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Sustainability of Four Agroecosystems in the State of Veracruz, Mexico

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ABSTRACT

Objective: To evaluate the sustainability of four agroecosystems in the state of Veracruz, Mexico: sugarcane, maize grain, orange and moringa.

Design/Methodology/Approach: Producers that provided information about the crops' management were located. Semi-structured interviews were conducted to identify critical points affecting sustainability, and the indicators were weighted using the bottom-up criterion and the PSR model.

Results: The most sustainable crop was moringa, and the least sustainable was maize for grain. Conventional crops are characterized by being monoculture plantations and demanding large amounts of non-renewable external inputs that undermine their sustainability. Lack of technical training for producers was identified as a critical point.

Study Limitations/Implications: The results obtained are limited to the analysis of four production systems and their environmental, social and economic dimensions.

Findings/Conclusions: Moringa is presented as an alternative crop with low environmental impact that generates employment and strengthens social capital.

Keywords: moringa, sustainable agriculture, sustainability indicators.

INTRODUCTION

Current agricultural practices of crop management under the principles of the Green Revolution favor high production in the short term; however, they have generated an environmental cost that compromises the long term (Gliessman, 2003). As a result, natural resources have been degraded, global ecological processes have been altered, the social conditions for their preservation have been weakened and in extreme cases they have been dismantled (Gliessman, 2003).

In conventional crops in the state of Veracruz, Mexico, these principles have traditionally been applied in terms of management and technology. Therefore, it is necessary to implement more sustainable forms of agriculture based on

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a better understanding of ecological processes. Likewise, the modification of consumption patterns in favor of the long-term preservation of soil productivity, and the promotion of greater equity that favors each link in the agrifood chain, from the farmer to the final consumer (Gliessman, 2013) (Gliessman, Engles, & Krieger, 1998).

Sustainable agriculture is characterized by long-term sustainability, with the ability to permanently harvest biomass from an agricultural system that is capable of renewing itself without putting itself at risk (Masera, Astier, & López-Ridaura, 2000).

Assessing agricultural sustainability involves recognizing that the pressure to increase yields conflicts with the long-term requirements of sustainable development (Abbona, Sarandón, & Marasas, 2006). Conventionally, agricultural systems have been evaluated by means of cost-benefit analysis to determine their economic profitability; however, this approach is not functional in the long term because it sidesteps the social and environmental dimensions that are becoming increasingly relevant (Sarandón *et al*., 2006).

In contrast to the conventional cost-benefit analysis, Sarandón (2002) considers that a sustainable agroecosystem must meet four requirements, it should be: 1) sufficiently productive, 2) ecologically sound (conserving the natural resource base and preserving the integrity of the environment at the local, regional and global levels), 3) economically viable, and 4) culturally and socially acceptable.

The objective of this research was to evaluate the sustainability levels of four agroecosystems in the state of Veracruz, Mexico, the three conventional agroecosystems with highest economic value and *Moringa oleifera* Lam. (moringa), a recently introduced crop for which there are still no records in the state, through the use of indicators for the characterization of sustainability and identification of critical points that affect agroecosystems according to Sarandón and Flores (2009).

MATERIALS AND METHODS

The study was conducted in the state of Veracruz, Mexico (22° 28′ N, 17° 09′ S, 93° 36′ E, 98° 39′ W), and with an altitude from zero to 5,610 m, (SEDECOP, 2020). The average annual precipitation is 1500 mm, and the mean annual temperature is 23 °C (INAFED, 2020). The research included the following stages:

1. The three crops of highest economic value in the state of Veracruz were identified. The most recent economic value was obtained from the state's System of Agrifood and Fishery Information (Sistema de Información Agroalimentaria y Pesquera, SIAP, 2018), where sugarcane (*Saccharum* spp.), maize grain (*Zea mays* L.) and orange (*Citrus sinensis* L.) were identified as the three crops with the highest commercial value.

2. Characterization of the agroecological spatial scope. Nineteen cooperating production sites were located to provide information on crop management through semi-structured interviews (Table 1). The information obtained was organized in a database for tabulation and evaluation.

3. Selection of indicators and evaluation. To identify the critical points affecting sustainability, indicators were selected based on the bottom-up criterion (Astier, Mazera, & Galván-Miyoshi, 2008) and the PSR (Pressure, State, Response) model, which explains the cause and effect of management practices on agroecosystem components (Abbona *et al*., 2006) applied by Sarandón and Flores (Sarandón & Flores, 2009).

Table 1. Characteristics of the crops and average data of the producers.

N ° producers	Culture	Floor	Weather	Average extension (ha)	Average production value (Mx)	Average age	Average schooling (years)
6	Sugar cane	Phaeozem, andosol	Warm sub humid, temperate humid	1.00	50.165	44.6	8.67
6	Grain corn	Phaeozem	Warm sub humid	33.33	292.25	56.8	8
3	Moringa	Vertisol, leptosol y phaeozem	Warm sub humid	0.50	45.00	47.5	17
4	Orange	Phaeozem	Warm sub humid	20.00	553.85	44.25	10.2

MX: total production value of producers in thousands of Mexican pesos.

In this context, the pressure indicators are constituted by crop diversification, yield and commercialization; status indicators include cultivated area, availability of workforce and access to basic services; finally, the response indicators included soil preparation, fertilization, and pest, disease and weed control. The indicators were ordered according to their environmental, economic, and social performance (Table 2).

In order to compare the four agroecosystems and ease the evaluation of the three dimensions of sustainability, the indicators were standardized and weighted. A scale of zero to four was created for standardization purposes, where four represents the value closest to sustainability and zero the value furthest from it. The weighting factor depends on the importance of the indicator for the system's operation, ranging from one to two. Indicators that contribute the most to sustainability were assigned a value of two, and those that contribute the least were assigned a value of one. The weighting value was determined by the product value of standardization* weighting factor. The weighting factor was estimated as the average of the responses by producers associated with each crop.

The overall sustainability of the agrosystems was obtained by averaging the values obtained for the three dimensions as shown in the formulas (Table 3). The value of each indicator is a quotient whose numerator is the weighted sum of indicators and sub-indicators considered, and the denominator is the number of variables considering their weighting (Sarandón & Flores, 2009).

Representation of Indicators. The results obtained from Tables 2 and 3 were represented graphically in order to identify the critical points of each agroecosystem. The critical points refer to the management of the agroecosystem as a variable of improvement or deterioration of sustainability.

RESULTS AND DISCUSSION

Figure 1 shows the three crops of highest economic value in Veracruz according to their value: industrial sugarcane ($50,165), orange ($27,693), and white maize grain ($8,768). Industrial sugarcane places Veracruz as the national leader with a yield of 69.85 t ha^{-1}. The state's harvest in the 2018 cycle made possible a sales flow of 15 billion 249 million pesos with a yield of 73.11 t ha^{-1} (SIAP, 2019). Regarding orange, Veracruz is also the national leader with an indicator of 14.87 t ha^{-1}, and a yield above the national average of 13.95 t ha^{-1} (SIAP, 2019).

White grain maize is a crop of high economic and social importance, due to the surface sown, the value of production, and from occupying 20% of the economically active population (INIFAP, 2017). On the national scale Veracruz ranks eighth in production, with yields of 2.25 t ha^{-1} (SIAP, 2018), lower than the national mean which is 3.2 t ha^{-1} (AgroDer, 2012).

Characterization of the Agroecological Spatial Environment

Social Dimension. Moringa producers had the highest

Table 3. Mathematical formulas used to estimate sustainability by dimensions and in general of Veracruz crops.

Dimensions	Model
Environmental	ES=((a1+2a2+a3+(2(b1+b2+b3+b4)/4))/7
Economical	ES=(2(c1+c2)/2)+d1+d2+d3)/5
Social	SS=(f1+(2(f2+f3))/2)+g1+h1+i1)/6
General	GS=(SA+SK+SS)/3

ES: Environmental sustainability; ES: Economic Sustainability; SS: Social Sustainability; GS: General Sustainability.

Table 2. Sustainability indicators for four Veracruz agroecosystems selected under the Bottom-up criterion and the PER model proposed by Sarandón and Flores (2009).

CV	Environmental	WF	KI	Economical	WF	KI	Social	WF
a1	Crop diversification	1	c1	Value ($/t)	1	f1	Scholarship	1
a2	Land preparation	2	c2	Yield (t/ha)	2	f2	Access to education	2
a3	Tillage type	1	d1	Commercialization	1	f3	Basic services	2
b1	Chemical fertilization	2	d2	External origin of inputs	1	g1	Training	1
b2	Control of pests and diseases	2	d3	Harvest destination	1	h1	Family involvement	1
b3	Weed control (chemical pesticide)	2				i1	Form of organization	1
b4	Packaging destination	2						

KI: Key of the indicator, WF: Weighting Factor.

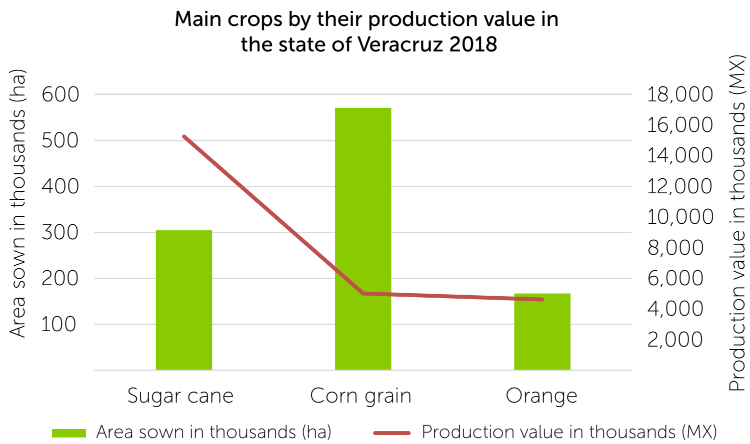

Figure 1. Conventional crops with higher production value in the state of Veracruz (SIAP, 2018).

level of schooling and training (Figure 2A), sugarcane and orange growers have the greatest access to basic services, while maize growers do not stand out in any area; it shoud be noted that most producers, except for moringa growers, have little or no training. In this sense, education and participation is an important aspect for social sustainability, since it is built from a local vision and requires the cooperation of the whole society (Masera *et al*., 2000).

Economic dimension. The highest unitary value per ton of biomass was for moringa followed by orange. The highest yield per ha is for sugarcane and orange followed by maize grain (Figure 2B). On the other hand, crops are highly dependent on non-renewable external resources, an aspect which makes them less sustainable. However, moringa has greater control over its value chain by transforming the biomass into finished product for delivery to the final customer, unlike sugarcane and maize grain agroecosystems that market their product without added value. On the other hand, when comparing the prices of traditional crops with respect to moringa, the low selling prices of sugarcane contrast with the high selling prices of moringa that allow very attractive yields to be obtained (Valdés-Rodríguez *et al*., 2014). In this sense, moringa presents an alternative for the primary sector as a high-value economic activity that promotes the reduction of working poverty.

Environmental dimension. Moringa shows high productive diversification; however, the other agroecosystems show a strong preference for monoculture, with an absence of diversification (Figure 2C). Fertilization, pest and disease control, and agrochemical container management are high impact actions that drive sugarcane, maize grain, and orange agroecosystems away from sustainability (Inés *et al*., 2013). This prolonged use of conventional practices implies greater dependence on external inputs. At the same time, intensive farming and monoculture degrade the soil, which increases dependence on fertilizers (Gliessman, 2003).

In contrast, moringa showed greater orientation towards sustainability, being a perennial tree that increases productive diversification, where biofertilizers and bioinsecticides are applied, as the leaves are the harvest product and for human consumption (Mota-Fernández *et al*., 2019). In addition, moringa does not require high application of agricultural inputs, compared to the high input demand of sugarcane, maize and citrus crops (Mrini *et al*., 2001).

Evaluation of Crop Sustainability

The results obtained from the evaluation of the indicators are presented in Figure 3. According to the findings on

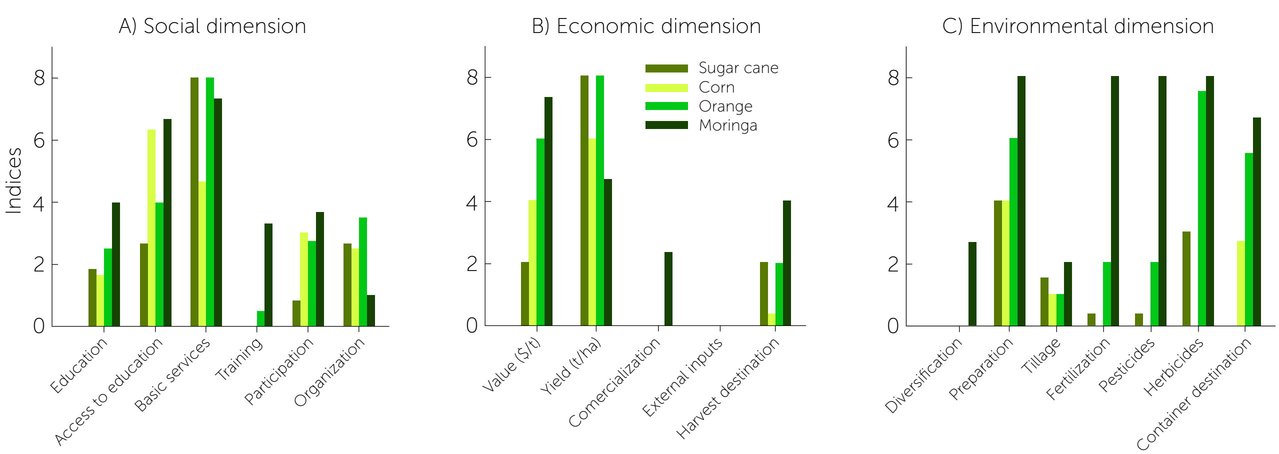

Figure 2. Indices of environmental sustainability of the four crops evaluated.

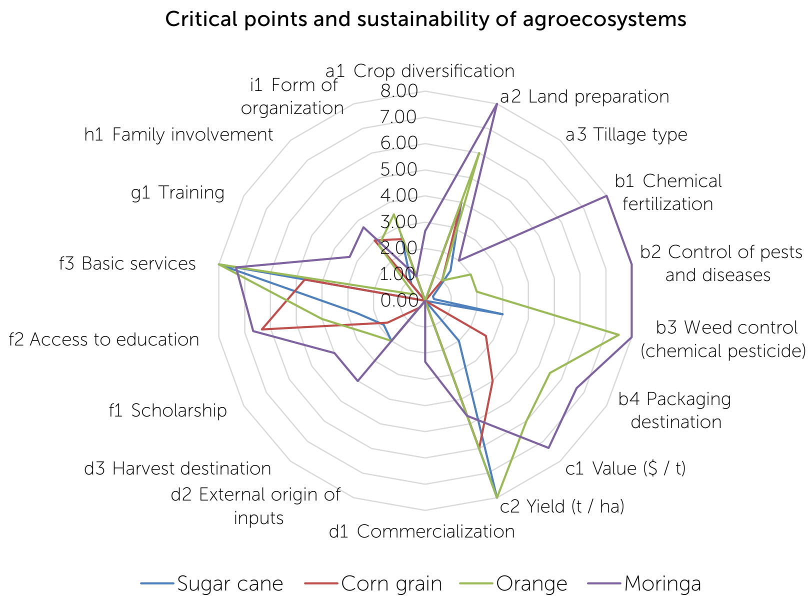

Figure 3. General sustainability index of the evaluated crops.

sustainability, the following critical points were identified that put it at risk:

Environmental dimension. Sugarcane, maize and orange crops generate practices with high negative impact on resources: land, water, air and soil. The presence of pests is recurrent due to monoculture. There is an excessive application of agrochemicals with negative impact on biodiversity, soil and water. The pressure they exert on natural resources causes them to move away from the best sustainable practices (Gómez-Limón & Arriaza Balmón, 2011).

Economic dimension. External dependence on non-renewable inputs was high in all four crops. In addition, however, sugarcane and maize grain lack a transformation process of fresh product that allows for added value; and there is a high degree of intermediaries. The economic sustainability of crops is associated with the benefits perceived by producers in the long term; it is important not to associate it with monetary retribution, but with management motivations and decision-making capacity to manage local resources efficiently (Meza & Julca, 2015).

Social dimension. For sugarcane, maize and orange producers, there was a lack of training and organization of producers, lack of standardization of production processes, and low educational level of producers. In order to aspire to social sustainability, there must be a starting point, such as the measurement of the social dimension that seeks to evaluate the quality of life, social integration and producer satisfaction (Sarandón *et al*., 2006).

General Sustainability

The overall evaluation shows that moringa stands out in each of the dimensions by obtaining the highest sustainability value, followed by oranges, while the farthest crop was maize (Figure 4).

CONCLUSIONS

According to the Sarandón and Flores (2009) model, moringa had the highest level of sustainability because of its low environmental impact due to the minimal use of agrochemicals, good solid waste management, high market value per ton processed, producer training, and community integration. White maize had the lowest level of sustainability due to its high environmental impact and loss of biodiversity, followed by sugarcane and orange.

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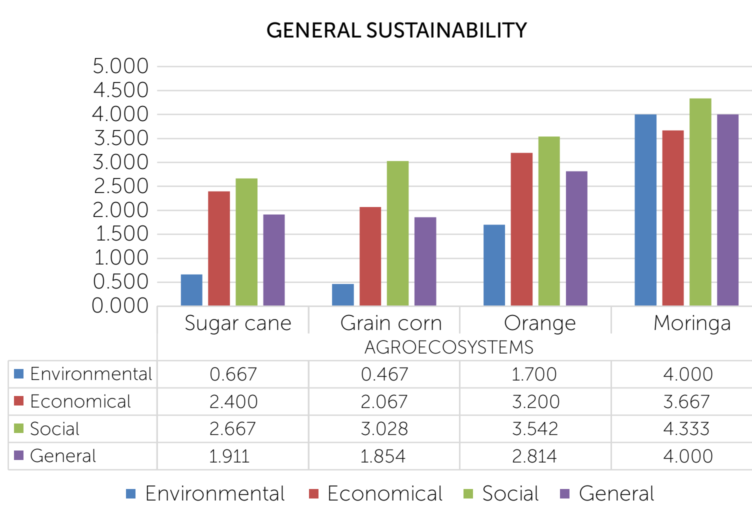

Figure 4. General sustainability of the evaluated crops.

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