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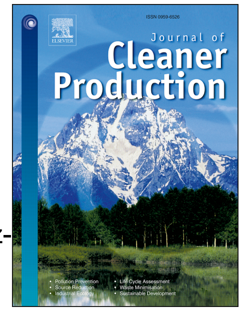

Evaluation of the sustainability of hybrid and native maize production systems

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Abstract

This paper investigates the sustainability of two maize production systems, native and hybrid, in two different agro-climatic areas of Mexico. Farmers from each system were surveyed, and the following data on agronomic management were collected: use of fertilizers, insecticides, type of irrigation, area sown with crops, number of crop cycles, diversity of crops, and livestock associations. Certain production characteristics such as yield of grain and management of crop residues were also recorded. Using the IDEA method, the sustainability level was scored for the agroecological, socio-territorial, and economic dimensions of each system. On a 100-point scale, the native maize production systems obtained their highest score in the agroecological dimension and lowest scores in the socio-territorial and economic dimensions. In the latter two dimensions, the hybrid maize production systems obtained a higher score. In the socio-territorial dimension, the native maize production systems obtained the highest scores for indicators of ethics and human development, which were important consolidating aspects of this system. These systems also received high scores for environmental and landscape valuation, autonomy and valuation of local resources, and their contribution to global food balance but, overall, were still superseded by hybrid maize production systems in this dimension. Meanwhile, in the economic dimension, poor scores were obtained in native maize production systems due to the lack of investment in infrastructure, poor economic viability and efficiency of production processes, and the need for external support/financial aid. However, the native maize production systems scored comparatively better in the agroecological dimension and supported greater diversity of annual crops and animals as well as better management of fertilization, organic material, and water

1. Introduction

The maize production sector consumes an important amount of resources yet also provides unquestionable benefits in terms of supplying food, enabling livelihoods, and functioning as an engine of economic growth. However, agriculture also contributes toward greenhouse gas emissions and climate change. According to the Research Group on Climate Change, Agriculture, and Food Security (CCAFS), worldwide agriculture contributed 13.5% of greenhouse gases (Sanhueza, Duery and Arévalo, 2013). According to different authors (Challinor, 2009; Chakraborty, 2011; Bender, 2011), crops may in turn be affected by climate change, which can modify crop phenology, increase crop diseases, create water stress, or affect other aspects of crops.

In 2013, Mexico was identified as one of the countries most affected by climate variability (Kreft *et al.*, 2015). Furthermore, maize production is the main peasant farming activity in Mexico. Nearly 2 million peasant producers participate in this activity, and 85 percent have less than five hectares.

Overall, 8 million hectares of maize are cultivated throughout Mexico, resulting in an annual production of 18 million tons. Currently, more than half of Mexico´s arable land is planted with maize. Maize is an important crop in Mexico considering its cultivated area and its cultural significance at the local level (González and Ávila, 2014). White maize represents around 90% of production volume and is destined for human consumption (SAGARPA, 2014). The State of Mexico are two main types of maize producers described in Table 1, 13.55% of production is destined for self-consumption (SAGARPA, 2014). The state of Mexico is the third largest producer of maize at the national level (SIAP, 2014). This state also has the largest number of producers, 3.2 million, who mostly belong to ejidos, or communal lands where agriculture activities are administrated by an Ejidal Commissariat or ejido chief. This number is high considering that there are only 4 million agricultural producers in the entire country (Table 1).

In particular, Sinaloa also stands out from other Mexican states, as this state now occupies first place in terms of maize production and has shown record production in recent years (SIAP, 2014). In Sinaloa, the most modernized form of agriculture in the country is practiced, which enables high productivity (Table 1). Agricultural areas constitute 33.63% of the state's area, or 1.18 million ha, of which 41% have irrigation infrastructure; the remaining 59% are composed of seasonal agriculture (García, 2010).

→Please insert Table 1 around here

Masera *et al*. (1999) proposed the use of a diagnostic evaluation for agroecosystems (agricultural systems), given differences in practices and production systems, in order to describe and determine their levels of sustainability. In this way, more integrated management proposals may be created and based on the identification of the limitations affecting the functionality of systems as well as their causes. In addition, the future possibilities and strong points of a system can be highlighted. Another evaluation system was developed by Jiang *et al*. (2016), who recommended the use of a carbon quota and carbon transaction mechanisms based on an established total for carbon emissions. These authors considered the control of carbon emissions to be an important policy instrument that can encourage emitters to reduce carbon emissions.

The IDEA (Indicateur de durabilité des exploitations agricoles) method is a tool that integrates several dimensions of sustainability, including agroecological, socio-territorial, and economic, and gives an overall panorama of the current state of a production system. The indicators corresponding to each dimension allow for the detection of specific problems or particular limitations that may be subsequently addressed in order to improve the sustainability of the system (Zahm *et al*., 2008).

The IDEA method has been used in several different contexts. M´Hamdi *et al*. (2009), Bir *et al*. (2011), and Fadul *et al*. (2011) evaluated the sustainability of dairy farms. Authors like Subić, Jeločnik, Ivanović, (2012).and Zahm *et al.* (2008) applied the IDEA approach to determine the sustainability of farm, and Thivierge *et al*. (2014) adapted and developed this set of indicators to measure the environmental sustainability of different agriculture.

This study used the IDEA method to evaluate the sustainability of native and hybrid maize production systems. Moreover, detailed sustainability indicators are reported, which can help the scientific and social community to evaluate and identify critical points in maize production, as maize forms a basic and essential part of the diet and the main crop of Mexico. Also, this study can help to guide agricultural practices and policies in concordance with the economic and environmental performance of different maize production systems.

2. Materials and methods

Hybrid and native maize systems were selected from two different agro-climatic areas with different agricultural management, landraces, and utilization of technology in order to evaluate differences in their levels of sustainability.

Crop lands forming part of these systems were selected using a non-probability sampling method (Maroco, 2007). Native maize production systems corresponded to the State of Mexico and hybrid production systems to the state of Sinaloa.

Visits to producers and their parcels were carried out weekly. Surveys and semi-structured interviews were applied, and a check list was used to ensure that all necessary information had been obtained. In this way, accurate information was directly obtained from the producers. Data were collected from March to December 2015.

2.1 Description of the native maize production systems: NMPS

The first study area corresponds with the municipality of Morelos, located in the northwestern portion of the State of Mexico, Mexico, with the geographic coordinates of 19º 36’ 11’’ N and 99º 31’ 11’’ W and an altitude of 2705 masl. The study area has an extension of 236.32 km^2, which represents 0.99% of the state’s area (INEGI, 2015a).

Producers of the State of Mexico plant 4 varieties of maize: white, yellow, cacahuacintle, and black.

Farm animals are also present, including dairy cows, horses, sheep, and other farmyard animals such as chickens and turkeys. Likewise, these parcels are fertilized with manure, and maize production relies only on rain water.

2.2 Description of the hybrid maize production systems: HMPS

The second study area is located in Culiacan in northwestern Mexico at an altitude ranging from 0 to 10 masl and has a territorial extension of 4,758 km^2, representing 10.96% of the state of Sinaloa’s area. This area was located at the following geographic coordinates: 25° 17’ N and 107° 49’ W (INEGI, 2015b).

In the parcels selected to evaluate the production of hybrid maize, producers are dependent on hybrid seeds and agrochemicals. Agriculture management is based on modernized production systems with high yields.

2.3 Evaluation of sustainability

Sustainability was evaluated using the IDEA method (Zahm *et al.* 2008). Each indicator has a maximum score, and each dimension has a maximum value of 100.

The final sustainability score of a livestock or agricultural farm is defined by the lowest value of the three dimensions and, thus, by the weakest aspect of the system (Vilain *et al.*, 2008).

2.3.1 Agroecological dimension

The agroecological dimension is integrated by 18 indicators and addresses the efficiency of the system in its use of environmental resources, consisting of three main components: local diversity, agricultural practices, and management of nutrients and organization of space (Zahm *et al*., 2008).

2.3.2 Socio-territorial dimension

Similar to the agroecological dimension, the socio-territorial also consists of 18 indicators and has three main components: quality of products and the surrounding environment, employment and provision of services, and ethics and human development.

2.3.3 Economic dimension

Lastly, the economic dimension has a total of 6 indicators, spread over the following four components: economic viability, independence, transmissivity, and efficiency.

The IDEA method enables the different components of sustainability to be examined in an integrative manner and assesses the overall state of a system, as this tool encompasses three integrated dimensions of the sustainability concept. Furthermore, this tool has the capacity to underscore the strengths and weaknesses of a system in a detailed manner. Finally, this tool allows producers to review a diagnostic of their production system in which the critical points or weaknesses are highlighted; if these points are addressed, the sustainability of a system may possibly improve.

2.4 Statistical analysis

In order to identify differences in sustainability between the maize production systems and their distinct dimensions, Kolmogorov-Smirnov tests were applied to determine if the resulting scores of the indicators varied significantly with respect to a normal distribution. After the data was determined to have a normal distribution, the datasets were analyzed by a model with a completely randomized design and Tukey’s average comparison test ($P \leq 0.05$). These analyses were carried out in the SAS statistical software (Statistical Analysis System, 2004).

3. Results

3.1 Description of the native maize production systems (NMPS)

For the NMPS, the number of hectares per producer ranged from 0.5 to 4, and several landraces, or varieties of native maize, were identified. White maize was the predominant variety and represented 41% of production, followed by yellow (33%), black (13%), and cacahuacintle (13%) maize varieties. Across 40% of the surface area dedicated to native maize, other crops are also cultivated, including peas (20%), fava beans (14%), and other

miscellaneous crops (6%). Planted seeds are selected in their entirety from the previous harvest, although 47% of these were obtained from exchanging seeds with family members or neighbors. Seasonal crops are predominant and represent 61% of crops. For the remaining portion of the crop area, other means of irrigation are employed, including flood irrigation (20%), habitual irrigation (11%), and channel irrigation (8%). On only 4% of farms, farmers own and operate their machinery, while the remaining 96% rent machinery specifically for the preparation of soil for planting. With respect to fertilizer use, 82% of farms used mixed fertilizer, or a mixture of chemical and organic fertilizer; 14% chemical fertilizer; and the remaining 4% only organic fertilizer. In the case of organic fertilization, dry manure was applied to 54% of the area, fresh manure to 31%, and composted manure, prior to application, to 15%. Finally, NMPS are largely systems of low yield in terms of grain/ha (Table 2). Crop residues are often destined for animal feed, and remaining stubble may be incorporated into the soil with machinery. This method is considered by farmers as a means of controlling weeds and supplying organic matter and nutrients to the soil.
→Please insert Table 2 around here

3.2 Description of the hybrid maize production systems (HMPS)
For the HMPS, the number of hectares per parcel ranged from 4 to 154. Parcels as a whole were monocrops, planted with 1 of 6 hybrid maize varieties, predominantly DK-2038 and 30P49, which were cultivated in 33% of the crop area, along with Caribu and other varieties in 20% and 15% of the crop area, respectively (Table 3). A total of 19% of the surface area was interspersed with different crops, such as wheat (8%); sesame (5%); and sorghum, beans, and garbanzos (6%). All of the planted seeds (100%) were bought directly from agrochemical distributors. Channel irrigation was the dominant irrigation method and was employed for 81% of crops. The remaining crops were seasonal. Agricultural labors are completely carried out with private/own equipment. Fertilization is entirely chemical. The average harvest is 11 tons per hectare, and 100% of the stubble is integrated into the soil during tilling, which is carried out before the following agricultural cycle (Table 3).
→Please insert Table 3 around here

3.3 Evaluation of sustainability
NMPS received a sustainability score of 51.23 and HMPS a score of 42 (Table 4).
3.3.1 Agroecological dimension
The NMPS has the highest scores (90) for the agroecological dimension, while HMPS received a score of 42. This difference may be mainly attributed to the lack of diversity in annual crops and animals (7.3) in HMPS, along with their dependence on energy (5.33), type of fertilization (4.9), and practices surrounding the management of organic matter (3.96), which all received comparatively lower scores. Considering all factors, the NMPS systems had an overall difference of 48.7 points, and, if these particular points are addressed in the HMPS, the sustainability score of this dimension could improve (Table 4).
3.3.2 Socio-territorial dimension
The sustainability score for the socio-territorial dimension of HMPS was 72, while NMPS received a score of 52. This difference is due to the superior scores received for the direct supply chains of the first system as well as opportunities for collective work; standards for

hospitability, hygiene, and safety; and contribution toward employment, which received scores of 5, 4, 2, and 4 points higher, respectively, than the corresponding scores of NMPS. If the latter system addresses these previous points, its socio-territorial dimension could be raised to a score of 67 (Table 4).

3.3.3 Economic dimension

The sustainability score for the economic dimension of HMPS was 76.06 and for NMPS was 51.23. In the case of NMPS, production activities are generally geared toward the family and fulfilling the needs of autoconsumption, which is also a reflection of cultural heritage and preferences. In this system, crop excesses are not a priority. The corresponding income levels and lack of investment in infrastructure disable this system from becoming more economically profitable or viable. Often, these familial enterprises are reliant on governmental support. Therefore, by a margin of 24.87 points, these factors differentiate the systems and demonstrate the weak points of the NMPS. Correspondingly, HMPS could also improve its score by 14 points upon improving its apparently low transmissibility, which would enable a potential score of 90 (Table 4).

→Please insert Table 4 around here

4. Discussion

4.1 Agroecological dimension

The final sustainability value for NMPS in the State of Mexico is consistent with the findings of Bird *et al*. (2011) who evaluated model dairy farms in Algeria. In the latter study, the agroecological dimension also had the highest value and represented the strongest aspect of the system. These findings may be attributed to high plant and animal diversity, low use of pesticides and fertilizers, low dependence on energy, and an adequate management of organic matter. For HMPS, the values obtained for the indicators of the agroecological dimension are low due to low crop diversity and few crop-animal associations. This was also mentioned by Schiere *et al*. (2002), in which interactions and associations between crops and animals were found to improve agroecological balance and represented an additional element of long-term sustainability. Mixed crop-animal systems generate less pollution, as the output of one system may serve as a resource or input for another.

Herrero *et al*. (2010) and Mc Dermott *et al*. (2010) mentioned that the integration of animal manure plays an important role in improving the equilibrium of nutrients in the soil and during crop production. The IDEA method attributes up to 5 points to the practice of organic fertilization from compost. Although 87% of farmers apply manure fertilizer, only 12% adequately perform this practice by first composting the manure, while another 50% apply manure after two weeks of drying. The remaining percentage of farmers apply fresh manure. The latter method presents a contamination risk, as the phosphorous content is susceptible of being leached, or manure may contaminate water supplies rather than improve the equilibrium of nutrients in soil.

4.2 Socio-territorial dimension

The results obtained for NMPS in the socio-territorial dimension are similar to the evaluation of the sustainability of dairy farms in Tunisia (M´Hamdi *et al*. 2009), where the socio-territorial dimension was the least favorable due to the low creation of employment and scarce access to services and commercialization networks. In the case of the NMPS in the present case study, no commercialization networks have been formed for the sale of maize since 5% of maize is used to obtain seeds, 20% for livestock feed, and the remaining 75% for either direct sale or sale by means of an intermediary. In this scenario, supply chains capable of guaranteeing higher incomes are inexistent. Collective collaboration with other farmers is also uncommon since agricultural tasks are largely performed by family members or supplemented by family labor, although 15% of operations do hire labor for preparing the terrain or during harvest.

4.3 Economic dimension

FAO (2012) designates agricultural and food cooperatives as important vehicles for reducing poverty, generating employment, and contributing to socioeconomic development and food security. In addition, these operations provide important services to their members, such as access to production inputs, markets, and information, in addition to opportunities to communicate with other members and participate in decision-making processes. For NMPS, our results showed a lack of cooperatives in contrast with HMPS. This is one reason that contributes toward the difficulties that small farmers face in obtaining fair prices for their products. Without cooperatives, farmers do not have group benefits or means of accessing consolidated purchases and production inputs of reduced price, or any of the benefits that could result from group efforts. In contrast, due to their cooperatives, HMPS farmers are able to obtain consolidated prices for maize and have greater access to means of investment, training, and purchase of machinery, in addition to superior support for managing pests and crop diseases.

In the sustainability evaluation of Tunisian dairy farms (M´Hamdi *et al*. 2009), upon examining the specific indicators, the low score for the economic dimension was associated with a low rate of adopting new technologies. In the case of the present study for NMPS, the low rate of adoption of technology also negatively affected the score for the economic dimension, in addition to the low efficiency of production processes and low productivity. In this system, the standard production yield of maize is 3 tons/ha. This relatively low yield renders these enterprises less economically inviable, especially considering the low market prices for maize and high dependence of these farmers on government subsidies.

5. Conclusions

The lowest sustainability scores for NMPS in the State of Mexico were 52 and 51 for the socio-territorial and economic dimensions, respectively. Meanwhile, for HMPS in Culiacan, Sinaloa, the lowest score was 42, corresponding with the agroecological dimension. NMPS should address the economic dimension of production, primarily by improving economic viability and the efficiency of production processes and reducing the need for external support/financing. Meanwhile, HMPS should consider improvements to its agroecological dimension, mainly in terms of incorporating greater diversity of crops and animals, improving their management of organic matter and fertilization practices, and reducing energy dependence.

An additional consideration is that the IDEA method favors the practice of applying organic fertilizer (manure). However, it does not penalize the potentially negative effects resulting from manure application. For instance, fresh manure without sufficient maturation time may cause contamination as a result of mineralization, specifically of phosphorous. In the present study, 87% of farmers apply manure, but only 12% apply matured, or composted, manure.

The IDEA method assigns a high value (20 points) to transmissibility, which describes the capacity of a system to be inherited and passed along to successors. Although in reality, NMPS has begun to lose its capacity to be transmitted from generation to generation as part of the logical consequence of a lack of successors due to its low profitability. For systems of high profitability that generate greater income, successors will be less likely to sell or abandon operations.

The sustainability indicators reported in this study can help the scientific community and authorities to evaluate and identify the critical points in maize production systems in order to guide future agricultural practices and sustainable policies.

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Tables

Table 1. Description of the maize production systems of the evaluated states in Mexico

State	Type of production	Number of producers (10^3)	National production (%)	Annual production (million tons)	Types of maize producers	Producers (%)	Surface area (ha)	Annual Production %
State of Mexico	manual	274.83	8	2.036	1st group (Small producer)	92	0-5	56.4
					2nd group (Medium producer)	7.9	<5	43.6
Sinaloa	mechanized	29.95	22	5.380	Irrigation	44.49	35-1500	98.04
					Temporary	55.57		1.95

Source: SAGARPA (2010).

Table 2. Description of the native maize production system (NMPS)

Variables	Description		Surface area (%)	Farmers (%)
Planted variety	White		41	70
	Yellow		33	5
	Black		13	15
	Cacahuacintle		13	10
Seed origin	Own seeds		53	60
	Exchanged seeds		47	40
	Bought seeds		/	/
Soil preparation	Use of machinery		96	93
	Manual		4	7
Type of irrigation	Seasonal		61	70
	Channel		8	17
	Flood		20	10
	Habitual		11	3
Type of fertilizer	Chemical and organic		82	80
	Chemical		14	13
	Organic		4	7
Type of organic fertilizer	Dry manure	Cow/horse/sheep/hens	54	50
	Fresh manure	Cow/horse/sheep	31	38
	Composted	Cow/sheep/worm	15	12
Applied agrochemicals	Herbicides and fungicides		34	33
	Herbicides		45	33
	None		20	30
	Fungicides		1	4
Crop associations	Yes	Peas	20	23
		Fava beans	14	17
		Squash	6	7
	No		60	53

Source: Authors.

Table 3. Description of the hybrid maize production system (HMPS)

Variables	**Description**		**% Surface area**	**% Farmers**
Planted variety	DK-2038		33	30
	30P49		32	20
	Caribú		20	17
	Cebú		6	7
	P3258W		5	13
	DK-2030		4	13
Seed origin	Own seeds		/	/
	Seeds from exchange		/	/
	Purchased seeds		100	100
Soil preparation	Machinery		100	100
	Manual		/	/
Type of irrigation	Seasonal		19	23
	Channel		81	76
	Flood		/	/
	Habitual		/	/
Type of fertilizer	Chemical and organic		/	/
	Chemical		100	100
	Organic		/	/
Type of organic fertilizer	Dry manure	Cow/horse/sheep/hen	/	/
	Fresh manure	Cow/horse/sheep	/	/
	Composted	Cow/sheep/worm	/	/
Applied agrochemicals	Herbicides and fungicides		/	/
	Herbicides		/	/
	None		/	/
	Fungicides		100	100
Crop associations	Yes	Wheat	8	3
		Sesame	5	7
		Sorghum	3	10
		Beans	1	13
		Garbanzo	1	3
	No		81	63

Source: authors.

47 **Table 4. Scores for the sustainability indicators of two maize production systems**

Components	Indicators	Maximum points	NMPS score	HMPS score
	Agroecological dimension			
Local diversity	Diversity of annual and seasonal crops	0-14	9.267	2.567
	Diversity of perennial crops	0-14	4.600	4.000
	Animal diversity	0-14	9.633	1.833
	Valuation and conservation of genetic resources	0-6	6.000	3.000
Spatial organization	Crop rotations	0-8	8.000	4.000
	Size of parcels	0-6	2.067	1.000
	Management of organic matter	0-5	3.967	0.000
	Areas with ecological regulations	0-12	9.133	4.567
	Contribution to environmental challenges	0-4	4.000	2.000
	Valuation of space	0-5	0.567	0.433
	Management of forage supply	0-3	1.367	0.000
Agricultural practices	Type of fertilization	0-8	4.900	0.000
	Organic, liquid effluents	0-3	3.000	3.000
	Use of pesticides	0-13	10.033	10.000
	Veterinary treatment	0-3	3.000	2.667
	Protection of soil	0-5	2.400	2.000
	Water management	0-4	3.800	1.000
	Energy dependence	0-10	5.033	0.000
	Total sum	100	90.767	42.067
	Socio-territorial dimension			
Quality of products and the surrounding environment	Quality assurance processes	0-10	0.000	3.000
	Valuation of built environment and landscape	0-8	6.467	3.000
	Management of non-organic waste	0-5	0.433	2.000
	Accessibility of spaces	0-5	4.467	4.000
	Social participation	0-6	1.433	3.067
Employment and provision of services	Value of direct supply chains	0-7	2.000	7.000
	Autonomy and valuation of local resources	0-10	8.833	6.000
	Provision of services/diversification of activities	0-5	0.100	3.000
	Contribution to employment	0-6	2.000	5.600
	Collective work	0-5	1.000	5.000
	Permanence/long-term stability	0-3	1.033	3.000
Ethics and human development	Contribution to global food balance	0-10	7.600	6.167
	Animal well-being	0-3	2.167	0.467
	Training of human capital	0-6	2.600	5.133
	Intensity of work	0-7	4.333	3.000
	Quality of life	0-6	4.533	6.000
	Degree of isolation	0-3	2.933	3.000
	Hospitality, hygiene, and safety	0-4	0.333	4.000
	Total sum	100	52.267	72.433
	Economic dimension			
Economic viability	Economic viability	0-20	3.467	20.000

	Degree of economic specialization	0-10	8.600	8.000
Independence	Financial autonomy	0-15	6.600	8.000
	Need for external support/financial aid	0-10	2.000	10.000
Transmissibility	Transmission of capital	0-20	20.000	5.067
Efficiency	Efficiency of production processes	0-25	10.567	25.000
	Total sum	100	51.233	76.067

Highlights

- The IDEA method was used to assess the sustainability of two maize production systems: native and hybrid.
- The agroecological dimension of sustainability was higher for native maize production systems, while the economic dimension was favored in hybrid maize production systems.
- The IDEA method favors certain practices and scores them highly without considering if these practices are performed correctly.
- The results of the IDEA method indicated the critical points of the production systems that can be improved.

In the last days, the research paper was sent Evaluation of the sustainability of hybrid and native maize production systems manuscript number JCLEPRO-D-16-05690, which was accepted however unfortunately the encountered a problem with some the electronic files:

In response to these observations, I included in the information I had previously written to Prof. Cecilia MVB Almeida and Rodrigo Lozano, PhD Co-Editor-in-Chief with the same information through mail because we could not upload the files to the magazine platform.

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