Article

Socioeconomic and environmental sustainability of rainfed maize production systems

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Abstract

The work was carried out in the state of Campeche through surveys with rainfed maize producers to describe the technological, management, socioeconomic and cultural characteristics of the production systems. Two multivariate analysis techniques were used to reduce and classify the information. For the environmental analysis, a sustainable agricultural aptitude index was generated with information on the physical-chemical characteristics of the soil. The results indicated that 65.5% of the producers that were interviewed used the conventional system for the production of rainfed maize, and although they were located in areas with an agricultural vocation, differences in technification and socioeconomic differences were identified. The other 34.5% of producers use minimal tillage and were located in areas with a livestock vocation. Despite the fact that the sustainable agricultural aptitude index placed 71% of the producers within the moderate category, it is necessary to implement strategies to minimize the extraction of nutrients in the soil since the producers pay very little when applying doses below the recommended. Negative values were obtained in the indicator of anaerobic potential mineralization of nitrogen associated with soil fertility in the two predominant soil groups Leptosols with -14.7 and Vertisols with -27.9.

Keywords: categorization, indicators, production systems.

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Introduction

From a food, political, economic and social point of view, corn production is one of the most important agricultural activities in Mexico (González and Alferes, 2009; Fernández *et al*., 2013). That is why it is highly demanded, since an annual consumption of 41.9 million tons is estimated, of which 57.6% correspond to white corn and whose production is self-sufficient and 42.4% correspond to yellow corn, but with a deficit trade balance having than import 80.2% of national consumption (FIRA, 2016).

Today, it is not enough to satisfy consumption and guarantee the country's food security, which is one of the main challenges of the agri-food sector (SAGARPA, 2013), the production of corn must be not only productive and profitable but also fair and sustainable. In this sense, several studies have been carried out to characterize and subsequently evaluate the different resource management systems for production. Only in Mexico there are approximately 34 studies that describe 25 case studies of different systems: agroforestry, agrosilvopastoral, commercial and basic crops, grasslands, forestry and aquaculture (Astier *et al*., 2012).

These include the peasant systems for the production of corn and milk (Brunett *et al*., 2005), which compare the sustainability of different types of milpa, traditional and with corn in monoculture (Sánchez and Romero, 2018), and even comparisons with respect to the peasant corn system and the diversified crop system (Astier *et al*., 2003), on traditional management and in transition to the agro-industrial system (Sánchez-Morales *et al*., 2014).

Consequently, the objective of this work was to carry out a socioeconomic and environmental characterization of the rainfed maize production systems in the state of Campeche, to generate pertinent information to propose improvements towards a sustainable production of maize in the state.

Materials and methods

The study was carried out in ten of the eleven municipalities of the state of Campeche, with the exception of Palizada during the spring-summer 2014 cycle. Information was obtained on the management of the rainfed maize crop through a direct interview with the producer with a questionnaire script. Structured on different topics such as: 1) technological and management (land preparation, type of machinery used, condition of the soil in the plot, sowing dates, type of seed, technology used, fertilization dose (kg ha^{-1}). Pest and disease control activities, place of sale, production supports); and 2) socioeconomic (planted area (ha), production objective, land tenure, government support and yields (t ha^{-1}). Sample size was calculated for a population of 20 000 producers with the sampling equation simple random for the estimation of proportions with the maximum variance condition, 95% confidence and 5% precision (Taro, 1967).

The variables in the questionnaire were tabulated as nominal dichotomous and ordinal. A factor analysis was performed to summarize the information and to describe it more easily. The factorization method that was used was the main components, which was calculated from the correlation matrix and the Varimax method was used for the rotation of the component solution (Landero and González, 2011).

The solution of each of the factors was saved as new variables in the original database that was subsequently used for the analysis of non-hierarchical grouping with the k-means technique (de la Garza *et al*., 2013). Once the classification was made, a new variable was generated with this information and the analysis of variance was carried out taking as a factor the group of belonging of each producer.

On the other hand, the environmental variables were obtained from the information of the homogeneous response units (URH) generated by Cano-González *et al*. (2015) for the sustainable productive zoning of corn cultivation in the Yucatán Península. Because these URH were formed from the interactions of soil types (IUSS, 2007), relief (degree of terrain slope) and type of vegetation or land use (INEGI series 3), the data of the variables were extracted. Physicochemical (organic matter (OM)= %, cation exchange capacity (CEC) = %, clay (ARC)= % and thickness of the first layer of soil =E (cm)) of each URH associated with the producer's plot.

With these variables the pedotransference functions (FPT) proposed by Aguilar *et al*. (2011); Aguilar and Bautista (2011), which served as environmental indicators of soil fertility for agricultural use to identify possible restrictions or degradation due to land use and management. From the FPT and considering also the first soil layer (E), a sustainable agricultural aptitude index (IAAS) was generated for each subgroup of soil following the function proposed by Aguilar and Bautista (2011): IAAS= (RMOD∗0.25) + (DC∗0.25) + (MPAN∗0.25) + (E∗0.25).

Where: RMOD= retention of dissolved organic matter (%); MPAN= anaerobic potential nitrogen mineralization (mg kg^{-1} soil); DC= carbon decomposition (mg kg^{-1} soil); E= thickness of the first layer of soil (cm). Subsequently, the values of each of the IAAS components were transformed into percentages, assigning equal weights (0.25) per variable, to generate categories (suitable, moderate and marginal) of the URH according to their suitability for sustainable agricultural use, considering that the most suitable soils are those with the least potential vulnerability (Aguilar *et al*., 2013).

The characterization of the rainfed maize production systems was carried out based on the main determinants proposed by Mansera *et al*. (1999) with the description of various components such as: technological and management, socioeconomic and cultural and biophysical. Descriptive statistics and multivariate analyzes were performed with the Statistical Package for the Social Sciences (SPSS) version 21 tool.

Results and discussion

It was found that the variables related to the soil condition of the plot and with the way of carrying out cultural activities such as plowing, fallow or plowing, light and agricultural harrow, spraying with a tractor and a combine harvester were adequate for the factor analysis. Eight components were extracted from the analysis, but following the Kaiser criteria, only the components that had the most information on the factors of the variable with eigenvalues >1 were selected (Landero and González, 2011; de la Garza *et al*., 2013).

The first component had an eigenvalue of 3.25, the second component with an eigenvalue of 1.23 and the third component an eigenvalue of 1.11. Taken together, these three components fulfilled the criterion of the percentage of accumulated explained variation, a range of between 60 and 95%, since the percentage of explained variation of the three components was 69.84%. Three groups of producers were formed. The first with 217 producers (34.5%), the second with 327 producers (52.2%) and the third group with 83 producers (13.3%).

Technological and handling characteristics

The first group belongs to a type of minimum tillage production (Rojas, 2001) since only 28.1% used agricultural harrow for preparing the land. The sowings were carried out in the month of June with native seed preferably and with yields that ranged from 2 to 3.7 t ha^{-1}. The work was carried out manually, including planting, hence the majority of this group of producers did not exceed extensions of cultivated area of 3 ha (Table 1).

Table 1. Technological and management characteristics of the storm maize production systems in Campeche.

Determinants	Sample producer group		
	1	2	3
Planting date	June 11-20	July 01-10	July 11-20
Seed type	57.6% creole, 18.9% hybrid, 12.0% variety and 11.5% recycled	69.4% hybrid, 12.2% creole, 9.5% variety and 8.9% recycled	81% hybrid, 8.3% variety, 6% creole and 4.7% recycled
Sowing	manual/espeque	62.9% seeder 37.1% manual/espeque	79.8% seeder 20.2% manual/espeque
Fertilization	43.8% did not fertilize, 30.4% at 30 days after planting, 19.8% at 15 of planting and 6.0% together with planting	64.2% together with planting, 14.4% at 15 days after planting, 12.8% at 30 days after planting and 8.5% did not fertilize	83.3% together with planting, 11.9% at 15 days after planting, 1.2% at 30 days after planting and 3.6% did not fertilize
Pentaphosphate (kg ha^{-1})	26.4	62.8	77.6
Nitrogen (kg ha^{-1})	13.4	26.6	32
Harvest	manual	54.7% machinery and 45.3% manual	75% machinery and 25% manual

In a study carried out in Chiapas regarding the attitudes and perceptions of producers of rainfed maize towards improved seeds, Sánchez-Toledano *et al*. (2017) typified farmers as conservatives by showing resistance to the use of improved seeds and greater interest in socio-cultural objectives such as maximizing family benefits, preventing the depopulation of rural communities and maintaining soil fertility (Sánchez-Toledano *et al*., 2017).

The producers of the first group were geographically concentrated in the southern part of the state: 20.3% Candelaria, 20.3% Carmen, 18% Calakmul, 15.2% Escarcega and 26.2% in the northern part of the state (Figure 1).

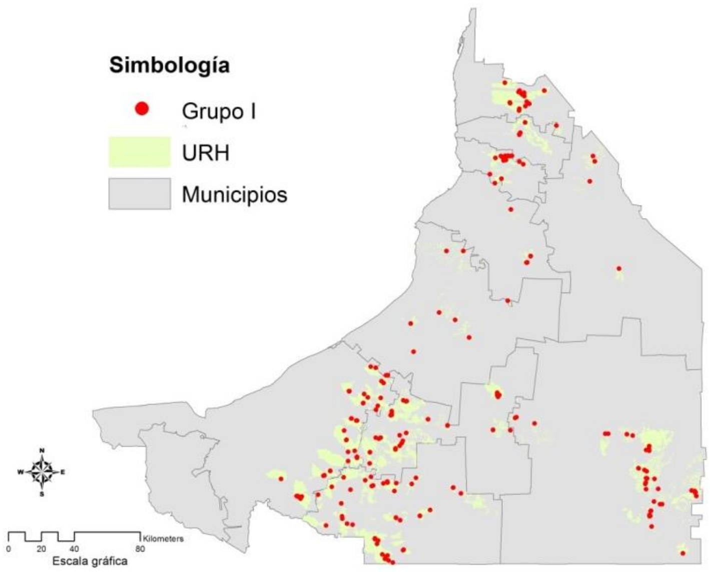

Figure 1. Geographical distribution of the first group of rainfed maize producers.

These areas, north and south of the state, are characterized by a moderate and marginal aptitude for agriculture with the development of mainly rainfed crops, among which corn and pepper stand out, oriented to self-consumption and surplus to the local market (Uzcanga *et al*., 2010). On the other hand, both the second and the third group of Campeche producers use conventional tillage (Rojas, 2001), since it was identified that they use plow, harrow passes and cultivators to move the soil.

The second group was located mainly in four municipalities, 21.7% Hopelchen, 13.5% Champotón, 13.8% Tenabo and 10.1% Campeche, which corresponds to the north-central area of the State. These producers planted during the first days of the month of July and although the preference for hybrid seeds prevailed, 30.6% of the producers planted other types of seeds from which those of creole origin stand out.

The percentage of producers that use sowing machinery is very similar to that that uses hybrid seeds and in the same way for those that sow manually and use other materials. Pat *et al*. (2013) these types of producers are known as regional producers and they generally make up and do not carry out all the activities of the technological package (Figure 2).

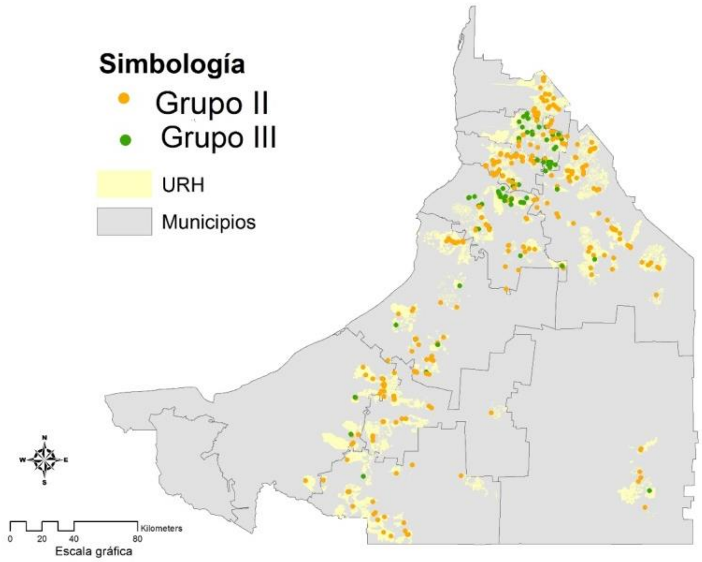

Figure 2. Geographical distribution of the second and third group of rainfed maize producers.

The third group of producers carried out fallow and fallow activities that the second did not, which coincides with Tucuch *et al*. (2007) as a deep-rooted work among producers of rainfed maize in high potential areas. It was also identified that the most frequent planting date was during the period from July 11 to 20, a date that was within the optimal period (June 15 to July 15), for this type of tillage according to (Medina and Rosado, 2015), with a high preference for hybrids and the use of machinery to carry out the cultivation tasks (Table 1).

Most of these producers were grouped in two municipalities, 41.7% Hechelchakan and 35.7% Campeche. Particularly, in the municipality of Hecelchakan, as indicated by Pat *et al*. (2013), one of the most important Mennonite regions in the state is located, which mostly owns agricultural machinery and uses a technological package of improved mechanized fertilized storm (TM/FM).

Socioeconomic characteristics

Regarding socioeconomic characteristics, the prevalence of common tenure of the plots was observed. The surface varied according to the group of producers, for example: the first group that uses its production mainly for subsistence, the surface varied from 0.5 to 3 ha.

Most of the producers in group two and three, allocate their production for sale, have larger areas of planted area, yields and according to Sánchez-Toledano *et al*. (2017) can be classified as producers in transition whose main objective is of economic interest such as increasing sales, generating employment in the area and maintaining soil fertility (Table 2).

Table 2. Socioeconomic characteristics of the rainfed maize production systems in Campeche.

Determinants	Sample producer group		
	1	2	3
Sown area (ha)/ producers (%)	0.5-3 ha (51.4%), 3.1-5 ha (17.1%), 5.1-10 ha (15.7%), 10.1-20 (7.4%), >20 ha (8.4%)	0.5-3 ha (55.9%), 3.1-5 ha (17.7%), 5.1-10 ha (14.4%), 10.1-20 (5.8%), >20 ha (6.2%)	0.5-3 ha (54.2%), 3.1-5 ha (16.7%), 5.1-10 ha (16.7%), 10.1-20 (7.2%), >20 ha (4.8%)
Production objective	67.3% subsistence and 32.7% income	81.3% income and 18.7% subsistence	91.7% income and 8.3% subsistence
Tenure of the plot	64.5% common, 17.5% rented, 16.6% private	72.5% common, 22.3% private and 5.2% rented	78.6% common and 21.4% private
Government supports	Yes= 66.3% Not= 36.4%	Yes= 81.3% Not= 18.7%	Yes= 85.7% Not= 14.3%
Yields (t ha^{-1})/ producers (%)	0.33-2 t ha^{-1} (13.4%), 2-3.7 t ha^{-1} (37.5%), 3.8-5.4 t ha^{-1} (32.4%), 5.5-7.2 t ha^{-1} (14.8%), 7.2-8.9 t ha^{-1} (1.9%)	0.33-2 t ha^{-1} (15.6%), 2-3.7 t ha^{-1} (40.1%), 3.8-5.4 t ha^{-1} (30.3%), 5.5-7.2 t ha^{-1} (11.6%), 7.2-8.9 t ha^{-1} (2.4%)	0.33-2 t ha^{-1} (15.7%), 2-3.7 t ha^{-1} (36.1%), 3.8-5.4 t ha^{-1} (34.9%), 5.5-7.2 t ha^{-1} (10.8%), 7.2-8.9 t ha^{-1} (2.4%)

The management characteristics of the crop of the different groups identified are mainly due to the mechanization of the land, which according to Pat *et al*. (2008), caused the differentiation between traditional producers, who adopted a mixed way of life that combined slash-and-burn agriculture with wage labor and producers who engaged in mechanized agriculture with government support, located to the east from the state of Campeche.

In this study, a high dependence on government supports oriented to agricultural productivity and intermediation was observed. Less than 10% of the producers in the second and third groups maintain contract marketing schemes. The difference between the second and third groups is that producers located in Mennonite fields in the municipality of Hecelchakan are profitable with or without subsidy while regional producers are profitable only with subsidy (Pat *et al*., 2013).

Environmental characteristics

The predominant soil group among the sampled producers were Leptosols with 32.1% that are characterized by having limited agricultural potential due to their shallow depth and high stonyness despite their rich layer of organic matter (RMOD= 81.4%). 20.1% were Vertisols that are identified by their high clay content (57%) and are considered according to IUSS (2007), fertile soils, although with difficult management during the dry season.

Nitosols with 13.9%, Phaezem with 13.4% and Luvisols, with 12.1% of greater agricultural use, were in less frequency and according to IUSS (2007), they present good fertility conditions (Table 3).

Table 3. Physical and chemical characteristics of the predominant soil group in the sample of producers.

Soil group (%)	Clay (%)	OM (%)	CEC (%)	Thickness (cm)	RMOD (%)	EC (mg kg^{-1})	MPAN (mg kg^{-1})
Cambisol (0.5)	16	4.7	16.8	16	58.9	671.4	-11
Gleysol (4.5)	35	3.8	20.6	20.9	57.6	618	-1.5
Leptosol (32.1)	36.3	10.7	38.2	16.4	81.4	835.9	-14.7
Lixisol (1.4)	51.6	4.2	20.6	25.7	42.7	581.6	18.5
Luvisol (12.1)	31.8	3.5	22.9	15.1	67.7	632.2	-11.2
Nitisol (13.9)	67.4	4	28.7	19.3	53.1	572.5	17.9
Phaeozem (13.4)	39.3	6.7	40.5	29.8	99.6	756.5	-30.4
Regosol (1.9)	16.6	3.8	14.2	16.4	54.3	639.8	-7.7
Vertisol (20.1)	57	3.9	43.9	21.9	104.9	667.9	-27.9

OM= organic matter; CEC= cation exchange capacity; RMOD= retention of dissolved organic matter; EC= carbon evolution; MPAN= anaerobic potential nitrogen mineralization.

Figure 3 shows the spatial distribution of the URH and the IAAS ranges of each category. Although the URH represent the area of influence of the producer, it does not mean that they are working with agriculture in its entirety, because the agricultural frontier of the State is approximately 98 720 ha (Cano and Uzcanga, 2014). The surface of the URH represented for this study microregions with the same subunit of soil, pending hydrography and therefore, the fitness conditions were applied to the URH (Figure 3).

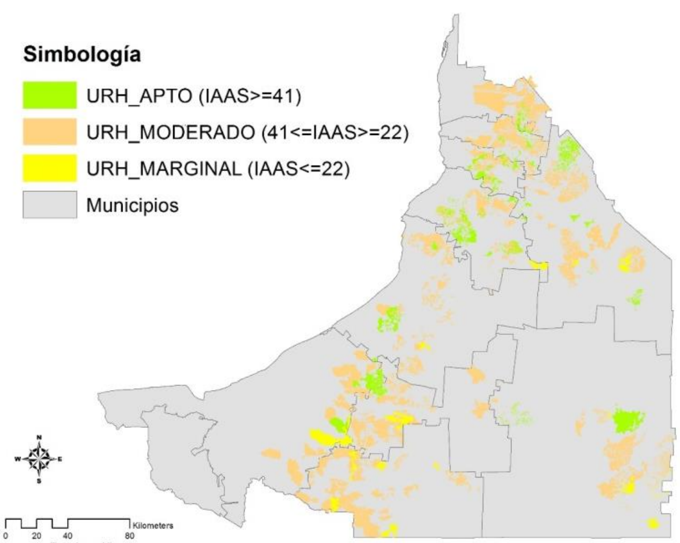

Figure 3. Spatial distribution of the URH by aptitude of the IAAS in Campeche.

In 10 of the 11 municipalities in the state of Campeche, a ‘moderate’ IAAS predominated, impacting on a potential surface of 535 641.3 ha. Hopelchen being the one that concentrated the largest area (39 527.9 ha). On the contrary, the municipalities of Carmen and Candelaria concentrated the largest area with IAAS of the ‘marginal’ type and, in order of importance, Campeche, Calakmul and Hopelchen concentrated the largest area with IAAS of the type ‘apt’ (Table 4).

Table 4. Area in hectares of the URH by category of the sustainable agricultural aptitude index.

Municipality	Sustainable agricultural aptitude index (IAAS) (ha)		
	Apt	Moderate	Marginal
Calakmul	21 089	54 502.5	8 049.7
Calkini	3 016.1	53 337	
Campeche	21 325.1	37 868.2	3 742.4
Candelaria		87 194.4	13 974
Carmen	14 761	58 425.3	16 290.3
Champoton	10 468.8	47 358.9	1 663.8
Escárcega	3 867.6	64 227.8	7 298.8
Hecelchakan	4 820.6	39 967.9	
Hopelchen	17 277.3	76 328.5	5 377.8
Tenabo	10 091.5	16 430.8	
Total	106 717	535 641.3	56 396.8

On the other hand, it was found that 70.9% of the producers' plots were located within a moderate aptitude for sustainable agriculture and of these 52.2% cultivate corn in a conventional way. Another 22.4% of the plots presented suitable conditions and of which 34.35% use minimum tillage. Finally, a minimum of 6.7% plots were located in marginal conditions where 13.4% of the producers use the conventional production system, although with greater technical knowledge (Table 5).

Table 5. Classification of producers and category of sustainable agricultural aptitude index.

Group	Apt		Moderate		Marginal		Total	
	sample	(%)	sample	(%)	sample	(%)	sample	(%)
I	52	24.2	143	66.5	20	9.3	215	34.4
II	73	22.3	233	71.3	21	6.4	327	52.2
III	15	17.9	68	81	1	1.2	84	13.4
Total	140	22.4	444	71	42	6.7	626	100

Despite the fact that in the three producer groups a moderate type IAAS predominated (66.5%, 71.3%, 81%) respectively, the producers of the first group are geographically distributed according to Uzcanga *et al*. (2010) in municipalities with a livestock vocation. While the producers of the second and third groups were located in municipalities with an agricultural vocation, the third group standing out for having a greater participation in the production of corn to the state (SIAP, 2017) (Figure 4).

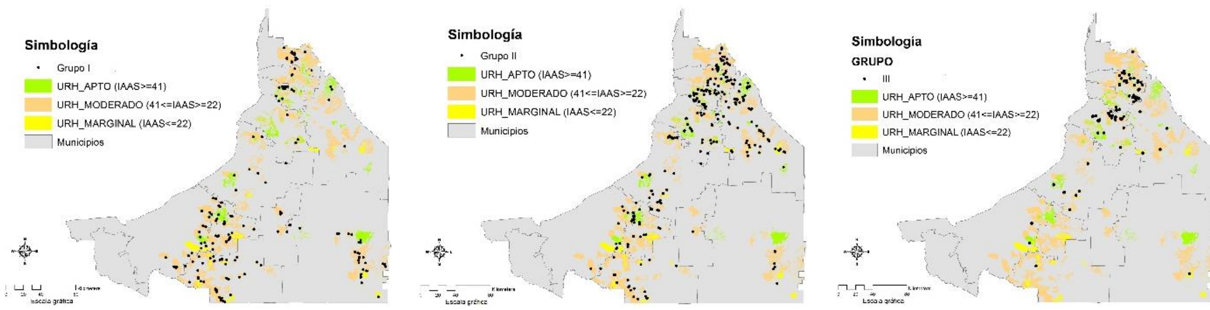

Figure 4. Geographical distribution of sustainable agricultural aptitude index by group of producers.

Conclusions

Three groups of rainfed maize producers in the state of Campeche were identified, and the most representative were those located in the north central area of the state, whose production is characterized by the use of fertilizers, hybrid seeds with alternating agricultural machinery in labor as sowing and harvesting, its production is mainly destined for the commercialization of grain through intermediaries.

Regarding the sustainability of corn production, most of the production units are in moderate condition, which means that producers must adopt agricultural practices that allow the conservation of organic matter and the provision of sufficient nitrogen fertilizers to compensate the extraction of nitrogen by the crop. Failure to adopt these practices, there is a risk that in the medium term this condition will change to marginal.

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