locate 171 121 ha potential in Huimanguillo, 70 386 in Balancan and 41 337 in Macuspana.

Production costs of pineapple cultivation

The study was developed in the Papaloapan region in the south of the state of Veracruz, including the municipalities of Chacaltianguis, Isla, José Azueta, Juan Rodríguez Clara and Playa Vicente, the climate is humid tropics with summer rains and hot sub humid tropics with rains of summer with heights ranging from 0 to 800 meters above sea level, 42% of the producers do not use excess mesh, 42% combine their fields with and without shade mesh and the remaining 14% use shade mesh, the average age is 48 ±8.6 years, 22.7 ±8 years of being a pineapple producer and 14.1 ±3.1 years of study. As pineapple is a biannual perennial crop, it can be grown at different times of the year.

In the production process two phases are identified (Figure 2), the establishment of the plantation, which lasts approximately six months and includes work from the acquisition of vegetative material, preparation of the cultivation land, planting, application of fertilizers, control of pests and herb control and maintenance, which lasts approximately one year, begins with flower induction, fruit protection work, fertilization, pest control and herb control and finally harvest.
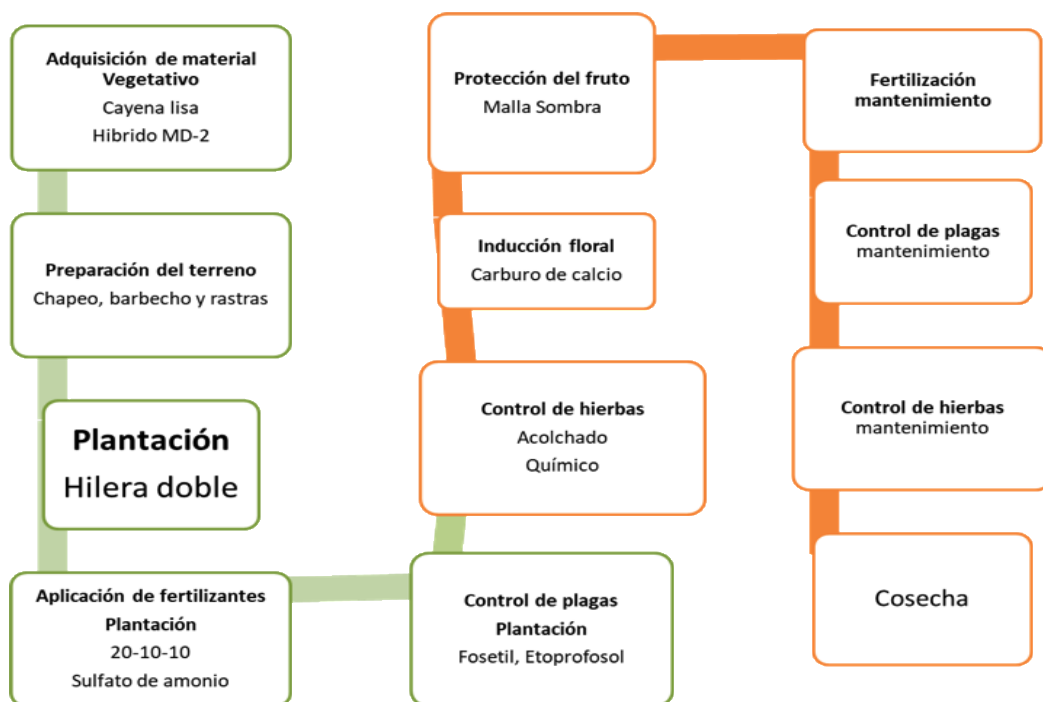

Figure 2. Technological package of pineapple cultivation in Mexico.

The average of the production costs of the producers that use shade mesh, both of establishment and maintenance of the plantation are presented in Table 3, it is observed that the establishment represents 75% and the remaining maintenance 25%, it is also observed that the shade mesh represents 36% of the production cost, however, the mesh has a useful life of 5 production cycles, therefore, more than a cost it is an investment. The next most important concepts are labor, with a percentage of 20%, which shows the social importance of the crop, due to the generation of employment, a situation that is also highlighted in a study carried out in the Philippines (Henry and Chato, 2019), next in importance is the cost of fertilizers with 13% and seed with 9%.

Areas with productive and economic potential

Obtaining high yields is not a sufficient condition to make the decision to produce, it is required that the productive activity be profitable, to know this data the costs presented in Table 3 were considered, where it was observed that an initial investment of more is required of 186 thousand pesos per ha to produce pineapple, including this figure is the investment of the shade mesh, which is used for five production cycles, therefore an investment analysis was carried out, with a period of 8 years, given that the production cycle is 18 months to obtain five harvests.

These costs will be added fixed costs: depreciation of the mesh, plus administration that varies according to yield. To estimate the profitability indicators, it was considered that the income comes from the pineapple yield during the five harvests, according to the shade mesh technological package, which begins to harvest at 18 months, the price considered for the analysis was 4.34 \$ kg^{-1}, which was the average price to the producer in 2019 (SIAP, 2020). With the information on costs and income, the cash flow for the eight years considered was estimated and updated, which in turn allowed estimating the R B/C, NPV and IRR indicators.

The results show that the minimum yield required by a producer of a pineapple plantation when applying the technological package of shade mesh, so that it begins to make a profit, is 45.8 t ha^{-1}, with which a RB/C of 1 is obtained , a NPV of 0 and an IRR of 9%, equal to the discount rate, which are the equilibrium conditions (Gittinger, 1982), therefore, plantations that obtain yields higher than this amount are profitable, although the average In the last 5 years it was 46.2 t ha^{-1} (SIAP, 2020), there are states that currently present yields above this average, such as Oaxaca, Quintana Roo, Jalisco, Colima and Veracruz itself, which is the main producer, this result shows why this crop is in the process of expansion, following a global trend.

Table 4 shows the profitability analysis in the eight states whose yield simulation identified areas with values higher than 45.8 t ha^{-1}, the area with productive and economic potential is also presented. The RB/C presented indicates that the stream of benefits updated during the life of the plantation versus the stream of updated costs, was 1.88, 1.71, 1.28, 1.30, 1.69, 1.32, 1.34 and 1.53 pesos in the states of Campeche, Chiapas, Oaxaca, Puebla, Quintana Roo, Tabasco, Veracruz and Yucatán respectively, which means that for each peso invested, 0.88, 0.71, 0.28, 0.69, 0.32, 0.34 and 0.53 pesos will be obtained at an update rate of 9.5%, although they are positive values, are lower than the cost benefit ratio value reported by Bonet *et al*. (2020) when carrying out the economic evaluation of the response of the pineapple crop to irrigation in the Ciego de Avila province, Cuba with the cultivar Española Roja, which was 5.1.

Table 4. Profitability indicators of pineapple plantations in states with productive and economic potential.

State	URH	Potential surface	Average yield	R B/C	IRR (%)	NPV ($)
Campeche	66	62 929	90	1.88	73.5	559 377.70
Chiapas	192	115 998	71	1.71	47.3	316 114.20
Oaxaca	67	81 730	60	1.28	31.3	175 277.40
Puebla	5	1 157	61	1.3	32.8	188 080.80
Quintana Roo	4	33	80	1.69	59.8	431 344.30
Tabasco	54	80 468	62	1.32	34.3	200 884.10
Veracruz	177	254 138	63	1.34	35.8	213 687.40
Yucatan	15	213	72	1.53	48.7	328 917.50
Total/average	580	596 666	70	1.51	45.4	301 710.40

But very similar to those obtained by Hidayah and Abdul (2019) when evaluating the profitability of pineapple production with small producers in Malaysia where they obtained a cost-benefit ratio of 1.72. Likewise, the NPV and IRR values are positive, showing the high potential to produce pineapple in 580 URH and about 600 000 ha, being Campeche the state with the highest profitability and Veracruz the one with the largest potential area.

In a similar evaluation carried out in the Peruvian Amazon (Álvarez, 2009), it was found that, in four localities, the profitability of rubber (rubber name in Peru), measured by the sales price/unit cost indicator, was already favorable. that their figures ranged between 0.24 and 0.41. Similarly, Cruz, *et al*. (2013), in a feasibility study of polycultures, among them cocoa in Huehuetan, Chiapas, obtained R B/C indicators that ranged between 1.89 and 2.59.

In other crops, such as vanilla, Barrera *et al*. (2011), found that in the Totonapan region (Puebla-Veracruz), the profitability of the plantations was 14% and in Colombia, Sierra *et al*. (2013), when working with passion fruit plantations, their internal rate of return reached 47%. Similar results have been found for the states of the Humid Tropics of Mexico for cocoa, (Espinosa *et al*., 2015), for coffee (Espinosa *et al*., 2016) and for rubber (Moctezuma *et al*., 2017).

Figures 3 and 4 show the results of the sensitivity analysis in the profitability indicators that would be obtained if the price of pineapple falls to 50%, it was observed that after a price drop of 25%, the economic indicators presented values negatives.

In 2019, 22 585 ha of pineapple were planted in the southeast of the country (SIAP, 2020), so the potential area of 596 666 ha estimated in the eight states is almost 26 times the current area and production would increase in a greater proportion, thus managing to continue to satisfy the domestic demand for pineapple and take advantage of the opportunities offered by the world market in view of the expectation of an increase in demand derived from this product reflected in the consumption of fresh, juice or preserved in the North American market and if, in addition, it is considered that in these regions a higher cost benefit ratio would be obtained, the economic impact would be high.
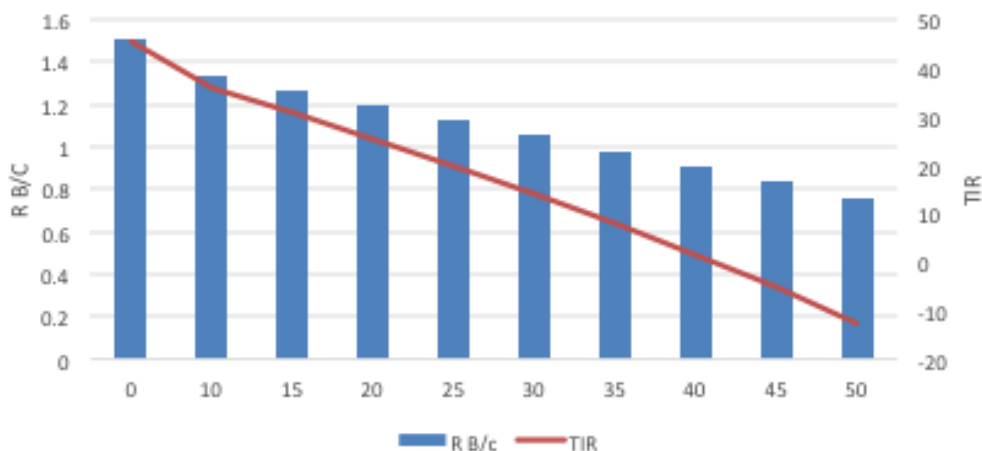

Figure 3. Sensitivity analysis of pineapple price in the IRR and cost-benefit ratio.
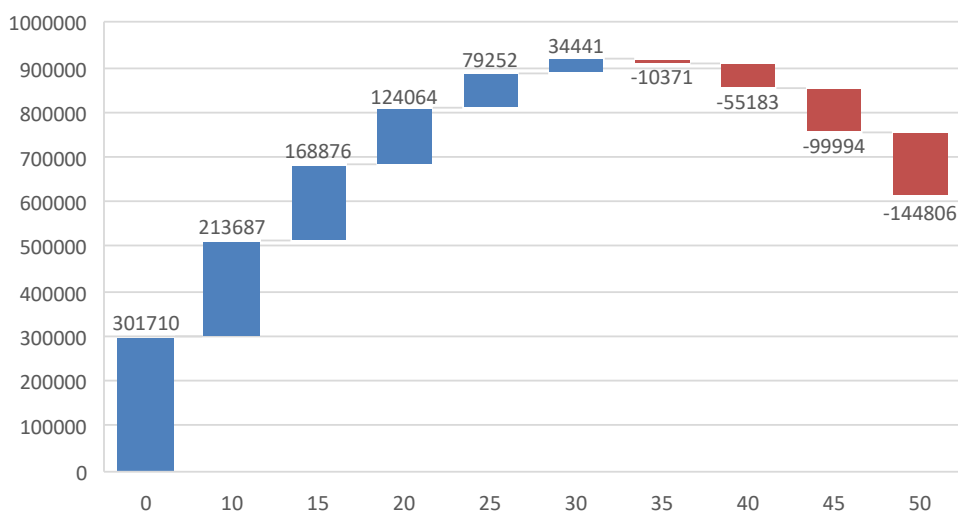
Figure 4. Sensitivity analysis of the price of pineapple in the net present value.

Conclusions

Pineapple production using a spare mesh technology package is economically viable for certain yield levels in the humid tropic region of Mexico (>45.8 t ha^{-1}), a value higher than the national average, a value slightly higher than the current average, but which shows that currently producing pineapple is profitable.

It was detected that there are regions with productive potential to produce pineapple with yields greater than 45.8 t ha^{-1}, RB/C greater than 1.51, therefore, it is recommended that, given the importance of pineapple cultivation in the Humid Tropics of Mexico, as an income and labor generating crop, it would be important to carry out comprehensive studies that consider, in addition to the productive part, marketing and market aspects.

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