Characterization of corn producers and sustainability indicators in Chiapas

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Abstract

Currently, the information on the maize agroecosystem in the Frailesca region of Chiapas, Mexico, and its forms of management, is insufficient to address it with sustainable development strategies. In the present investigation it was characterized; through a typification of corn producers and their relationship with energy efficiency and its management methods. It is a descriptive and exploratory research from a socio-agronomic approach in 300 cases of farmers, with the support of descriptive statistical techniques, as well as exploratory multivariate of main components and clusters. Six producer groups or typologies were identified based on 11 main components that explain 73% of the total variability. All producer groups are energy efficient, which is associated with the productive and economic efficiency of the agroecosystem. Regarding grain yield, in all producer groups, it ranges between 2.8 and 4 t ha^{-1}. In addition, three large groups of management systems were identified (conventional, agroecological and mixed) carried out by maize producers in the Frailesca region, Chiapas.

Keywords: corn, sustainability, types of producers,

Introduction

Corn is one of the most important cereals in the world (CNBPA, 2008; Hellin *et al*., 2013). Its use has extended to animal feed and biofuels (Ferraro, 2008), which has demanded greater production. In Mexico, its production increased 88% from 1980 to 2010, while on the surface it only increased 3% (SIAP, 2016). This increase has been achieved through the genetic improvement of the species and their management through modern methods that involve the use of synthetic fertilizers, agrochemicals and machinery, in order to obtain higher yields.

In the state of Chiapas, in rural communities such as those found in the Frailesca region, 88% of producers use fertilizers and 76% use insecticides and herbicides (Aguilar, 2010). Furthermore, 32% of producers use improved seeds, while 68% use seeds of local origin, known as creoles (Delgado *et al*., 2018). This shows that industrial energy expenditure is high in rural communities in the region (Guevara *et al*., 2018). On the other hand, the high industrial energy expenses as part of the energy inputs in the production process (IDAE, 2009), are closely related to the emission of greenhouse gases (GHG).

The Frailesca region bases its economy on the agricultural sector and highlights its average corn yield with 3.24 t ha^{-1} (SIAP, 2017); through different technological variants used by producers. Therefore, the characterization of the agroecosystem, based on systemic indicators is very important, especially for more detailed studies regarding the energy and economic efficiency of each variant (Mandal *et al*., 2002; Hellin *et al*., 2013), as well as the analysis of the sustainability of the agroecosystem under current technologies.

The objective of this work was to characterize the corn producers of Frailesca, Chiapas, based on their systemic typification with sustainability criteria (productive, socioeconomic and energy) and based on the technology used with a view to evaluating the agroecosystem in terms of its energy, economic efficiency and sustainability.

Materials and methods

Location and characteristics of the study area

The investigation was carried out in the Frailesca region in the state of Chiapas, Mexico. This region is made up of the municipalities of Villaflores, Villa Corzo, El Parral, La Concordia, Angel Albino Corzo and Montecristo de Guerrero (Figure 1). In addition, it is the region with the highest corn production in the state with an average yield of 3.24 t ha^{-1} (INEGI, 2012).

Figure 1. Location of the municipalities of the state of Chiapas where the study was conducted.

Methodology

An interdisciplinary research methodology with a socio-agronomic and economic approach was used (Guevara, 2007), with a development-oriented systemic analysis (Chambers, 1993; Hagmann and Guevara, 2004) and with an ethno-agricultural approach and exploration method by routes or transects (Hernández, 1985). Interviews and surveys were designed and applied to 300 producers from 75 communities, 45 users in small properties/ranches and four corn traders. Each survey corresponded to 35 variables grouped into socioeconomic, productive and energy criteria (Table 1).

Table 1. Most relevant variables* studied to characterize and typify corn producers in the Frailesca area of Chiapas, Mexico.

Criteria	Variables
Socioeconomic	Property type
	Sales revenue (corn and stubble)
	Production costs
Productive	Agricultural area
	Livestock area
	Stubble production
	Agricultural yield of corn
Energetic	Energy intensity
	Energy performance
	Energy efficiency

*= the 35 variables are presented in Table 3 with the results of the main components.

The latter are related to the use, production and energy efficiency of the corn agroecosystem. The calculations were made from the equivalences that appear in Table 2. The variables based on economic criteria grouped together all those related to production and marketing costs.

Table 2. Energy equivalence of the inputs used and products used in the analysis.

Input	Unit	kcal unit^{-1}	Source
Human work	h	250	Funes (2001)
Animal work	H	1 800	Funes (2001)
Seed (in general)	kg	25 714.3	Perales *et al*. (2005)
Diesel	L	9 243	Masera and Astier (1995)
Gasoline	L	8 150	Masera and Astier (1995)
Ammonium sulfate (21%)	K	10 755	IDAE (2009)
Herbicide	L	57 000	Funes (2001)
Insecticide	L	44 000	Funes (2001)
Machinery		21 000	Masera and Astier (1995)
Farm tractor	h	1 015.4	Funes *et al*. (2011)
Product (corn, dry grain)	kg	3 656.7	Funes (2009)
Bean	kg	3322.1	Funes (2009)

The energy efficiency of corn cultivation was estimated according to Funes (2009) and the input and output information of the agroecosystem obtained from the interviews was used. In this sense, direct energy was considered for the calculation of the inputs and outputs of the system (Pimentel, 1980).

Direct energy calculation (Ed)

Energy associated with fuel consumption (E_{dc}) (Mcal ha^{-1}), $E_{dc} = C_c \times E_{eg}$; $C_c =$ it is the fuel consumption (L ha^{-1}), $E_{eg} =$ it is the energy equivalent of diesel (41 MJ L^{-1}).

Energy associated with employed labor (E_{dh}) (MJ ha^{-1}), $E_{dh} = E_h \times \frac{n_{ob}}{C_{tob}}$; $E_h =$ it is the energy equivalent of human labor (1.96 MJ h^{-1} for men and 1.57 MJ h^{-1} for women); $n_{ob} =$ it is the number of workers who participate in a certain task and $C_{tob} =$ the work capacity of agricultural workers (ha h^{-1}).

Energy associated with animals used in traction activities (E_{da}) (MJ ha^{-1}); $E_{da} = \frac{E_a \cdot n_a}{C_{ta}}$; $E_a =$ it is the energy equivalent of animal labor (5.05 MJ h^{-1}); $n_a =$ it is the quantity of animals that participate in a certain work; $C_{ta} =$ the work capacity of animals (ha h^{-1}).

Calculation of energy efficiency (Funes, 2001)

$$E_e = \frac{\sum_{i=1}^{S} m_i e_i}{\sum_{J=1}^{T} I_j \times f_j}$$

Where: $E_e =$ energy efficiency; S= number of products; M= quantity of product (kg); e= energy content of the product (MJ kg^{-1}); T= number of inputs; I= quantity of inputs (kg); f= energy required to produce an input (MJ kg^{-1}).

The following formula was used to calculate the energy produced and consumed:

EP=(Production×CE)/1000

EC=(Expenditure×CE/1000

Where: EP= energy produced; EC= energy consumed; production= yield (kg ha^{-1}); Expenditure= input expense; CE= energy content according to the energy equivalence shown in Table 1 in kcal/unit of measure.

Statistical processing

To reduce the dimensionality of the study variables, a principal component analysis (Escobar and Berdegue, 1990) was applied, in which the components with eigenvalues greater than one were extracted. The extracted components were considered new variables and were used in the cluster analysis to establish groups of production systems with similar characteristics or typologies. For the cluster analysis, the Ward method and the Euclidean Distance were used.

To perform the characterization of the typologies, the factor scores were transformed through equation 1 and were expressed in a proportional relationship with respect to the potential observed in the context of the sample of studied systems (equation 2).

$$xt_i = x_i - [0 - min(x)] \qquad\qquad 1)$$

$$x_p = {xt_i}/{max(xt)} \qquad\qquad 2)$$

Factorial analyzes of multiple correspondences were carried out to establish associations between the defined typologies and the qualitative variables related to the context and management of the systems (municipality, type of property, type of system, type of variety, preparation of soils and orography). Statistica software was used (StatSoft, 2007).

Results and discussion

The principal components factor analysis (AFCP) allowed the definition of 11 components or factors that extracted 73.77% of the total variance. Of the 35 variables included in the analysis, only those related to weed control costs, threshing costs, costs of selling corn grain and the benefit cost ratio (B/C) were not related to any of the components, which means that they are common variables for all cases and do not contribute to the typification of the corn producer groups in the studied area (Table 3).

Table 3. Main components and percentage of the variance extracted and accumulated.

Component	Associated variables (correlation with component)	Eigenvalue	(%) Variance explained	(%) Cumulative variance
I. Financial flows associated with corn and costs of green material and irrigation	Corn income (0.94), irrigation cost (0.98), corn harvest cost (0.98), corn carrying cost (0.98), collection cost of green material (0.99)	5.11	0.15	15.76
II. Maize acreage and income	Agricultural surface (0.9), corn surface (0.92), grain corn income (0.84), stubble income (0.71), total income (0.85)	4.05	0.12	28.44
III. Consumption and energy intensity	Direct energy (0.89), energy intensity (0.9)	2.15	0.06	36.47
IV. Ground preparation costs	Previous harvest tracking cost (0.95), chaporreo cost (-0.77), plowing cost (0.94)	2.45	0.07	43.47
V. Total and fertilization costs	Cost of 1st fertilization (0.85), cost of 2nd fertilization (0.89), total cost of corn production (0.63)	2.1	0.06	49.31
VI. Round and burn costs	Round cost (0.79), burning cost (0.81)	1.81	0.05	54.53
VII. Efficiency	Yield (-0.8) Energy efficiency (-0.74)	2.09	0.06	58.95
VIII. Seed costs and grain carrying	Seed purchase cost (0.72), grain transport cost (0.67)	1.46	0.04	62.96
IX. Furrowing and planting, sanitation and grain harvesting costs	Furrowing and planting cost (0.66), pest control cost (0.57), corn grain harvest cost (0.58)	1.67	0.05	66.84
X. Non-agricultural area	Livestock area (-0.71) Forest area (-0.74)	1.51	0.04	70.43
XI. Relationship between stubble production and corn harvest cost	Stubble production (-0.64) Corn harvest cost (0.71)	1.31	0.04	73.77

Components I, II and III are those that most influence the differentiation of agroecosystems. Together they account for almost 40% of the total variability. Component I is closely related to productive rationality through financial flows, it represents the level of investments and remuneration associated with the commercialization of corn. On the other hand, components II and III indicate that grain production is more associated with the cultivated area than with the yields and inputs used. The inverse relationship observed between the variables 'chaporreo cost' with the variables, 'previous harvest tracking cost' and 'plowing costs', is associated with the positive effect of soil preparation on weed control and as consequence the decrease of the expenses in the chapea or chaporreo.

Corn producers typification

Six types of producers were formed from the scores resulting from the factor analysis of principal components, using the Euclidean distance method (Figure 2). Group II, with 118 producers, was the most representative, including 39% of the interviewed farmers. This group presents high levels of efficiency and round costs.
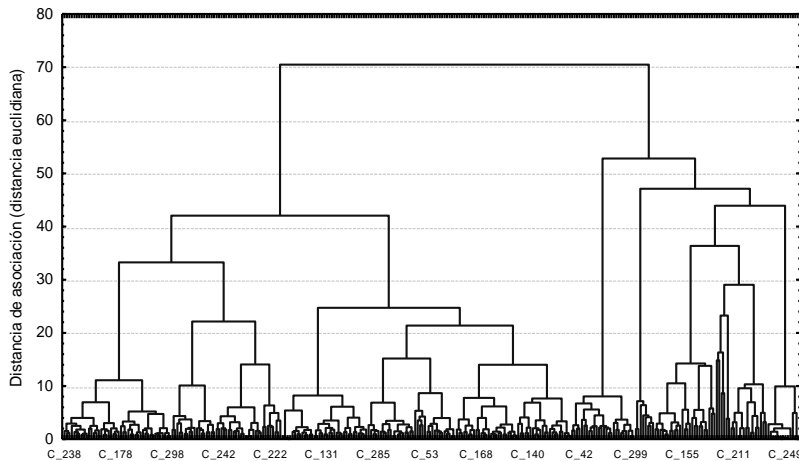

Figure 2. Types of corn producers in the Frailesca region of Chiapas, formed from the clusters of the hierarchical cluster analysis.

Type I includes 89 producers that are characterized by being energy efficient and have higher round and burning costs. They present low values in financial flows associated with corn (tender corn), seed costs and irrigation. It has small areas cultivated with corn and with low incomes for this concept. It shows low energy consumption and require less energy to produce one kg of corn. It present low costs in the preparation of the land, purchase of seed and carrying of grains; however, they have high chaporreo costs.

Type III is made up of 46 producers and represents the largest cultivated area and non-agricultural area. It shows the highest incomes and a high consumption and energy intensity, so that the producers present the highest total costs and among them, in fertilization, sanitation, grain harvest and corn harvest.

Typology IV presents low values in the financial flows associated with the production of corn (tender corn), seed costs and carrying grain. They have small cultivated areas and with low income from the sale of corn. They have a higher energy intensity and require more energy to produce a kilogram of corn. They are characterized by having higher costs in the preparation of the land, which means that the chaporreo costs increase every year (Figure 3).
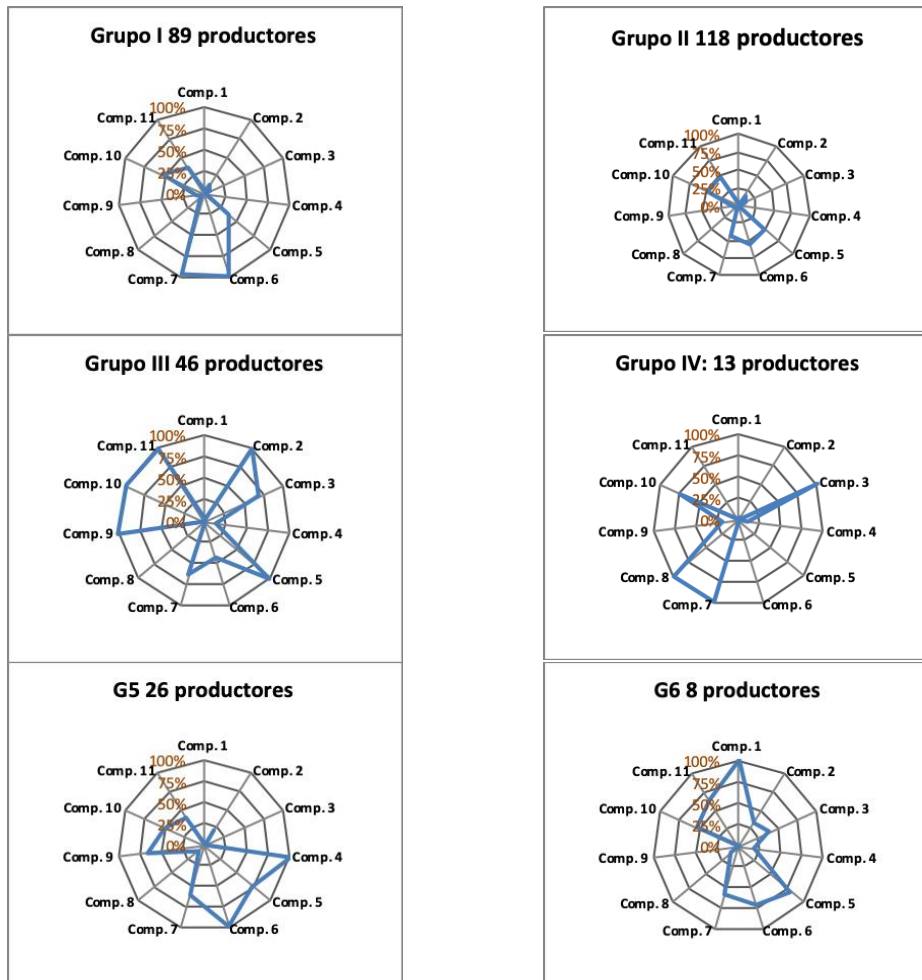
Figure 3. Types of producers, grouped based on the evaluated components. Comp. I. Costs and income of corn, green material and irrigation; Comp. II. Corn cultivated area and income; Comp. III. Consumption and energy efficiency; Comp. IV. Ground preparation costs; Comp. V. Total and fertilization costs; Comp. VI. Round and burn costs; Comp. VII. Efficiency; Comp. VIII. Seed costs and carrying grain; Comp. IX. grain cleaning and harvesting costs; Comp. X. Non-agricultural area; Comp. XI. Relationship between stubble production and corn harvest cost.

Type V consists of 26 producers. These producers stand out for presenting the highest costs of preparing the land, round and burning. They also have high total fertilization costs. They reflect high energy efficiency since they allocate small areas to cultivation, receive low income, have minimal financial flows associated with corn and have high burning costs and are also associated with irrigation. Finally, they have low costs for seed purchase and carrying grain.

Type VI is the smallest of the sample with eight cases. These producers are distinguished by presenting high financial flows associated with corn, low burning and irrigation costs, and minimum grain harvest costs. They present high total and fertilization costs. In addition, they have a cultivated area, income, consumption and energy intensity close to the average of the potential behavior in the context of the study, as well as an average energy efficiency of 10 Mcal produced per unit of energy consumed.

These typologies show good energy efficiency (10 Mcal in the production process). However, they differ in production practices as well as in financial flows because some producers sell corn (tender corn) and the others do it in grain. In addition, the producers that present better financial flows are those that sell only corn compared to those that only commercialize grain. For this reason, the energy study is very important, especially when it is necessary to know in detail the inputs and outputs of the agroecosystem (Funes *et al*., 2011; Purroy *et al*., 2019) and to estimate its efficiency.

Energy efficiency

Regarding energy efficiency (Figure 4), types III and V group the most efficient producers. While groups IV and II show the lowest values. However, in all cases, producers have an energy efficiency above 10 Mcal produced per unit of energy consumed. These results coincide with Pimentel (1980), who mentions that the average energy efficiency of corn cultivation is 10 Mcal produced for each Mcal invested, so it can be stated coincidentally with Purroy *et al*. (2019) that even under these conditions in the region, all producers have efficient energy balances and that the agroecosystem presents viable productive and economic indicators.
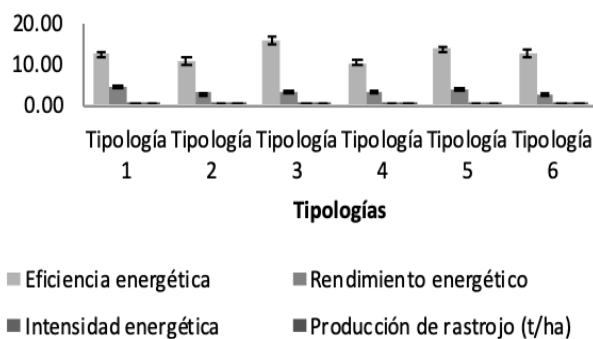
**Figure 4. Indicators of energy efficiency of corn producers in the Frailesca region of Chiapas.**

The least efficient group of producers was II with 2.8 t ha^{-1}, while the rest produced between 3.8 and 4 t ha^{-1}. However, these yields exceed those reported for Chiapas (1.9 t ha^{-1}) and 3.24 t h^{-1} for the Frailesca region (SIAP, 2017), where in addition 90% of the producers are self-consuming, and have a plot less than 2.1 ha, and an average yield of 2.5 t ha^{-1}, equivalent to 5.25 t plot^{-1} year^{-1}, under storm conditions (ASICH, 2007).

The way of production

The association of the groups of producers with the forms of production of corn, allowed to determine the most representative of the Frailesca region, among which three groups were found.

The conventional form of management, which agglomerated most of the producers (Figure 5). 93% of the sample studied (GI, GII, GIII, GV) is characterized by the high use of agrochemical inputs to produce a plot of corn. 38.8% and 15% of total production costs are invested in fertilizers and improved seeds. For the rest (46.2%) it is distributed among the different requirements of the crop.

Compared to the other forms of management, the conventional form of management has the highest production costs and despite this, it has the highest average cost/benefit values 1.4, 1.02, 1.15 and 1.09 for groups I, II, III and V respectively.
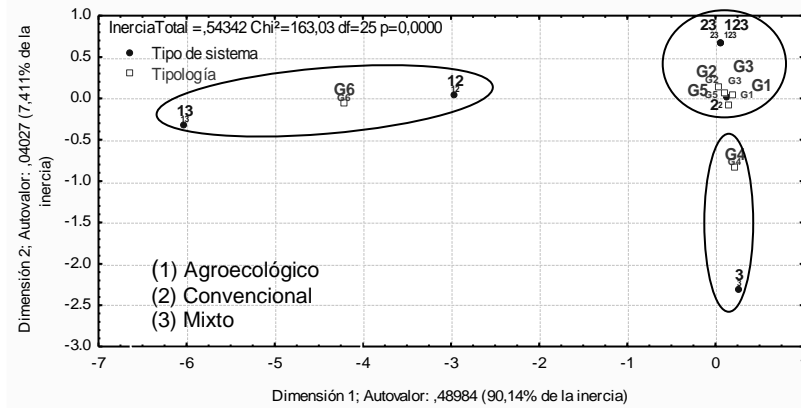
Figure 5. Associations between the defined typology and the forms of production.

The second group constitutes 4.3% of the sample, which was only associated with group IV and is characterized by a mixed form of management. Production costs are homogeneously distributed between the inputs and the activities used, which are: 33.3% for fertilization, 18.1% for grain transport and 17.5% for the purchase of improved seeds. The rest of the costs (31.1%) are mainly distributed in pest control, planting and furrowing, harvesting, threshing and sale of grain. The group of producers associated with this form of production has average cost/benefit values of 1.38.

Other producers that represent 0.7% and that is associated with typology VI practice an agroecological form, where 80% of the production costs are invested in labor for various cultivation activities, such as planting, weed control, control of insects, harvest, soil conservation and the rest use it to buy seeds and fertilizer. Even with the percentage destined to inputs, the cost/benefit calculations (1.02) place agroecological management with the lowest value among the three forms of management.

In this sense, in the short and medium terms, mixed and agro-ecological forms of management are considered less productive; however, in the long term they become sustainable with the implementation of agroecological practices (Espinosa *et al.*, 2011). In this regard, Aguilar *et al.* (2011) indicate that the maize agroecosystem practiced in an agroecological way in the long term shows greater sustainability compared to the conventional system.

Conclusions

Maize producers in the Frailesca region in Chiapas, Mexico are characterized by a complex series of socioeconomic, environmental and productive variables, which determine the existence of six types of producers, which lead to productive efficiencies above the official data reported for the region. Corn yields are above the state average. In this sense, all producer groups are energy efficient, a characteristic associated with the productive and economic efficiency of the agroecosystem.

In addition, there are three forms of management in the region: conventional, agroecological and mixed. For this reason, the types of producers and the management facilitate the analysis of the current context of the agroecosystem and allow defining possible care strategies for producers, based on their daily practice. These results lead to more in-depth studies on the energy efficiency and sustainability of the corn agroecosystem and its management in the region.

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