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Avocado (*Persea americana* Mill.) production in Huatusco, Veracruz, Mexico

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ABSTRACT

Objective: To characterize the avocado production system in Huatusco, Veracruz.

Design/Methodology/Approach: Interviews based on the snowball method were applied to avocado producers in Huatusco, Veracruz. Meanwhile, fruit and water samples were used to perform a multiresidue analysis of pesticides.

Results: The monoculture plantations are rainfed. They have a density of 100-150 trees ha^{-1}. The Hass variety predominates in Andosols, with 5-100% slopes. Most of the producers (92%) carry out conventional management, applying pesticides and chemical fertilizers. Herbicides and brushcutters are used to control weeds. No pesticides were detected in the water samples, while Imidacloprid, Thiabendazole, and alpha-Cypermethrin were identified in a fruit sample, with 0.0038±0.0014 mg/kg, 0.0022±0.0009 mg/kg and 0.0703±0.000 mg/kg concentrations, respectively. These concentrations fall within the limits allowed in Mexico.

Study Limitations/Implications: A detailed and frequent sampling of avocado fruits should be carried out to determine pesticide residues. It is also necessary to analyze samples of running water near the orchards to prevent pollution.

Findings/Conclusions: The empirical knowledge of the producers about the type of soil is more precise than the scientific classification: they identify five classes of soils beyond Andosols. Additionally, there is a marked inequality in land tenure, since large-scale producers (25% of all producers) own 86% of the established area. Although, in a preliminary sampling, pesticide concentrations did not exceed the limits of residues allowed in the avocado pulp, the number of pesticide applications should be reduced.

Keywords: *Persea americana*, Andosols, rainfed agriculture, conventional agriculture, pesticides.

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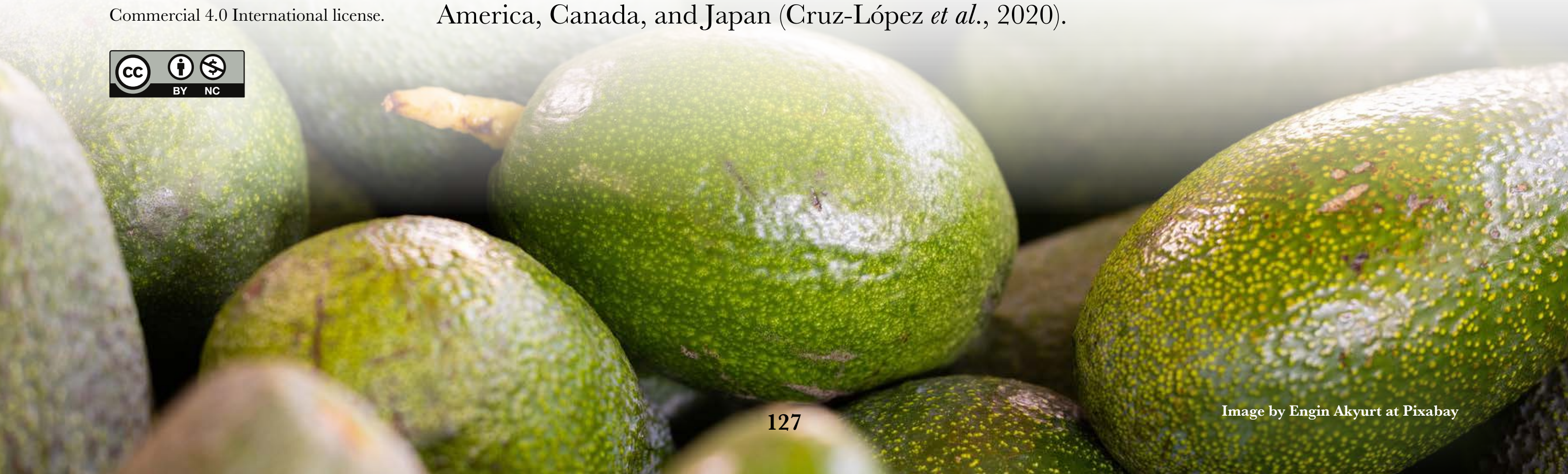
INTRODUCTION

There is a great worldwide demand for avocado (*Persea americana* Mill.) and Mexico is the main producer and exporter. In 2019, 722,000 t were exported, which represents more than 45% of the world total. The most important markets are: the United States of America, Canada, and Japan (Cruz-López *et al.*, 2020).



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In Veracruz, the producers do not only grow avocados: they carry out this activity to obtain additional income. They believe that their orchards are low-tech, as a result of a potential low soil fertility (Nataren-Velazquez *et al.*, 2020). Nineteen municipalities produce 7,393 t of avocado in 897 ha. Altotonga, Coscomatepec, Jalacingo, Atzalan, and Huatusco de Chicuellar (Huatusco) have the largest planted area. In Huatusco, 702 t are produced in 84 ha (SIAP, 2020); its orchards are located in a tropical high-altitude area where coffee is grown, while pear, plum, cherimoya, and kiwi are grown at a higher altitude (Guerra-Ramírez *et al.*, 2021).

The growing demand for avocado puts great pressure on the forests where it is cultivated, whose altitude ranges from 1,300 to 2,400 m.a.s.l. (Marroquín-Páramo *et al.*, 2017). The expansion and intensification of its cultivation results in a high potential for environmental impacts, such as the loss of native oak and pine forests, the reduction in carbon sequestration, the biodiversity loss (Denvir *et al.*, 2021), a change in land-use, and excessive water use (González-Estudillo *et al.*, 2017).

This growth also has social and economic impacts. Smallholder farmers, farm workers, and local communities receive a minimal share of the profits and suffer loss of their livelihood, governance, and community cohesion, as well as public health problems (De la Vega-Rivera & Merino-Pérez, 2021). Avocado production requires a fair treatment of workers and the sustainable use of natural resources.

In the future, avocado will be grown at higher and lower elevations, with less rainfall and in less suitable soil groups, which may lead to an increased application of fertilizers, pesticides, and irrigation (Franco-Sánchez *et al.*, 2018; Arima *et al.*, 2022). In the State of Mexico, avocado producers require technology to control pests, weeds, and diseases (Sangerman-Jarquín *et al.*, 2014), while, in Michoacán, water scarcity and the chemical contamination of groundwater are already problematic (Borrego & Allende, 2021). However, there is no information in this regard for Veracruz.

During the last 14 years, avocado has been introduced into a humid zone in Huatusco and its surrounding area, characterized by Andosols —a kind of soil that is susceptible to erosion, after the forest cover has been removed. The cultivation and production management of avocado has not been documented. The objective of this study was to agronomically characterize the avocado production system in the municipality of Huatusco, Veracruz.

MATERIALS AND METHODS

The localities studied in the municipality of Huatusco in 2021 were Elotepec, San Diego Tetitlán, and Huatusco (Figure 1).

Interviewees selection

We interviewed avocado producers in the municipality of Huatusco, Veracruz, using the snowball method —in which one person suggests another based on their knowledge and experience (Davis *et al.*, 2017). The sample size was determined by the point of informational redundancy and data saturation (Letts *et al.*, 2007). All the interviews (12) were semi-structured (Lazos-Ruíz *et al.*, 2016). The producers were classified according to

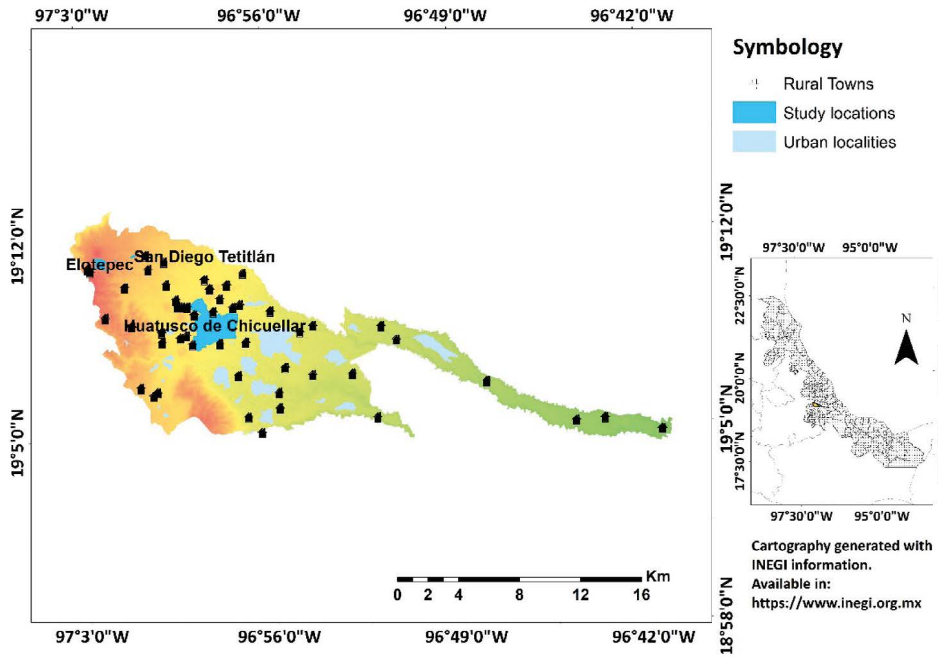

Figure 1. Study locations in Huatusco, Veracruz, Mexico.

the operating rules (2021) of the Producción para el Bienestar program of the Secretaría de Agricultura y Desarrollo Rural (SADER, 2020).

Analysis of pesticide residues in the fruit pulp and in the water

Water samples were collected from four representative sampling sites: two in a spring and two in surface streams that cross the avocado plots. In addition, two samples of locally produced avocado fruit were taken and the multiresidue pesticides were determined with QuEChERS extraction, by liquid chromatography tandem mass spectrometry (LC–MS/MS) (Aghris *et al.*, 2022).

RESULTS AND DISCUSSION

Among the studied localities (Figure 1), there was an altitudinal contrast and different soil classes, forms of management, and strata of producers. The producers interviewed indicated a diversity of characteristics related to the production system (Table 1).

Land tenure

Land tenure belonged to the private property system. Fifty percent of the interviewees were small-scale owners, 25% were medium-scale owners, and the remaining 25% were large-scale owners (SADER, 2020) (Table 1). Out of the total 243.85 ha, 209 were distributed among large-scale producers, 24 ha among medium-scale producers, and 10.85 ha among small-scale ones. In the State of Mexico, 33% of the producers concentrate 67% of the surface, while 82% only owns 4%, which proves the great inequality in land tenure and income (Sangerman-Jarquín *et al.*, 2014).

Table 1. Particularities of avocado orchards in Huatusco, Veracruz, Mexico.

Producer type	Property	Area (ha)	Slope (%)	Age	Management	Elevation (m)
Big scale	La Represa	100	10-100	1, 11, 13	Conventional	1729
Medium scale	El Nogal	9	10-100	13	Conventional	1771
Medium scale	El Cafetal	10	5-100	5, 7	Conventional	1396
Medium scale	Ahuacapa	5	20-60	4	Conventional	1351
Small scale	Huerto San Carlos	3.5	20-60	3, 7, 8	Conventional	1362
					Semiorganic (1 ha)	1362
Big scale	La Selva	24	15-60	10	Conventional	1405
Big scale	Finca Pastoría	85	15-60	3 (35 ha), 4	Conventional	1408
Small scale	El Encino	0.2	10-60	2	Organic	1817
Small scale	Centro Elotepec	0.15	20-60	10	Conventional	1962
Small scale	El Plan	1	20-60	2	Conventional	1856
Small scale	La Raya	2	20-45	10	Conventional	1834
Small scale	Xometla	4	50-100	4, 5	Conventional	1872

In Huatusco, 84 ha of avocado were reported in 2020 (SIAP, 2020), while a 290% growth in the avocado surface was reported the following year. Several orchards were established in areas that had primary vegetation, but the negative effects on biodiversity are unknown.

Age of the plantation and slope of the plots

The oldest plantations are 13 years old, while the youngest are one year old (Table 1). By the end of 2022, Finca Pastoría, in Felipe Reyes, was expected to increase its area by 30 ha.

The slopes (Table 1) ranged from 5% (steep) to 100% (very steep) (FAO, 2009). Soil erosion and runoff rates from hillside avocado orchards are not sustainable under current cultivation practices, where ground cover is suppressed (Atucha *et al.*, 2013).

Altitude of the plantations

Hass avocado plantations in Michoacán are located between 1,600 and 2,200 m.a.s.l. (Anguiano *et al.*, 2007), while in Huatusco they are located between 1,351 and 1,872 m.a.s.l. (Table 1). According to the producers, this is an adequate altitude and they recommend establishing new plantations between 1,200 and 3,000 m. Frost and hailstorms limit avocado cultivation in the region, mainly above a 1,700 m altitude. Hail is responsible for up to 90% of the losses of small fruit. Some orchards have lost up to 50% of their total production and anti-hail rockets have been used to counteract the problem.

Type of production system

Most producers (92%) perform conventional management, applying pesticides and chemical fertilizers (Table 1). One small-scale producer practices organic management and another is trying out a semi-organic system to reduce the use of chemical products.

The interviewees indicated that organic avocado production reduces damage to the environment.

One orchard uses a coffee agroforestry system, while the rest of the plots are monocultures with Fuerte, Hass, Hass-Méndez, Méndez, and Pinkerton varieties. Certified plants from Michoacan were established. Two producers used non-certified plants from Veracruz and Puebla. Native avocados and avocado-like species, such as *Persea schiedeana* (Cruz-Castillo *et al.*, 2017), are not produced in commercial orchards in the study region. In Temascaltepec and Coatepec de Harinas, State of Mexico, Hass avocado production predominates (97%), while native avocado is cultivated to a lesser extent (3%) (Sangerman-Jarquín *et al.*, 2014).

Plantation establishment

Eighty-three percent of the producers established their trees using a square system, varying their separation from 8 to 10m (100-150 trees/ha). In one orchard, the producers used a quincunx system, while another orchard has a contour system with 7 m between plants and 9 m between rows. The holes for the stumps were either 30×30×30 cm or 60×80×80 cm (depth×width×length). Twenty-five percent of the plots were filled with vermicompost, rooting agents, lime or beneficial fungi, and in one plantation recycled wire mesh was used to control rodents. In the municipalities of Coscomatepec, Calcahualco, and Alpatlahuac, Veracruz, the density ranges from 125 to 180 trees/ha (Nataren-Velazquez *et al.*, 2020).

Soil, fertilization, and irrigation

The best soils for avocado cultivation have a pH of 5.5 to 6.5. They are sandy loam, well-drained, loose, and deep soils that guarantee good root development (Amórtegui-Ferro *et al.*, 2001). As a result of their good permeability, the suitable soil groups for the establishment of avocado plantations are Andosols and Luvisols (Anguiano *et al.*, 2007). All the plantations were established on Andosols (INEGI, 2019) and the producers know that the soils must be drainable, with an ideal pH of 5.7 to 6.0. In addition, they have identified a great diversity of soil classes, which they known as ***polvilla***, ***barial***, ***sámago***, ***colorada***, and ***barrialillo***. Producers associate black soil with good fertility.

Prior to fertilization, producers carry out a soil analysis in 50% of the plots, in two out of which they also consider the analysis of fruit, root, and leaf. This procedure is associated with medium- and large-scale producers. They mainly apply: diammonium phosphate, potassium nitrate, calcium nitrate, magnesium sulfate, calcium superphosphate, and elemental sulfur. In large-scale orchards, the pH of the water used to apply fertilizers and pesticides is regulated. In 25% of the plots, they also add vermicompost, fulvic and humic acids, coffee pulp, and manure. In the only organic orchard, producers use manure to supplement nutrients.

In some plots, fertilizers are applied without using soil analysis. As a result, fewer nutrients are applied to maximize production or an excessive application leads to nutritional imbalances that limit production give rise to environmental problems (Shunfeng *et al.*, 2018).

Irrigation is non-existent and all the plantations are rainfed. Producers indicate that a tree requires 40 to 70 liters of water per week and that the average annual rainfall exceeds 1,000 mm. The Hass variety requires between 1,200 and 1,800 mm of annual rainfall (Bartoli, 2008). The avocado water footprint ranges from 1,981 m^3/t (Mekonnen & Hoekstra, 2020) to 4,945 m^3/t (Reyes-Pineda & Naranjo, 2021). The relevant information for the study region is non-existent.

Pruning

In all orchards, sprout pruning is carried out when the trees are 0.5 to 2 years old. Subsequently, the canopy formation is pruned, leaving 3 to 4 lateral branches. In two orchards, producers perform clearance pruning, which improves aeration and light entry (Huaraca *et al.*, 2016). In some orchards, the size of the trees has been reduced by eliminating their central axis (Viteri *et al.*, 2021). This practice is important, as the excessive humidity in Huatusco promotes vigorous growth in avocados.

Pests and diseases control

Stem, seed, and fruit borers, thrips, red spider mites, whiteflies, and white grubs are controlled with malathion, imidacloprid, dimethoate, abamectin, naled, and dimethyl. Two orchards applied soybean or lemon oil, mineral salt, garlic and chili-based products, resins, cucumber extract, and *Beauveria bassiana* for biological control. A couple of producers mentioned performing manual control of the stem borer. The avocado seed borer (*Heilipus lauri*) has been reported in Huatusco (Castañeda-Vildózola *et al.*, 2009). In Acaxochitlán, Hidalgo, Ortega-Licona *et al.* (2016) reported that four borers attacked the avocado fruit: *Heilipus lauri*, *Conotrachelus perseae*, *Cryptaspasma perseana*, and an unidentified Tortricidae species. The use of geostatics-based spatial distribution could help avocado growers in Huatusco. In Coatepec de Harinas, State of Mexico, producers carried out biological control of *Trips* spp. using *Amblyseius swirskii* (Acosta-Guadarrama *et al.*, 2017). This methodology has also been used to control the red spider mite (*Oligonychus punicae* Hirst) in two municipalities of the State of Mexico; this has resulted in the optimization of the use of agricultural inputs, causing less environmental damage (Lara-Vázquez *et al.*, 2018).

Regarding diseases, the producers mention that the fruit is attacked by clavibacter, anthracnose, scab, and black spot, which are controlled with calcium sulfide solution, copper sulfate pentahydrate, pyraclostrobin, azoxystrobin, fludioxonil, metiram, thiabendazole, quintozene, and thiram. During flowering and fruit mooring, they use hydrated copper to prevent fruit drop. Unlike the case of Huatusco, other places use the fungicides azoxystrobin + fludioxonil (Gonzalez *et al.*, 2020) to control *Colletotrichum* spp. and *Lasiodiplodia theobromae*, which cause anthracnose and peduncular rot, respectively. Diseases are frequent, as a result of a high relative humidity (70-85%) and temperatures of 20 °C or more. This situation favors an excessive application of pesticides to combat diseases. In the State of Mexico, anthracnose causes economic losses that can reach up to 20% of the production (Tapia-Rodríguez *et al.*, 2020).

Weed control

The producers control weeds by hand using a brushcutter or machete and they use glyphosate in 25% of the orchards. In one plot, they apply paraquat on the slopes and glyphosate on the level ground, arguing that this reduces erosion on the slopes. The producers did not mention either the use of cover crops to control weeds and incorporate plant residues or of microorganisms that improve soil quality (Huaraca *et al.*, 2016).

Analysis of multiresidue pesticides

In an environment with high temperatures and excess humidity, pesticide applications are numerous. Consequently, analyzing pesticide residues in fruits and running water is of the utmost importance. No pesticides were detected in water samples from spring and surface streams. In one of the avocado pulp samples, the presence of three pesticides —with values below the maximum residue limit allowed in Mexico (MRL)— was identified: Imidacloprid at 0.0038±0.0014 mg/kg (MRL of 1 mg/kg), Thiabendazole at 0.0022±0.0009 mg/kg (MRL 10 mg/kg), and alpha-Cypermethrin at 0.0703±0.000 mg/kg (which has no registered MRL for Mexico). A greater presence of pesticide residues in the pulp than in the peel can be the result of the lipophilic characteristics of the pulp is lipophilic and the analyte diffusion from the peel into the fruit. Likewise, analytes may leach during the harvest and the transportation process and some of them may enter the fruit (Betancourt-Arango *et al.*, 2021). This is the first time that pesticide residues have been documented in an avocado producing area of the state of Veracruz.

Harvest and postharvest handling

The dry matter of the fruit (22-24%) is considered to carry out the harvest. The fruits are also harvested when they become opaque or matte green. In the postharvest period, the fruits are refrigerated at 5 °C for 15 days, when they are sent to distant cities such as Monterrey. High dry matter values (*e.g.*, 26±2%) prevent weight loss, cold damage, and pulp damage after maturation (Escobar *et al.*, 2019).

Commercialization

The consumer market has a domestic scope and the produce is sent to self-service warehouses located in Orizaba, Huatusco, and Nogales, in Veracruz, and to the cities of Puebla and Monterrey. Small-scale producers sometimes sell their crops to large-scale producers or rent refrigeration facilities. They also point out that the small and medium-sized commercial ranges (120-150 g and 150-170 g, respectively) are sent to supply centers in Puebla. The yields mentioned by the producers are in a range of 3.2 to 10 t/ha. In 2020, the volume of avocado production in Mexico amounted to 2.4 million ton in a harvested area of 220,000 ha, which gives an average yield of 10.9 t/ha (STATISTA, 2020). In the south of the State of Mexico, the production is destined for domestic consumption: it is mainly marketed in the supply centers of Toluca, State of Mexico, and Mexico City, as well as in regional markets (Rubí-Arriaga *et al.*, 2013).

CONCLUSIONS

The empirical knowledge of the producers about some variables of the production system is similar to the data we found in scientific publications. Producers identify five types of soils (in addition to Andosols): ***polvilla***, ***barrial***, ***sámago***, ***colorada***, and ***barrialillo***. Likewise, they associate black lands with good fertility. Avocado cultivation does not represent their main economic activity. There is inequality in land tenure, since large-scale producers (25%) own 86% of the established area. Most of the orchards use a monoculture system with the Hass varieties. Conventional management predominates in orchards with steep and very steep slopes. An excessive volume of pesticides and chemical fertilizers is applied. Glyphosate is one of the main herbicides used. In a preliminary study, no pesticide residues were found in running water near the orchards, and the pesticides found in the pulp are within the limits allowed in Mexico. The consumption market has a domestic scope and its yields have a range of 3.2 to 10 t/ha. The environmental impact and the effects on biodiversity need to be taken into consideration, because many of the orchards substituted primary vegetation.

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