

Economic Indicators, Capacity of the Ecosystem of Prickly Pear Cactus (*Opuntia Megacantha*) and Environmental Services in Teotihuacan, México to Supply Urban Consumption.

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Abstract

A study of prickly pear was carried out with 100 producers of the fruit using a semi-structured survey to ascertain the nature of cultivation and economic environment. The Prickly pear region includes an area of 12,000 ha, planted with prickly pear variety *Opuntia amyclaea*, *Opuntia violacea* and *Opuntia matudae*. The size of the orchard in the villages studied was of 1-20 ha, with a predominance of 1-3 ha. The productive life for the prickly pear orchard varied between 20 and 60 years. The cow manure is used as a source of organic matter and the dose applied depends on the amount of organic wastes produced by the cattle and age of the cactus (an estimated 500 t ha⁻¹). The average volume of fruit production per ha is 10 to 15 t of prickly pear. In economic analysis of gross margin was U.S. \$ 1,920.00 per ha, each farmer obtained an average annual gross income of \$ 5.376 for an average production. 44.7% (U.S. \$ 12.672 million) of these profits are distributed initially in the population, by way of inputs and labor. Sustainability factors equivalent to providing environmental services are discussed.

Keywords: Prickly pear, farming systems, *Opuntia amyclaea*.

1. Introduction

In Mexico pre-Hispanic times, the cacti had various uses (food, drink, medicine, housing construction, fabrication of blankets and tools) and were important so large that they rose to a divine state (deified) (Bravo and Sánchez, 1991). The nopal is a cactus of the subunit Opuntioideae and genus *Opuntia* and its main center of origin is Mexico (Maki-Díaz et al., 2015); The characteristics of this plant are: 1) flat articulated stems (cladodes) and diurnal flowers of vivid colors that together with the spines are implanted in the areolas; 2) the prickly pear (fruit) is ovoid, juicy with seeds and red, green, white or yellow sugar pulp. The prickly pear (tuna) has gained worldwide importance due to the access of countries such as Italy, South Africa and Israel amongst others to international markets. In Mexico the cultivated of prickly pear plants occupy 230 thousand hectares, of which 67 thousand are used for fruit production with an estimated yield of 400 thousand tons of fruit per year (INEGI, 2009). One of the prickly pear (tuna) producing niches is to be found in the Valley of Mexico, where the fruit of the *Opuntia megacantha* has been selected since before the Spanish conquest (Peña et al., 2012; Sahagún, 2006).

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Through the collection of wild plants, cultivation of (wild) plants near human settlements, and cultivation of varieties (by selective propagation methods), thus creating a commercial fruit, light green in color and 8-16 cm long (fruits with much demand of consumption amongst the urban population of Mexico City's metropolitan zone). This situation has permitted the region of San Juan Teotihuacán, to the north of the city, with extensive arid zones and poor soils, to become the ecological centre with the largest production. Similar to what happens with the region reported for the cultivation of nopal-vegetable in the southeast of the city (Losada et al., 2001), an important feature of fruit (tuna) production is the limited use of external inputs which means it is an ideal product to satisfy the requirements for sustainability demanded/required by the urban environments.

The distribution of the benefits of cultivation amongst the population that manages it, and the production capacity of the eco-system prickly pear to maintain the population, constitute indicators of fairness and economic capacity that are important for the evaluation of the economic universe of the crop. The aim of this research was to study the universe of tuna cultivation and its economic impact on two towns in the Teotihuacán valley and to evaluate its potential as a option for sustainability.

2. Methodology

2.1 Characteristics of the zone studied

The tuna producing region of Teotihuacán in a broad valley of some 523 km² located to the northeast of the old lake of Texcoco and of Mexico City, of which 8% (42 km²) belong to urban areas and, 50% (261 km²) are considered areas dedicated to permanent agriculture, 21% (110 km²) contain maguey plantations associated with other crops and the other 21% (110 km²) is covered with shrubs and natural grasslands. The tuna producing region includes a zone of 12,000 hectares sown mainly with plants for fruit of the variety Alfayuca (*Opuntia amyclaea*) and smaller proportion of the purple variety (*Opuntia violacea*) and xoconostle (*Opuntia matudae*) distributed within the municipalities of Acolman, Otumba, Temascalapa, Nopaltepec and San Martín de las Pirámides. The area has large extensions of plains as well as ridges and hills with elevations in the range of 2,200 and 2,400 masl. Water resources are limited to the presence of a river that crosses the municipality of San Juan de Teotihuacán (rio San Juan), intermittent and seasonal streams and bore-holes providing water from a water table between 185 and 250 m. deep. There is a great variety of soils in the region that include shallow layers of "tepetate"⁶ (Sedimented volcanic material) and lime stone, basaltic andesite with high contents of iron, magnesium, calcium and sodium and phaeozem with brown-colored earth rich in organic matter (Challenger and Soberón, 2008).

The region's dominant climates are dry steppes, and cool semi-dry, with an average annual temperature of 16 °C, a maximum of 33 °C and a minimum of 2 °C. Rainfall is low in the range of 400 to 600 mm/year, distributed throughout the summer between May and September and frosts in the winter (McClung, 2006). The region's flora is predominantly xerophilous which includes a wide variety of cactus species and others plants. In the hilly areas the woodland vegetation reported includes firs, oyamel (*Abies religiosa*), cupressus, pines, lime trees and oak. (INEGI, 2009).

2.2 Collection and analysis of data from study sites

The procedure began with the obtaining of the standard of the producers of the prickly pear (tuna). Direct information was obtained from 100 fruit (prickly pear) producers through a semi-structured survey using an approach designed to provide knowledge of the characteristics of the crop and the economic environment in which production is carried out. Before carrying out widely, the questionnaire was put to the test in the field and adjusted accordingly. In the absence of reliable statistical sources to provide information on the number of producers in the area, the methodology used involved the application of the matrix to producers identified as having those orchards. These orchards were detected by direct observation or by informants in the localities of Nopaltepec and San Martín de las Pirámides. Once the information was obtained, a transversal margin analysis was carried out to measure equity and capacity, determining the distribution in the communities of the profits obtained from the sales of prickly pear (tuna).

⁶It is an ambiguous indigenous term, related to the appearance of horizons more or less hardened in or near the surface of the ground. From the Nahuatl language, tepetlat: stone mat (from tetl 'stone' and petlatl 'mat, mantle').

3. Results

3.1 Characterization of the productive environment of the fruit

In contrast to the crops typical of the zone, the prickly pear is a plant that is grown in orchards. It does not compete with other local crops: maize, barley, wheat and beans, but instead complements the basic agricultural activities which is why it is largely grown on hillsides or on flat land unsuitable for conventional crops. Land-holding is mainly organized in ejidos ⁷ (95%) while a few producers reported they are private property owners. The size of the orchards in the villages studied vary between 1 and 20 ha, the predominant size being between 1 and 3 ha. The principle variety of fruit produced is the pale green Alfayuca (*Opuntia amyclaea*), and in recent years there has been an increase in the production of what is known as the purple fruit (a smooth dark red variety) and xoconostle (*Opuntia matudae*). The most producers (64%) have Orchards a surface 1 to 3 ha in area in contrast to the 23% with holdings of 4 to 8 ha while a few (9%) have areas of 12 to 20 ha.

A fruit (prickly pear) producing is a plant that is cultivated in the community over a long period of time, the variation ranging from 8 to 20 years which is direct evidence of the familiarity with and the productivity of the crop in contrast to the annual crops in the zone. The productive age of the prickly pear fruit orchards varies from 20 to 70 years due to which it has been selected as an ideal crop for the climate and environmental conditions in the zone. The distance between prickly pear plants varies from 4 to 6 m between plants and rows that results in the presence of a significant variation in number of plants (Table 1).

3.2 Management of the orchard for production

The production cycle in an established orchard begins in the month of March once the frosts are no longer a threat. It is characterized by the production of tender leaves (suitable for human consumption) which are allowed to grow and later pruned. The height at which they are pruned varies from 1.3 to 2.4 m, although most growers opt for a height of 1.5 to 2 m to facilitate the picking of the fruit.

Table 1. The distance between plants, rows and the number of plants per ha. In the case of prickly pear in the villages studied.

Nopaltepec			San Martín de las Pirámides		
Distance/ plants	Number / plants per ha	% of producers	Distance between rows	Number/ plants per ha	% of producers
5	400	45			
4	625	51			
6	277	4			
			3	1111	2.3
			4	625	41.8
			5	400	51.2
			6	277	4.7

The pruning season most commonly reported by prickly pear growers is the period covering February, March and April, although others reported pruning during the months of November and December. Most of the leaves or "pencas"⁸ product of pruning are piled up next to the plants for them to decompose and be incorporated into the soil, while a small number of them are used to grow hedges around the orchards. After this, the flowers from which the fruit will form later on appear in the period from April to July. During this time, fertilization and fumigation are carried out.

⁷The ejido in Mexico is not a set of lands, but a moral person, as such has legal personality and own property, is formed by a set of property (land) and rights denominated ejidal property. The constitutional recognition of the ejidos is embodied in Fraction VII of article 27 of the Mexican constitution (agrarian law published in the Official Gazette of the federation on February 26, 1992) (Orozco, 2010).

⁸Fleshy leaf of cactus (*Opuntia sp.*)

3.3 Fertilization and fumigation of the prickly pear orchards

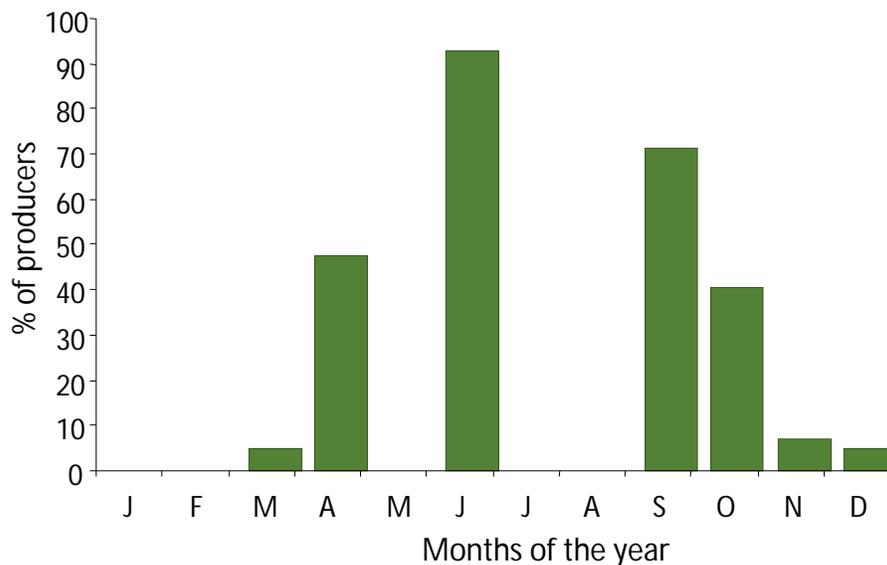
The plants are fertilized with chemical fertilizers, amongst which the preference was for triple 17 (17 N - 17 P - 17 K) and urea (46 N). The use of this type of fertilizer was recommended by fellow producers, neighbors, local government personnel, agronomists and other individuals. The time of year in which inorganic fertilizer is used is not fixed, the triple fertilizante 17 (N, P, K) and inorganic nitrogen fertilizer are applied to the orchards during all year round, October and March are the most common months.

Cow faeces, a source of organic material is used by all the producers and comes from the dairy producing zone of Tizayuca (at 30 km to the west in the state of Hidalgo). The manure is free and the cost involved is for transport. The amount applied depends on the availability of the excreta and the age of the prickly pear orchard but is in the range of 15 to 60 kg of dry manure per plant, which permits us make an estimate of 500 t ha⁻¹. This fertilization takes place once or twice per year, before the rainy season begins, in the months of February, March and April (60.5, 27.9 and 9.3% respectively). The prickly pear is very prone to pests and diseases and the producers are permanently watching in order to avoid them affecting the fruit harvest.

3.4 Fruit (prickly pear) production

Fruit production begins in March, increases in April and rises significantly during June, while in September, October and November production falls, as can be seen in Figure 1. The yield /ha is 10 to 15 tons of fruit.

Figure 1. Times of year in which fruit is produced as reported by producers in the zonestudied.



3.5 Management of fruit for harvesting and marketing

An important aspect to be noted is that machines for removing prickles are not accepted by producers as they are slow compared to the speed of an expert who can clean as many as 20 crates per day using the traditional method. Traditionally the fruit is put on a bed of straw and brushed with twig brooms and after that, packed in wooden crates with a capacity of 25 kg. The fruit harvest is carried out early in the day to take advantage of the humidity (dew) on the fruit. Fruit packing is done in a number of different ways, the most important being the selection of first and second class fruit according to its size, the thickness of the peel and the color of the fruit, and then setting the produce out in layers, piles or in some other form. Marketing the fruit is a great problem for growers as most of it is sold in the region's three principle "tianguis"⁹ or markets, the buyers being intermediaries who pay a low price and later sell the fruit at the Central de Abasto, Mexico City's main wholesale market or ship it to other states.

⁹Market of provisional posts, the Nahuatl tianquiztli 'market', from tiamiqui 'sell, trade'.

Some more experienced growers manage to sell it to supermarkets in the capital city or take it themselves to the cities of Guadalajara, Puebla or even Tijuana. At the present there is little possibility of being able to export this product. In the early 1980s, an organization involving more than 700 producers, the “Unión de Tuneros de Teotihuacan” was set up in the zone and managed to export the fruit to the city of Los Angeles in the United States. However, due to problems of corruption the association went broke and its debts make up part of the rural payments overdue. The major problems facing prickly pear growers is the economy and water.

3.6 Post-harvest management

Once the fruit production season is over, the prickly pear orchard is weeded, or local sheep are allowed to graze on it during the months from October to December in an agro-pastoral system (35% of the producers). The productive life of a prickly pear orchard varies from 20 to 60 years, for which reason it is considered a perennial crop (between 30 and 40 years mainly).

3.7 Analysis of the gross economic profit margin

The results of the gross margin analysis is presented in Table 2. The mean orchard size was 4.33 hectares and the area of prickly pear plant sown was 2.8. Average production per hectare was approximately 12.8 t ha⁻¹, yielding a production of 400 crates per hectare which were sold at an average price of US\$3.75 each. This gives a total of US\$1,920.00 per hectare planted, meaning that each grower received an average annual gross income of US\$5,376 for their product. In the region there are 15,000 hectares of prickly pear fruit plants which generates US\$28,800,000 in capital for the zone, directly benefitting approximately 5,537 families. 44.7% (US\$ 12,672,000) of the profits are initially distributed amongst the population to cover the costs of inputs and labor.

Table 2. Analysis of the gross economic margin in prickly pear growing in the villages studied.

Costs and profit per hectare of fruit/year	USD	USD	USD
Items	Costs	Income	Profit
Tools	224		
Weeding	185		
Pruning	62		
Fertilization	63		
Fumigation (pests)	78		
Harvest	369		
Transport	205		
Brooms	5		
Straw	58		
Gloves	10		
Cost of crates	3		
Total	1061	1920	859

4. Discussion

The region of San Juan de Teotihuacan geographically forms part of the Valley of Mexico, having an extension of approximately 523 km². The space of maguey plants and natural vegetation has also been adapted for an agricultural system producing of prickly pear for human consumption. The prickly pear or nochtli (*Opuntia megacantha*) is one of the fruits produced by the *Opuntia* genus found in arid and semi-arid ecosystems. The form of production in prickly pear fruit orchards began in Mexico 4,500 years ago along with the domestication of maize, beans, squash and other crops (MacNeish et al., 1971). At the same time, Man began to select useful plants in order to sow them near their dwellings with the aim of improving them, favoring the management of a number of plants in the family orchard. Today, these orchards are distributed throughout Mexico's rural areas, but those containing prickly pear plants grown for fruit as the main component are found on the central high plains and in the north. With the increase in the demand for prickly pear fruit some growers have changed their form of production to plantation scale. However, this is not the case of those included in this study.

At northeastern Mexico City's metropolitan zone, the cultivation of the prickly pear was initially used as a resource for erosion control and subsequently became an important economic alternative. A number of important characteristics to highlight in the cultivation of prickly pear in orchards with reference to the concept of sustainability were related to the limited use of external inputs, the source of fertilizers and agro-chemicals, the high level of labor for cultivation and the fruit yield related to economic productivity.

In the study sites, it performs mixed fertilization (cattle manure and chemical fertilizer), thus mitigating the depletion of soil nutrients, thus decreasing pressure on agricultural land. According to Wopereis et al. (2006) results in the compensation of the output of nutrients, the use of organic inputs strengthens the sustainability of the use of agricultural parcels. This agrees with Pimienta (1994), who recommends the fertilization of fruit of the prickly pear (tuna) (the joint application of mineral and organic fertilizers) induces positive responses in the cultivation.

Mineral fertilizers release nutrients, meeting the immediate needs of the plant and manures are continuous supply of nutrients, in addition to providing microelements, which in the case of mineral fertilizers are not applied. García et al. (2010) also points out that the use of compost and green manures is economically viable and environmentally sustainable. Improves the quality of the fruit (prickly pear) and lengthens the productive life of the plant.

The natural inputs contribute to the recovery of fertility (Bučienė et al., 2003) and the physical characteristics of the soil (Agostini et al., 2003). Using compost and green manures provides ecosystem services, with considerable ecological value (Reid et al., 2005) and the cost / benefit ratio of this type of resources is difficult to quantify. However, overall benefits (soil formation and nutrient recycling) are estimated at 350 billion dollars annually (Pimentel et al., 1997).

As was pointed out above, the establishment of a family prickly pear orchard is done by planting leaves from the plants in the region, while the use of external inputs refers to the type of fertilizer used (triple 17), which is applied in small quantities in contrast to the extensive use of pesticides (foley). Otherwise, the inputs used were local and during the harvesting season (June-October) a large amount of labor is required as most of the work is done manually while the use of machinery to remove the prickles is recent.

According to the data reported in this paper the average fruit yield obtained was 13 t ha⁻¹, which contrasts with values of 20 and 25 t ha⁻¹ reported for countries such as Italy, Israel, Colombia and the USA. One difference between yields is related to the way in which they cultivated as our research focused on the family orchard with restricted use of external inputs while in other countries a plantation system with extensive external inputs is used. A reduction of yields has been reported to occur in crops grown organically and in others which are closer to sustainable conditions, as is the case of the prickly pear grown for fruit (García and Nobel, 1992). The agricultural activity of prickly pear orchards, in addition to avoiding damages to the productive ecosystem also generates socio-economic benefits.

Gallegos and Mendez (2000) mention that this cultivation promotes attachment to the land. This is important, because it is difficult to conserve ecosystems when population growth puts pressure on natural environments by expanding urban spots and increasing resource demand (Challenger and Dirzo, 2009).

5. Conclusion

The analysis of the production process indicates that the cultivation of prickly pear is one of the few agricultural options due to the edaphic and climatic conditions of the study area. But, it has advantages over other agricultural activities because of practices that attenuate, avoid and even restore damage to the productive ecosystem; this could ensure sustained income and a moderate impact on the environment.

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7. References

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