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Profitability analysis of prickly pear cactus in different production systems in the state of Mexico

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Abstract. The production of prickly pear in the State of Mexico covers an area of 15,953 ha with a yield of 11.3 t ha^{-1}. However, the prickly pear production chain faces technical, social, and economic problems that are reflected in low prices and reduced profitability, where organic prickly pear production is seen as an alternative to the above problems, as well as to the growing demand for this organic fruit nationally and internationally. This research consisted of measuring the productivity and profitability of prickly pear cactus in San Martín de las Pirámides and Axapusco, State of Mexico, during the 2019 production cycle. To evaluate productivity, the A×B factorial experimental design with random block arrangement was used, and to determine profitability, the following expression was used: $CT=P_x X$. Based on the analysis of the results, organic production had the highest number of productive cladodes (83), number of fruits per plant (242), and total fruit weight (140.9 g), variables that defined the yield at 21.5 t ha^{-1} compared to intermediate and conventional management (8.2 and 11.8 t ha^{-1}). In addition, organic production obtained a profitability of 150.35% and 88.92% when land rent is included, compared to the intermediate and conventional approaches, which reached 44.14% and 48.15%, respectively, and -22.04% and -10.63%, taking land rent into account. It is concluded that organic production improves the quality of prickly pear in the long term and leads to high yields, highlighting that it generates greater opportunities to address the low profitability of the crop in the region.

Keywords: *Opuntia Albicarpa Scheinvar, organic, productivity, profitability*

Introduction

The prickly pear cactus grows on land that is difficult to use for other crops such as corn and beans due to limitations in topography, climate, and soil (Mondragón-Jacobo and Gallegos-Vázquez, 2013).

Therefore, the prickly pear is a potential genetic resource due to its wide adaptation to moisture deficits, thriving in arid and semi-arid climates (Reyes-Agüero *et al*., 2005). According to various authors, Mexico is the center of origin of the prickly pear (Bravo-Hollis, 1978; Reyes-Agüero *et al*., 2005) and ranks first worldwide in terms of cultivated area, production, and consumption, in addition to having the widest genetic diversity of varieties (Gallegos-Vázquez, *et al*., 2009).

However, despite these competitive advantages, the prickly pear production chain faces a complex problem that is reflected in low prices for farmers and, consequently, low crop profitability (Gallegos-Vázquez and Mondragón-Jacobo, 2011).

In the context of Mexico national production, there is an area dedicated to the cultivation of prickly pear cactus o of 44,463 ha (SIAP, 2025), distributed across three producing regions of the country: Center-North, Center, and South (Gallegos-Vázquez *et al*., 2009). The Central region accounts for 37.04% of the production area. and is also the most important market in the country due to its proximity to Mexico City (Mondragón-Jacobo and Gallegos-Vázquez, 2013), as it consumes around 47% of national production, with an average of 4.38 kg per capita, where the white prickly pear variety is the favorite among Mexican consumers (Financiera Rural, 2018).

There is currently growing demand for organic prickly pear cactus, both nationally and abroad. This increase in consumer demand is due to greater awareness of health, environmental protection, and conservation issues, leading consumers to value and prefer healthier products (IICA, 2018). However, organic agriculture still faces challenges such as lack of infrastructure in terms of equipment and transportation, high certification costs, deficiencies in pest and disease control, limited development of marketing spaces, low demand due to high prices, and low purchasing power due to exponential population growth (Gómez-Cruz *et al*., 2010; Zárate-Martínez *et al*., 2025).

Faced with this problem, some researchers reveal that different production systems, different agronomic management, the selection of genotypes (varieties and hybrids), and the efficient use of chemical or organic fertilizers are factors that affect crop health, quality, and yield, which in turn impacts the profitability of each producer's crop (Bravo-Avilez, *et al*., 2023, Castillo-González *et al*., 2025, González-Torres *et al*., 2024, Lugo-Palacios *et al*., 2024, Seminario-Peña *et al*., 2023).

Therefore, the aim of this study is to generate information about organic production and its peculiarities, which would allow producers to decide to venture into this type of management that promises to generate higher yields, quality, and income in the long term in the region. In this context, the objective of this research was to measure the productivity and profitability of prickly pear cactus cultivation in different production systems in the State of Mexico.

Material and Methods

Location of the experiment.

The research work was evaluated in two municipalities in the State of Mexico; the first was in San Martin de las Pirámides, located at 19º 42′ 21″ north latitude and 98º 50′ 15″ west longitude, with an altitude of 2303 meters above sea level, and the second was Axapusco, located at 19º 43′ 10″ north latitude and 98º 47′ 50″ west longitude, with an altitude of 2350 meters above sea level (INEGI, 2025).

Field phase: productivity and fruit quality

Conducting the experiment and genetic material

The general procedure included preliminary visits to compare and contact potential cooperating producers. These visits were carried out between April and May 2019, with the aim of: 1) Establish relationships with producers who could provide their land or plots with prickly pear cactus crops for the purpose of conducting evaluations; 2) Learn about and compare the validity of the different production approaches of interest. This activity was carried out by visiting several plots of land in each municipality

(San Martin de las Pirámides and Axapusco), inspecting and recording their crop management conditions; 3) Accessibility to each producer's plots of land to facilitate the work. Based on the analysis of the information gathered during visits to the two areas, six producers were finally selected. Each producer had a different production system, but it was confirmed that their crops consisted of prickly pear, specifically the "Reyna" variety (*Opuntia Albicarpa* Scheinvar) (Table 1). The following criteria were considered for each plot or garden: 1) age of the crop or variety, attempting to ensure that crops were of similar age for comparison purposes; 2) condition of the garden in terms of management and health; 3) willingness of owners to make their land and crops available as units for observation and experimentation. Once the land had been selected, technical, productive, and economic information on prickly pear cultivation was obtained based on surveys, direct observation, fieldwork, and meetings with producers.

Table 1. Information on the land or orchards of the selected farmers where the research was carried out (INEGI, 2025).

Municipality	Approach	Producer	Feature	Variety
San Martín de las Pirámides	Organic	Israel Alcívar Guzmán	Feozem soil, 15 cm deep, low organic matter content, pH of 5.5, and 7% slope.	Reyna
	Intermediate	José Martín Benites de la O	Feozem soil, 20 cm deep, low organic matter content, pH of 5, and 3% slope.	Reyna
	Conventional	Emiliano Díaz Martínez	Feozem soil, 20 cm deep, low organic matter content, pH of 5, and 1% slope.	Reyna
Axapusco	Organic	Vicente García López	Feozem soil, 30 cm deep, low organic matter content, pH of 5, and 1% slope.	Reyna.
	Intermediate	José Calixto Hernández	Feozem soil, 30 cm deep, low organic matter content, pH of 4.5, and 5% slope.	Reyna
	Conventional	Mario González Ávila	Feozem soil, 20 cm deep, low organic matter content, pH of 5, and 5% slope.	Reyna

Design and experimental unit

The experiment was set up using a completely randomized block design with a factorial arrangement A×B, where factor A refers to the environments (San Martín de las Pirámides and Axapusco) and factor B to the treatments (three production systems: T_1: organic; T_2: intermediate (organic + conventional) and T_3: conventional (management with synthetic chemical products). The experimental unit consisted of five randomly selected plants in plantations established at a distance of 4.0 m between rows and 3.0 m between plants, with an approximate population density of 800 plants ha^{-1}. Likewise, in each experimental unit of the plots, the plants were marked, and 10 fruits were

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subsequently collected from the center of the cladodes located on the periphery of the plant, adopting the strategy proposed by Gallegos-Vázquez *et al*. (2018), in relation to the measurement of variables.

Variables and data collection

Fruit length and width (FL and WF) in cm; measured from the base of the fruit to the scar of the receptacle (polar diameter) and the widest part of the fruit (equatorial diameter), using a Wesrward 29AD36 digital Vernier caliper. Total fruit weight (TFW), pulp weight (PW), and shell weight (SW) in g; measured using an Ohaus Analytical Plus digital scale, accurate to one hundredth of a gram. Total number of seeds (TNS) and number of aborted seeds (NSA); evaluated by direct counting of the sampled fruits. Number of productive cladodes per plant (NCP): the number of cladodes with at least one fruit was counted. Number of fruits per plant (NFP): prior to sampling and harvesting the fruits, a direct count of the total number of fruits per plant was performed. Yield (YLD): based on the total number of fruits per plant and the average fruit weight, the kg of fruit per plant were estimated. Based on this data and the planting density, an extrapolation was made to estimate the yield in t ha^{-1}. Total soluble solids (TSS) in °Brix: a GEMA portable optical refractometer was used. Measurements were taken in three sections of the fruit (apex, center, and base) by extracting a drop of juice, with the average being taken as the final reading.

Statistical analysis

An analysis of variance and comparison of means was performed using Tukey's test ($P \leq 0.05$). The statistical analysis was performed using SAS statistical software version 9.4 (SAS Institute, 2016).

Socioeconomic phase: profitability of the prickly pear cactus

For this estimate, the costs and total production income for each production system were obtained. The information was obtained through interviews with producers, informal conversations, fieldwork, and price inquiries at commercial establishments in the region. The costs used to determine the profitability of prickly pear cultivation were divided into two parts. Direct costs included inputs and means of production (organic inputs, agrochemicals, machinery and equipment rental, and labor); indirect costs included the annual cost of capital investment (machinery, land rent, and overhead costs). With regard to total income per hectare, the prices paid to producers in 2019 and the yield per hectare, estimated by the number of boxes obtained and the weight of each one, were taken as a reference.

To determine profitability, the following expressions were used, based on Ayala-Garay *et al*. (2013); the following formula was used:

$$CT = (Px)(X) \quad [1]$$

where CT = Total production cost, P_x = Price of input or activity x, and X = Activity or input. On the other hand, total income per hectare is obtained by multiplying the crop yield by the market price; its algebraic expression is as follows:

$$IT = (Py)(Y) \quad [2]$$

where IT = Total income ($ ha-1), P_y = Market price of the crop ($ t); Y = Crop yield (t ha^{-1}).

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Finally, profitability is equal to:

$$Profitability = IT - CT \quad [3]$$

Results and Discussion

The current situation in the study area confirms that despite the acceptance that organic agriculture and the philosophy behind it have achieved, in the case of prickly pear production, only 17.4 ha of organic plantations have been adopted, out of the nearly 16,000 ha established in the Central Region (Mejía-Lara, 2020). However, the small area devoted to organic prickly pear production is expected to show growing momentum in the future, given its multiple contributions, which translate into economic, environmental, and social benefits. It could be a response to the challenges facing today's society in terms of combating phenomena such as food security, poverty, climate change, and environmental degradation.

Field phase: fruit productivity and quality

Table 2 shows significant differences ($p \leqslant 0.05$ and $p \leqslant 0.01$) among environments for the variables number of productive cladodes per plant (NCP), fruit width (FW), number of fruits per plant (NFP), total fruit weight (TFW), pulp weight (PW), and yield (YLD). These differences are mainly attributed to the production systems evaluated, as the climatic and soil conditions in both municipalities are highly similar (INEGI, 2005).

Table 2. Mean squares and significance of the analysis of variance of prickly pear cactus evaluated in two environments in the state of Mexico.

F.V.	G.L.	NCP	NFP	FL	WF	TFW	SW	PW	TNS	NSA	TSS	YLD
Environments (Env)	1	625.63*	10193.63**	0.27	0.27*	1017.33**	2.21	924.63**	0.13	282.13	0.02	139.66**
Treatments (Treat)	2	4594.23**	42906.43**	1.19**	0.99**	2161.86**	17.94	1813.85**	1119.2	288.53	2.56**	468.29**
Env×Treat	2	438.23*	3178.03**	0.06	0.13	24.56	3.11	33.65	550.43	68.13	0.13	29.53**
Error	24	93.35	444.68	0.07	0.06	82.92	6.56	59.32	526.18	118.10	0.16	4.92
C.V. (%)		16.47	12.54	3.50	4.54	7.11	8.60	7.84	8.08	14.43	3.04	16.02
Mean		58.63	168.03	7.89	5.51	127.92	29.75	98.16	283.73	75.26	13.46	13.84

*, **significant at 0.05 and 0.01 probability, respectively. F.V: sources of variation; Env×Treat: interaction environments×treatments; C.V: coefficient of variation; G.L: degrees of freedom; NCP: number of productive cladodes per plant; NFP: number of fruits per plant; FL: fruit length; WF: fruit width; TFW: total fruit weight; SW: shell weight; PW: pulp weight; NST: total number of seeds; NSA: number of aborted seeds; TSS: total soluble solids and YLD; yield.

No significant differences were detected for fruit length (FL), shell weight (SW), total number of seeds (TNS), or number of aborted seeds (NSA) because of environment, treatment, or the environment × treatment interaction. In contrast, total soluble solids (TSS) showed highly significant differences ($p \leq 0.01$) for the environment × treatment interaction, indicating differential responses between municipalities and production systems.

With regard to treatments, there are differences ($P \leq 0.01$) in most variables except for shell weight (SW), total number of seeds (TNS), and number of aborted seeds (NSA). This suggests that production systems effectively influence fruit yield and quality parameters, such as length (FL), width (WF), total fruit weight (TFW), and total soluble solids (TSS), which are the main parameters in terms of fruit

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quality (Bravo-Avilez *et al*., 2023; Gallegos-Vázquez, 2020; Zárate-Martínez *et al*., 2025). In turn, this study coincides with the findings reported by Zavaleta *et al*. (2001), who obtained larger fruit size, weight, and yield in the xoconostle crop with organic treatment compared to the control. In another study conducted by Lugo-Palacio *et al*. (2024), they mention that when vermicompost is applied to the cultivation of *Opuntia ficus*, the yield increases by up to 100% compared to the control used.

For the source of variation in environments×treatments (Table 2), contrasts ($P \leq 0.01$) are shown in the variables number of fruits per plant (NFP) and yield (YLD), as well as a significant difference ($P \leq 0.05$) for the number of productive cladodes per plant (NCP). The results show that the treatments differ in the ecological niches and production systems of the prickly pear cactus crop, which can be attributed to differences in soil fertility (Table 1) and the differential nutrient input in each production system, since the climates in both municipalities are very similar (INEGI, 2025). In this regard, Gallegos-Vázquez *et al*. (2013), infer that each plot is different, stating that these differences are greater if we consider that each farmer manages their land according to their experience, economic possibilities, and production objectives. In turn, Mondragón-Jacobo (2001) reports that the productivity of the nopal tunero is variable and is due in part to the germplasm itself, as well as to the design and management of the orchard. In relation to orchard management, Pimienta-Barrios and Ramírez-Hernández (1999) mention that organic mineral nutrition has a positive effect on prickly pear productivity, similar to the results obtained in this research study.

In the case of the coefficient of variation (C.V.), it ranged from 3.04 to 16.47, which shows that the information described here was collected correctly. As for the overall average yield, it ranged from 13.84 t ha^{-1} for both municipalities, which exceeds the average reported in the State of Mexico, which was 11.3 t ha^{-1} (SIAP, 2019).

As for Tukey's mean test ($P \leq 0.01$) in Table 3, evidence shows that the organic production system recorded the highest number of productive cladodes per plant (82.6), number of fruits per plant (242.2), and highest total fruit weight (140.9 g), These variables define yield, which reached 21.5 t ha^{-1} in the organic production system, 11.8 t ha^{-1} in the conventional system, and 8.2 t ha^{-1} in the intermediate approach. These differences are attributed to the management of the orchard and greater absorption of organic assimilates by the plant. These results corroborate the reports of Mejía-Lara (2020), who considers that organic prickly pear production is feasible as a beneficial alternative for producers from a technical, productive, economic, environmental, and health point of view. Likewise, the premises of Nobel (1994) can be accepted, who indicated that when attention is paid to management practices, particularly moisture availability and soil fertility optimization, prickly pear cactus productivity can be extraordinarily high; such is the case of the reports by Barbera and Inglese (1993), who reported that under the best environmental and cultural conditions, yields of up to 35 t ha^{-1} per year have been obtained in southern Italy, yields that correspond to those reported by Gallegos-Vázquez (2020) for the subtropical region of the Juchipila Canyon, Zacatecas, Mexico, where they obtained 34.8 t ha^{-1} per year for the cultivar “Apastillada” (*O. ficus-indica*) and 34.2 t ha^{-1} per year for “C-17” (*O. albicarpa*), a variant with many similarities to Reyna, which is the prickly pear variety evaluated. In this regard, Gliessman (2002) and Monreal (2003) argue that the incorporation of organic inputs conditions the soil and incorporates biota to optimize plant nutrient absorption, vigor, and health, improving the physical, chemical, and microbiological characteristics of the soil. For their part, Gomiero *et al*. (2011) mention that organic systems have higher levels of organic carbon, greater aeration and moisture retention, as well as lower acidity, nutrient loss, and erosion, and generally better soil quality. On the other hand,

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Seminario-Peña *et al*. (2023) state that organic anonas are a promising alternative for increasing the yield, emergence, and establishment of *Pachycereus pringlei* (S. Watson, Britton & Rose) seedlings, as well as improving their morphological and physiological characteristics.

Table 3. Comparison of means for the variables evaluated in three production systems in two environments in the state of Mexico.

TRAT	NCP	NFP	FL	WF	TFW	SW	PW	TNS	NSA	TSS	YLD
Organic	82.6 a	242.2 a	8.3 a	5.7 a	140.9 a	30.5 a	110.4 a	296.0 a	71.0 a	14.0 a	21.5 a
Intermediate	41.3 b	118.1 c	7.6 b	5.2 b	111.9 b	28.2 a	83.7 c	279.0 a	73.0 a	13.0 b	8.2 c
Conventional	52.0 b	143.8 b	7.8 b	5.6 a	131.0 a	30.6 a	100.4 b	277.0 a	81.0 a	13.5 b	11.8 b

Means with the same letter are not statistically different at α = 0.05. TRAT: Treatment; NCP: number of cladodes per plant; NFP: number of fruits per plant; FL: fruit length; WF: fruit width; TFW: total fruit weight; SW: shell weight; PW: pulp weight; TNS: total number of seeds; NSA: number of abortive seeds; TSS: total soluble solids; and YLD: yield.

Regarding the variables FL, WF, TFW, PW, and TSS, identified as fruit quality parameters, Tukey's test ($P \leq 0.05$) showed significant differences in the effect of organic and conventional production approaches compared to the intermediate approach in the variables length, width, and total fruit weight, with the highest values obtained in the organic approach, although statistically equal to those recorded for the conventional approach. The total weight of the fruit (140.9 g) obtained using the organic approach was higher than the average weight of the variety (131.3 g) reported by Gallegos-Vázquez and Mondragón-Jacobo (2011), which is similar to the average fruit weight found for the conventional approach (131.0 g).

With regard to pulp weight (PW), the three treatments (production systems) were statistically different, with the highest values found in the organic approach (110.4 g), followed by the conventional approach (100.4 g), and the lowest weight in the intermediate approach (83.7 g). In this regard, Gallegos-Vázquez and Mondragón-Jacobo (2011) reported that, on average, the pulp weight of the Reyna variety represents 62.9% of the total fruit weight, while the results of this study showed that the pulp weight reached 78.4%, which indicates that under the organic approach, higher quality fruit (prickly pear) is obtained.

No significant differences were found for the variables total number of seeds (TNS) and number of aborted seeds (NSA). In this regard, Gallegos-Vázquez and Mondragón-Jacobo (2011) and Mondragón-Jacobo and Gallegos-Vázquez (2013) mention that the “Reyna” variety is characterized by having abundant aborted seeds, without specifying quantities. Finally, statistically significant differences ($P \leq 0.05$) were found in the total soluble solids (TSS) content between the organic approach and the conventional and intermediate approaches, reaching values similar to those reported by Gallegos-Vázquez and Mondragón-Jacobo (2011) for the “Reyna” variety with values of 14.94 °Brix.

The quality of the fruit intended for consumption as fresh fruit is determined by its external appearance, size, shell color, the proportion of seeds, pulp, and shell, and its sugar content. In this regard, Calderón (1977) indicates that the color of the shell, number of seeds, size and fullness of the fruit, increase in the percentage of edible pulp and sugar content (minimum content 11 °Brix), ascorbic acid, and decrease in firmness and acidity are essential requirements for the consumption of fresh fruit. Considering the above, Table 4 compares the results obtained in this study with the specifications set for the Reyna variety in NMX-FF-030-SCFI-2006 (General Directorate of Standards, 2006): Non-Industrialized Food Products for Human Consumption - Fresh Fruit - Prickly Pear (*Opuntia spp*.). This comparison shows that the variables related to fruit size are acceptable, with fruit length (polar diameter) and average weight slightly higher in the organic and conventional approaches than those established in the standard, while those obtained in the intermediate approach were lower. With regard to total soluble solids content, the standard specifies that the total soluble solids content must not be less than 10 °Brix in all commercial types; However, the same standard adds that this parameter must be associated with each variety, so in the case of the Reyna variety, considered the sweetest prickly pear, it is set at 14.8 °Brix, with the values corresponding to the three production systems being slightly lower. These results corroborate the findings of Mejía-Lara (2020), who, when presenting the results of the strategic project on organically managed nopal cactus in the Teotihuacán Valley region, established the feasibility of producing under an organic production model, with lower investment and verifiable favorable technical results, despite the skepticism and low credibility of many producers who have not dared to embrace technological change.

Table 4. Comparison of average values obtained with those established in the Mexican Standard for prickly pear.

Source	FL (mm)	MD (mm)	AW (g)	TSS (°Brix)
NMX-prickly pear fresh fruit*	---	55.4	128.9	14.8
Organic	83.0	57.0	140.9	14.0
Intermediate	76.0	52.0	111.9	13.0
Conventional	78.0	56.0	131.0	13.5

*NMX-FF-030-SCFI-2006; FL: fruit length; MD: maximum diameter; AW: average weight; TSS: total soluble solids.

Socioeconomic phase: profitability of the prickly pear cactus

In this study, it was very important to calculate the production costs and income from the crop for both municipalities, since most producers do not keep track of the costs they incur, nor the income and prices that are determined by supply and demand. Therefore, prickly pear prices vary depending on production, quality, supply, and market demand. In relation to our study, producers market the fruit in regional markets, or they negotiate prickly pear at the roadside or at the producer's home, where the main aspect that influences the marketing of the fruit is the quality and volume of production. In this regard, Table 5 shows the prices of prickly pear in the July-September 2019 production season. The results show that organic prickly pear fetches a price 3.5 times higher than premium prickly pear obtained using conventional and intermediate approaches, almost four times higher than fruit classified as second-grade, and up to seven times higher than third-grade. The sale of organic prickly pear results in a positive economic impact for the producer, which means they have the opportunity to access better living conditions.

Table 5. Prices of prickly pear in San Martin of the Pirámides, State of Mexico.

Handling	Quality	Sale Price	Fruit Characteristic
Conventional and Intermediate	First	$ 100.00 *	Of 5-7 cm, weight 100-140 gr and free of physical damage.
	Second	$ 90.00 *	Of 3-5 cm, weight 80-100 gr and free of physical damage.
	Third	$ 50.00 *	Not contemplated.
Organic	Equal	$ 350.00 *	Equal

*Retail prices for prickly pear for the July-August-September 2019 season; presented in 25 kg boxes.

Production costs

The costs and income of each production approach per hectare were obtained (Table 6), where the results show that direct costs (organic inputs, machinery rental, work equipment, labor, boxes and gasoline) in organic production represent 58.29%, within which 33.37% of these are equivalent to labor (with a total of 92 days per hectare), coinciding with Flores-Valdez and Gallegos-Vázquez (1993), who indicated that the cultivation of prickly pear cactus occupies an average of 80 days per hectare per year. Indirect costs (purchase of machinery and equipment, land rental, and certification) account for 41.71% of total costs. Regarding the income generated by organic production, this was calculated based on the volume of prickly pear obtained per hectare, sold at $14.00 Mexican pesos (MXN) for kg, generating an income of $77,000.00 MXN for ha^{-1} and a profit of $36,243.76 MXN for ha^{-1}. It is important to mention that for most producers, economic considerations are the most important factor in the decision-making process regarding their incorporation into organic production or the expansion of their production unit; in this regard, Gómez-Cruz *et al*. (2010), infer that during the transition process, large investments are required to cover the labor required for organic management and the cost of certification, and not all producers can afford this conversion. However, those who achieve this change have seen that organic agriculture is an economic activity with the potential to generate jobs and foreign currency, as reported in this study.

Table 6. Production costs and income in Mexican pesos (MXN) of prickly pear cactus production systems.

Production cost	Organic	Intermediate	Conventional
Indirect	$17,000.00	$10,000.00	$10,000.00
Direct	$23,756.24	$11,780.00	$15,200.00
Total	$40,756.24	$21,780.00	$25,200.00
Revenue	$77,000.00	$16,980.00	$22,520.00
Utilities	$36,243.76	-$4,800.00	-$2,680.00

As for production in other production systems, their profitability depends on the quality of the fruit and the harvest season in order to compete in the market. Price differences are determined by opportunity, that is, the time of year in which the fruit can be harvested; year after year, the best prices are set by early and very late prickly pears (Gallegos-Vázquez and Cervantes-Herrera, 2017). This does not differ from other producing areas, such as the state of Zacatecas, which faces a similar problem reflected in low prices for the producer and, consequently, low profitability of the activity, which has not allowed the potential deployment of this crop to generate greater economic and social development (Gallegos-Vázquez *et al*., 2003).

In the intermediate production system, direct costs represented 54.09%, of which 21.12% was equivalent to labor with 23 days per ha^{-1}. Meanwhile, indirect costs represented 45.91% of total costs, higher than the organic approach at 4.2%. Regarding revenue, a total of 4,925 kg of three grades was obtained, generating an income of $16,980.00 MXN for ha^{-1}. Subtracting production costs and not including land rent, the profit is $6,600.00 MXN. Although the profit for producers is minimal, it represents income for two reasons: first, because labor costs are not taken into account in production costs, and second, because it has become the only productive option for generating income in the region. However, if the cost of renting the land is taken into account, this generates a negative balance of -$4,800.00 MXN, which indicates that the crop is not profitable. This coincides with other studies, which mention that plantations are in a state of deterioration, mainly due to profitability problems (Gallegos-Vázquez and Méndez-Gallegos, 2000; Corrales-García and Flores-Valdez, 2003), a situation which, in the opinion of Gallegos-Vázquez *et al*. (2003), leads to a vicious circle in which

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producers do not obtain sufficient quality and productivity to improve their income, and therefore do not achieve levels of capitalization that allow them to invest in solving the various problems they face.

In the case of the conventional production system, the results obtained show that direct costs represent 60.32%, which is 2.03% and 6.23% higher than the organic and intermediate approaches, respectively. Within direct costs, labor accounted for 23.81%, with 30 workdays ha^{-1}, and indirect costs represented 39.68% of total costs. In terms of profits, 6,225 kg of three grades were obtained, generating an income of $22,520.00 MXN for ha^{-1}. After deducting production costs, this generates a profit of $7,320.00 MXN. As in the previous approach, despite the small profit, for producers it represents an important source of income, complementing other income such as: rental of accessories, sale of handicrafts, car washing, and waiters in restaurants located in the tourist area of the Pyramids. When considering the cost of land rent, a negative balance of -$2,680.00 MXN is generated.

In terms of yield per production system (Table 7), the results show that the organic approach had a profitability of 150.35% and 88.92% when land rent is included in the costs, while for the intermediate and conventional approaches, it is 44.14% and 48.15%, and if land rent is taken into account, profitability is negative in the order of -22.04% and -10.63%, respectively.

Table 7. Profitability of prickly pear cactus crop in Mexican pesos (MXN).

Production system	Organic ($)	Intermediate ($)	Conventional ($)
Production cost (excluding land rent)	30,756.24	11,780.00	15,200.00
Utility	46,243.76	5,200.00	7,320.00
Profitability	150.35%	44.14%	48.15 %
Production cost (including land rent)	40,756.24	21,780.00	25,200.00
Utility	36,243.76	-4,800.00	-2,680.00
Profitability	88.92%	-22.04 %	-10.63 %

Due to the profitability obtained in each of the approaches, it is important to consider some production options or alternatives, taking as an example the company “La Flor de Villanueva” in the municipality of Acatzingo, Puebla, which increases the production period with varieties that allow for supply during several months of the year, thanks to the agroclimatic conditions of the region. However, another alternative implemented was the production of organic fruit, which allows for diversification and generates higher profits (Reyna-Cabrera *et al*., 2024). As observed in the organic system in the central region dedicated to the production of prickly pear, this generates a profitability that allows producers to invest in improvements for the crop. In addition, this type of production is less vulnerable to changes in crop and input prices because it is diversified and uses few external inputs (Zamilpa *et al*., 2016; Marín *et al*., 2017).

Conclusions

The different production systems directly influence the agronomic parameters, yield, and quality of the prickly pear fruit. The organic approach generated higher income for producers, which creates more opportunities to address or minimize the low profitability of crops in the region. The organic system or approach is feasible for use by producers in the cultivation of prickly pear and can also be replicated in other crops of agricultural interest.

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

All data generated or analyzed during this study are included in this published article.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FUNDING

Not applicable.

AUTHOR CONTRIBUTIONS

Conceptualization, L.G.A.M. and C.G.V.; methodology, L.G.A.M., C.G.V. and R.H.M; validation, L.G.A.M., C.G.V. and R.H.M.; formal analysis, L.G.A.M. and R.H.M; investigation, L.G.A.M. and R.H.M; resources, C.G.V., G.A.S., A.L.G., J.A.A.V. and L.G.A.M.; data curation, L.G.A.M., C.G.V. and R.H.M.; writing—original draft preparation, L.G.A.M. and R.H.M; writing—review and editing, L.G.A.M., C.G.V. and R.H.M.; visualization, L.G.A.M. and R.H.M; supervision, C.G.V.; project administration, C.G.V.; funding acquisition, C.G.V.

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