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Articule

The fertilizer source conditions the yield and quality of ‘Hass’ avocado fruits

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Abstract

Optimal nutrition of fruit trees is critical to obtaining high yields of quality fruit for the fresh fruit market. Producers apply different types of fertilizers in the management of ‘Hass’ avocados, which generates differences in production. Therefore, this work aimed to study the response of the yield and quality of ‘Hass’ avocado fruits to the fertilization source. An experiment was established in an eight-year-old ‘Hass’ avocado orchard in Villa de Allende, State of Mexico. In 2018 and 2019, four sources of fertilizer applied to the soil were studied: control, organic, mineral, and combined. Yield (kg tree^{-1}), number, individual weight and size of the fruits were measured. To evaluate the postharvest behavior, the fruits were stored for nine days at 22 °C and 90% RH. In this period, dry matter content, cumulative weight loss, firmness, and color were measured. Organic fertilizer led to a higher yield (kg tree^{-1}) and number of fruits. Dry matter content (23.3%) and weight loss (9%) did not differ between treatments. At maturity of consumption, the firmness of the fruits of the mineral source was superior to the control. The hue angle of the exocarp in the fruits of the combined source was similar to the control. In general, the fruits of the mineral and organic sources developed better external color. In conclusion, the application of organic fertilizer improved fruit yield, whereas with the mineral source, the fruits were superior in quality and postharvest behavior.

Palabras clave:

Persea americana Mill., fruit quality, fruit tree nutrition, postharvest management.

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Introduction

Optimal nutrition of fruit trees is critical to obtaining high yields of quality fruit for the fresh fruit market and depends on several factors, including the source of fertilizer. Salazar-García *et al*. (2009) found that the average fruit yield over three years in 'Hass' avocado trees nourished with mineral fertilization at doses close to or above the optimum increased by at least 20% compared to the producer's fertilization plan.

In apricots, mineral fertilization to the soil with the formula 40-20-20 improved flowering and fruit set (Armas-Reyes *et al*., 2000) and N in the form of NH_4^{+}/NO_3^{-} increased °Brix, glucose, fructose and sucrose contents, and CIE-a* and CIE-b* values in fruit color compared to N in the form of urea (Khasawneh *et al*., 2021).

In 'Kent' mangoes, the application of mineral sources increased the yield and size of the fruit (Salazar-García *et al*., 2014), but increasing doses of N increased the green hue of the fruit peel, which detracted from its quality (García-Martínez *et al*., 2015). On the other hand, for several decades, organic fertilizers have been used as alternative sources to nourish fruit trees.

In 'Hass' avocado orchards, it has been found that: a) trees fertilized with manure do not achieve optimal development of reproductive shoots and fruits; however, the response is improved when combined with mineral fertilizers applied to the soil or foliage (Villalva-Morales *et al*. 2015) and b) the application of organic fertilizers improves soil fertility and the nutritional status of the tree, which translates into higher flowering and fruit growth rates and that the yield of high-quality fruit is higher than that of trees nourished with mineral fertilizers (Tapia-Vargas *et al*., 2014; García-Martínez *et al*., 2021).

Nonetheless, high doses of cattle manure or chicken manure have been reported to decrease the yellow color in 'Golden' apples (Amiri and Fallahi, 2009). Another relevant effect of organic fertilizers is on soil health. Its constant application increases the content of organic carbon and total nitrogen in the soil compared to mineral sources (Dong *et al*., 2012), which explains the beneficial effect on the nutrition of fruit trees. This work aimed to study the response of the yield and quality of 'Hass' avocado fruits to the fertilization source in an andosol in Villa de Allende, State of Mexico, an expanding avocado-producing region.

Materials and methods

Study area

The research was conducted in a 'Hass' avocado orchard located in San Jerónimo Totoltepec, Villa de Allende, State of Mexico, 19° 19' 43" north latitude and 100° 12' 33" west longitude, at an elevation of 2 300 masl, annual rainfall is 1 129 mm, and the average annual temperature is 16 °C (SMN, 2010). The planting density is 192 trees ha^{-1}. The soil is an Andosol with a slope of less than 5%. The trees were eight years old at the beginning of the study.

Fertilizer sources

Three sources of fertilizer were studied: 1) mineral; 2) organic and 3) combined (mineral plus organic). The source of mineral fertilizer consisted of applying the mixture composed of urea ($CO(NH_2)_2$), calcium triple superphosphate ($(Ca(H_2PO_4)_2\ H_2O)$), potassium chloride (KCl), magnesium sulfate ($(MgSO_4)\ H_2O$), zinc sulfate (SO_4Zn), borax ($Na_2B_4O_7\ 10H_2O$) and Ultrasol micro mix®.

The dose was determined according to the nutrient demand by the trees, considering the target yield of 20 Mg of fruit ha^{-1}, the diagnosis of soil fertility, the nutritional status of the tree and the efficiency in the use of fertilizer (Salazar-García and Lazcano-Ferrat, 2003).

For organic fertilization, cattle and sheep compost was used at a ratio of 3:1 (based on weight) and the combined source consisted of a mixture of both mineral (0.6 kg) and organic (19 kg) sources.

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Additionally, there was a control treatment (producer's practice), which consisted of applying 500 g of urea tree^{-1}. The amount of each nutrient supplied with each fertilizer source is shown in Table 1.

Table 1. Amount (g) of each nutrient applied to each tree according to the fertilizer source.

Nutrient	Mineral	Organic	Combined	Control
N	535	484	654	230
P	131	168	131	na
K	605	605	605	na
Ca	103	1 027	550	na
Mg	29	340	170	na
S	189	507	196	na
Fe	6.3	715	276	na
Cu	0.256	1	1	na
Zn	420	5	420	na
Mn	3.1	14	7	na
B	16	na	8	na

na= not applied.

Experimental design

The experiment was installed in a generalized randomized block design, forming two blocks, each with 16 trees of similar vigor and nutritional status. Each block consisted of four replications per treatment using a tree with experimental unity.

The amount of fertilizer from each source was divided into three equal parts. The first third was applied in September 2018 and the remaining two in January and May 2019. These dates corresponded to the phenological stages of vegetative bud sprouting, beginning of flowering, and fruit growth.

The fertilizer was applied to the soil in a circular band 50 cm wide and 15 cm deep, located at half the distance between the trunk of the tree and the projection limit of the tree canopy.

Experiment management and monitoring

The management of the orchard during the development of the experiment included: mechanical control of weeds with a brush cutter and a tractor harrow, it was not irrigated because the rainy season began in June and ended in October. The trees received chemical control for fungal diseases and no pruning was performed.

Response variables

Yield, size and shape of fruit

The fruits were harvested in November 2019, quantifying the number and total weight per tree with a Santul® digital scale. A random sample of 20 fruits was obtained from each tree, recording the weight individually with a Santul® digital scale, and the diameter and length (cm) with a Pretul® vernier. The fruit shape index was calculated using the diameter/length ratio (Herrera-González *et al*., 2017).

Postharvest behavior

For this stage, 10 fruits per tree with a weight between 100 and 130 g (40 fruits per treatment within each block) were selected, placed in plastic boxes and transported to the laboratory. There they were cleaned and classified by size.

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To homogenize ripening, the fruits were immersed in a solution of 500 mg L^{-1} (pH 5.9) of 2-chloroethyl phosphonic acid (ethephon) for five min. They were then stored in a ripening chamber at a temperature of 22 °C and 90% relative humidity (RH) for nine days. Three fruits per treatment were used to measure the response variables during the ripening period.

Dry matter (DM)

A sample of 100 g of mesocarp was taken from each fruit and placed on an aluminum tray to dry it (70 °C for 48 h) in a forced convection oven (AOAC, 1990). The percentage of dry matter was calculated with the formula reported by Osuna-García *et al*. (2017).

Weight loss (WL)

The daily weight of the fruits was recorded for nine days, calculating weight loss as a percentage of the initial measurement (García-Martínez *et al*., 2015).

Firmness

The firmness was measured with a Wagner® FDV-30 digital texture meter, with a maximum capacity of 30 lb and graduation of 0.01 lb, provided with a conical tip of 7 mm in diameter at the base by 7 mm in height. Five measurements were taken, one every third day, and the data were reported in Newtons (N).

Color

The color of the exocarp and mesocarp was measured using a 3Nh® reflection colorimeter (China) that uses the CIE L*a*b* color space. The hue angle and chroma were calculated according to McGuire's (1992) formulas.

Statistical analysis

The data were analyzed by applying the normality test, homogeneity of variances, Anova, and Tukey's test ($p< 0.05$) for comparison of means. The analysis was executed with the R statistical software (R Core Team, 2024).

Results and discussion

Yield, size and shape of fruit

The data on yield and physical characteristics of the fruits are displayed in Table 2. The organic treatment stood out in yield, size, and shape of fruit. Fruit weight was lower than that reported in other studies. Villalva-Morales *et al*. (2015) obtained fruits of 150 g in five-year-old trees without fertilizer application, and fruits of almost twice as much that weight (260 g) in trees fertilized with 200-100-200 kg ha^{-1} of N, P, K + foliar fertilization with 30-10-15 kg ha^{-1} of Ca-Mg and B, respectively.

Table 2
Yield and characteristic of 'Hass' avocado fruits due to the effect of the fertilization source.

Source of fertilization	Num. of fruits	Fruit weight (g)	Yield (kg $tree^{-1}$)	Length (cm)	Diameter (cm)
Control	57 c	136.8 a	7.2 c	8 a	5.6 a
Organic	217 a	139.3 a	30.7 a	8 a	5.6 a
Mineral	101 b	139.5 a	13.9 b	7.8 ab	5.7 a
Combined	92 b	117.2 b	10.9 bc	7.6 b	5.2 b
CV	15	7.1	22.4	11.6	11.8

Means with the same letter within the columns are statistically equal (Tukey $p\leq 0.05$).

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Organic fertilization generated 4.2 times more yield compared to the control, 2.8 times more than combined fertilization and 2.2 times more than mineral fertilization. The higher yield of the organic source was attributed to the contribution of organic matter to the soil. This effect was reported in 'Golden Delicious' apple orchards, where the application of cow manure (30 Mg ha^{-1}) and chicken manure (15 Mg ha^{-1}) improved fruit weight and yield per hectare, which was associated with greater nutrient availability, better biological activity of soil microorganisms, and greater moisture retention (Amiri and Fallahi, 2009).

In addition to the contribution of nutrients, organic matter increases soil porosity, moisture retention capacity and aeration (Osman, 2013). On the other hand, when organic matter decomposes, it releases nutrients slowly and gradually, which ensures their availability to trees (Navarro and Navarro, 2003). In contrast, mineral fertilizers provide nutrients, but they can reduce the water potential of the soil due to the effect of salt concentration (Havlin *et al*., 2017), mainly in rainfed conditions, which negatively affects productivity.

The yields per tree recorded in the present experiment were lower than those published by Salazar-García *et al*. (2009), who reported 139.4 kg tree^{-1} with mineral fertilizer for the normal dose (calculated with the site-specific fertilization method) and 149.9 kg tree^{-1} for the high dose (1.5 times the normal dose) in trees 10 to 12 years old. The calculated yield (Mg ha^{-1}) per treatment was as follows: control 1.4, organic 5.9, mineral 2.7 and combined 2.6.

These results contrast markedly with the yield of 26 to 32 Mg ha^{-1} obtained by Salazar-García and Lazcano-Ferrat (2003) in 14-year-old trees after applying an optimized fertilization plan in rainfed orchards in Nayarit. The scarcity of rainwater or irrigation water is a limiting factor for productivity in rainfed plantations, where water availability depends solely on rainfall (Haberman *et al*., 2019) both to achieve a market size and a number of fruits per tree that is commercially attractive.

The fruit shape index showed a difference between treatments ($p < 0.001$). The maximum value (0.72) was obtained with mineral fertilization; that is, fruits with a round shape. In contrast, the average of the rest of the treatments was 0.69 (more elongated fruits). For 'Hass' avocado, Herrera-González *et al*. (2017) have reported a shape index of 0.73. Authors such as Salazar-García *et al*. (2016) obtained a shape index of 0.69 for fruits produced in Jalisco, Michoacán, and Nayarit.

Postharvest behavior

Dry matter

The dry matter content of the fruits was not affected by the fertilization treatments; the average of the treatments was 23.3%. Guzmán-Maldonado *et al*. (2017) report values of 22-24% (Nayarit) and 26-31% (Jalisco). For their part, in Michoacán, Rosas-Flores *et al*. (2016) report values of 24.3%.

Weight loss

Regarding the weight loss of the fruits, at the end of the ripening period, no difference was observed between the treatments; the average value of the treatments was 9%. Rosas-Flores *et al*. (2016) reported weight losses of 10.4% in 'Hass' avocado fruits stored at 20 °C and 55% RH for 11 days. On the other hand, Herrera-González *et al*. (2017) calculated 8.3% in fruits stored at 22 °C and 85% RH for 10 days.

Firmness

In all treatments, the initial firmness was greater than 90 N and when the fruits reached the maturity of consumption, it decreased to less than 10 N. At consumption maturity, the fruits of mineral fertilization were superior to the fruits of the control (Figure 1). In this regard, Barrientos-Priego *et al*. (2016) observed that 'Hass' avocado fruits with a Ca concentration of 0.81 and 0.85% in the mesocarp showed greater firmness on the sixth day of the ripening period under environmental conditions compared to the control, the concentration of which was 0.78%.

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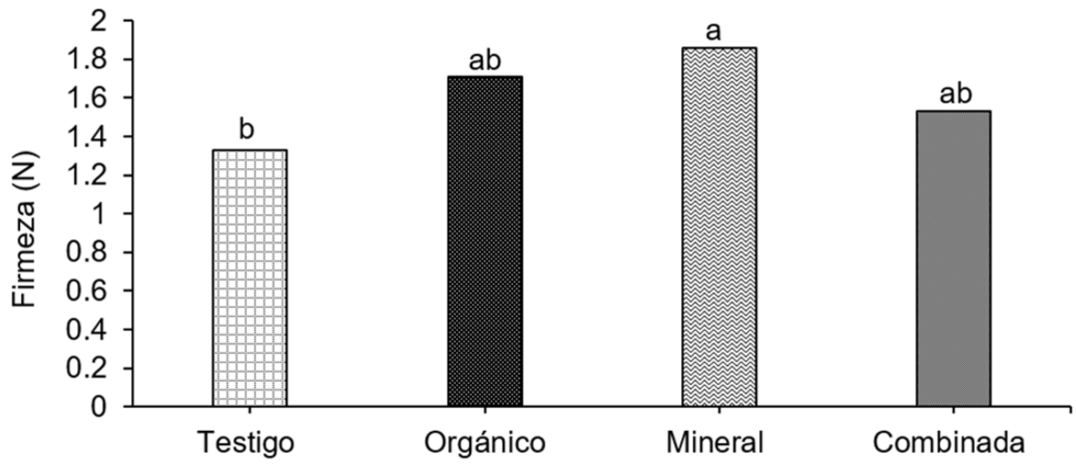
Figure 1. Firmness of 'Hass' avocado fruits after 9 days of ripening at 22 °C and 90% relative humidity.



The trees in the control treatment did not receive Ca, only N, which explains the lower firmness. In addition, nitrogen negatively affects the consistency of fruits. Nava *et al*. (2008) observed an exponential decrease in the firmness of 'Fuji' apple fruits with the application of N in the form of urea.

Color

Mesocarp color

The development of the mesocarp color was the typical of the cultivar in all treatments; no darkening problems were observed, and no differences were observed in hue angle and chroma.

Exocarp color

At maturity of consumption, the fruits that received mineral and organic fertilization presented higher values in hue angle, which corresponds to a green color with a tendency to blue compared to the rest of the treatments (Figure 2).

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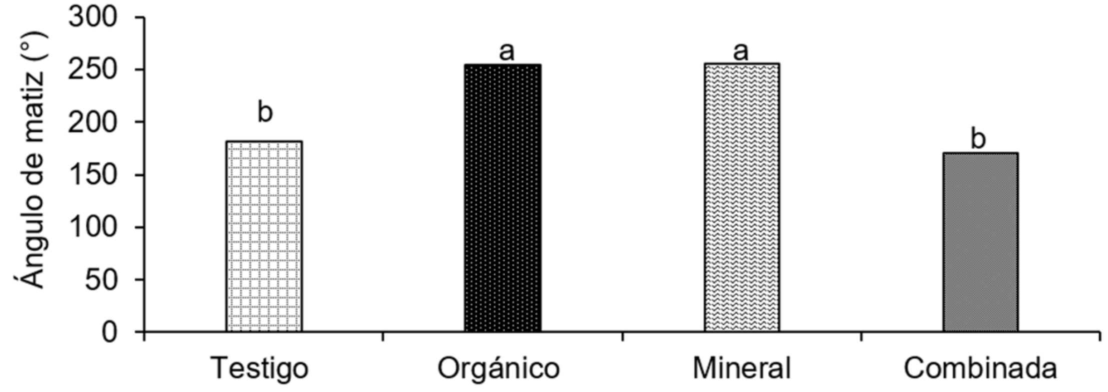
Figure 2. Hue angle (°) in the exocarp of 'Hass' avocado fruits after nine days of ripening at 22 °C and 90 relative humidity.

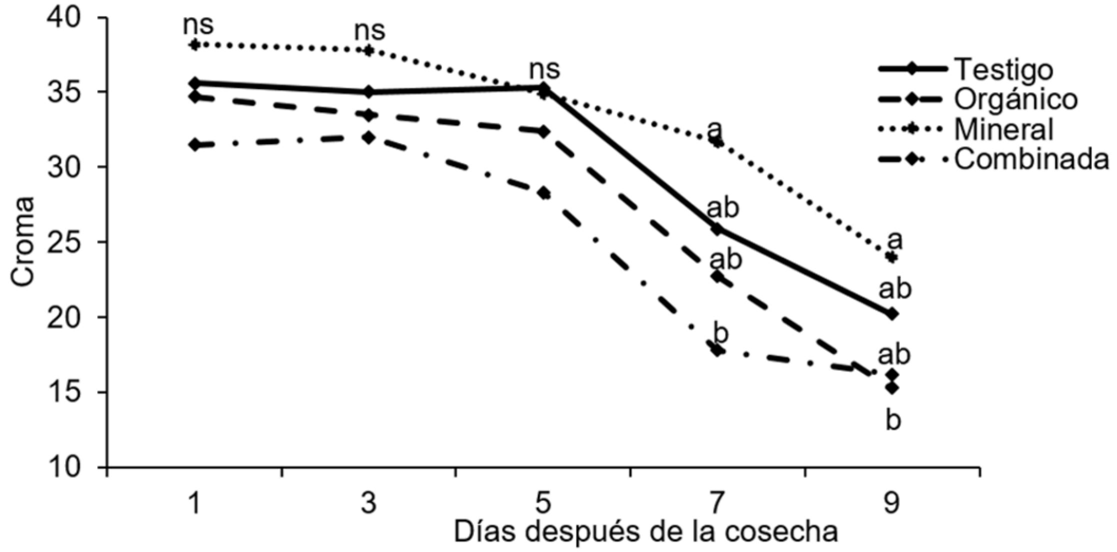


On the contrary, the fruits of the control treatment and the combined fertilization maintained a green coloration, which is associated with a higher chlorophyll content. Cox *et al*. (2003) indicate that, during the ripening of 'Hass' avocado fruits, the hue angle decreases from 120° to 60°, which corresponds to a change of color from green to orange or reddish. This allows us to infer that the mineral and organic source favors the production of fruits with a higher anthocyanin content in the exocarp (Ashton *et al*., 2006).

Chroma

The intensity of the color decreased as the ripening process progressed, but the differences between the treatments were observed on the seventh and ninth day after harvest (Figure 3).

Figure 3. Evolution of exocarp chroma in 'Hass' avocado fruits during the ripening period at 22 °C and 90% relative humidity.



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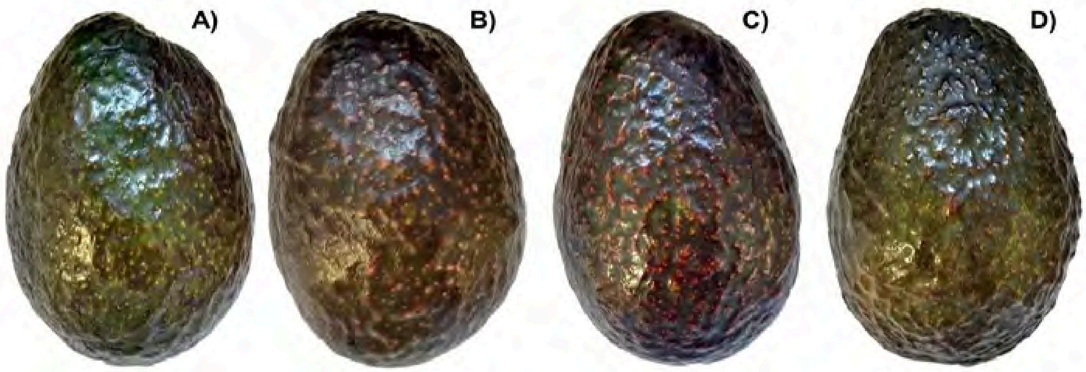
The fruits of trees that received only mineral fertilizer developed greater color intensity (Figure 4). In the works of Cox *et al*. (2003); Ashton *et al*. (2006), it is reported that during the maturation process, chroma values decrease. This implies a loss in the intensity of the color as the ripening process increases.

Figure 4. Exocarp color of 'Hass' avocado fruits after nine days of ripening at 22 °C and 90% relative humidity. A) control; B) organic; C) mineral and D) combined.



Lightness (L)

At the time of harvest, the lightness of the fruits of the trees treated with mineral fertilization was higher than the fruits that received the combined source (Figure 5A). Nevertheless, at maturity of consumption, the fruits of the control showed greater lightness than the avocados of the organic treatment (Figure 5B). Ashton *et al*. (2006) observed a decrease in L values in 'Hass' avocados as the ripening process progresses.

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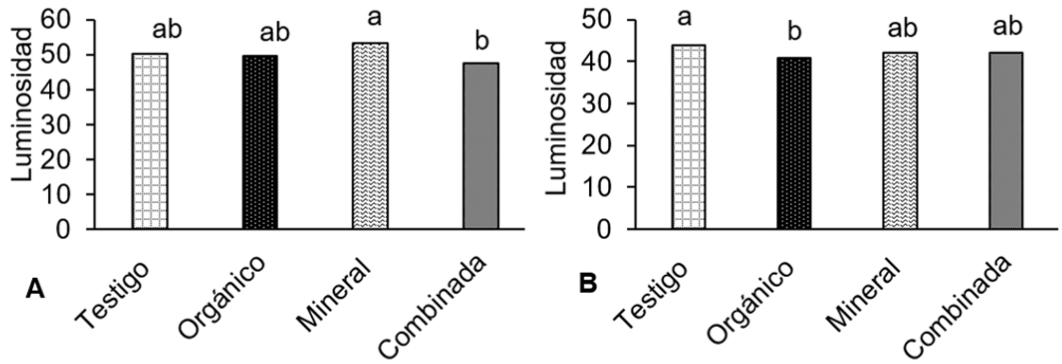
Figure 5. Lightness of the 'Hass' avocado exocarp during ripening at 22 °C and 90% relative humidity. A) At the time of harvest and B) After nine days.



Conclusions

The source of fertilizer affected the yield and quality of the fruits; the application of organic fertilizer resulted in a bigger number of fruits and more yield per tree, and the mineral source resulted in fruits with greater firmness at maturity of consumption, which prolonged their shelf life. In general, the fruits obtained from mineral and organic fertilization developed better external color.

The fertilizer source did not affect the dry matter content, weight loss, and mesocarp color. In conclusion, the application of organic fertilizer improved yield, whereas with the mineral source, the fruits were superior in quality and postharvest behavior.

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