Article

Management strategies in mango orchards and their effect on soil quality and productivity in Los Cajones, Michoacán

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Abstract

The different management systems and diversity of species in the orchards influence soil fertility and consequently crop productivity, for this reason the objective of the research was to assess fertility, soil quality and biodiversity management under three different mango production systems. The present study was carried out in the town of Los Cajones, Michoacán, in three mango orchards. The first evaluation was made up of a guide that integrated items of soil quality and biodiversity management applied to producers. The second evaluation was made by laboratory analysis of the soils of each orchard. The results of soil quality and biodiversity management indicate that the organic management system obtained the best values, as a result of the practices and structure of the orchard, while the orchard under conventional management presented the lowest values in both indicators. However, organo-mineral management obtained the best results in laboratory analyzes for the variables organic carbon (2.68%), organic matter (4.66%), nitrogen (1.59%), phosphorus (16.48 g kg^{-1}) and exchange capacity. cationic (29.18 $cmol^{+}$ kg^{-1}), followed by organic management. Organo-mineral fertilization promotes a better availability of nutrients to be used by the crop, in addition to reducing the amount of chemical inputs, promoting rational use.

Keywords: organic, organo-mineral, production systems.

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Introduction

Mexico is one of the main mango producers, with an average of 1 958 491 t per year (FAO, 2019). And in the Mexican Republic, Michoacán occupies the fifth place of production (SIAP, 2019). The most outstanding cultivars are Haden and Tommy Atkins, to a lesser extent Ataulfo and Kent. Production is usually conventional, which has caused chemical degradation, loss of available nutrients and acidification of the soil, making production systems more dependent on fertilizers and agrochemicals (Cisneros, 2016).

Another production alternative is organic or agroecological where the rule is the elimination of industrial inputs and the incorporation of compost or vermicompost as well as organic effluents in the nutrition of trees (Márquez *et al*., 2016). The progress of microbiology, chemistry and biochemistry applied to agriculture have allowed the combination of organic fertilizers with low-dose chemicals, trying to maintain a biological balance of the soil to make it more productive, a system called organo-mineral (García and Romero, 2016), which sometimes tends to transition from conventional to organic.

Each of the systems has advantages and disadvantages, but the most important thing is to analyze the ecological cost of that production, so the objective of the research was to typify the three mango production systems and identify those indicators that strengthen and affect the sustainability of farming systems.

Materials and methods

The investigation was carried out in the town of Los Cajones, Gabriel Zamora Municipality, Michoacan. The orchards were selected based on the information obtained through field trips, visits to key informant producers and common authorities in Los Cajones, Michoacán. The orchards were chosen according to the similarity of surface, diversity of management and structure of the orchard. So, three types of orchards were identified; a) vegetable orchard with organo-mineral management; b) orchard with organic management; and c) orchard with conventional management and the integration of cattle.

In situ and laboratory evaluations were made in each orchard. The first evaluation was made in the presence of the producers, with the application of a guide made up of items that were indicators for the quality of the soil and the management of biodiversity in the orchard (Altieri and Nicholls, 2002; Vázquez, 2013). The indicators were evaluated on a scale of 1 to 5 and 5 is considered optimal. The second evaluation was carried out in the laboratory on soil samples from each of the orchards. Texture, bulk density, pH, electrical conductivity, organic carbon, organic matter, total nitrogen, phosphorus, CEC were determined (NOM-021-RECNAT-2000).

The determinations were made in the genesis and soil classification laboratory of the Postgraduate Edaphology of the Postgraduate College-Montecillo *Campus*. The results of the variables were subjected to normality tests using the Shapiro-Wilk Test (α= 0.05). The variables that behaved according to the normal distribution were subjected to Analysis of Variance (Anova) (α= 0.05) as well as Tukey’s means comparison tests (α= 0.05). The package used was SAS Statistical Analysis System (version 9.4).

Results and discussion

By making the tour of the orchards and having talks with the producers who own them, it was possible to describe the main similarities and differences between the three sites. Orchard under organomineral management: it has an area of 2 ha and the Kent and Heidi mango varieties are established there. Don Genaro Arriaga (producer) is the one who performs the maintenance and work of the orchard, sometimes planting corn within the fields of the crop.

This orchard was previously under organic management, but the producer stopped working in this way because it was difficult to put the product at a good price and sometimes ended up selling the fruit as conventional. Tree nutrition is done by applying cow manure and sulfamin 45 (ammonium sulfate), incorporates all the plant residues of weeds and three or four times per cycle makes foliar applications of calcium and potassium only.

The orchard has no problem with pests, when they appear, they are ants that defoliate the tree and fight with malathion. The witch's broom sometimes occurs and sanitation pruning is performed after harvest and during flowering when it detects incidence in the trees. Weed control is done manually and the waste is incorporated into the soil. The irrigations to the orchard are made by means of rolled water for 12 hours, every 15 days according to the role of irrigation and availability.

The dry season in the region (November to May), especially the dry season, there is greater dryness in the soil and more hours are required to irrigate the entire surface. The mango production is sold to the packinghouse that takes its own cutters, although the price varies according to the days that pass since the first cuts of fruit begin. The production is destined for export, hence a higher price than the national one is obtained. Orchard under organic management.

With an area of 2 ha, with 200 mango trees. Don Manuel Zavala (the producer) along with one of his sons performs the tasks that are required in the orchard. This orchard has Globalg, AP certification and for the application of pollution risk reduction systems. In addition to the Ataulfo and Heidi varieties, there are papaya plants and mamey, nanche and soursop trees. It also sows beans that are used for its own consumption and offers the benefit as a vegetable cover, as well as green manure when it incorporates plant material.

The orchard is surrounded by live fences, with different trees such as jackfruit, lemon, teak, coconut palms and banana plants. The nutrition of the crop is through foliar and soil fertilization, the products used are obtained through purchase. Abiomor (liquid earthworm humus), diatomaceous earth, micronized lime and sulfur, and it produces sulfocalcium broth, compost, biofertilizers and ashes. Foliar fertilizations are applied every 7 or 15 days and diatomaceous earth, sulfocalcium broth, biofertilizer, micronized lime and ash are used, according to the phenological stage in which the tree is found.

Fertilizations to the soil are few during the year, which are carried out with diatomaceous earth, compost and sulfocalcium paste, as well as the incorporation of plant residues and pruning within the drip zone of the tree. The producer mentions that he uses garlic to start heating the trees, to prepare them for floral differentiation. The control of pests and diseases is done through the application of sulfocalcium broth and the placement of bait stations (Wax Tramp) for the control of fruit flies, although they mention that there is very little incidence.

The highest is the incidence of witches' broom, which is controlled by pruning and the application of sulfocalcium broth. Weed removal is done mechanically with a brush cutter, and the residue is left on the ground to be incorporated. Irrigations are carried out using rolled water during the months of November to May, approximately 14 irrigations are carried out. Sometimes irrigation is used and sulfocalcium paste is applied.

The sale of the fruit is made to a certifying association, which allocates the production for export. The producer mentions that the advantage is that the sale of his production is secure and he does not have to struggle to find a buyer. However, he is not satisfied with the sale price, since he considers that the value of his production should be higher than what he has been paid in recent seasons.

Orchard under conventional management. With an area of 2 ha, it only has 200 mango trees, established Kent and Haden varieties. The producer (David Constantino) is the one who performs the work together with a family member. It has the presence of cattle in the orchard at sometimes of the year. Sometimes the producer sows' small areas of jamaica and watermelon, for the purpose of self-consumption.

The nutrition of the crop is carried out using chemical fertilizers such as 18-46-00 and sulfamin 45 (ammonium sulfate), they are applied directly to the soil, two to three times per cycle, according to the tree's response. Sometimes up to 10 foliar applications are made with calcium and potassium when they have flowering problems. Pests (thrips and ant) are controlled with products like malathion and dimethoate. For diseases, they only use sulfocalcium broth and this is in the witch's broom, since affectations of other types of disease are minimal or null.

Weed controls are carried out through two methods, one is with grazing, which is only used in the months when there is no production and through the use of herbicide, this second when the grass begins to grow and there is no grazing the applications are made. The pruning remains are not used as they are burned. Irrigation varies every 12 to 15 during the months of November to May, according to the availability of water and the need for the crop. They are made by rolling irrigation, approximately 6 to 12 h can use the water.

The sale of the production is made to different packages or at the foot of the orchard, the producer mentions that he sells it to whoever is paying the best, so it may be one or the other package and most of the time they cut the fruit themselves, hiring two day laborers when production is in full swing. In the *in situ* analysis of the soil, the organomineral and organic orchards showed clayey soils and the conventional sandy soils. Both orchards have a soil layer of approximately 10 to 15 cm with plant residues in various stages of decomposition, contrary to what was found in the conventional orchard (Table 1).

Table 1. Result of the variables selected by the producers to measure *in situ* the quality of the soil of their orchards.

Item	Orchard		
	Organo-mineral	Organic	Conventional
Soil structure	Clayey	Clayey	Sandy
Compaction and infiltration	Non-compact soil, water infiltrates moderately	Non-compact soil, water infiltrates easily	Non-compact soil, water infiltrates moderately
Soil depth	Deep surface soil 10-15 cm	Deep surface soil> 15 cm	Deep surface soil 10-15 cm
Plant waste status	Waste in various stages of decomposition and well decomposed old waste	Waste in various stages of decomposition and well decomposed old waste	No presence of organic waste
Soil cover	76-100%	76-100%	26-50%
Erosion	No apparent degradation	No apparent degradation	No apparent degradation
Slope level	0-5%	0-5%	6-15%
Biological activity	Presence of biological activity in a large part of the surface	Abundant presence of worms and arthropods throughout the land	Minimum biological activity
Crop productivity	Average, average production of the region	High, more than the average production in the region	Production between the average and a little more than the average
Mineral fertilizer ratio in productivity	Low-dose fertilizer is applied	No use of fertilizers chemical or synthetic	Does not require, but applies more fertilizante de lo recomendado
Organic amendments	Sometimes it applies	Always do and apply	They are never made or applied
Combination between mineral and organic fertilizer	Similar amounts of both fertilizers	Only organic fertilizer	Lots of mineral/little organic fertilizer
Soil color	Black	Black	Brown
pH	7.1 optimal	8.1 some restrictions	7.1 optimal

Land cover is a fundamental element for this type of ecosystem, especially with regard to soil protection and water conservation (Infante, 2015). In none of the three orchards is soil degradation observed, the highest productivity of the crop occurs in the organic orchard, followed by the organo-mineral and the conventional with mango yields in 2019 of 25 t ha^{-1}, 10 t ha^{-1} and 8 t ha^{-1} respectively. It is important to mention that more than double the production or up to three times more was obtained in the organic orchard.

In the management of the organo-mineral orchard, low doses of fertilizer are applied and some organic amendments are made, Das *et al*. (2009) suggest that combining chemical and organic fertilizers improves flowering and yield. In the organic orchard the application of nutrients is done by incorporating plant residues from pruning, green manures, compost, organic amendments and foliar application of biofertilizers, similar management of cultivation reported Medina-Urrutia *et al*. (2011) in producing states of Mexico.

Contrary to the orchard under conventional management, which its greatest incorporation is through chemical fertilization, application of pesticides and they never carry out organic amendments, except what is left of feces when there is grazing. The pH in the organo-mineral and conventional orchards is neutral (7.1) and in the organic orchard the pH is (8.1), which implies a low availability in the soil of some nutrients and phosphorus, so the producer uses the application of foliar fertilization to correct this availability.

The results obtained from the analysis of the soil in situ, allowed to integrate and interconnect some physical, chemical and biological properties of the three study orchards. Through the amoeba graph (Figure 1), it is possible to verify if these properties favor the sustainability of the orchards.

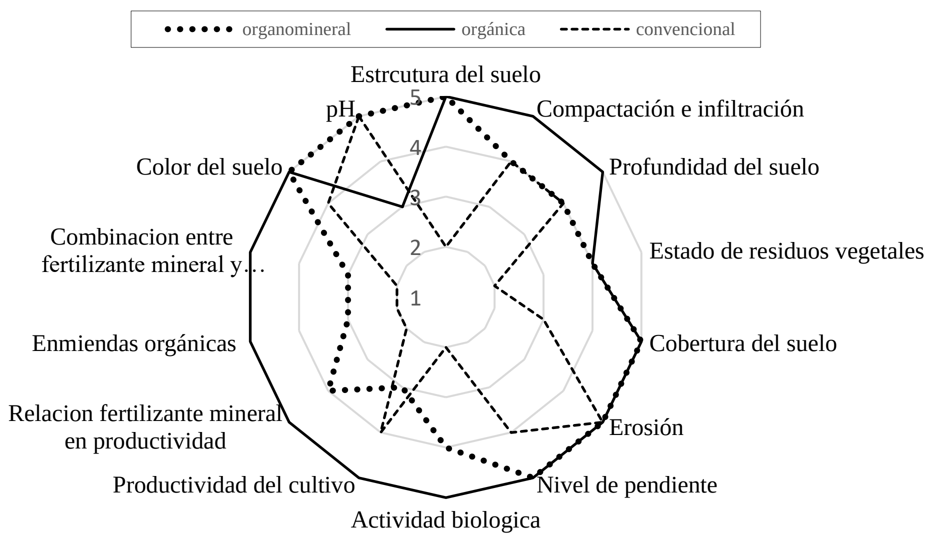

Figure 1. Results of the evaluation of the sustainability of the soil *in situ* in mango orchards in Los Cajones, Michoacán. The outer limits represent the ideal sustainability value and the intermediate one the threshold value.

Figure 1 shows that the soils of organic and organo-mineral orchards have similar properties, not the conventional one, and that the organic orchard tends more to complexity because there are more indexes in favor of soil sustainability. Except for the pH that was slightly more alkaline in the organic orchard and the amount of organic waste that was 75-100%, all other indicators are at the highest levels.

The results of soil analysis with the respective tests of homogeneity of variances and independence of the data, as well as the analysis of variance (Anova) with (α= 0.05) indicate that; of all the variables analyzed, only EC and Da were not significant, the rest were highly significant such as pH, organic carbon, organic matter, nitrogen, phosphorus, and cation exchange capacity (Table 2).

Table 2. Statistical significance (*p*< 0.05) in the physical and chemical variables of soils obtained from mango orchards under different management in Los Cajones, Michoacán.

Source	pH	EC	Da	OC	OM	N	P	CEC
Orchard	**	ns	ns	**	**	**	**	**
R^2	0.469	0.205	0.04	0.628	0.626	0.419	0.284	0.431
CV	4.25	34.81	15.77	19.03	19.05	24.65	50.4	31.43
Mean	6.92	0.5	1.77	2.02	3.51	1.2	11.61	21.72

EC= electrical conductivity; Da= bulk density; OC= organic carbon; OM= organic matter, N= total nitrogen; P= phosphorus; CEC= cation exchange capacity.

The quality of the soil is directly related to the functionality of the agroecosystem, the physical, chemical and biological properties will allow the soil to function within the limits of the exosystem and in this way, sustain or improve crop productivity. Castellanos *et al*. (2000) suggest that an ideal soil pH for nutrient absorption is in a range of 6 to 6.5, since at this scale all nutrients are available.

Although other authors indicate soils with a pH of 6.5 to 7.5, they also have nutrient availability and there are no problems in nutrition management. Laboratory pH analysis showed values between 6.7 and 7.2 (Table 3), values indicated by Mora *et al*., 2002 as ideal for mango cultivation. Similar to the results found by Medina-Méndez *et al*. (2014) with pH ranges between 6.6 and 7.1 by age of the trees from 11 to 30 years.

Table 3. Average values of the chemical parameters.

Management	pH	OC	OM	N	P	CEC
	%				g kg^{-1}	cmol^{+} kg^{-1}
Organo-mineral	6.7 ±0.31 b	2.68 ±0.26 a	4.66 ±0.45a	1.59 ±0.24 a	16.48 ±6.37 a	29.18 ±6.04 a
Organic	6.77 ±0.19 b	1.75 ±0.29 b	3.05 ±0.51 b	1.13 ±0.17 b	9.81 ±6.82 ab	15.56 ±2.55 b
Conventional	7.28 ±0.35 a	1.62 ±0.53 b	2.82 ±0.93 b	0.95 ±0.41 b	8.54 ±3.95 b	20.56 ±9.87 b
R^2	0.469	0.628	0.626	0.419	0.284	0.431
CV	4.25	19.03	19.05	26.65	50.4	31.43
DMS	0.34	0.45	0.78	0.34	6.89	8.05

CV= coefficient of variation; DMS= minimum significant difference; OC= organic carbon; OM= organic matter; N= nitrogen; P= phosphorus.

The organic carbon content of the soil allows even indirect measurement of soil stability. There is talk of complex molecular structures that modify the quality of the soil by providing sites for the exchange and production of cementitious material for the formation of aggregates (Cotler *et al*., 2016), which improves the infiltration rate, the content of microbial biomass and recycling of nutrients. In the organomineral orchard, the highest OC value was presented (2.68%), followed by the organic orchard (1.75%) and at the end the soil of the conventional orchard (1.62%).

This property intervenes in the buffer capacity on the reaction of the soil (pH) (Martínez *et al*., 2008). These values are well above that also obtained in soils of mango orchards by Mali *et al*. (2016), who as maximum values found 0.91%. The three production systems presented acceptable levels of organic matter (Table 3), ranging from medium (2-3%) to high (3-5%), according to Salgado *et al*. (2013) and NOM-021-RECNAT-2000.

This organic matter varies in space and time due to the interaction that occurs between the physicochemical properties of the soil that act simultaneously at different scales. The knowledge of this spatial variability allows to measure the fertility of the soil and cover the demand of the trees in order to increase production (Mali *et al*., 2016).

However, the highest value (4.66%) obtained under organo-mineral management is the result of the high content of clays since they exert a control over the physical protection of OM (Sánchez-Hernández *et al*., 2011; Labrador, 2012). Nitrogen content, based on the classification of Salgado *et al*. (2013); Hazelton and Murphy (2016); NOM-021-RECNAT-2000, indicate that the three soils presented very high contents (>0.25).

Organic management obtained 18% more nitrogen with respect to the conventional one, this due to the practices carried out when incorporating in the vegetable orchard some cultivation of legumes and the residues of plant tissues from pruning and weeds. Organo-mineral production was 67% more compared to the conventional one, since they carry out manure applications, straw residues and nitrogenous fertilizers, it is even above the orchard with organic production (Table 3).

In the organo-mineral orchard the amount of phosphorus in the soil was high (16.48 g kg^{-1}) according to the Olsen classification. The soils of the organic orchard presented only 9.81 g kg^{-1} and the soil of the conventional orchard quantified only 8.54 g kg^{-1} of P. These values are in ranges of medium (5.5 -11) to high (>11), ranges proposed by Salgado *et al*. (2013) and NOM-021-RECNAT-2000.

According to the observations made in the orchards, it is considered that the highest value of phosphorus has to do with the type of soil texture and organic management that was done in past years and that was changed to organo-mineral for not obtaining a price of organic fruit. However, some producers agree that, despite fertilizing mango orchards in a conventional way, a good strategy is the incorporation of organic waste (Zhi, 2017).

The cation exchange capacity (CEC), is an indicator of the buffering power of the soils, it has to do with the loading sites of the clays (Pérez *et al*., 2017) and the nutrient reserve capacity. The highest values (29.18, 20.56 cmol (+) kg^{-1}) and the organic orchard soil (15.56 $cmol^{+}$ kg^{-1}) were presented in the organomineral and conventional orchard soil. As can be seen, the soil of the organic orchard has the lowest CEC, contrary to what the theory shows, since in clay soils the CEC is higher than in those that are classified as sandy soils.

Regarding the health of crops *in situ*, it was possible to demonstrate that in organo-mineral and organic orchards, producers indirectly manage semi-natural environments, because they do various practices, but do not contemplate the functions they provide. These practices occur more in the rainy season than in the dry season, in both areas of the orchards throughout the year there is presence of weeds.

The producer that performs conventional management does not carry out semi-natural environment management within the orchards and weeds only appear in the final stages of cultivation since he later introduces the cattle to feed (Table 4). The orchards under conventional and organic management have conservation strategies, because according to where it is located conditions arise.

Table 4. Result of the variables selected by the producers in relation to the management of the biodiversity in their orchards.

Item	Orchards		
	Organo-mineral	Organic	Conventional
Management system	Conventional monoculture, with rational use of agrochemicals	Organic monoculture with diversification, with the use of organic or biological inputs	Conventional monoculture, with high use of agrochemicals
Genetic diversity	Two varieties of the main crop	Two varieties of the main crop	Two varieties of the main crop
Harvesting free area	No surface	26-50% of surface	25% of surface
Productive biodiversity	None	4-5 species	None
Ecological connection with the external area	Less than 12% of the perimeter has live fences	Between 51 and 75% of the perimeter is surrounded by live fences	Less than 12% of the perimeter has live fences
Species diversity of usable species	One or no species	6-7 species	One or no species
Species diversity in living barriers	One species	> 3 species	None
Semi-natural environment management	Exist, but without considering their functions	Exist, but without considering their functions	Do not exist
Presence of weeds	Throughout the crop cycle	Throughout the crop cycle	Only in final stage of cultivation
Conservation zone area	Only in the rainy season	At least one side has a conservation area	At least one side has a conservation area
Surrounding diversity	Surrounded by crops or road	At least one side due to natural vegetation	At least one side due to natural vegetation

In the conventional orchard, at least on one side (12% of the total area) of this there is wild vegetation, since it is on the slopes of a hill, with this benefits such as biological corridors and the ecosystem benefits that the hill can offer are obtained. The organo-mineral orchard only during the rainy season can present conservation areas (12%) since this orchard is surrounded by other orchards and dirt roads. But in the organic orchard there are at least 55-75 of the area of living fences, which allows the ecological connection to the external area to increase (Table 4).

In productive biodiversity, only the organic orchard has on its land, in addition to the two commercial mango species, four to five more species as mentioned in the review of the orchards (Table 4). It is documented that the diversification of crops in mango orchards for self-consumption and some income from the sale of surpluses notably favor the agroecosystem for different reasons such as control of soil erosion, increased fertilization.

When legumes are planted, entomopathogenic control and the most important thing is the increase in the yield of the mango crop, plus the harvest of the crops intercropped between the fruit trees. In addition, the complementary relationship of synergistic effects that exists between some components of the system (Dhara and Sharma, 2015; Murmu *et al*., 2018). In the organic orchard the yield is tripled compared to the conventional orchard, this agrees with Dhara and Sharma, (2015) who obtained better production in mango when intercalating legumes, due to the interaction between tree and leguminous species help to improve the state of soil fertility.

According to Figure 2, from the management of biodiversity, it is observed that the organic orchard has greater surrounding diversity, presence of weeds, conservation areas, ecology connection and living fences than conventional and organo-mineral orchards. The conventional orchard reflects less interaction between the components of the agroecosystem.

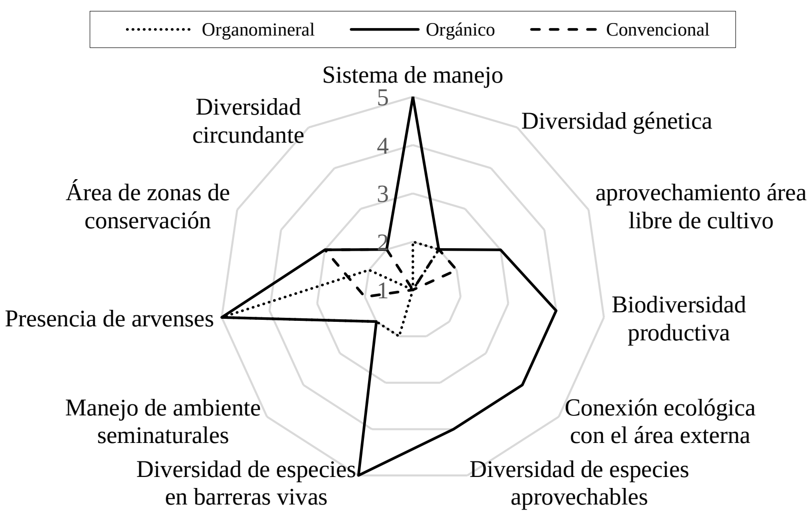

Figure 2. Results of the management of biodiversity in mango orchards in Los Cajones, Michoacán. The outer limits represent the ideal sustainability value and the intermediate one the threshold value.

According to the methodology proposed by Vázquez (2013), depending on the parameters evaluated, it is possible to observe that in the three orchards there is a difference in the relationships that are present to have a more stable and resilient agroecosystem. In the organo-mineral orchard there are fewer elements that promote interactions than in the organic orchard, such as living barriers and diversity of usable species.

This biodiversity constitutes an indicator of the proper functioning of agroecosystems, which in turn increases their capacity for self-regulation due to the multiple relationships between their biotic and abiotic components (Vargas-Batis *et al*., 2014). In the organic orchard there are more interactions that promote the stability of the orchard, such as ecological connection with the external area and productive biodiversity.

Conclusions

The three orchards studied show notable differences in the quality of the soil and not in the health of the crops. It does not agree that the orchard with the highest yield in the 2019 cycle (20 t ha^{-1}) that was organic has the most fertile and resilient soil. This is mainly due to the management practices of the producer, which is the application of the products via foliar, as well as the presence of biodiversity of the crops, incorporation of weeds and high productivity.

Each of the producer's states that they are satisfied with the way they manage their orchards, as well as recover the investments made each cycle. Regardless of the production system, it is concluded that the orchards have the capacity to produce mango and other foods adapted to bioclimatic conditions and the needs of the market and constitute themselves as productive, profitable and some sustainable systems at the service of farmers and consumers.

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