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Article

Production systems and soil fertility of Hass avocado in Oaxaca

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Abstract

Avocado production has experienced remarkable growth in recent decades, positioning itself as an important agricultural activity in Mexico. The increase in productivity is threatened by multiple factors that intervene in production, including adverse climatic conditions derived from climate change; therefore, proposing alternatives that may have a lower environmental impact is of great importance. The objective was to study production systems with respect to fertilization management, their effects on soil conditions, and their relationship with yield in Hass avocado production units in the state of Oaxaca. Twenty-eight production units were studied in the Sierra Sur region in Villa Sola de Vega and in the Valles Centrales region in Zaachila; they presented three types of production systems: agroecological (organic fertilization), conventional (synthetic fertilizers) and combined (alternation between both). Soil sampling was carried out for fertility analysis in accordance with NOM-021-RECNAT and yield was estimated. Analysis of variance indicated statistically significant differences in iron (Fe) content and yield only. The best results in terms of improving soil fertility were obtained under agroecological management, whereas the highest yields were recorded in units with combined management. There was a significant positive correlation of Ca with BD, pH, EC, N, Na, and Fe. Agroecological management significantly improved soil properties; however, during the production cycle analyzed, no increase in yield was obtained.

Keywords:

agroecological management, climate change, inorganic fertilization, production systems.

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Introduction

Avocados (*Persea americana* Mill.) are a fruit that can provide multiple health benefits when included in a healthy diet, due to their high saturated and unsaturated fat content, low carbohydrate levels, high dietary fiber content, and distinctive fatty alcohols and C7 carbohydrates (Ford *et al*., 2023).

Their cultivation is one of the most economically important agricultural activities in Mexico, which is the world's largest producer, followed by Peru and the Dominican Republic (FAOSTAT, 2023). In 2024, national production was 2 669 031.6 t; the state of Oaxaca contributed 17 467.6 t, ranking ninth in production and seventh in planted area with a total of 3 643.9 ha (SIAP, 2024). Avocado crops require specific soil conditions, such as deep soils (0.8 to 2 m) with good drainage, organic matter contents above 2.5%, and medium textures such as loam, sandy loam and sandy clay loam. Regarding climatic conditions, temperatures of 14 to 24 °C and relative humidity of 60 to 70% are required (SADER, 2024).

Garrido-Ramírez *et al*. (2018) indicated that the best yields are obtained in climates (A)C(w2)(w), C(w2)(w) and (A)C(w1)(w) and at an altitude of 1 200 to 2 300 m. Oaxaca has a great variation in altitudes, climates and of course in soils, which favors the establishment of this crop. Nevertheless, it faces various factors that limit productivity, such as water deficit, the effects of climate change, the presence of pests and diseases, the absence of specialized technical support; in addition to above, the lack of fertilization plans based on scientific research has contributed to excessive applications of inorganic fertilizers that deteriorate natural resources and cause economic losses (Saldaña and Cota, 2022; Antonio-Luis and Palacios-Torres, 2024).

In this context, this study aimed to analyze the impact of production systems, as a function of fertilization management, on soil conditions and their relationship with yield in Hass avocado production units located in the Sierra Sur and Valles Centrales regions of the state of Oaxaca.

Materials and methods

Description of the study area

The study was carried out in two regions of the state of Oaxaca during the 2023-2024 production cycle: Sierra Sur (Villa Sola de Vega) and Valles Centrales (Zaachila) (Figure 1).

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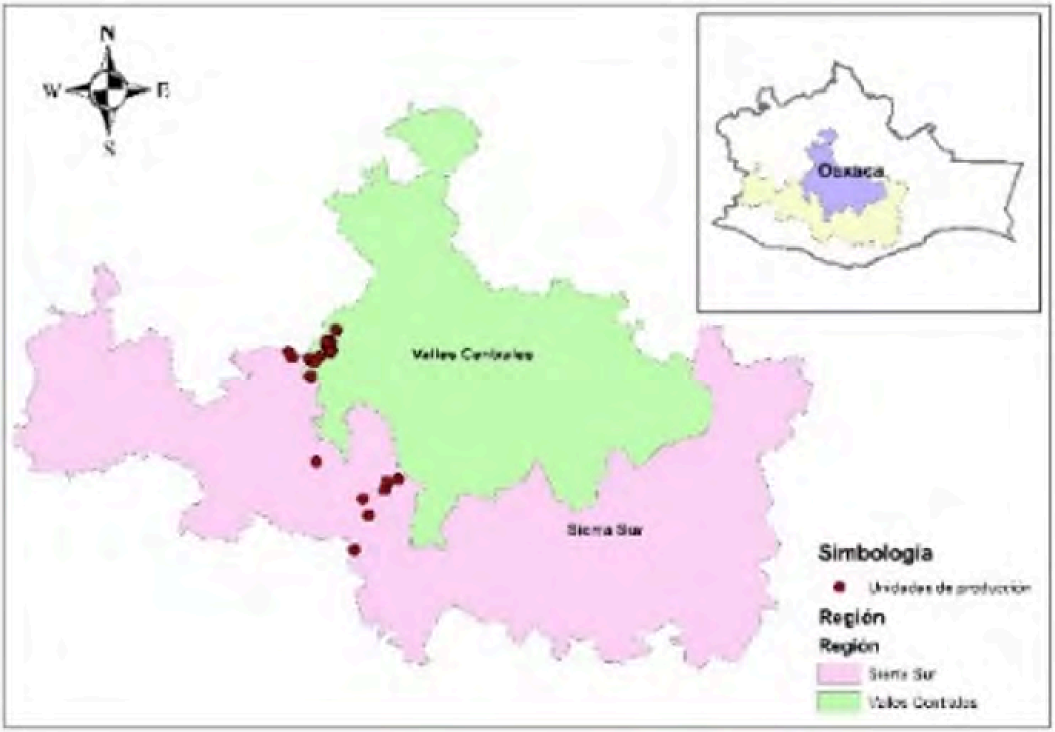
Figure 1. Production units in the Valles Centrales and Sierra Sur regions of Oaxaca.



In Valles Centrales, the predominant climate is temperate sub-humid with rainfall in summer, classified as (C(W2) (W)), with altitudes ranging from 2 000 to 3 000 m, and the annual temperature ranges between 12 and 18 °C. In the Sur region, the predominant climate is temperate sub-humid with rainfall in summer (C(W2) (W)) and semi-warm sub-humid with rainfall in summer (A(C)w2(w)), the temperature ranges from 12 to 26 °C, and precipitation from 600 to 2 500 mm (INEGI, 2010).

Description of production units

To define the production systems, the production units were characterized by collecting data on the number of trees, planted area, fruit yield, and production system practiced. The information was collected using a direct questionnaire; to this end, 18 production units were selected in the Valles Centrales region and 10 in the Sierra Sur region. The trees of the production units were between 3 and 4 years old, fertilization was carried out only during the rainy season and supplemental irrigation was applied with minimal irrigation sheets in the dry season.

Production systems

Agroecological production system. The production unit does not use inorganic fertilization; it only incorporates cattle, goat and sheep manure, using half a 50 kg sack of dry material per tree, without composting. Pest and disease control is carried out sporadically with applications of sulfur-lime mixtures, ash broth and in some cases, soapy water made with household soap. The most commonly used foliar fertilizers are supermagro (obtained from an anaerobic process) and leachates (obtained from vermicompost) prepared locally.

Combined or transitional production system. This includes conventional management with agroecological practices; inorganic fertilizers are applied at an average rate of 100 g of urea with 100 g diammonium phosphate (18-46-00) per tree. Manure (25 kg) is also added. To control pests and diseases, chemical products are used, alternating with products made from plant extracts such as neem (Azadirachta indica A. Juss.), as well as a mixture of copper sulphate with hydrated lime (Bordeaux broth).

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Conventional production system. It is characterized by nitrogen fertilization at doses of 200 to 300 g of urea (46-00-00) per tree, applied in the rainy season; for its part, pest and disease control is carried out only with chemical control (Malation®).

Soil fertility

In each production unit, soil subsamples were collected following a zigzag sampling design. Between 12 and 15 subsamples were obtained at a depth of 30 cm and homogenized to form composite samples of 1 to 1.5 kg. For each study unit, four composite samples were considered. These were stored in clean, properly labeled polyethylene bags and transferred to the Soil Chemical Analysis Laboratory of the Chapingo Autonomous University (UACH), by its Spanish acronym, where fertility was determined in accordance with the methodologies established in the Official Mexican Standard NOM-021-RECNAT (SEMARNAT, 2022).

Statistical analysis

A completely randomized experimental design was applied, considering the average of the four composite samples of each production unit as the experimental unit and its production system as the replication. Edaphic variables were considered along with fruit yield in tons per hectare (t ha-1), calculated from yield per tree and the number of cuts in a year of production. Analysis of variance (Anova) and Tukey's comparison test of means (*p* # 0.05) were performed using the SAS® V.9.0 statistical package (SAS Institute, 2002). To determine the relationship between soil variables and yield, Pearson's correlation coefficients (r) were estimated for the studied variables.

Results and discussion

Texture analyses indicated that, in the municipalities of Zaachila and Villa Sola de Vega, the soil presented a medium texture. This characteristic is within the optimal requirements for avocado crops since the texture of the soil directly influences the distribution and retention of water. In sandy loam soils, it has been observed that, under heavy rainfall, water reaches a uniform distribution at field capacity (-30 kPa), adequately covering the root zone during heavy rainfall (López-Amaya, 2022).

According to the analysis of variance (Anova), there were statistically significant differences in the production systems only for yield and iron (Fe) and the rest of the variables were not significant. Agroecological management showed a slight, non-significant increase in the content of organic matter, nitrogen, calcium, magnesium, sodium, electrical conductivity and pH, compared to the combined and conventional production systems. There were no statistically significant differences in bulk density as a physical property of soil; however, the average values were lower in soils with agroecological and combined management than in the conventional production system. The incorporation of organic fertilizers into the production system directly influenced nutrient availability and the improvement of the physical properties of the soil (Table 1).

Table 1. Comparison test of means of soil analysis in production systems of Hass avocado (*Persea americana* Mill.) Cv., in the Sierra Sur and Valles Centrales regions, Oaxaca.

Variable	Unit	AG	CB	CV	HSD
Bulk density (BD)	(t m-3)	1.09a	1.06a	1.11a	0.16
pH		6.24a	5.72a	5.73a	1.84
Electrical conductivity (EC)	(dS m-3)	0.13a	0.05a	0.08a	0.09
Organic matter (OM)	(%)	2.7a	2.45a	2.12a	1.12

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Variable	Unit	AG	CB	CV	HSD
Inorganic nitrogen (N)	(mg kg-1)	56.31a	43.05a	35.13a	21.2
Phosphorus (P)	(mg kg-1)	2.84a	1.99a	3.41a	2.87
Potassium (K)	(mg kg-1)	162.34a	180.18a	162.54a	69
Calcium (Ca)	(mg kg-1)	6432a	3136a	3192a	4896.6
Magnesium (Mg)	(mg kg-1)	301.4a	177.1a	174.3a	338.72
Sodium (Na)	(mg kg-1)	111.84a	102.46a	78.89a	35.83
Iron (Fe)	(mg kg-1)	9.88b	52.99ab	54.9a	44.6
Copper (Cu)	(mg kg-1)	0.94a	1.81a	1.17a	1.26
Zinc (Zn)	(mg kg-1)	0.9a	0.47a	1.19a	1.18
Manganese (Mn)	(mg kg-1)	5.87a	7.73a	12.49a	11.17
Yield (YIE)	(t ha-1)	4.73c	9.96a	7.4b	2.19

Means with the same letter in each column are statistically equal (p = 0.05); HSD= honestly significant difference; AG= agroecological management; CB= combined; CV= conventional handling.

The increase in organic matter impacts other properties, such as increased moisture retention and improvement of microbial biomass; this is in line with what was reported by Cristóbal-Acevedo *et al*. (2011), who indicate that the organic (agroecological) production system presents better results in terms of the availability of nutrients, improves moisture conditions, and conserves nitrogen and carbon due to the increase in organic matter.

In contrast, the conventional production system is associated with increased leaching of nutrients, such as nitrogen. In this sense, Trinidad and Velasco (2016) mentioned that fertilizers and organic matter strongly influence the physical, chemical and biological characteristics of the soil. In the agroecological production system, it was determined that the pH and EC values increased, possibly due to the type of fertilizer used in the production units. These results coincide with Álvarez-Sánchez *et al*. (2006), who report that the addition of organic materials causes significant changes in soil pH, electrical conductivity and inorganic nitrogen. The same behavior was reported by Zanor *et al*. (2018), where soil pH was increased by the application of bovine manure to nutrient-deficient agricultural soils.

Nutrient availability is an essential factor for the growth and development of trees and is closely related to their nutritional status (García-Martínez *et al*., 2021). In this sense, although improvements of soil properties and nutrient availability were evident for the agroecological production system, these did not influence yield, as observed in the combined production system. This increase can be attributed to inorganic complementary fertilizations and the application of organic fertilizers as amendments to improve soil properties.

These results are similar to those reported by López-Martínez *et al*. (2001), who indicate that combining organic fertilizers with chemical fertilizers is a viable alternative for improving the yield of corn crops. In this sense, organic matter improves physical characteristics, such as porosity, water retention and permeability, and stimulates the microbial flora, which in turn facilitates the transformation of soil compounds into available nutrients, such as Zn, Cu and B, for crops (Campos *et al*., 2020). In other words, improving soil properties is essential for achieving higher yields and ensuring sustainable agriculture in the medium term in avocado cultivation.

The correlation matrix and the significance of the variables evaluated in the Hass avocado orchards showed a significant positive correlation between Ca with BD, pH, EC, N, Na, and Fe (Table 2). This indicates that, when the value of Ca increases, the values of these variables also increase. Ca is essential in the plant, especially at the root level, as it influences the number and length of root hairs, which are essential in the absorption of nutrients (González *et al*., 2020).

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Table 2. Matrix of correlation (r) coefficients and significance of soil analysis in production units of Hass avocado (*Persea americana* Mill.) Cv., in the Sierra Sur and Valles Centrales regions, Oaxaca.

	BD	pH	EC	OM	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	YIE	NP
BD	1	0.67*	0.31	0.07	0.06	-0.53*	0.06	0.53*	0.22	0.42	-0.36	-0.35	-0.48*	-0.39	-0.09	-0.08
pH		1	0.73*	0.28	0.28	-0.37	0.3	0.82*	0.16	0.57*	-0.52*	-0.3	-0.22	-0.51*	-0.06	-0.23
NP																1

*= significant difference ($p \leq 0.05$); YIE= yield; NP= number of plants per hectare; EC= electrical conductivity.

On the other hand, the positive correlation among Ca, EC, and pH was also reported by Acevedo *et al*. (2020) when evaluating the degradation levels of three strata (0-5, 5-18, and 18-50 cm deep) in two production systems in Lara, Venezuela. The pH showed a positive correlation with Ca, which means that an increase in pH generates a greater presence of this element. This behavior was reported by Rodríguez-Garay *et al*. (2016) when evaluating the spatial behavior of soil chemical attributes and their relationship with coffee yield and quality in Sasaima, Colombia.

On the other hand, Fe correlated negatively and significantly with pH, EC, N, Ca and Na (Table 2). This is common in different avocado growing areas since there are often deficiencies or contrasting values derived from the particular characteristics and management conditions of the soils where the avocado is grown, as reported by Méndez-García *et al*. (2008) when studying the nutritional status, physical and chemical characteristics of the soil, and chemical quality of the irrigation water of avocado (*Persea drymifolia* L.) trees in orchards of Nepantla, Tepetlixpa, state of Mexico. Finally, the correlation between pH and macroelement P was negative; in contrast, pH and Fe showed a significant negative correlation. This coincides with the findings by Rodríguez-Garay *et al*. (2016), who reported that an increase in pH does not promote the availability of P and does not increase the values of Fe and Zn in avocado orchards.

Conclusions

Agroecological management slightly improved soil properties in avocado production units in the Sierra Sur and Valles Centrales regions of Oaxaca; nevertheless, it was not reflected in an increase in yield during the evaluated cycle. There was a significant positive correlation of Ca with BD, pH, EC, N, Na and Fe. Combined management obtained the highest yields, evidencing its potential as a sustainable agricultural alternative by integrating the benefits of agroecological management with the rational use of inorganic inputs.

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