Article

Characterization of maize agroecosystems in the coastal plain of the Istmo, Oaxaca

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Abstract

Agroecosystems are ecosystems transformed by humans by using resources to produce food, fiber, and raw materials. The study was carried out in 2017 with the objective of identifying and characterizing the corn agroecosystems in the coastal plain of the Istmo of Oaxaca and knowing their current status. The methodologies of the participatory rural survey and the study of agroecosystems were used. A questionnaire was applied to a sample of 60 corn producers. The information was systematized in Microsoft Excel 2010 and processed in SAS® V9.0 for principal component analysis (PCA) and canonical discrimination. Of 103 variables, 10 were selected by ACP and 12 incorporated into value judgment, in the biophysical, social, economic and technological dimensions. Three agroecosystems were identified (Mahalanobis square distance and multivariate tests with approximation of F) ($p< 0.01$): 1. Juchitán de Zaragoza-Chicapa de Castro maize agroecosystem (AE1); 2. Álvaro Obregón-Emiliano Zapata (AE2) corn agroecosystem; and 3. La Venta-La Ventosa corn agroecosystem (AE3). In the three AE they sow Zapalote Chico corn in a traditional way and with low mechanization (soil preparation and sowing). Although the yields are very similar in the three AE, in monthly income AE1 and AE3 stand out, in contrast to AE2, where it is lower, due to their livestock activity (goats in intensive grazing) different from the other AE (dual-purpose cattle), low cultivation area, few hired wages, etc. The corn is for self-consumption, although surpluses are sold in the local market.

Keywords: *Zea mays* L., annual yield, Istmo of Tehuantepec, traditional agriculture.

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Introduction

Corn (*Zea mays* L.) is one of the three most important cereals in the world. It is a source for human food and for livestock (González *et al*., 2013). In Mexico, it is the most important and diverse cultivated species and surpasses sorghum, wheat, barley, rice and oats (López *et al*., 2010; SAGARPA, 2017).

The high diversity of corn in Mexico is manifested in traditional agricultural systems, where they use native varieties adapted to local conditions. They are preferred and a key component in food security in the rural sector (Cabrera *et al*., 2018). 9.6 million hectares are planted annually with an average national yield of 2.2 t ha^{-1}.

The national *per capita* consumption in 2015 was 297 kg and in southern Oaxaca, higher than 350 kg (SIAP, 2016). In 2016, Oaxaca was sixth place with 552 438.33 ha and an average yield of 1.31 t ha^{-1} (SIAP, 2017). 90% of farmers grow corn at different altitudes (0 to 2 800 m) and different edaphoclimatic conditions; which has allowed the identification of more than thirty breeds widely used in food (Aragón *et al*., 2005; Salinas *et al*., 2013).

The coastal plain of the Istmo of Tehuantepec is an important agricultural area (López-Romero *et al*., 2005) and the corn crop of the Zapalote Chico breed is the most representative, 73% of the 111 000 cultivated ha (López *et al*., 2009; López *et al*., 2010). 85% is temporary with average yields of 1.3 t ha^{-1} (SIAP, 2015). This genotype is very early and allows three harvests a year. Its low size avoids the effect of strong winds and the Totopo (crushed corn tortilla with a crunchy texture and perforations inside) and other foods of the population of zapotecas descent are made (CONABIO, 2010; INEGI, 2014; Cabrera *et al*., 2018).

Agroecosystems (AE) are transformed ecosystems and provide natural resources for agricultural activities. Each AE has its own characteristics that differentiate it from others (Hernández-Xolocotzi and Ramos, 1977; Masera *et al*., 2000). Traditional AE have a socio-economic and cultural connotation linked to the valuation, appropriation and use of local resources by humans and society. The characteristics of AE are determined by biophysical, sociocultural, economic, technological factors, and the purpose of production, among others (Masera *et al*., 2000).

These factors are also used in the AE characterization process, which aims to group agricultural systems that operate in a similar way to know their current situation and problems or to study their evolution over time (Vilaboa-Arroniz *et al*., 2009).

Studies related to corn AE in the coastal plain of the Istmo of Oaxaca, focus on technical-productive aspects, but do not contemplate social, cultural and organizational aspects of the peasantry in the production process. Therefore, the present study was developed with the objective of identifying and characterizing the corn agroecosystems in the area and knowing their current state.

Materials and methods

Characteristics of the study area

The study was carried out in Juchitán de Zaragoza, which has the largest surface area of the coastal plain of the Istmo of Tehuantepec, Oaxaca and coincides with Irrigation District No. 19. It includes, in addition to the municipal seat, five municipal agencies and two agencies of cop.

It is located between the parallels 16° 12' and 16° 38' north latitude and 94° 44' and 95° 08' west longitude, in an altitudinal range of 0 to 500 m. The climate is Aw_0 (w) ig, classified as warm subhumid, the driest of the subhumid, with rains in summer. Average temperature of 26 °C and an average annual rainfall of 978 mm. The natural vegetation extends over a large plain and includes low deciduous forests and thorn scrub. Vertisols, Phaeozem, Arenosols, Luvisols, Fluvisols, Cambisols, Solonchak and Gleysols soils predominate (INEGI, 2010a; 2010b; UABJO, 2014).

Methodological process

The research was based on participatory action research according to Colmenares (2012). The approach was mixed, exploratory and descriptive. The design was non-experimental and the data was generated directly without prior processing. The criterion for the selection of the communities was dedication to agricultural activity, as there are fully fishing communities.

The investigation included six communities in the municipality: Juchitán de Zaragoza, Álvaro Obregón, Emiliano Zapata, La Ventosa, La Venta and Chicapa de Castro. The diagnostic methodology to analyze the communities and their context was that of the participatory rural survey (SRP) by Selener *et al*. (1999). To generate the field information, the survey was used through the application of a questionnaire, the dialogue with the producers and the field trips.

The questionnaire was structured in two sections, the diagnosis to identify the social, economic, productive and organizational characteristics in the peasant production units, from its analysis the diagnosis was reached. The second was for the characterization of cropping systems, using the methodology for the study of agroecosystems of Hernández-Xolocotzi (1977). The questionnaire was applied to farmers by stratum (localities). The selection criteria were that they were corn growers and belonged to the 1 200 registered in the CADER registry.

The sample size was 60 producers (5% of the population); 22, 20 and 18 for AE1, AE2 and AE3, respectively. The selection was made by the 'snowball' technique. It consists of a first approach with a local expert to whom the questionnaire is applied; then name potential key informants in the community.

The data generated was classified in environmental, economic, social and technological axes for analysis. 103 study variables were proposed at the beginning, to reduce dimensionality a principal components analysis (PCA) (SAS) was applied. With this analysis, the 10 variables with the greatest relative weight were selected, five from the biophysical axis, two from the social axis and three from the economic one.

In the technological axis there were no variables due to their homogeneity. The second criterion for selecting the variables was the 'value judgment' according to Masera *et al*. (2000), to incorporate variables for the characterization of AE: social axis (2); economic (2); and technological (8). Finally, 22 variables were considered in the biophysical axes (5); social (4); economic (5); and technological (8) (Table 1).

Table 1. Determinant variables for the characterization of agroecosystems.

Axis	Variables		Total
	Multivariate analysis	Value judgment	
Biophysicist	1. T. Maximum mean (mmax) 2. T. Minimum mean (mmin) 3. T. Annual mean (ma) 4. Precipitation (pp) 5. Altitude (msnm)		5
Social	1. Ethnicity (etn) 2. Family integrants (itfam)	1. Family members participating in the production unit (ifup) 2. Organization (org)	4
Economic	1. Monthly income (imens) 2. Access to PROAGRO (proagr) 3. Amount of labor (mmdeo)	1. Sources of income (fuening) 2. Corn price (pmaíz)	5
Technological		1. Tillage (lab); 2. Sowing (siemb); 3. Soil conservation practices (cons); 4. Supplies (insum); 5. Planting area (sups); 6. Number of plots (npar); 7. Technical consulting (atecni); and 8. Cumulative yield (kg ha^{-1}) (racum)	8

Canonical discriminant analysis (CDA) was performed with the CANDISC (SAS) procedure to detect discrepancies between localities. The Mahalanobis square distance and multivariate tests with an approximation of F.

Results and discussion

Identification and characterization of agroecosystems

According to the study of the determining variables, in the discriminant functions of maximum separation ($p< 0.01$), three agroecosystems were identified: 1) maize agroecosystem in Juchitán de Zaragoza-Chicapa de Castro; 2) maize agroecosystem in Álvaro Obregón-Emiliano Zapata; and 3) maize agroecosystem in La Venta-La Ventosa (Figure 1).

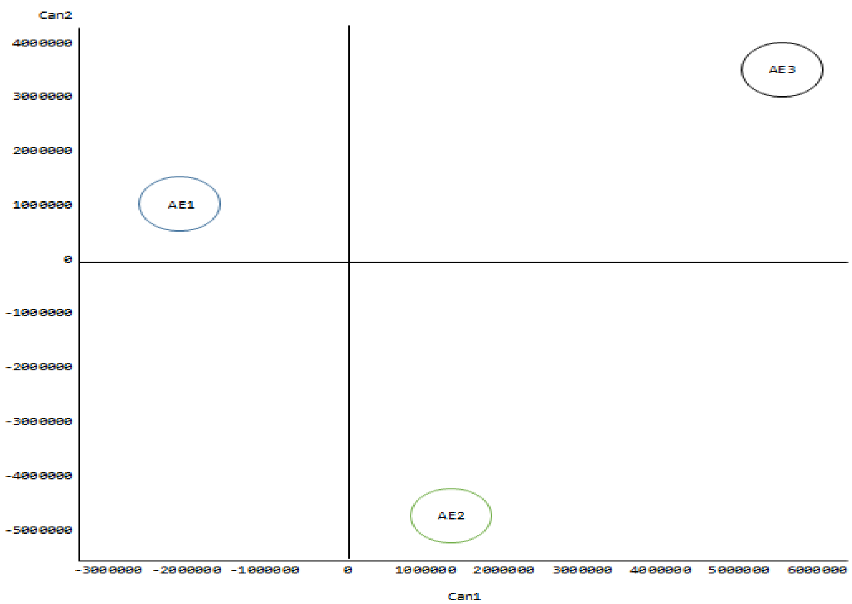

Figure 1. Separation of agroecosystems by canonical discrimination with their determining variables.

Maize agroecosystem in Juchitán de Zaragoza-Chicapa de Castro (AE1)

AE1 is located in the towns of Juchitán de Zaragoza and Chicapa de Castro, at altitudes of up to 22 m; Average annual temperature of 27 °C and maximum and minimum of 31.7 and 16.8 °C, respectively. Average annual rainfall is 980 mm. Aragón *et al*. (2005) indicate that in Oaxaca, corn is grown from 0 to 2 800 masl under different climatic and edaphic conditions.

According to Cervantes-Herrera *et al*. (2015), corn produces acceptably in areas where it rains annually from 600 to 1 000 mm well distributed for four to seven months. It comprises zapotecas peasants (100%) with peasant production units (UPC) made up of five individuals, the head of the family with the collaboration of two children. This is advantageous, Serrano-Ojeda *et al*. (2016), report that in the center of Puebla the UPF are made up of four people (Figure 2).

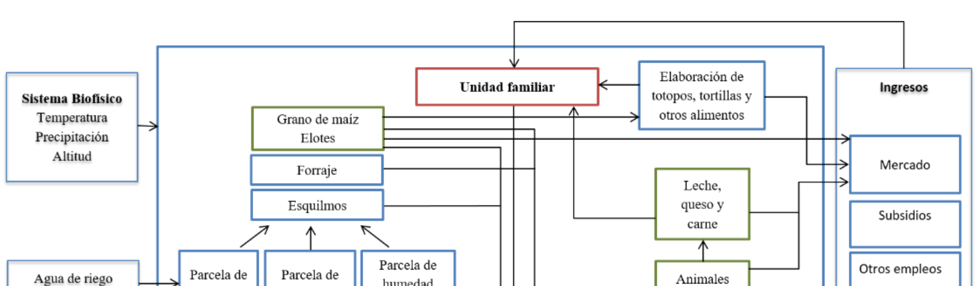

Figure 2. Representation of the corn agroecosystem in Juchitán de Zaragoza-Chicapa de Castro (AE1).

According to Cervantes-Herrera *et al*. (2015), family intervention is a form of productive training, transmission of knowledge and assessment of productive activity. Only 13.6% of the farmers belong to a working group organized for the production of corn, a very low percentage that does not reflect group participation and does not ensure the operation and continuity of projects or other processes.

The farmers of AE1 grow native corn of the Zapalote Chico breed, known locally as Xhuba'huini. It is endemic to the Istmo of Tehuantepec and the coastal regions of Oaxaca and Chiapas at average altitudes of 600 m, although samples of other races are reported between 1 550 and 1 900 masl (Aragón *et al*., 2005). The main characteristics refer to its earliness (90 days), resistance to drought and pests.

It is a low-growing plant (110-150 cm) that supports the strong winds in the area. Its cobs are short with a low number of rows of semi-floury grains, it has the lowest glume/grain index in the mexican races, large germ and average protein content of 12.7%, one of the highest of the corn races.

It is the basis of food and is used to prepare tortillas, atoles, corn and make tortilla chips (CONABIO, 2010; Cabrera-Toledo *et al*. 2016). The preference of local genotypes occurs in several states of Mexico (Herrera *et al*., 2002; Vásquez-Carrillo *et al*., 2010); For example, in Chiapas (Aguilar-Jiménez *et al*., 2011) and Puebla (Zagoya, 2015), it is due to its lower cost and desirable characteristics for food preparation.

The cultivation begins with the mechanized preparation of the land (90.9%) and traditional (9.1%) with an Egyptian plow. Sowing is under two methods: traditional with the use of animal and human force (68.2%) and with mechanical seeders (31.8%). Due to time issues, given the short cycle of Zapalote Chico maize, farmers combine conventional technology (primary tillage) and traditional technology (secondary tillage, furrowing, sowing and weeding), also reported by Turijan *et al*. (2012).

81.81% fertilize only with nitrogen, 46 to 69 kg N ha^{-1} in the first labor or hilling. This treatment is achieved with two and three lumps of urea. It is low when considering the 92-46-00 formula recommended by Cabrera *et al*. (2018). The main pest is the arriera ant (*Atta* spp.) and for its control they use Dichloro Diphenyl Dichloroethanol scattered in the nests.

59.1% of farmers in AE1 manually control weeds. In San Felipe Teotlalzingo, Puebla, machinery is used to till the soil, but sowing, weeding and fertilization is manual using a shovel and hoe or with the team (Zagoya, 2015). They allocate an average of five ha for planting corn, divided into two to four plots. 41% of the farmers use practices to preserve soil fertility by incorporating crop residues and manure; crop rotation, legume-associated crops, etc.; efficient in traditional agriculture (Cervantes-Herrera *et al*., 2015).

Only 13.6% of the farmers of AE1 have participated in technical assistance programs through the organization to which they belong. Macedo *et al*. (2003), indicate that the traditional farmers of the common Cofradia de Suchitlan, Colima, receive government support, but lack training and technical assistance, which denotes the lack of technical advisers that enable the continuous adaptation of these AE that face challenges to improve its sustainability.

The harvest is manual after three months; they generally hire outside wages. Thanks to the precocity of the Zapalote Chico, the plots are sown three times a year under three humidity conditions: temporary, irrigation and residual humidity. The latter is known as *Igudxa* sowing, which takes advantage of the residual humidity of the storm and the serene ones from October to December.

A single cultivation system under temporary and two multiple cultivation systems was identified, one under irrigation and temporary (31.8%), and the other under irrigation, temporary and humidity (13.6%), with an average accumulated production of 3 665 kg ha^{-1} year^{-1}, low if compared with the average yields of 2 950 kg ha^{-1} cycle^{-1} reported by Cabrera *et al*. (2018). Per crop cycle, 10 wages are hired out of the 30 required for cleaning canals, planting, hilling, irrigation and harvesting.

The UPF main source of income is agriculture, from the sale of corn and livestock (sale of milk, cheese and animals in local markets). Similar to the AE of Tierra Caliente, Michoacán (Villa-Méndez *et al*., 2008) and the common Cofradia Suchitlán, Colima (Macedo *et al*., 2003), where 60 and 83% of the peasants, respectively, depend economically on the UPC.

The average monthly income per UPC is $6 750.00 and exceeds that reported by Serrano-Ojeda *et al*. (2016) for the central region of Puebla, with an income in those with the highest food security of $2 566.00 per month. In AE1, 27% complements income with the support of the Productive PROAGRO, useful for the production process and other basic needs. The UPC in the region that are supported are lower than those of Tulancingo, Hidalgo, where 36% of the corn growers receive it, possibly because there are more consolidated organizations (Ayala-Garay *et al*., 2013).

The destination of the production varies, 36.4% of the UPC of AE1 corn for self-consumption, 45.4% sells only surpluses and the remaining 18.2% sells everything produced due to income needs or the lack of infrastructure for storage. In Tlaxcala, 40% use corn for self-consumption, 2% for sale, and 58% for both (Damián *et al*., 2007b; Damián *et al*., 2008). This differs from what was reported in the common Cofradia Suchitlan, Colima, where 83% of the UPC satisfy their food needs (Macedo *et al*., 2003).

This indicates that corn meets different needs by being sold directly or marketed transformed due to its various forms of consumption. The commercialization is local and is sold by the liter (750 g), at a price of $7.00. Economically, the rent of labor is important in this AE, as they are day laborers outside the UPC with an income of $170.00 day^{-1} and an average of 8 days ha^{-1} per cycle, although it can be up to 12 days ha^{-1} per maize cycle.

Maize agroecosystem in Álvaro Obregón-Emiliano Zapata (AE2)

AE2 is located at an altitude of 6 m. The maximum temperature is 29.8 °C, the annual average is 26 °C and the average precipitation is 942 mm annually. Structurally, AE2 presents a variant in the livestock subsystem with the rearing of sheep under an extensive grazing regime, in contrast to AE1 and 3 which are dedicated to raising dual-purpose cattle (breeding and milk).

The peasants are zapotecos (95%) and mestizos (5%) (Non-zapoteco speakers) and do not belong to any organization for the production of corn. UPF are made up of 6.5 people on average. The head of the family is in charge of the UPC and 2 to 3 of the children collaborate in it.

Serrano-Ojeda *et al*. (2016) report that in the center of Puebla the UF are made up of four people and two actively collaborate in the UP. According to SAGARPA (2017), traditional agriculture is based on the intensive use of family labor.

In the same way, they grow Zapalote Chico corn. To reduce time, the preparation of the land is mechanized (100%) and the sowing is mechanical (75%) and traditional with Egyptian plow (25%). 80% use nitrogen fertilizers (46 kg N ha^{-1}), at the time of hilling and matting, far from the doses of 92-46-00 (kg ha^{-1} of nitrogen, phosphorus and potassium, respectively) recommended by Cabrera *et al*. (2018). They do not use insecticides, since the pests are not significant.

Weed control is manual and is only carried out at the edges of the plots (90%). 50% incorporate diverse amounts of crop residues and manure from the livestock subsystem prior to soil preparation to preserve fertility (Figure 3).

Farmers in the Atoyac River sub-basin, Oaxaca, indicate that it is necessary to fertilize, carry out two weeding, rotate with legumes, and incorporate manure and residues to achieve harvests (Ruiz-Vega and Silva-Rivera, 2006). In addition, they are an important source of organic nitrogen (Salazar-Sosa *et al*., 2009; Salazar-Sosa *et al*., 2010), allow the development of microorganisms that promote fertility (Damián *et al*., 2013), improve structure and texture, increases aeration, root penetration, retains water and strong and healthy plants resistant to pests and diseases are achieved (Aguilar *et al*., 2003; Damián *et al*., 2008).

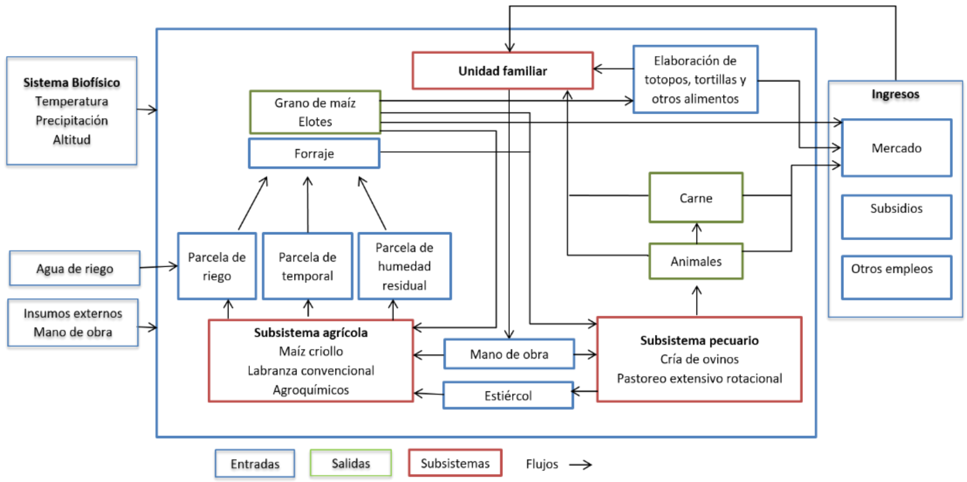

Figure 3. Representation of the maize agroecosystem in Álvaro Obregon-Emiliano Zapata (AE2).

This scheme is similar to that of Tlaxcala, where 84.4% use nitrogen fertilizers and 66.4% incorporate manure into the soil (Damián *et al*., 2007a; Damián *et al*., 2007b). Likewise, Mayan farmers from Peten, Guatemala, do not use fertilizers or fertilizers for the milpa and weed control is manual (Lara *et al*., 2012). In AE2, each producer cultivates 3.6 ha in 1 or 2 plots.

According to Ayala-Garay *et al*. (2013), is similar to Tulancingo, Hidalgo; where they cultivate 3.36 ha on average, but less than Tlaxcala (Damián *et al*., 2008), where they are 5 ha and higher with respect to the central region of Puebla with 2.36 ha on average (Serrano-Ojeda *et al*., 2016).

The cultivation area is important since, the larger the area, the higher the production, which enables self-sufficiency and surpluses for sale, provided that there are the necessary inputs (Pat-Fernandez *et al*., 2011). In this AE, three crops are also grown per year: a simple temporary system (75% of farmers), multiple irrigation and temporary systems (75%) and an irrigation system, temporary and humidity (10%); with which a cumulative production of 3 312 kg ha^{-1} $year^{-1}$ is generated.

In this there is no technical advice for growing corn. In each crop cycle, an average of five wages are hired to support sowing, hilling and harvesting activities. The UPF depend on agricultural activities, direct sale of corn and the production of tortilla chips, livestock activities (sale of animals) and the salaried work of their children outside the UPC, with an average of 12 wages per cycle for each of the members.

The income includes the support of the Productive PROAGRO (85% of the producers); for an average monthly income of $3 675.00. This diversity occurs throughout the country and is similar to that of the Tehuacán Valley, Puebla, where peasants cultivate, raise goats, trade firewood and non-timber species (Aguilar *et al*., 2003).

Corn is for self-sufficiency (80%) and sale (20%), similar to the 96% identified in Tulancingo, Hidalgo (Ayala-Garay *et al*., 2013). Like the AE1, the sale is local and the liter of corn sells for $7.00. payment for labor is $130.00 per day.

Maize agroecosystem in La Venta-La Ventosa (AE3)

The AE3 is located at altitudes of 39 m, with maximum temperatures of 32.8 °C and the annual average of 27.5 °C, with annual rainfall of 1 007 mm, above the optimal range. The peasants are zapotecas and mestizo (50%).

The UPF are made up of six individuals and the activities are in charge of the head of the family and two of the children occasionally participate. Different from the four in the central region of Puebla (Serrano-Ojeda *et al*., 2016). Likewise, farmers do not belong to work groups or local organization, a situation that does not allow for economies of scale (Ayala-Garay *et al*., 2013).

Structurally, AE3 differs from AE2 and AE1 in the agricultural subsystem, as it is sown in the latter under humid conditions, although the livestock subsystem is similar to AE1, as it has dual-purpose livestock (Figure 4).

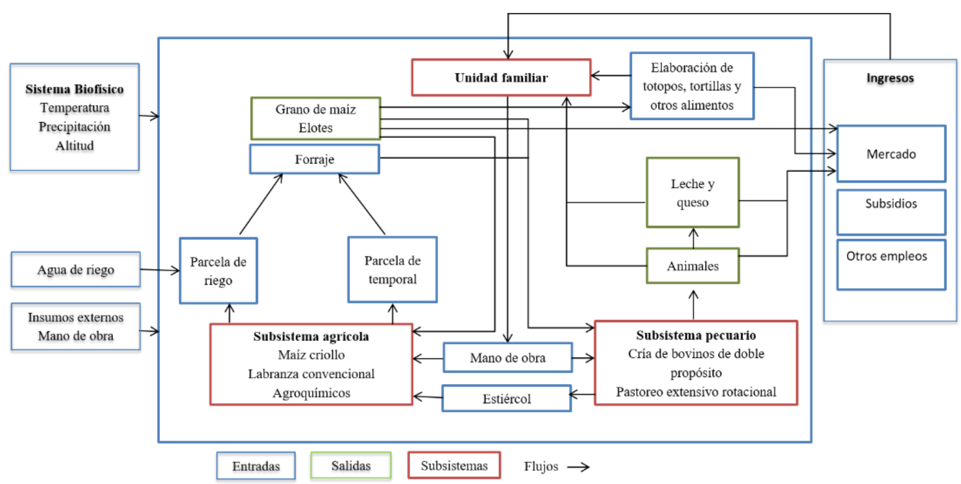

Figure 4. Representation of the corn agroecosystem in La Venta-La Ventosa (AE3).

The seed is from Zapalote Chico selected from the previous harvest due to adaptation characteristics to the region and for the preparation of tortillas and chips for self-consumption (Ayala-Garay *et al*., 2013). Land preparation is mechanized (100%) and sowing is mechanical (94.4%). 83.3% use nitrogen fertilizers at a rate of 46 to 69 kg N ha^{-1}, based on urea. Matte is applied one day before hilling. There are no serious pests. Traditionally they incorporate crop residues and manure (77.8%). On average, 4.7 sowings have been distributed in 1.2 plots, that is, more compact surfaces than in the other AE.

This area is higher than that used in Hidalgo, where 2.5 ha of corn are cultivated on average (Ayala-Garay *et al*., 2010). Only 27.7% of producers occasionally receive technical advice. This situation occurs in several states of the country. In Tlaxcala, 91.6% of corn producers lack technical assistance (Damian *et al*., 2007a; Damian *et al*., 2007b).

This factor is of utmost importance, since it reinforces the skills and capacities of farmers and is decisive for increasing agricultural production (Damián *et al*., 2008; Ayala-Garay *et al*., 2013). In AE3, three cultivation systems were detected based on humidity, irrigation (61% of producers), temporary (22%) and a multiple system under irrigation and temporary (16.6%).

In the latter it is possible to obtain an accumulated production of 3 244 kg ha^{-1} $year^{-1}$. In the Valley of Tehuacán, Puebla, the peasants have irrigated and seasonal agriculture to produce more food per year (Aguilar *et al*., 2003). In this AE, for each crop cycle they hire an average of eight wages to support the activities of cleaning channels, sowing, hilling, irrigation and harvesting.

The average monthly income of the UPF of this AE is $6 000.00, for livestock and agricultural activities. Like AE1 and AE2, 94.4% of the producers have the support of PROAGRO Productivo. Corn is for self-supply (88.9%) and for sale (11.1%). Figures similar to those of Cuetzalan, Puebla, where 18% is sold (Damian *et al*., 2013).

The grain is sold locally by the liter for $8.00. The hired labor generates an expense of $150.00 per day. The members of this AE also work as day laborers with 12 wages $cycle^{-1}$ to supplement their income.

Conclusions

Three corn AE were identified: EA1 (Zaragoza-Chicapa de Castro); AE2 (Álvaro Obregón-Emiliano Zapata) and AE3 (La Venta-La Ventosa), different in biophysical, economic and social aspects, although very similar in technical terms. Relevant as they allow the UPF to sustain themselves despite the occasional involvement of two to three people in agricultural activities. Environmentally the AE are similar and are located on an altitudinal gradient between 6 and 39 m, with an annual mean temperature between 26 and 27.5 °C and an annual rainfall between 943 and 1 007 mm.

The precocity of the Zapalote Chico and the irrigation allow three harvests per year under single crop systems (temporary or irrigation) and multiple systems (irrigation and temporary, irrigation, temporary and humidity and temporary and humidity). Ethnically, there is persistence of the zapoteca culture in the three AE, although AE1 and 2 differ from AE3, as the latter has a zapoteca (50%) and mestizo (50%) population.

Socioeconomically, the three AE are important as they include two to three people per UPF in productive activities and generate 5 to 10 wages ha^{-1} $cycle^{-1}$ and 12 wages ha^{-1} cycle outside the UPC, which improves income and support social; this partially remedies the low organizational capacity and is manifested in AE1 with 13.6% of organized producers and that has an impact on the low capacity to receive technical support (13.6, 0 and 27.7% for AE1, 2 and 3, respectively).

AE1 and 3 have the highest incomes $6 750.00 and $6 000.00, respectively; higher than AE2 ($3 675.00 per month), due to the low surface area (3.6 ha), low price of wages ($130.00), low amount of wages hired (5), low surpluses sold (20%) and the sheep system in intensive grazing, which limits income by not selling milk, cheese and meat.

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