Article

Yield, quality and post-harvest behavior of 'Hass' avocado fruits of orchards with different fertilization

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Abstract

In fruit trees, productivity differs between orchards due to the particular condition of the nutritional status of trees, soil fertility, rootstock, crop health and agronomic management. The objective of this research was to compare the yield, quality and post-harvest behavior of 'Hass' avocado fruits in two orchards with different fertilization management. The first was located in Valle de Bravo and the second in Villa de Allende, State of Mexico. The evaluation was carried out in 2017. In each orchard the yield, quality, post-harvest behavior and extraction of nutrients by the fruits were measured. In addition, the tree's nutritional status and soil fertility were diagnosed. The fruits of the Valle de Bravo orchard surpassed those of Villa de Allende in yield, weight, length, diameter and oil concentration and density, however, they had less firmness and weight loss. The avocados of Valle de Bravo had higher concentration of K, S, Zn and B, those of Villa de Allende concentrated more Ca, Fe, Cu and Mn. In Valle de Bravo the trees showed deficiencies of Ca, S, Cu, Mn, Zn and B, while, in Villa de Allende, the deficient elements were K, S, Zn and B. In conclusion, the highest yield of fruit obtained in the Valle de Bravo orchard was related to the better nutritional status of the trees and increased soil fertility.

Keywords: *Persea Americana* Mill., fruit quality, nutriment extraction, nutritional status.

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Introduction

In fruit trees production, the quality of the fruit and its post-harvest behavior differs between orchards due to the particular condition of the nutritional status of the trees and the fertility of the soil, among other factors. This situation affects the commercial relationships between producer and buyer. It is important to understand the problem in order to attend it and improve the delivery, to the market, of fruits of quality and uniform maturity.

Mexico is the world's leading avocado producer, followed by Peru, Colombia and Chile (FAOSTAT, 2017). With a yield of 10.6 Mg ha^{-1} (SIAP, 2019), the State of Mexico ranks third nationally in production. In the State of Mexico production is concentrated in the southern region, mainly in the municipalities of Coatepec Harinas, Ixtapan de la Sal, Temascaltepec, Valle de Bravo, Donato Guerra and Villa de Allende. In this area, avocado production is carried out on small surfaces and the management of tree nutrition is done empirically.

The absence of research-based fertilization recommendations causes fruit producers to apply excessive amounts of inorganic fertilizers (Shunfeng *et al*., 2018) that generate serious environmental problems. In addition, under these conditions, orchards do not reach the productive potential in terms of yield and quality of fruits.

Visual diagnosis of orchards indicates that trees have nutritional deficiencies and yields suggest that there is generally loss of soil fertility from the nutrient extraction in the harvest and inadequate management of fertilization. No studies have been conducted in the area. In contrast, in Nayarit, Salazar-García and Lazcano-Ferrat (1999) identified frequent deficiencies in K, S and B in 'Hass' avocado trees that developed under temporal conditions.

In Michoacán, Maldonado-Torres *et al*. (2007) identified deficiencies in Zn, Mn and Cu in 'Hass' avocado trees. In Morelos, another avocado-producing area, Sotelo-Nava *et al*. (2017) compared two avocado agro-habitats and found that foliar concentrations of Ca, Mg, B, Cu and Mg were within the optimal sufficiency range, while N, P and K had differences between sufficiency and deficiency. Under no circumstances did the trees show an optimal level in all nutritions.

The nutritional condition of avocado trees is related to the availability of elements in the soil. For example, Maldonado-Torres *et al*. (2007) reported that the soil in an orchard sample had acidic pH, low levels of organic matter (MO) and high to very high levels of Cu, Fe, K, Ca, B and Zn, even though, in the leaves, these elements were in deficit concentrations. Salazar-García and Lazcano-Ferrat (1999) reported, in Nayarit orchards, pH values on the ground from 5.1 to 7.1 and MO between 0.3 and 3.4%, as well as low concentrations of N, P, Ca, Mg, Zn and Cu, but high levels of Fe and Zn.

In Morelos the soil pH was located in the range of 6.2 to 7.1 and MO between 2.5 and 3.3%, very low concentrations of N and B; Ca, K, Mg, Fe, Cu and Mn (Sotelo-Nava *et al*., 2017). Differences in soil physicochemical characteristics make it difficult to extrapolate fertilization recommendations between one region and another and require the generation of specific information for each producing area.

Depending on the nutritional variations and soil fertility indicated, it is explained that yields and quality of production differ between orchards, as demonstrated by García-Martínez *et al*. (2015) in Mango 'Kent', who observed differences in the quality and post-harvest behavior of the fruit by the effect of different doses of fertilization to the soil. Therefore, the objective of this research was to compare the yield, quality and post-harvest behavior of avocado fruits 'Hass', coming from two orchards with different management in tree nutrition. The hypothesis is that the quality and maturation of the fruits differs between orchards due to the nutritional status of the trees and the fertility of the soil.

Materials and methods

Study area

The research was carried out 'Hass' avocado orchards located in two municipalities of the State of Mexico. The first is located in Santa María Pipioltepec, Valle de Bravo, 19° 14' 10" north latitude and 100° 06' 30" west longitude, at an altitude of 1 950 m, with precipitation of 1 000 mm per year and average annual temperature of 18.8 °C (SMN, 2010). The area of the orchard is 1 ha, has slope of 66% and the trees were 8 years old; the planting distance is 7 m between trees and 8 m between lines (178 trees ha^{-1}).

The second orchard is located in San Jerónimo Totoltepec, Villa de Allende, 19° 19' 43" north latitude and 100° 12' 33" west longitude, at an altitude of 2 300 m, with precipitation of 1129 mm per year and average annual temperature of 16 °C (SMN, 2010). The area of the orchard is 1 ha, has a slope <5% and the trees were 8 years old; the planting distance is 6 m between trees and 7 m between lines (192 trees ha^{-1}). Both orchards are located in andosol.

Orchard management

The management of the orchards in the last 5 years was as follows: in Valle de Bravo manual weed control was carried out, annually between 50 and 60 kg tree compost of sheep and cattle manure was applied, the water supply was by irrigation by micro-spray in the months of April to May and the rest of the year was supplied with rain, pests were not controlled and the trees were not pruned.

In Villa de Allende there was mechanical control of weeds (trimmer or tractor), no fertilizers were applied, the water supply was from the annual precipitation, pests and diseases were chemically controlled, and the trees received no pruning.

Variables and frequency of measurement

Fruit yield

Yield data for each orchard were provided by the producer after harvest (November 2017).

Weight, diameter and length of fruit

For the weight (g) a random sample of 120 fruits from 30 trees (4 fruits per tree) was harvested inside each orchard, the fruit was weighed on a Santul® digital balance and the data were used to classify them according to the calibers established by NMX-FF-016-2002. To determine the diameter and length (cm), 30 random trees were selected in each orchard, in each tree 10 fruits were chosen and both variables were measured with a vernier Pretul®.

Quality and post-harvest behavior of the fruit

On 05 November 2017, 150 fruits were harvested in each orchard in physiological maturity weighing between 200 and 300 g (5 fruits/tree; 30 trees), placed in plastic boxes and transported to the laboratory. Upon arrival, they were cleaned with a dry cloth to remove dust and sorted by size. These fruits were used to evaluate post-harvest variables.

Dry Material (MS)

10 fruits were used, each divided into its three components: exocarp (shell), mesocarp (pulp) and seed. The samples were placed in aluminum trays and dried (70 °C by 48 h) on a forced convection stove (AOAC, 1990). The results were expressed in porcentajand with respect to the initial weight.

Oil content and density

The dry matter of the mesocarp was used to extract the oil. The extraction was performed on a Soxtlet equipment, using petroleum ether as solvent. The flask was installed in a water bath at 60 °C, the solvent return time was 30 min and the extraction lasted six hours per sample (AOAC, 1990). The results were expressed as a percentage of oil extracted with respect to fresh pulp. The density of the oil was measured with a Brand® 25 ml.

Cumulative Weight Loss (PAP)

The daily weight of 10 fruits was recorded for 16 days. Cumulative weight loss was expressed as a percentage of the initial weight (García-Martínez *et al*., 2015).

Firmness of the pulp

5 fruits were used in each evaluation. It was determined with a Wagner® Model FDV-30 digital texture meter, with a maximum capacity of 30 lb and graduation of 0.01 lb, equipped with a conical strut 7 mm in diameter at the base by 7 mm in height. The force needed to penetrate the mesocarp into the equatorial zone on two opposite sides of the fruit was quantified, after removal of the exocarp. The data were reported in Newtons (N).

Mesocarp color

Five split fruits were used and the reading was done, every third day, in the middle part of the area occupied by the mesocarp. A 3Nh® (China) reflection colorimeter that uses the CIELab scale was used, based on the parameters L^*, a^* and b^*, the hue angle [°Hue= arcotan (b^*/a^*)], Chroma [C= (a^*2+b^*2) ^ 0.5] and luminosity (L) were calculated (Guire, 1992).

Concentration and nutritional removal of the fruit

The harvesting of the fruits for this variable was carried out on September 24, 2017. In each orchard, 20 trees were chosen at random and one fruit was harvested for each tree. In the laboratory, the fruits were washed with distilled water and cut into 1 cm^3 pieces, they were dried (60 °C by 72 h) on a forced convection stove, ground and sifted with a 1 mm sieve. Of each ground fruit, 5 g was taken and a composite sample was formed for each locality. For the chemical analysis, the procedure used for foliar analysis was used. From the nutritional concentration data and yields of each orchard, the amount of nutrients removed per harvest was calculated.

Nutritional status of the tree

It was determined by foliar analysis. The trees were sampled on September 24, 2017. The procedure described by Salazar-García and Lazcano-Ferrat (1999) was used for this purpose. According to the position on the slope of the terrain, the orchard of Valle de Bravo was divided into three sections (high, medium and low), in each section 12 trees were sampled and a sample composed of section was formed. In the orchard of Villa de Allende 36 trees were sampled at random and a composite sample was formed.

The leaves were placed inside paper bags and transported to the lab in an icebox. Upon arrival, they were washed with distilled water, put in paper bags and dried on a stove with forced air movement, at a temperature of 60 °C by 72 h. The dry samples were ground in a stainless-steel mill fitted with a Siemens® 682662 series single-phase motor, until the resulting material went through a 1 mm sieve.

A plant standard sample (laboratory reference sample) was used in all analyses to control the quality of the results. The determination of N was made by the semimicro-Kjeldahl procedure (Sáez-Plaza *et al*., 2013). For K, Ca, Mg, Fe, Cu, Zn and Mn, the sample was digested with a mixture of HNO_3 and $HClO_4$ (Tan, 1996) and quantification was performed by atomic absorption. The P was quantified by the vanadomolybdate method (Burns and Hustby, 1986). B was determined by the Azomethine-H method (Shunfeng *et al*., 2018) and S by turbidimetry according to the technique described by Tan (1996).

Nutritional diagnosis of trees was made using the Kenworthy Balance Index (Kenworthty, 1973). Standard values and coefficients of variation of nutrition generated by various authors were used. For elements N, P, Ca, Mg and Fe Palacios (1986) information was used. In the case of K, Cu, Mn and Zn data were taken from Maldonado-Torres *et al*. (2007). The value for S was obtained from the data published by Salazar-García and Lazcano-Ferrat (1999). Finally, for B the values obtained by Razeto and Castro (2007) were used.

Soil fertility

It was determined through chemical soil analysis. Sampling was carried out on 06 October 2017, at a depth of 0 to 30 cm at the four cardinal points of the middle part of the ground surface where the tree top is projected. The floor was removed with a stainless-steel auger 2.5 cm in diameter. In Valle de Bravo, 12 samples were taken in each section to form three composite samples, one per section. In the orchard of Villa de Allende, 36 samples were taken to form a composite sample.

The floor was placed in plastic bags and transported to the lab in an icebox. The samples dried in the shade at room temperature, then they ground with a porcelain mortar until they passed through a 2 mm sieve. Finally, they were stored in paper envelopes for further analysis.

A standard soil (internal reference sample) was used in chemical analysis to control the quality of the results. PH was measured in a water-soil solution, ratio 2:1 (Weil and Brady, 2017). Electrical conductivity was measured in saturation paste extract (Tan, 1996). The texture of the soil was analyzed by the Bouyoucos method (Scott, 2000). The MO was quantified by the Walkley-Black method (Sleutel *et al*., 2007).

The concentration of nutriments was measured by chemical methods. The N was quantified by semimicro-Kjeldahl (Saéz-Plaza *et al*., 2013) and P by Olsen (1954) method. The interchangeable cations (K^+, Ca^{2+}, Mg^{2+} and Na^{1+}) were extracted with ammonium acetate (Havlin *et al.*,2017) and quantification was performed by atomic absorption spectrophotometry. The microelements (Fe^{2+}, Cu^{2+}, Zn^{2+} and Mn^{2+}) were extracted with a DTPA solution (Tan, 1996), $CaCl_2$ and triethanolamine and quantification was performed by atomic absorption spectrophotometry. B was analyzed by the procedure of Azometina-H (Razeto and Castro, 2007) and S by turbidimetry (Tan, 1996). The results obtained were classified by reference values (Castellanos *et al*., 2000).

Statistical analysis

Statistical tests were applied to identify differences between locations. To variables, weight, diameter, length, dry matter, oil content and density, a t-test was applied for independent samples (Sánchez-Turcios, 2015). For firmness, cumulative weight loss and color, longitudinal data analysis was used (Hedeker and Gibbons, 2006). A $p\leq 0.05$ value was used and the analyses were performed with the SAS® 9.0 statistical package. Nutritional concentration data on soil, fruit and leaf were not statistically analyzed because only one value was obtained from the composite sample.

Results and discussion

Yield, weight, diameter and length of fruit

In Valle de Bravo the yield was 8 Mg ha^{-1} and in Villa de Allende, 6 Mg ha^{-1}. These results contrast with the information reported by Salazar-García *et al*. (2009), who obtained maximum yields of 28.2 Mg ha^{-1}, in trees from 10 to 12 years, for temporary orchards with mineral fertilization. This indicates that there is a potential to increase yield in the orchards under study by optimally designing fertilization programs.

The weight of the fruit showed differences ($p\leq 0.01$); in Valle de Bravo a value of 167.6 g was recorded and in Villa de Allende, 149.6 g in Valle de Bravo, 73% of the fruits were concentrated in class >170 g, Villa de Allende had only 64% in the same category. In temporary conditions, Salazar-García *et al*. (2009) noted that, with optimal tree nutrition, 61% of ‘Hass’ avocado fruits were concentrated in category >170 g, while, with poor fertilization only 45% of the fruits concentrated in the same category. The size of the fruit was different between orchards ($p\leq 0.01$) in Valle de Bravo, the length and diameter were 8.5 and 6.1 cm and in Villa de Allende, 8.1 and 5.8 cm, respectively.

Quality and post-harvest behavior

Dry matter

In both orchards, the proportion of each section of fresh fruit to the total was: 72% mesocarp, 14% seed and 14% exocarp. In 'Hass' avocado, Krumreich *et al*. (2018) report a ratio of 71.8% mesocarp to 21.2% seed and 6.8% exocarp. The MS content showed differences in exocarp and mesocarp ($p\leq 0.05$). In the exocarp, Valle de Bravo obtained 28.3% and Villa de Allende, 25.9%.

In the mesocarp, Villa de Allende obtained 26.8% and Valle de Bravo, 24.1%. The seed showed no differences (Valle de Bravo, 38.6% and Villa de Allende, 40.5%). In 'Hass' avocado it is reported that physiological maturity is reached when the dry material of mesocarp has 21.1% (Herrera-González *et al*., 2017). This criterion is used as a harvest index in this crop.

Oil concentration and density

The concentration ($p\leq 0.01$) and oil density ($p\leq 0.05$) had differences. The concentration and density values of oil were 16.3% and 0.84 g cm^{-3} for the fruits of Valle de Bravo and 12.2% and 0.79 g cm^{-3} for Villa de Allende. Munhuweyi *et al*. (2020), mention that avocado pulp contains 11 to 19% oil.

Cumulative weight loss

The PAP presented a difference from the beginning of the maturation process ($p\leq 0.01$). The fruits of Villa de Allende reached a final value of 16% and those of Valle de Bravo, 11% (Figure 1A). Factors such as temperature, relative humidity (Maftoonazad and Ramaswamy, 2005), fruit size, concentration of nutrition and thickness of the epidermis affect the amount of water some fruit loses. The lower concentration of MS in the exocarp of the fruits of Villa de Allende favored perspiration and explained the high values of PAP.

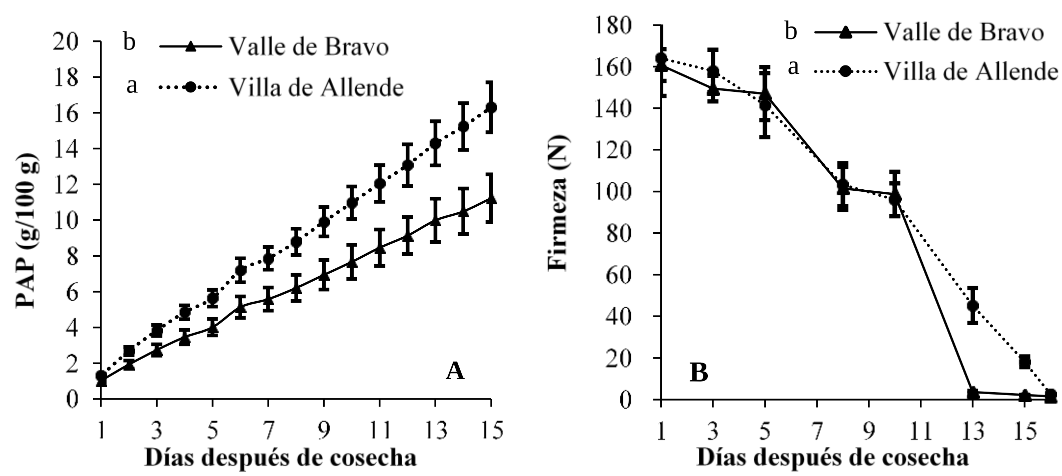

Figure 1. Post-harvest behavior of 'Hass' avocado fruits from two orchards evaluated in the State of Mexico. A) Cumulative weight loss (PAP); and B) Firmness. Different letters in the locality indicate statistical difference ($p\leq 0.05$).

Firmness of the pulp

During the maturation process, the fruits from Villa de Allende were firmer compared to those of Valle de Bravo ($p\leq 0.05$). Although the values were similar the first 10 days of the maturation period, from day thirteen, in the fruits of Valle de Bravo firmness decreased and reached the maturity of consumption three days earlier, compared to Villa de Allende (Figure 1B).

The preservation of firmness in the fruits of Villa de Allende was associated with the highest concentration of Ca (0.13 g 100 g^{-1}) in the fruit. Barrientos-Priego *et al*. (2016) report that 'Hass' avocado fruits with a calcium concentration of 0.81 and 0.85 g 100 g^{-1} in the mesocarp, presented greater firmness on the sixth day of the maturation period under environmental conditions, compared to the witness, whose concentration was 0.78 g 100 g^{-1}.

In 'Fuerte' avocado, Saucedo-Hernández *et al*. (2005) noted that fruits, from trees with foliar calcium nitrate applications, were firmer during the maturation process, compared to the witness (without application).

Mesocarp color

The color of the mesocarp in the fruits of Villa de Allende was higher in L (63.7 to 80.5) and °Hue (95.7 to 97.3) ($p\leq 0.01$); the pulp developed a light green hue, while in Valle de Bravo the color was dull yellow (L: 53.2 to 77 and °Hue: 94.4 to 93.9). The yellow color on the pulp of the fruits has better acceptance among consumers. Ashton *et al.* (2006) noted that the increase in the values of °Hue from 101 to 113 coincided with the increase in the total concentration of chlorophylls and carotenoids.

Composition and nutritional extraction of the fruit

The concentration of Ca, Fe, Cu and Mn was higher in the fruits of Villa de Allende (Table 1). In these fruits, the highest concentration of Ca corresponded to high firmness values at the end of the maturation period. The trees in this orchard received foliar applications of Ca (Calcio-Boro, AgroScience®) during fruit development. Solís-Fraire *et al*. (1998) found a tendency to increase the content of Ca in the mesocarp of the fruit by effect of the foliar application of Ca $(NO_3)_2$.

The concentration of K, S, Zn and B was higher in the fruits of the Valle de Bravo orchard. Elements K and B are key in fruit quality and explain why Valle de Bravo fruits were superior in weight, diameter and length. A higher concentration of K in tree leaves favors the rate of transport of saccharose in the phloem and, adequate concentrations of B improve the growth rate and prevent malformations in the fruit (Havlin *et al*., 2017).

The extraction of N, P, Ca, Fe, Cu, Zn and Mn was superior in the fruits of the orchard of Villa de Allende (Table 1). Only the amount extracted from B was higher in the Valle de Bravo orchard. The order of nutrition extraction in Valle de Bravo was: K> N> P= Mg> Ca> S> Fe> B> Zn> Cu> Mn, and in Villa de Allende it was: K> N> P> Mg> Ca> Fe> Zn> Cu= Mn> B.

Table 1. Concentration and nutritional extraction in 'Hass' avocado fruits of two orchards in the State of Mexico.

Element	Nutritional concentration		Nutritional extraction	
	Bravo Valley	Villa de Allende	Bravo Valley	Villa de Allende
	($g\ 100\ g^{-1}$ ms)		($kg\ Mg^{-1}$ fresh fruit)	
N	0.9	0.9	2.2	2.4
P	0.2	0.2	0.4	0.5
K	1.8	1.6	4.4	4.4
Ca	0.06	0.13	0.2	0.3
Mg	0.2	0.2	0.4	0.4
S	0.05	0.04	0.1	0.1
	($mg\ kg^{-1}$ ms)		($g\ Mg^{-1}$ fresh fruit)	
Fe	26	36	6.3	9.6
Cu	7	10	1.7	2.7
Zn	18	17	4.3	4.6
Mn	7	10	1.6	2.7
B	22	9	5.3	2.5

ms= dry material.

This data is consistent with the results of Maldonado-Torres *et al*. (2007), who report the following extraction order: K> N> P> Mg> Ca> Fe> B> Zn> Cu> Mn. The information obtained highlights the importance of fertilization with K, B and Zn to improve yield and quality in the orchards studied, as producers do not usually apply these elements as part of tree nutrition management.

Nutritional status of the tree

Trees in both orchards showed normal levels of N and P (Table 2). In the Sierra Purépecha, Michoacán, Maldonado-Torres *et al*. (2007), they found that 69% of orchards analyzed had optimal concentrations of N in the leaves of 'Hass' avocado trees, while for P the number of cases was higher (85%).

In the low section of the Valle de Bravo orchard, the below normal condition in K was related to excess Mg and the zero application of potassium fertilizers. Mg and K have similar chemical properties and compete for the site of adsorption, absorption, transport and function in the roots, and within the tissues of plants (Nguyen *et al*., 2017).

In the orchard Villa de Allende, the low foliar concentration of K was associated with the high extraction by the harvest and the low supply of potassium fertilizers. The scarcity of S in the leaves is due to the fact that this element is highly mobile in the soil and is easily lost (Havlin *et al*., 2017), in addition, no orchard studied received applications of sulfur fertilizers.

Table 2. Concentration of nutrients in the leaves and nutritional balance index based on Kenworthy's methodology (1973) for 'Hass' avocado trees in the orchards of Valle de Bravo and Villa de Allende, State of Mexico.

Nutrient	Valle de Bravo			Villa de Allende
	High section	Middle section	Low section	
N (%)	2.19 (n)	2.31 (n)	2.23 (n)	2.04 (n)
P (%)	0.16 (n)	0.15 (n)	0.13 (n)	0.12 (n)
K (%)	1.02 (n)	0.87 (n)	0.78 (dn)	0.74 (dn)
Ca (%)	1.28 (dn)	1.72 (n)	1.88 (n)	1.81 (n)
Mg (%)	0.74 (an)	0.87 (an)	1.10 (ex)	0.63(n)
S (%)	0.15(es)	0.17(es)	0.09(es)	0.13(es)
Fe (ppm)	149 (an)	150 (an)	125 (an)	103 (n)
Cu (ppm)	5 (es)	7 (es)	6 (es)	20 (n)
Mn (ppm)	32 (es)	40(es)	58 (es)	149 (n)
Zn (ppm)	19 (es)	18 (es)	15 (es)	15 (es)
B (pppm)	18.3 (es)	18.9 (es)	16.5 (es)	20.4 (es)

n= normal; dn= below normal; an= above normal; ex= excessive; es= shortage.

The scarcity of Cu, Mn, Zn and B observed in the leaves of the trees of the Valle de Bravo orchard is due, because this orchard, does not receive applications of micronutriments to the soil or foliar vial. Additionally, Cu and Mn deficiencies are associated with high MO content in the soil (Weil and Brady, 2017). The foliar concentration of Fe, above optimal, was associated with the constant application of sheep and bovine manure composts. These amendments contain high concentrations of Fe (Havlin *et al*., 2017) because this element is an important part of the diet of animals.

The normal levels of Cu and Mn in the orchard of Villa de Allende are related to the application of fungicides containing these elements. In Nayarit, Salazar-García and Lazcano-Ferrat (1999) found excessive levels of Cu due to the application of copper fungicides. The scarcity of Zn and B in the leaves of the trees is the result of the high extraction by the harvest and the zero application of fertilizers containing these elements.

In this regard, Maldonado-Torres *et al*. (2007) found frequent deficiencies of Zn in avocado orchards in Michoacán, while Salazar-García and Lazcano-Ferrat (1999) reported deficiencies of B in all the orchards analyzed.

Soil fertility

In the orchard of Valle de Bravo the texture of the soil was different between the sections. The upper part was classified as loam-sandy; sand: 58%, slime: 31.8% and clay: 9.9%. Soils with higher sand content have less restriction on water movement through the profile and storage of moisture (Wang *et al*., 2020) and lower nutrient content (Havlin *et al*., 2017). The middle section was classified as clay loam, sand 9.9%, slime 79.4% and clay 6.9%.

The low section was classified as clay loam, sand 6.9%, slime 78.7% and clay 14.5%. The difference in the availability of moisture in the soil causes that in the high part the trees to be small (height < 3 m), while in the low part the trees have a height greater than 7 m. In the orchard of Villa de Allende, the texture of the soil was classified as clay loam; sand 10.3%, slime 70.4% and clay 19.3%. Weil and Brady (2017) mention that soils with higher slime and clay content have higher fertility than sandy soils, as they retain higher moisture and have higher N content and interchangeable bases.

In the orchard of Valle de Bravo the pH of the soil changed from neutral to moderately acidic (Table 3), while in Villa de Allende the pH was classified as moderately acidic (Table 3). These values are consistent with Bayuelo-Jiménez *et al.* (2019), who report pH values of 6 in andosol with an agricultural vocation in the Purépecha Plateau, Michoacán. The soil of the orchards studied has no problems of nutritional availability. The nutrients in the soil are available in a pH range of 5.5-6.5 (Porta *et al*., 2019).

Table 3. Results of soil analysis of two orchards evaluated in the State of Mexico.

Variable	Valle de Bravo			Villa de Allende
	High section	Middle section	Low section	
pH	6.7 (n)	6.3 (mac)	6.1 (mac)	5.8 (mac)
EC (mS cm^{-1})	1 (ls)	1.6 (mbs)	1.7 (mbs)	0.6 (ls)
MO (%)	13.8 (a)	17.7 (ma)	11.2 (mda)	4.3 (b)
N (%)	0.58 (ma)	0.71 (ma)	0.48 (a)	0.24 (m)
P olsen (ppm)	131 (ma)	55 (ma)	123 (ma)	79 (ma)
K (ppm)	1515 (ma)	1080 (a)	1152 (a)	871 (a)
Ca (ppm)	7707 (ma)	7907 (ma)	5800 (ma)	1609 (m)
Mg (ppm)	1401 (ma)	1453 (ma)	1417 (ma)	400 (mda)
Fe (ppm)	66 (ma)	74 (ma)	78 (ma)	19 (mda)
Cu (ppm)	11.9 (ma)	1.0 (m)	3.3 (ma)	0.3 (b)
Zn (ppm)	138.6 (ma)	7.3 (a)	28.7 (ma)	0.1 (mb)
Mn (ppm)	18 (mda)	18 (mda)	41 (a)	6 (mdb)
B (ppm)	1.5 (mda)	1.0 (m)	1.3 (m)	0.3 (b)
S (ppm)	0.001	0.001	0.001	0.002
Na (ppm)	17 (mb)	53 (mb)	33(mb)	29 (mb)

n= neutral; mac= moderately acidic; ls= salt-free; mbs= very low in salts; ma= very high; mda= moderately high; a= high; m= medium; mdb= moderately low; b= low; mb= very low.

EC values did not indicate salinity problems. Avocado trees reduce more than 80% of their relative yield when EC soil reaches 2 dS m^{-1} (Crowley, 2008). The MO content was superior in the Valle de Bravo orchard, this is due to the constant application of compost for fertilization and the incorporation of green fertilizers. Cooper *et al.* (2020), reported that the application of compost increases the carbon content in the soil.

The soil of the Valle de Bravo orchard showed higher levels N, P, K, Ca, Mg, Fe, Cu, Mn, Zn and B, the continuous application of animal manure, in this orchard, explains the highest concentration of nutrients in the soil of Valle de Bravo compared to the orchard of Villa de Allende, where the application of fertilizers is scarce. Mendez-García *et al*. (2008) noted that the high P content in the soil of avocado orchards is related to the application of organic fertilizers.

In addition, the increase in pH due to the application of organic amendments is one of the factors that improve the availability of nutrition, particularly P (Reyna-Ramírez *et al*., 2018). The highest concentration of B in soil in the Valle de Bravo orchard was associated with higher MO content. According to Havlin *et al*. (2017), the B present in the soil comes from organic waste from plants and microorganisms. Finally, the Na concentrations found in this study are consistent with the low levels reported by Salazar-García and Lazcano-Ferrat (1999) and do not adversely affect crop development.

Conclusions

The productivity, quality and maturation of ‘Hass’ avocado fruits was different between orchards due to the particular condition of the nutritional status of the trees and the fertility of the soil. The highest yield was presented in the Valle de Bravo orchard and avocados were higher in weight, length, diameter, content and density of mesocarp oil, also had less weight loss. This information will allow the design of optimal fertilization programs to increase yields and improve quality in both orchards.

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