AGROECOLOGICAL MANAGEMENT OF SMALLHOLDING COFFEE CROPPING SYSTEMS IN THE HIGHLANDS OF VERACRUZ, MEXICO †

[MANEJO AGROECOLÓGICO DEL SISTEMA DE CULTIVO DE CAFÉ EN LAS ALTAS MONTAÑAS DE VERACRUZ, MÉXICO]

H. J. Beltrán-Vargas[1], D. Flores-Sánchez[1], V. Vázquez-García[1] and A. Espinosa-Calderón[2]

*[1] Colegio de Postgraduados, Carretera México-Texcoco km. 36.5, Montecillo, Edo de Mexico, CP 56264, Mexico, E-mails: hecjabel@hotmail.com, *dfs@colpos.mx, vvazquez@colpos.mx*
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Carretera los Reyes-Texcoco km. 13.5, Texcoco, Edo de Mexico, CP 56250, Mexico, espinoale@yahoo.com
**Corresponding author*

SUMMARY

Background. In the high mountains in the state of Veracruz Mexico, agriculture is characterized by smallholding coffee cropping systems. VIDA A.C., a rural organization, promotes the management of coffee cropping systems through agroecological practices aimed to enhance biodiversity, build soil fertility, conserve resources, food security, social equity. **Objective.** To Characterize the agroecological management of coffee cropping systems carried out by smallholder families of rural organization VIDA A.C., and determine their importance to support their livelihoods. **Methodology.** Research integrated both qualitative and quantitative methods. Tools such as participant observation, interviews, workshops, and transect walks contributed qualitative data. For quantitative data, a structured survey was applied to 50 families to characterize their coffee cropping systems. **Results.** Coffee cropping systems are distinguished by their high diversity. This diversity is found in the varieties of coffee, shade trees and crops. Coffee management considers at least eleven practices, ranging from seed selection to marketing. All family member participates in the management of coffee systems. **Implications.** The study shows that rural families have incorporated diverse knowledge and strategies to carry out agroeocological management of coffee cropping systems. Research contributed to the baseline of these systems, and there is a room of opportunities to deep in agroecological principles. **Conclusions.** Coffee cropping systems are distinguished by having high diversity and implementing agroecological practices that confer a distinctive quality to coffee. Families contribute to the reproduction of coffee cropping systems, as a mean of subsistence, identity and territorial conservation.

Key words*:* shade trees; rural family; biodiversity; agroecology; food sovereignty.

RESUMEN

Antecedentes. En las altas montañas del estado de Veracruz, México, el café se produce en pequeñas unidades de producción. VIDA A.C., una organización rural, promueve el manejo de los sistemas de cultivo de café a través de prácticas agroecológicas dirigidas a mejorar la biodiversidad, aumentar la fertilidad del suelo, conservar los recursos, seguridad alimentaria y la equidad social. **Objetivo.** Caracterizar el manejo agroecológico de los sistemas de cultivo de café que realizan las familias campesinas de la organización rural VIDA A.C., y determinar su importancia para su subsistencia. **Metodología.** La investigación integró métodos cualitativos y cuantitativos. Los métodos cualitativos empleados fueron observación participativa, entrevistas, talleres participativos y caminatas en el área de estudio. Para la obtención de datos cuantitativos se aplicó una encuesta estructurada a 50 familias para caracterizar los sistemas de cultivo de café. **Resultados.** Los sistemas de cultivo de café se distinguen por su alta biodiversidad, misma que se puede encontrar en las variedades de café, árboles de sombra y cultivos. El manejo del cafetal comestible considera al menos once prácticas, que van desde la selección de semillas hasta la comercialización. Todos los integrantes de la familia participan en el manejo del cultivo de café. **Implicaciones.** El estudio muestra que las familias rurales han incorporado diversos conocimientos y estrategias en el manejo agroecológico de los sistemas de cultivo de café. La investigación contribuyó a la línea de base de estos sistemas, y existen oportunidades para profundizar en los principios

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ORCID = H. J. Beltrán-Vargas: http://orcid.org/0000-0003-1043-071X**; D. Flores-Sánchez:** http://orcid.org/0000-0002-0140-3907**; V. Vázquez-García:** http://orcid.org/0000-0002-0689-4397**; A. Espinosa-Calderón:** http://orcid.org/0000-0002-7128-4712

agroecológicos. **Conclusiones.** Los sistemas de cultivo de café se distinguen por tener una alta diversidad e implementar prácticas agroecológicas que le confieren una calidad distintiva al café. Las familias contribuyen a la reproducción de los sistemas cafetaleros, como medio de subsistencia, identidad y conservación territorial.
Palabras clave: árboles de sombra; familia rural; biodiversidad; agroecología; soberanía alimentaria.

INTRODUCTION

Coffee (*Coffea arabica* L., *C. canephora P.)* is an important agricultural commodity around the world. Global coffee production worldwide represented in 2020 an area of 11,043,032 ha and a total production of 10,688,153 green coffee tons (FAO 2022). Latin America is an important region for coffee production, accounting for 57.4% (FAO, 2022). It is estimated that 25 million farmer families grow coffee (Da Matta *et al*., 2019), and it provides a livelihood of 100 million people worldwide (Guido *et al*., 2020). Smallholders with less than 5 ha contribute with 60% of world production, and 60% of global coffee is grown in shaded coffee cropping systems. These systems are characterized by enhancing biodiversity by means of two strata understory of coffee shrubs and an overstory of shade trees (Holwerda *et al*., 2021**).** Biodiversity within these cropping systems not only provides ecological services but also contribute to economic and social benefits and food security (Perfecto and Vandermeer, 2015). Then, shaded coffee cropping system plays a critical role in rural livelihoods of smallholders, contribute to enhance biodiversity conservation, reduce and mitigate environmental impacts and promote sustainable development (Anderzén *et al*., 2020; Harvey *et al*., 2021). However, several coffee cropping systems have been simplified, reducing their biodiversity and structure (strata) becoming monocrops. This simplification has been promoted as a mean to increase yields and cash income, as consequence there are loss of biodiversity, the proliferation of pests and diseases and food insecurity, among others (Perfecto *et al*., 2019, Siles *et al*., 2022). Furthermore, coffee smallholders face prices fluctuations, market and climate change what impact negatively on incomes and yields and increase their vulnerability (Jezeer *et al*., 2017; Morton, 2007).

Coffee cropping systems in Mexico play an important economic and social role in smallholders. During 2021 this crop was cultivated in 711,708 ha, a total production of 944,412 tons of coffee cherry, with an average yield of 1.20 t ha^{-1} (SIAP, 2022). The state of Veracruz concentrates 20% of the national production, its socio-environmental conditions give a special value to the grain that makes it particular. Both peasant and indigenous communities have established this crop in Mountain Mesophyll Forest. Their traditional knowledge and sustainable management have contributed to protecting these agroecosystems (Nájera, 2002). In the high mountains of Veracruz, the rural organization, VIDA A.C. (Vinculación y Desarrollo Agroecológico en Café) has promoted the management of coffee cropping systems through agroecological practices which are aimed to enhance biodiversity, build soil fertility, close nutrient cycles, use of local resources, reduce dependency on external inputs, conserve resources, maintain crop performance and food quality (Altieri *et al*., 2012; Herrmann *et al*., 2018). Biodiversity has been a key factor since it is means of food and nutrition security (Fernández and Méndez, 2019). In these systems, multiple species converge, i.e. native trees, fruit trees and medicinal plants, among others. Due to several plants are used as food, VIDA A.C. has introduced the concept edible coffee cropping system (Pérez, 2019). Then, the implementation of agroecological practices is a smallholder strategy that maintains healthy systems and ensures food security (IAASTD, 2009). The objective of this paper is to describe the management practices of coffee cropping systems from an agroecological perspective. Plantations are managed by 50 peasant families who belong to VIDA A.C., an organization with previous experience in certification processes that is presently interested in establishing a participatory guarantee system (PGS). The study was conducted in agreement with the organization VIDA A.C.

MATERIAL AND METHODS

The research was carried out with 50 families belonging to the rural organization, VIDA A.C. (Vinculación y Desarrollo Agroecologico en Café). This organization is integrated by 846 families from the municipalities of Ixhuatlán del Café (19°03′N 96°59′W), Cosautlán de Carvajal (19°20′00″N 96°59′00″W) and Amatlán de los Reyes (18°50′45″N 96°54′54″W), state of Veracruz, Mexico (Figure 1). VIDA A.C. formed from the organization UGOCP (Unión General, Obrero, Campesina y Popular), a social resistance movement created to face the global coffee crisis and the disappearance of INMECAFE (Instituto Mexicano del Café) (Ramos, 2019). Families cultivate coffee, anthuriums (*Anthurium andraeanum* Linden), make handicrafts and herbal products, and they have savings groups and ecotourism.

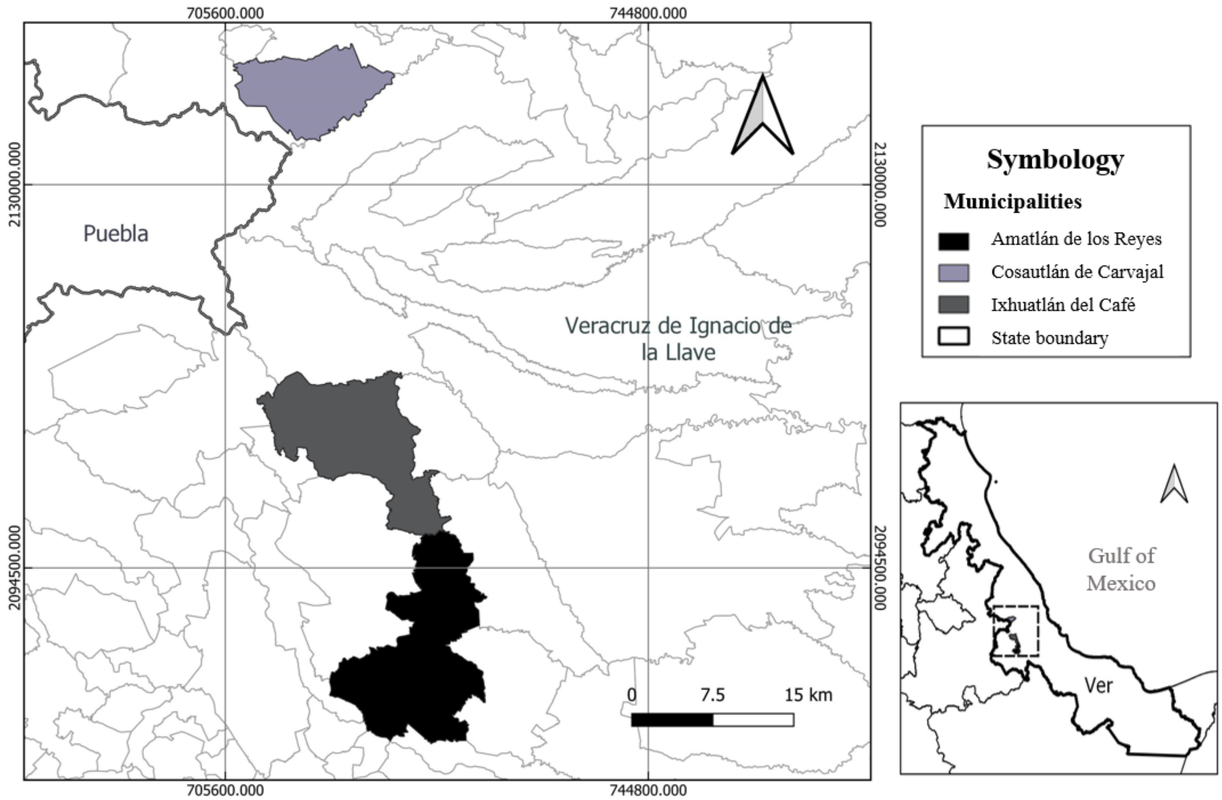

Figure 1. Study area, municipalities of Ixhuatlán del Café, Cosautlán de Carvajal and Amatlán de los Reyes, Veracruz

Research integrated both qualitative and quantitative methods. Tools from participatory rural appraisal (Ye *et al*., 2002) such as participant observation, interviews, workshops, and transect walks contributed qualitative data. Participant observation was used to analyze the activities of families around coffee cropping systems and participate in coffee harvesting, seed selection, coffee drying, among others. Interviews were conducted with families to identify the context in which they lived, the history of the organization and its leaders. Participatory workshops were aimed to know families' perceptions around coffee cropping systems and their components.

For quantitative data, a structured survey was applied to 50 families: 30 in Ixhuatlán del Café, 9 in Cosautlán de Carvajal and 11 in Amatlán de los Reyes. The survey was aimed to characterize their coffee cropping systems, and it included questions related to: a) socioeconomic attributes of the families (number of family members, age, schooling, occupation; economic activities; agricultural area and crops); b) coffee management (agronomic practices); c) coffee processing; and d) sexual division of labor.

Qualitative data was analyzed with ATLAS.ti. Information collected from the survey was processed by means of SPSS software to establish generalities, plots were made with RStudio software. In the results section personal testimonies from members of families are included. VIDA A.C. approved the use of its members' real names throughout the paper.

RESULTS AND DISCUSSION

The coffee cropping systems of family production units range from 1.7 to 1.89 ha, and numbers of fields varying from 1 to 4 per family; however most of families (70%) had only one plot. Within the interviewed families (50), 26 coffee cropping systems are managed by men, and 24 by women. The amount of land to cultivate coffee differs according to gender, land available for men averaged 1.89 ha and 1.5 ha for women. Land distribution was not equalitarian among families since 40% of coffee growers stated that their partner has land, and 10% mentioned that they had given land to their partner.

Biodiversity in edible coffee cropping systems

As agroecological strategy, families cultivate several coffee varieties, which are selected by their productivity, cup quality, canopy, resistance to pest and diseases, experience, tradition, among others. Families mention up to 18 varieties (Figure 2). Coffee varieties have differences in phenotypic characteristics. Every family decides spatial or arrangement distribution of varieties within plots, according to their experience, knowledge, available land, easiness of culture, so on. Coffee cultivars can be either planted in rows or mixed with other varieties, but famers decide the best distance between plants to avoid competition between them, and they can cultivate up to eight varieties per plot.

Tipical and Bourbon were the first varieties cultivated, and coffee growers are still cultivating these varieties (Escamilla *et al*., 2005). Families replaced coffee plantations with resistant varieties such as Sarchimor and Geisha when coffee rust (*Hemileia vastatrix* Berk. & Broome) arrived (Chávez *et al*., 2020). These varieties are cultivated by more than 50% of families. These varieties are distinguished by their quality as peasant stated:

"We wish to have a varieties of coffee, but good coffee, because most of the coffee-growing area has varieties such as Colombia, Costa Rica and some Catimors that don´t have a good quality. If we belong to an organization that cultivates good agroecological coffee, then we want quality in all aspects. That's why we only mention some of them, Bourbon, Masellesa, Geisha and Sarchimor" (Martin Cantor Hernandez, April 2022, Ixhuatlán del Café).

In addition to quality, productivity and resistance to rust are other important factors involved when selecting a variety. Colombia, Costa Rica, Oro Azteca and Garnica are characterized by their resistance to rust; Caturra and Catuai for their productivity; and Tipical and Bourbon for their quality (Escamilla *et al*., 2015).

Coffee cropping systems has up to 80 species of shade species, the most frequent species (27) are presented in Figure 3. Other study reported 102 species (Ramos *et al*., 2019). According to women and men peasants the most important shade trees are vainillo (*Inga vera* Willd), banana (*Musa* ssp.), orange (*Citrus sinensis* (L.) Osbeck), avocado (*Persea americana* Mill.), ixpepe (*Trema micrantha* (L.) Blume), chinene (*Persea schiedeana* Nees) and xochicuahuilt (*Cordia alliodora* (Ruiz & Pav.) Oken). These shaded and multi-cropping coffee systems provide multiple ecosystem services: shade, food, income, forage, soil conservation, barrier to prevent erosion or as buffer zone, nutrient cycling, pest and diseases regulation, pollination, among others (Harelimana *et al*., 2022). It means that incidence of pests and diseases is not high. In addition, other management practices are carried out to mitigate the impacts of these agents.

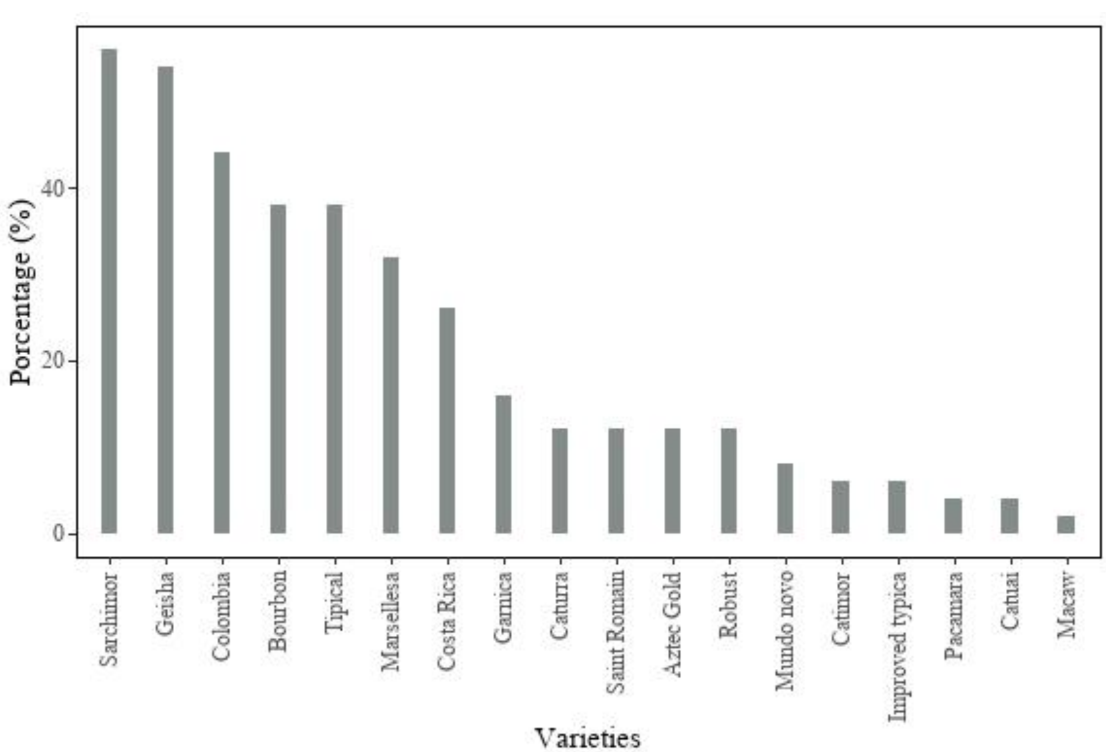

Figure 2. Coffee varieties cultivated by families of the rural organization VIDA A.C.

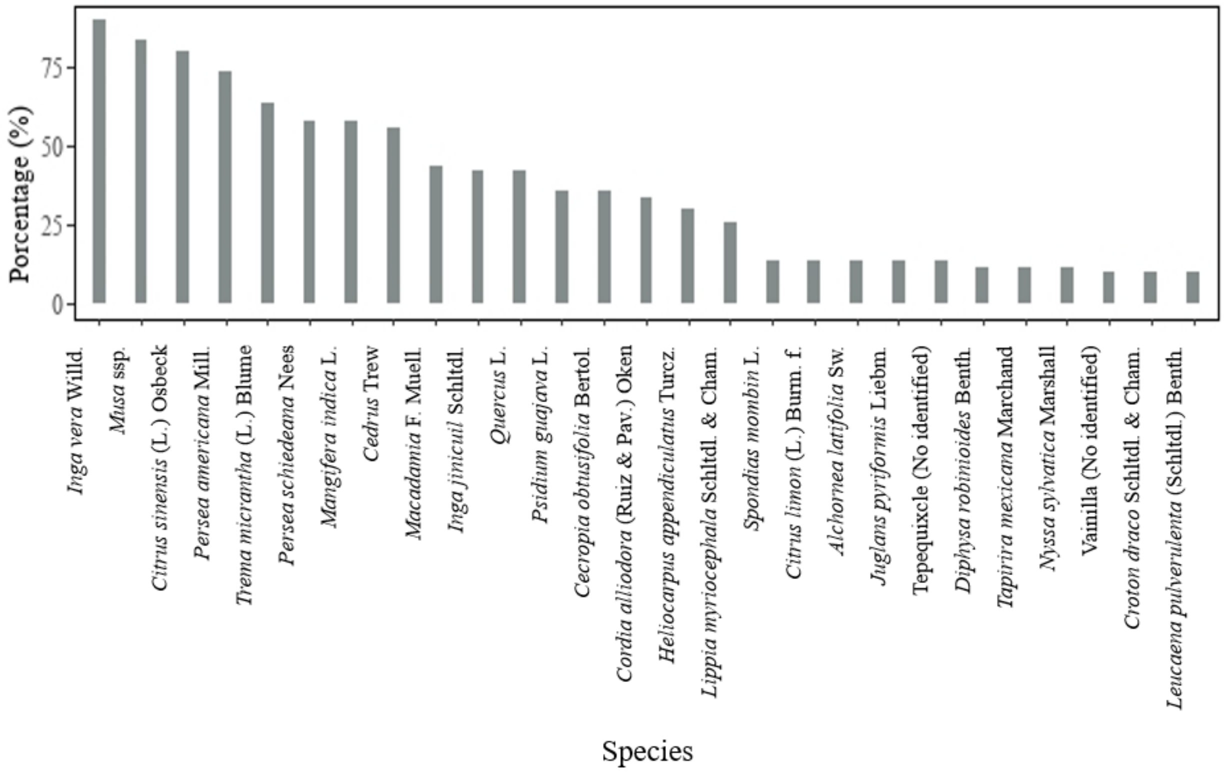

Figure 3. Shade species found in coffee cropping systems of families belonging to the rural organization VIDA A.C.

Along with shade species, families cultivate different crops (Figure 4). There are up to 28 species (including coffee). The main diversity corresponded to fruit trees. There are several species of banana, orange and avocado. The most frequent crop is roatan banana, followed by tepejilote (*Chamaedorea tepejilote* Liebm.), parlor palm (*Chamaedorea elegans* Mart.) and two species of orange. Some identified species are protected to promote their production (Vibrans, 2021) such as tepejilote, parlor palm, chinene and native avocado. In some cases, tepejilote and camedor have become crops due to their high demand. Species such as banana, orange, lemon, among others, are exotic or introduced and have been adopted in the edible coffee cropping systems as complementary crops. Families have adapted certain crops according their convenience. For example, some communities of Ixhuatlán del Café grow bananas to commercialize their leaves. Communities of Cruz de los Naranjos in Amatlán de los Reyes and Plan de Ayala in Ixhuatlán del Café cultivate roatan banana to sell fruits, and foliage that is used in flower arrangements. Edible coffee cropping systems are distinguished by their high diversity, according to Moguel and Toledo (1999) these systems are classified as traditional polycultures since they include different combinations of native trees, fruit trees, several coffee varieties and other useful plants, creating a multiestrata systems (Hernández-Martínez, 2008).

Harvested food products are used for self-consumption, to sell in local markets, and product exchange known as *trueque*. This practice contributes to have trust and social cohesion among families and communities (Bellante, 2017; Baumann, 2022). This diversification, is a strategy to have several sources of food, income and other uses (medicine, firewood). Members of the organization VIDA A.C. have seen this strategy as a mean not only of food sovereignty and nutrition security (Anderzén *et al*., 2020; Fernández and Méndez, 2019), but also to conserve local resources, and enhance ecosystems services.

Agroecological practices in coffee cropping systems

Coffee cropping systems were recognized as organic, during ten years they were certified by CERTIMEX (Hernández y Nava, 2019). For that purpose, the organization VIDA A.C. along with its members established an organic management plan. This plan establishes general directions regarding to coffee management, every family carries out this and adapts this plan according to local resources and its particularities. In this research, coffee management was determined according to the most frequent practices implemented by coffee families. At least eleven practices are identified, ranging from seed selection to marketing. Figure 5 shows the sequence of coffee practices.

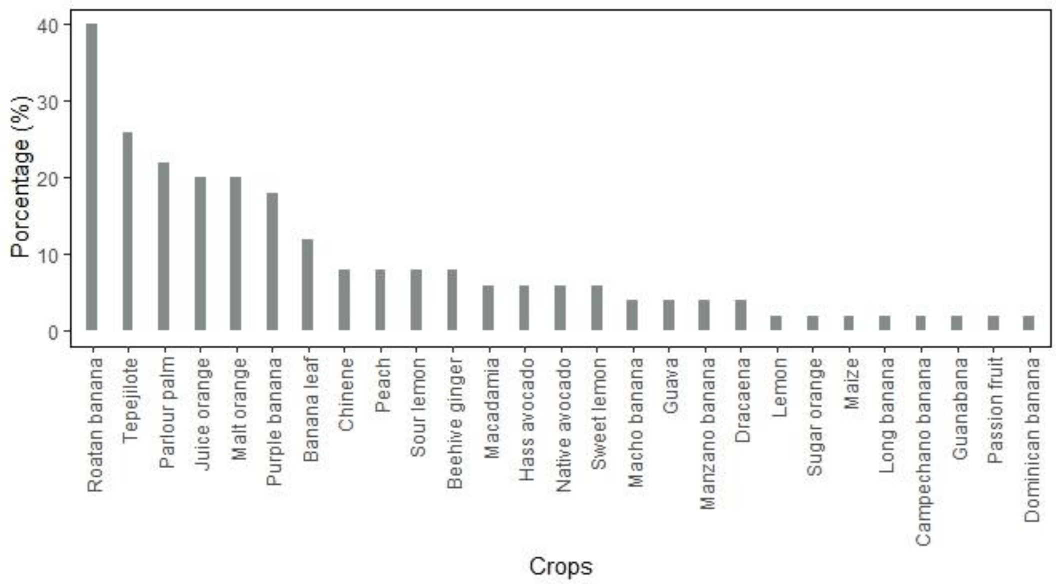

Figure 4. Diversity of cultivated plants in coffee cropping systems of families belonging to the rural organization VIDA A.C.

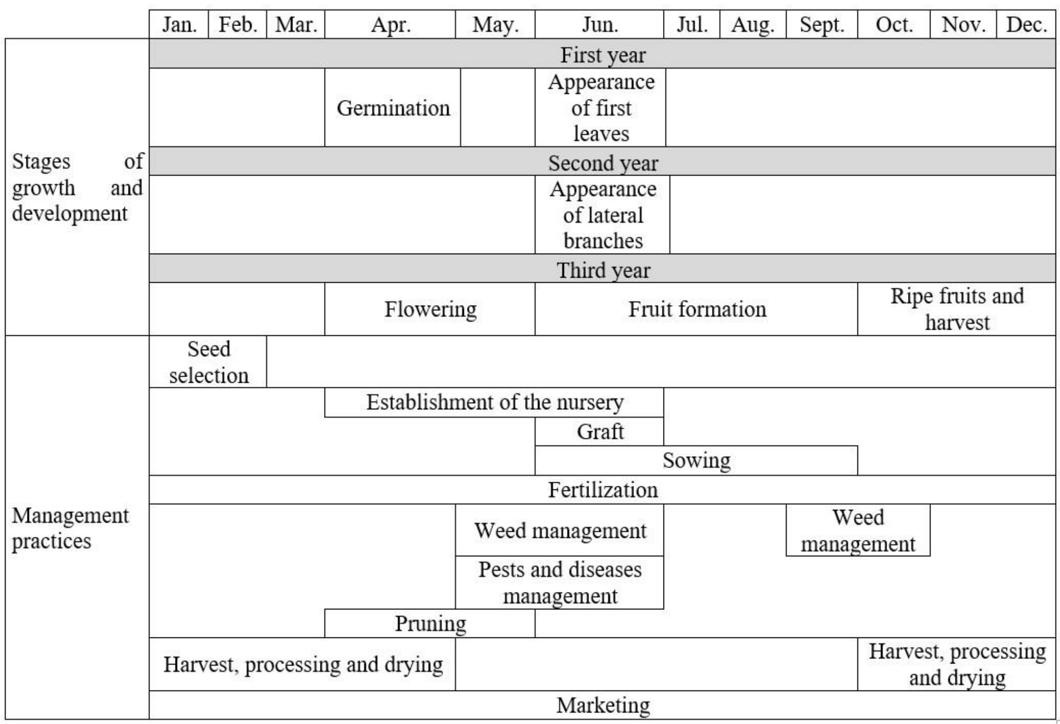

Figure 5. Stages and management practices of coffee cropping systems of families belonging to the rural organization VIDA A.C.

Establishment and maintenance of coffee cropping systems and soil conservation

The first practice is the selection of seeds to establish a new coffee plantation. This practice is typically done in January or February. Coffee-growing families choose young and healthy plants, selecting middle branches and central grains. The number of selected grains depends on the number of plants that coffee-growing family will plant. The seedbed is prepared after the coffee harvest between April and June. The seedbed is done with substrates that contain a high level of porosity to facilitate the root development of plants. The substrate is a mixture of soil, compost or bokashi. Seedlings stay in the seedbed for 2.5 months.

Veracruz is the only state that has problems with nematodes (Escamilla *et al*., 2005). In some communities, families graft coffee seedlings to obtain a high-resistant plant, and avoid problems with nematodes (Morales *et al*., 2018). The graft is made with a Robusta (*Coffea canephora* P.) seedling (root system) and an Arabica variety which confers resistance or tolerance to plant-parasitic nematodes. Both varieties are mainly used for grafting, and farmers do not report other varieties for this purpose. Robusta seedlings must have open cotyledon leaves and Arabica *(Coffea arabica* L.) seedlings must look like a matchstick. A diagonal cut is made on both seedlings and attached with grafting tape. The newly-cultivated seedlings are then placed in bags already containing substrate and composted for transplantation. Most of the farmers (82%) made seedbeds in the last production cycle, of which 98% used their own seeds, and only 2% used seeds donated by conventional coffee plantations. Plants with a height of 20-25 cm of height are planted in the field. First, a hole with dimensions of 40x40x40 cm is dug, after that organic fertilizer is applied and finally establishing the coffee seedling. Around 84% of farmers planted their own seedlings within the last production cycle, none bought them, and 6% did not sow.

Coffee is usually planted at different plant density which varies according to gender, 1,910 and 2,341 coffee plants ha^{-1}, for women and men, respectively. Plant density in coffee systems cultivated by women is 18% lower than systems manage by men. Plant density corresponded to average value in each field, and there is not a distinction for each variety. This is a women's strategy to cultivate other crops, they cultivate ten crops while men grow six crops.

In some circumstances, coffee-growing families use a buffer zone to prevent cross-contamination among plots by employing various strategies to avoid polluting them. The main strategy is to use live or dead barriers (54%), but other strategies such as ditches (40%), and paths (20%) are also used. An important number of families (44%) do not use a buffer zone on their plots. In most cases, there is no risk of contamination because the plots are favored by the slope, wind direction, and crops organically produced by their neighbors, among others. A peasant stated that the risk of contamination is low due to agricultural practices implemented:

"Normally, even though they are conventional. However, everything is agroecological. In other words, chemical products and hoes are hardly used, it is only to cut the weeds to a reasonable length. Then, they cultivate parlor palms, right? For flower arrangements… only then will they have enough barriers to preserve the soil, even for contamination risks. So, normally we do not need to establish barriers in the adjoining plots, right?" (Juan Jimenez Cruz, April 2022, Ocotitlan, Ixhuatlan del Café).

Live barriers also are used to prevent soil erosion, promote a good diet by producing diverse foods, and generate other sources of income through forage sales. Families usually establish the following live barriers species: tepejilote (*Chamaedorea tepejilote* Liebm.), parlor palm (*Chamaedorea elegans* Mart.) and dracaena (*Dracaena vand*.).

Families have adopted different strategies to conserve soil. A general practice is to keep litter and herbaceous substrate, which provides organic matter for recycling nutrients and preventing erosion (Docampo, 2012; Álvarez *et al*., 2014). Figure 6 shows strategies that are used for soil conservation. Practice such as terraces, are carried out in the middle of the year or later months to take advantage of the fact that the soil is softer due to the rains. Other practices such as live barriers and terraces are also practiced in other regions of México, and are the most frequent for soil conservation (Escamilla *et al*.,2005; Morales *et al*., 2018).

The main erosion management strategy is "*desmonte alto*" which consists of cutting weeds at a height of 5 cm in order to leave the soil covered with vegetable substrate. This kind of cutting allows a considerable amount of weed to cover soil. The cutting is done before and after the harvest, in April, May or June and in September or October.

Coffee fertilization

For crop nutrition, farmers carry out several practices, among them the establishment of legumes (Fabaceae Lindl.), residue retention and application of organic fertilizers. Figure 7 shows organic input used by coffee-growing families, and Table 1 summarizes amount applied of each organic input. Several studies have demonstrated that the use of local organic inputs reduces costs, improves soil quality, enhances nutrient cycling, and nutrients are available for the growth and development of coffee plants (Tumwebaze *et al*., 2016; Casanova *et al*., 2019).

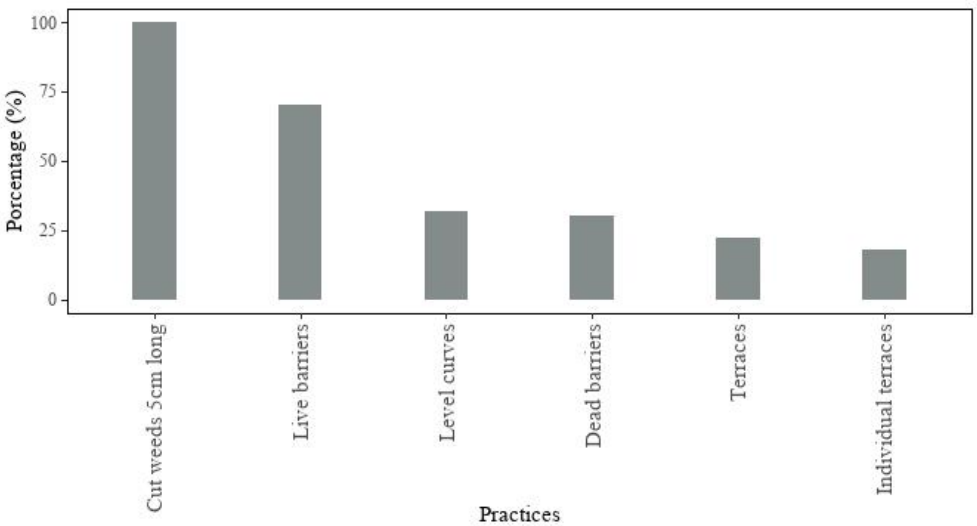

Figure 6. Soil conservations practices of coffee cropping systems of families belonging to the rural organization VIDA A.C.

The main source of organic matter is coffee pulp. It is used by more than 50% of families. This resource is widely available, and it comes from their agroecological fields, only one case use pulp from conventional fields. The average amount applied per year is 2595 kg ha^{-1}, and according to the nutrient content of pulp (Korikanthimath and Hosmani, 1998) the amount of NPK applied by farmers was 62-13-109 kg ha^{-1}. Several studies have demonstrated that coffee pulp improve soil structure and soil microbial life (Cervantes *et al*., 2015a, 2015b).

Biol is used by 40% families. This organic input is a liquid fertilizer made from the decomposition of organic materials through decomposers in the absence of oxygen (INIA 2008). Ingredients used by farmers are bovine manure, molasses, milk, yeast, ash, eggshells, whey, fruits, among others. Farmers applied biol twice per year at a dosage of 136 L ha^{-1}. It is known that this biofertilizer contains nutrients (N, P, K, Ca, Mg, etc.) and plant growth regulators that stimulate plant development (Gomero and Velasquez, 1999). Biols can be nutritionally richer than commercial fertilizers such as Regena MIN HL-15 (Bustos *et al*., 2017). However, there is not local references related to nutrient content of biol what could be necessary to have an estimation of nutrients applied.

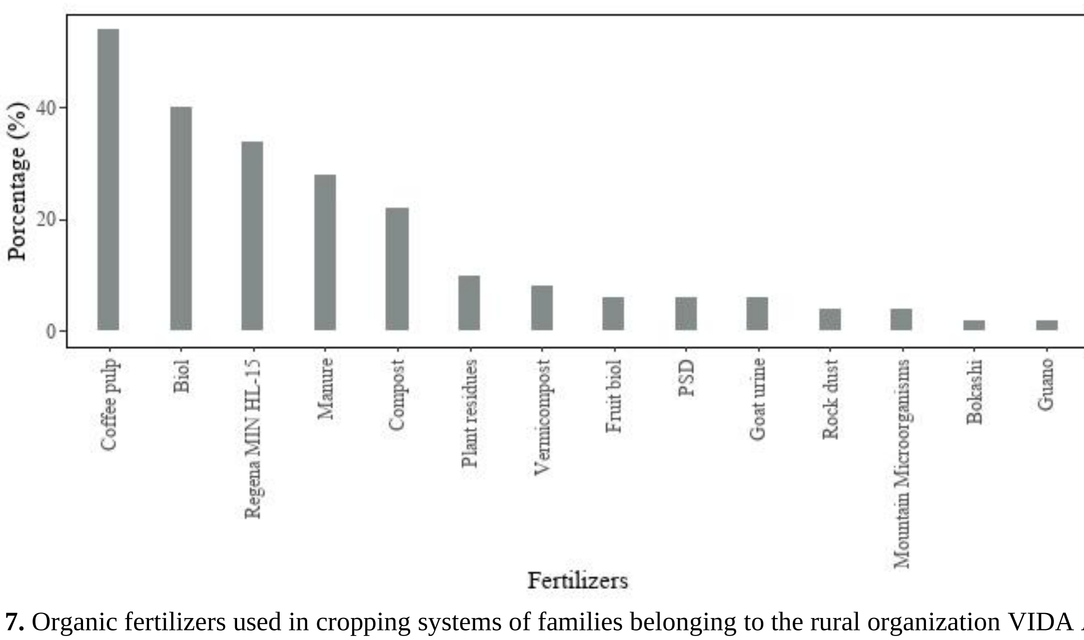

Figure 7. Organic fertilizers used in cropping systems of families belonging to the rural organization VIDA A.C.

The organic fertilizer Regena MIN-HL15 is used by 34% of families. This commercial fertilizer is the unique input bought by farmers. It is applied twice per year, at an average dosage of 376 kg ha^{-1}. According to the nutrient content of this fertilizer, the amount of NPK applied by farmers is 23-11-22 kg ha^{-1}.

Dung is used to manure the coffee cropping systems (28% of families). It is applied when it is dry in order to avoid phytosanitary problems. Manure is directly applied to soil or used as raw materials for biols and composts. The main sources of dung are donkeys (43%), horses (36%), cows (21%), chickens (14%) and sheep (7%). Around 79% of families applied once per year, remaining families (21%) applied twice per month, as soon as the manure is dry. In these cases, families own animals. This input provides macronutrients and improves soil properties (Rittenhouse, 2015). Nutrient content of manure depends on the C:N ratio and the appropriate timing, rate, and method of application to crops. The average amount of manure applied is 513 kg ha^{-1}. According to Van der Vossen (2005) nutrient content of NPK (%) is 2-0.8-1.8, respectively. Based on these values, the amount of nutrients applied to coffee cropping systems is 10-4-9 kg ha^{-1}.

Table 1. Amount applied of organic fertilizers used in cropping systems of families belonging to the rural organization VIDA A.C.

Organic input	Amount applied	
Coffee pulp	2,595	kg ha^{-1}
Regena MIN-HL 15	376	
Manure	513	
Compost	3,843	
Biol	136	L ha^{-1}

Compost is applied by 22% of families. This organic fertilizer results from an aerobic process of transformation of organic waste through the action of decomposing organisms (Fortis-Hernández *et al*., 2009). The main organic materials to elaborate compost are cow dung, coffee pulp, ash, weeds, leaf litter and coffee straw. Other sources used, but less frequent, are cane bagasse, stubble, kitchen waste, mountain microorganisms and soil. The manure came from extensive agriculture (82%) and intensive agriculture (9%), and unknown origin.

Compost is one of the most complex organic fertilizers to make, and it demands significant effort. A peasant stated that:

"Making compost is almost the hardest activity for organic production because there is no material, and it takes a lot of physical effort to manage composts. Some plots are located very far away, and there is an extra family effort to carry compost to plots (Gisela Illescas Palma, August 2022, Ixhuatlan del Cafe)"

The amount of compost applied is on average 3,843 kg ha^{-1} (1.8 kg per plant), distributed twice per year. That amount is lower than the recommendations of Morales *et al*. (2018), who recommend applying between 3 and 10 kg of compost per plant. The average NPK content (%) of coffee pulp, composted, is 3.8-0.4-6.5 (Sánchez *et al*., 1999; Njoroge, 2001). Based on these data, the amount of NPK applied was 146-15-250 kg ha^{-1}.

Families used another nine organic sources for coffee nutrition, but less than 10% of families. These organic inputs were plant residues, vermicompost, bokashi, among others. It is important to mention that in most of the cases organic inputs are made of local resources which reduces external dependency, only in a few cases families bought commercial fertilizers.

According to the estimations of nutrients applied per organic input (coffee pulp, Regena MIN HL-15, manure, and compost), N supplied to coffee ranged from 10 to 146 kg ha^{-1}, P from 4 to 15 kg ha^{-1}, and K from 9 to 250 kg ha-$^{-1}$. To produce 1000 kg ha^{-1} of fruits, coffee needs 31 kg N ha^{-1}, 2 kg P ha^{-1} and 37 kg K ha^{-1} (Sadeghian-Khalajabadi *et al*., 2006). Average yield recorded by families is 4793 kg ha^{-1}, then the total uptake is 149 kg N ha^{-1}, 10 kg P ha^{-1} and 177 kg K ha^{-1}. If farmers use only one input could not be sufficient to satisfy coffee needs, mainly in the case of N. However, families used up to three organic inputs what can satisfy nutrient demand. Besides, another important contribution are residues from weeds, trees (leaves, branches), understory which remain on the soil surface and through the decomposition process nutrients are released and untaken by coffee.

Soil fertility studies carried out in regions close to the study area indicate and average content of organic matter of 2.88%, nitrogen 0.14%, phosphorus 2.86 g kg^{-1}, potassium 0.16 g kg^{-1} and pH of 5.8 (Brigido, 2014). Another study carried out in the community of Zacamitla reported acid soil with a pH of 4.3, organic matter of 5.7%, content of nitrogen phosphorus and potassium of 2, 2.2, and 5 g kg^{-1}, respectively (Vásquez-Montiel *et al*., 2019). These data demonstrate relative large variation of organic matter and macronutrient contents that can be related to soil management. It is necessary to carry out studies related to soil fertility and nutrient balance in coffee cropping systems in order to have local references and improve crop nutrition. It creates a room of opportunity for future research.

Pest and diseases

In the study area the main pests and diseases are coffee leaf rust (*Hemileia vastatrix* Berk. & Broome), coffee berry borer (*Hypothenemus hampei* Ferrari), and hispid pocket gopher (*Heterogeomys hispidus* Le Conte). Families recognized other pests and diseases such as rooster's eye (*Mycena citricolor* Berk. et Curt. Sacc.) and coffee thread blight (*Corticium koleroga* Cooke Van Hoehnel), but they don't represent an economic impact on them.

Coffee leaf rust (*Hemileia vastatrix* Berk. & Broome), a fungus disease, is one of the main limiting factors of coffee production worldwide (Talhinhas *et al*., 2017). A farmer stated that rust is presented due to climate irregularities (variations in rain and temperature). In the year 2015 this disease caused more than half of production losses compared to the previous year (Sotelo Polanco and Cruz-Morales, 2017). This scenario has changed, nowadays 44% of families mentioned that this disease is presented in their coffee cropping systems. This percentage has been reduced, due to the renewal of coffee plantations by resistant varieties to rust (Chávez *et al*., 2020). The main strategies to control this disease are through organic substances and cultural practices. More than 30% of families use mineral broths, among them sulphocalcic broth, made from sulfur and lime, and the broth of bordeaux, composed mainly of copper sulphate and lime. Copper oxychloride (Cu_2 $(OH)_3$ Cl) is another input used to manage this pest. This is an inorganic compound that acts as a fungicide to inhibit the proliferation of fungi in crops (Paredes and Anaya, 2015). The remaining strategies used are vegetable extracts and Royaout©, a botanical fungicide which is permitted in organic production. Royaout© contains *Bacillus subtilis*, an efficient substance to manage coffee leaf rust (Ramírez-Rodríguez, *et al*., 2020). Shade regulation is essential to control rust and borer (Vargas, 2007). Families control shade and use pruning residues as dead barriers. A cultural practice carried to manage rust is shading, coffee cropping systems should have up to 60% shade, and this is made through pruning. Escamilla *et al*. (2005) report a canopy cover for Veracruz of 74.8%.

Coffee berry borer (*Hypothenemus hampei* Ferrari) is an insect that affects coffee fruits. Around 40% of the coffee-growing families mentioned having problems with this pest. It can reduce production by more than 50%. It also reduces physical and organoleptic characteristics of coffee (Camilo *et al*., 2003). Nevertheless, the number of coffee fields affected by this insect was less than Escamilla *et al*. (2005) reported. The main strategy used to manage this insect is ethanol alcohol traps (80%). Fernández and Codero (2005) found good results combining ethanol and methyl alcohol. Another strategy to manage this pest is to avoid leaving fruit on the plots during harvesting.

Hispid pocket gopher (*Heterogeomys hispidus* Le Conte) is a rodent that mainly eats the root system of plants. This pest was reported by 52% of the coffee-growing families. In México around 9% of the coffee cropping systems has this pest (Escamilla *et al*., 2005). The strategies used to control this pest are mainly grouped into mechanical and cultural controls (Verdejo, 2013). In the study area families use several methods to control this pest: scavenging (35%), hunting (23%), trapping (15%). Other coffee growers establish plants such as *matagallina* (*Euphorbia cotinifolia* L.) to keep rodents away due to toxic properties (Avendaño and Flores, 1999), and other used manure on the sidewalks of these animals for its control. These practices are based on local knowledge, and it could be interesting to evaluate these ecological process in order to have evidence that proves the efficacy of these practices.

Another practice carried out is pruning which is directly related to crop productivity (Escamilla *et al*., 2005) and it is done by removing branches or plants to promote crop growth or mitigate health problems. The number of coffee growers who do this practice was 90% which is higher than Álvarez *et al.*, (2014) (85%) and Escamilla *et al.*, (2005) (82%) found. This practice is usually done after the harvest between April and May.

Harvest and post-harvest

Edible coffee cropping systems are managed by both men and women. There are gender-differentiated strategies related to agrobiodiversity management: women grow up to 10 crops while men 6 crops (Table 2). Yields of crops are different between men and women. Fields managed by women have lower yields. It is related to the fact that they carry out household activities that are not necessarily paid (Avolio and Di Laura, 2017); however, women have more diverse incomes than men, due to the higher number of crops which commercializing them in local markets.

The coffee harvest is carried out from November to April (Figure 5). The harvest is an activity in which all members of the family participate, a family activity, and require external labor, which is also common in other regions (Nájera, 2002; Vargas, 2007; Jurado, 2017). Harvest begins when fruits are ripe and with good characteristics (size, color). When fruits are not cut on time they have a dark color. These fruits are called "ball", and are harvested later. Some families harvest their coffee with two baskets, one basket for good quality fruit and another basket for the rest of the fruits. Families normally have to wait for the fruits to ripen, which happens in one month. However, a producer stated that due to climate change, the harvest of the grains could start in October (Figure 5):

"The harvest has been changing a lot due to global warming, right? It [the harvest] already started at the end of September. Years ago, there was a lot of native coffee, and now there are more varieties, such as Colombia and Costa Rica. Then the coffee begins to ripen until November, almost till the beginning of November. Now, plants and new varieties have acclimatized. Now, the harvest begins more or less around the end of October or in the middle of October. The harvest comes early when it blooms in January, January and February. When it blooms until April, the harvest is late." (Jose Lucio Cantor Hernandez, August 2022, Ixhuatlan del Cafe)

Average coffee berries yield is 4,793 kg ha^{-1} (Table 2) which is higher than yield of the state of Veracruz and the country, 1,820 kg ha^{-1} and 1,470 kg ha^{-1}, respectively (SIAP 2022). Families are concerned about growing not only productive varieties, but also good quality coffee like Sarchimor, Giesha, Bourbon. However, data on coffee quality were not evaluated. Women´s yield was 40% lower than men's. It can be related to plant density, men reported 18% more plants per ha than women. In other countries such as Colombia and Ecuador, yields of farms managed by women were 2.5% lower than men's farms (Avila-Santamaria and Useche, 2016).

As soon as the coffee-growing families harvest their coffee, they process it through coffee pulping machines. Families who use a machine clean it properly before using it. After pulping, the grains go through a fermentation process where the mucilage attached to the grain is released (Vargas, 2007). This process usually lasts for 24 hours (Palomares *et al*., 2012). Fermentation process is carried out by 92% of coffee-growing families, and only 2% stated that they used a demucilaginator and did not ferment their coffee. Demucilaginator is a machine that removes mucilage from coffee (Federación Nacional de Cafeteros de Colombia, 2022) and generally uses little water. To carry out fermentation 50% use trays, 41% containers and 20% use concrete tanks. There are some families who have been experimenting with "honey" coffee. Honey coffee is characterized by having a two-day fermentation and later is dried. This process allows to obtain a natural sweetness.

Water is an important factor in processing coffee in order to have good quality and avoid contamination. The types of water used in processing coffee are from the water supply network (54%), pluvial (30%), well (22%), wellspring (15%), river (2%) and storage tank (2%). Residues from coffee processing such as coffee pulp are applied in the coffee fields (64%), used for composting (26%) and vermicomposting (11%). Wastewater destinations are coffee plantations (57%), soil (22%), biol (15%), pulp (13%), plants (7%) and septic tanks (2%).

The final processing procedure carried out by the coffee-growing families is drying. Drying is done when the grain is exposed to heat which results in a loss of moisture. Drying is an important process of which determines the uniform grain's green, and as well as a good yield and the approval of the markets (Palomares *et al*., 2012). Families use different places to dry the aromatic grain: screens (47%), rooftop (45%), mechanical dryers (13%), floor (9%) and solar dryers (6%). If they use the ground or rooftop to dry the grains, sacks or tarps are employed so that the coffee does not come in direct contact with ground. Families are aware that they must keep these drying spaces clean.

Dry coffee is stored, preventing that lose its physical and organoleptic characteristics. Families mainly use barriers such as pallet stacks to store the grains. The transport of coffee is done by 53% of the coffee growers through plastics inside sacks provided by the organization VIDA A.C.

Table 2. Yields of crops in coffee cropping systems of families belonging to the rural organization VIDA A.C.

Crop	Coffee growers (%)	Yield (kg ha^{-1}) men	Yield (kg ha^{-1}) women	Average yield (kg ha^{-1})
Coffee berries	100	5,935	3,556	4,793
Roatan banana	32	644	525	585
Tepejilote	10	1,001	273	564
Red banana	8	117	78	97
Juice orange	6	281	40	201
Malt orange	4	0	167	167
Native avocado	4	300	100	200
Chinene	2	0	24	24
Long banana	2	0	80	80
Campechano banana	2	0	71	71

The following producer describes the transport of the aromatic grains:

"In fact, when we manage coffee, for example, when it is going to be shipped, well, what we do is, well, the truck that is going to be used is cleaned well, and plastic is put on it to prevent contaminating them [the grains]. Apart from that, it is not contaminated because the coffee goes into a bag. It also goes in a sack… that is, we take those, those precautions" (Juan Jimenez Cruz, August 2022, Ocotitlan, Ixhuatlan del Cafe).

The process implies that the coffee-growing family must invest a lot of effort. For some families to complete their process of production is considered a tremendous achievement. A producer points out the following:

"Many producers can't industrialize their coffee because it is too much, it is too much work. Exhausted, they go to harvest, process it after spending a whole day working. Industrialization is another process that requires a lot of time and physical and economic effort, so that is why most producers stay within the first stage, selling it as coffee berries. So, having the family involved is very important because one has to go harvest while others, the young ones, take ownership of the other links in the chain" (Clara Palma Martínez, August 2022, Ixhuatlan del Cafe).

Although the harvest and processing of grains is done between October to April, the commercialization of coffee is done throughout the year of the following year. Coffee can be commercialized in different ways: berries (harvested coffee that is red and yellow in color); ball (dried coffee with pulp); parchment (dried coffee without pulp); gold or green (coffee that has been threshed); roasted (gold coffee that has been thoroughly roasted) and ground (roasted coffee that has been thoroughly ground). Coffee-growing families also market grain residues such as pulp, and defective grains.

Organization VIDA A.C. receives parchment coffee from families belonging to this organization. However, families do not sell all their harvests in parchment, because they require money for food and to cover family needs. A producer mentioned the following:

"We would like to try to make all grains parchment, but, well, how will we eat then? We must see how we are going to pay the harvest, well, as well as the house expenses, including gas and everything… We give the second-class coffee to the «coyote»" (Briseida Venegas, February 2022, Ixcatla Ixhuatlán del Café).

The production that is not marketed with the organization is sold to intermediaries, also known as "coyotes", who go to communities to buy the aromatic grains. There is also a multinational company in the municipality of Ixhuatlán del Café called *Agroindustrias Unidas de Mexico* (AMSA) that buys the grain. This company mainly buys coffee berries, but also receives grains whilst they are in different stages of processing. In other regions such as Chiapas, coffee growers have to sell their harvest to intermediaries to buy food and pay bills (Sotelo-Polanco and Cruz-Morales, 2017). Moreover, coffee growers in Mexico do not have enough income to pay the production costs of this crop (Chávez *et al*., 2020).

Then, families deliver their harvest, and their payment is established through an agreement made between them and the organization VIDA A.C. Some families have to wait for a few months to receive the value of their harvest. For most of them is feasible since they have other sources of income. Other families periodically receive part of the value of their harvest.

The rural organization also promotes an egalitarian distribution of incomes. For example, 15% of men share their harvest with their partners, and 4% of women share the money of their harvest with their partners. Although some members of the organization do not make this agreement with their families, they spend the money in family's subsistence and farm maintenance, among others. A coffee grower commented on how the family distributes the money:

"You know what you need to buy, for example, oil, you need to buy what you need for the kitchen, right? If we are going to wash clothes, we buy soap. The most essential thing for the house... when you need some tomatoes, you have to buy them, even if it is from the store on the street, right? Everything is done according to how the family decides and plans." (Jose Lucio Cantor Hernandez, April 2022, Ocotitlán, Ixhuatlan del Cafe).

VIDA A.C. created in 2015 its own coffee brand called Femcafe. This name was chosen because coffee is produced from a social sense and gender perspective. VIDA A.C. recognizes its coffee as the first feminist coffee in Mexico for making women's work visible, promoting gender equality and social, environmental and food justice, as well as raising awareness in the marketing chain through trust between families (producers) and consumers. Femcafe has reached both national and international markets (USA, Europe). Coffee families complied with all quality standards, environmental protection, gender equality and other parameters required by this market. In this way, the organization's coffee reached considerable prices and higher than conventional coffee and certified or fair market coffee. This coffee has also been certified organic

Table 3. Distribution of the work of the coffee-growing family.

Activity	Man (%)	Woman (%)	Boy (%)	Girl (%)	External labor
Seed selection	86	32	8	6	2
Nursery establishment	92	38	20	14	5
Nursery maintenance	88	46	22	20	7
Sowing	96	30	16	10	9
Fertilization	90	20	16	10	9
Weed management	100	10	6	2	35
Pests and diseases management	86	8	6	2	3
Pruning	88	6	4	0	6
Harvest	96	90	46	38	38
Processing	86	44	20	22	4
Drying	76	52	16	18	2
Commercialization	70	40	2	2	1

by CERTIMEX; however, in 2020 organic certification was not achieved due to delays in the procedures derived from COVID-19 pandemic. Now, VIDA A.C. is opting for participatory organic certification. It is clear for its members the benefits of this type of certification, and it is an opportunity to continue for marketing their products as agroecological and organic.

Maintenance of edible coffee cropping systems demands a lot of work and effort; through the process of production all the family members participate (Table 3). Men participate in high proportions in all the management practices of the coffee plantation. However, also there is the intervention of the different members of the family. In addition to harvest, women have an important participation in activities that can be done close to home, such as maintenance of the seedbed, processing and drying. In this way, women take care on different types of work (Sosa, 2019).

Boys and girls also participate in different farming activities, but to a lesser degree since they contribute during their free time once they conclude their school tasks. They acquire traditional knowledge and skills regarding to coffee management, so they are integrated into the social and economic life of their families. In addition to the harvest, they take care of activities that can be carried out near to the house, such as the maintenance of the nursery or grain processing. They also, participate in activities such as transplanting and fertilization where they transport plants or supplies from the home to the plot. However, girls are in charge to carry out reproductive activities (Vargas, 2007), in the absence of the mother, the care tasks fall on the girls. The main activities that require external labor are weed control and harvest (Nájera, 2002).

Income from coffee cover partially all family needs, so families have had to diversify their productive activities. Most of the families (79%) carry out more than four economic activities to generate income for the family. These activities include ecotourism, handicrafts, flower production, among others. However, there is not data about family incomes from each economic activity. It opens an opportunity for research regarding activities and their contribution to family income.

CONCLUSIONS

Coffee cropping systems is a productive space that integrates a set of ecological, economic and social elements and relationships that generate its sustainability. Coffee cropping systems are characterized by having high diversity (up to 80 species) and implementing agroecological practices which confers a distinctive quality to the coffee and the crops, and contribute to food sovereignty and nutrition security. The family is an important social organization, where all the members contribute to the reproduction of coffee cropping systems, not only as a means of subsistence, but also as a means of identity and territorial conservation.

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Compliance with ethical standards. The study was conducted in agreement with the organization VIDA A.C. which approved the use of its members' real names throughout the paper. Informed consent was obtained from families involved in the study.

Data Availability. Data are available with Diego Flores-Sánchez (Email: dfs@colpos.mx) upon request

Author contribution statement (CRediT). H. J. Beltrán Vargas: conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft, writing; **D. Flores-Sánchez**: conceptualization, investigation, methodology, project administration, supervision, validation, writing – review & editing**; V. Vázquez García**: conceptualization, investigation, methodology, supervision, validation**; A. Espinosa Calderón**: supervision.

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