/ Dr. Oded Achilea

A. Some botanical facts

The avocado plant ***Persea Americana*** (Spanish: Aguacate & Palta) is a large and ever-green tree, belonging to the *Lauraceae* botanical family. Some other important crops included in this family are the aromatic species Laurel and Cinnamon. Originating in Central America and Mexico, it is relatively a newcomer to the horticultural industry, as it was only in the early 1900s that avocado trees were grafted and planted commercially.

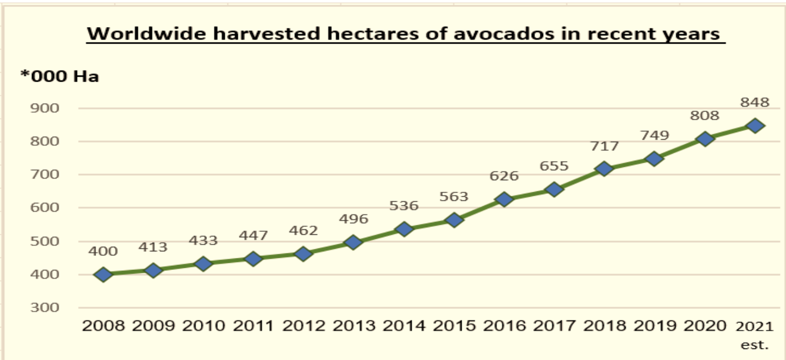
There are 3 distinct types:
Mexican: Suitable for a rather dry and cool Mediterranean and subtropical climates. Very sensitive to salinity. The fruit is small, with thin skin and short postharvest life.
West Indian: Suitable for humid and warm tropical climates, markedly less sensitive to salinity. The fruit is very large, but usually- of inferior quality and short postharvest life.
Guatemalan: Ideal for subtropical climatic conditions. The fruit is medium to large-sized, with thick skin, and has best postharvest characteristics.
There are also interracial hybrids.

Figure 1. **The fruits of some commercially important avocado cultivars**

'Hass'	*'Fuerte'*	*'Reed'*	*'Wilson Popenoe'*	*Parthenocarpic (seedless) 'Fuerte'*
				

B. A crop of continuously developing worldwide demand

Figure 2. The harvested area of avocados is steadily increasing since 2008. (Reference: Statista, 2022)



The apparent reason for this global trend is the increased awareness to the fruit's health values, and the growth of global sector of people that are ready to pay a premium for consuming it.

C. Fruit characteristics

The prominent health qualities of the avocado fruit are its high oil content, (up to 18% w/w), and the uniquely high share (88%) of unsaturated fatty acids in total fats. The fruit's oil concentration increases continuously during fruit maturation until harvest. The fruit is ready to eat only after a softening process, which starts after being harvested. Some other very important health values of the avocado fruit, driving its consumers popularity, are its high contents of dietary fibers, potassium, several vitamin-B group members, and folic acid. Same as all vegetal produce, avocado fruits have no cholesterol, whatsoever. Moreover, regular consumption of avocados, helps lowering a person's LDL ("*bad*") cholesterol.

D. Optimal growth conditions

Avocado trees grow well over a wide range of soil textures, given imperatively that they are well-drained, not compacted, and well- aerated. Under low rainfall conditions, 40-100 cm deep soil profile is sufficient, but under extensive rainfalls, well-drained soil, at least 1.5 m deep, and planting on 30-50 cm high hills, is recommended. High organic matter is favorable. Waterlogged soils frequently host a serious soil-borne root-rot disease, provoked by the fungus *Phytophthora cinnamomi*. Planting new plots near areas with history of this fungus must be avoided.

E. Roots nature and water management

Avocados are surface-rooting trees. Their fine fibrous rootlets, which absorb water, minerals and air, are distributed as follows: 60% in the top 7.5cm, and 90% in the top 15cm. Unlike many other plants, avocado roots are not equipped with ultra-fine root hairs. Therefore, they feature rather inefficient water sourcing capacity, resulting in hyper-sensitivity to drought. The roots function best, when protected by a heavy undisturbed mulch of dry tree leaves, and are kept reasonably moist. Additionally, avocados have only limited control over their transpirational water loss. Both these attributes make it a HIGH water-consuming crop. Mature avocado trees need annual 1000-1250 mm of rainfall or irrigation. They need at least weekly 25 mm of water, which should be supplied by rainfall or irrigation. But young trees need more frequent watering. Avocado trees are specifically sensitivity to heat and drought during flowering and fruit-set. Such stresses may decimate fruits number.

F. Soil and watering chemistry (Reference: Bender, 2016)

- ✓ Optimum soil pH is at 5.5–7.0.
- ✓ The higher the EC (electrical conductivity, expressing the concentration of soluble salts), of the irrigation water, above 0.3 dS/m, the worse will the avocado tree perform, in terms of fruit yield and quality. But the trees can tolerate soil solution EC<0.7 dS/m. Chloride anion (Cl^-) is specifically toxic to avocados, hence its concentration in the irrigation water must be <150 ppm. Yield loss of 12% incurs for every 35.5 ppm chloride in the irrigation water. Salinity stress shows as leaf-tip chlorosis and necrosis, stunted growth and deformed fruits. If low salinity and chloride conditions can't be met, special management practices must be employed, as follows:

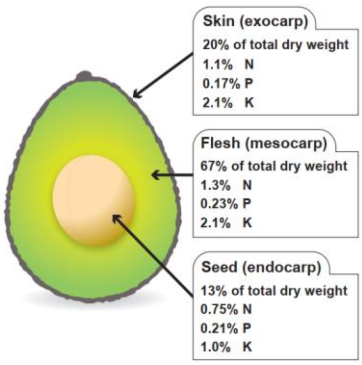
Photo 1. Avocado leaves showing excessive salinity/ chloride

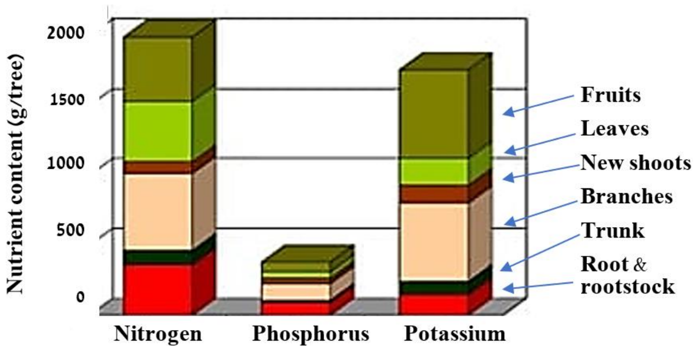
- ❖ As West-Indian varieties are more salt-tolerant than Mexican ones, the former ones are advantageous. It is common, therefore, to plant a Mexican variety that is grafted onto a West-Indian rootstock.
- ❖ 10-20% over-dosed irrigation should be applied, to leach the salts to underneath the soil layer of main roots system.

G. Central role of the mineral nutrition

The maximum attainable yield of a certain plot can be reached, depending on appropriate management of the trees, including pruning, adequate weed-, pests- and disease- control, and efficient cross pollination. But even more so- on the availability of nutrients to the trees. Avocado trees need to be continuously supplied with mineral nutrients, in order to maintain their vegetative and reproductive growth, as well as, to compensate for the nutrients exported from the soil in the form of harvested fruits. Naturally, the soil properties strongly affect the availability of the applied nutrients to the crop.

Figure 3. Distribution of N-P-K in the main parts of '*Hass*' avocado fruit (left) and in the tree (right).
References: Rosecrance, 2012, and others.





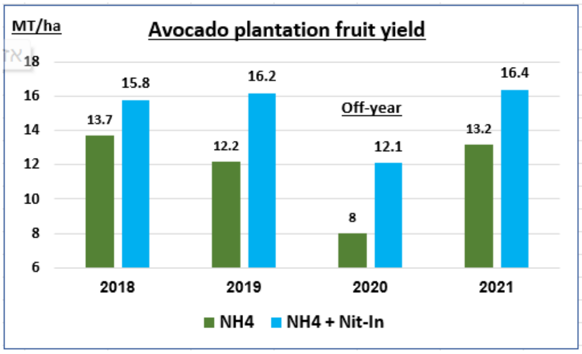
Nitrogen

Nitrogen is a central ingredient in the structure of all amino acids, which form all structural (protoplasm) and functional (enzymes) proteins, found in all living cells. N is a dominant part also in the chemical structure of chlorophyll and nucleic acids, as well as in secondary metabolites and precursors of plant hormones. Abundant supply of nitrogen is, therefore, a prerequisite for active vegetative growth, which, in turn, serves as the basis for bountiful flowering, fruit-set, fruit growth and bulking up. Nitrogen is generally applied through the irrigation system in a method called fertigation, by means of a fertilizer injector, that injects small amounts of a concentrated nitrogen solution into the irrigation system.

Nitrogen source for Avocadoes

Nitrate nitrogen (NO_3^-) is very mobile in the soil, and moves easily with water to the roots, where uptake occurs, but it can also be easily leached below the rootzone, and lost to the groundwater, thereby contaminating it. Ammoniacal nitrogen (NH_4^+), however, thanks to its positive charge, tends to bind to the surface of soil's clay particles, and to organic matter, and is hardly taken up by plant roots, until it is converted to nitrate by soil bacteria, in a process called nitrification. Nitrification of ammonium cations gives rise to the production of hydrogen cations (H^+), which slightly acidity of the soil. Nitrification process is temperature-dependent, e.g., at 10°C ammonium nitrification can be completed after some 85 days, but at 25°C it will be completed in 7-14 days. Therefore, nitrate acts like a quick-release fertilizer, for immediate use by the plant, while ammonium nitrogen acts like slow-release fertilizers, available to feed the plant for a longer period of time. Moreover, the addition of a nitrification inhibitor to ammonium-N fertilizers, considerably slows the nitrification process and maintains the nutritive effect for extended period of time. Urea is a nitrogen-rich fertilizer (usually 46% N) and is one of the cheapest forms of nitrogen in the market. Having no electrical charge, it can move through the soil with the irrigation water, but will be quickly converted to ammonium ions in the presence of moisture. These characteristics make it a popular, inexpensive N source in agriculture and horticulture. An N nutrition experiment in avocado plantation, held recently in Israel, demonstrated the advantage of adding a nitrification inhibitor to an N-ammonium fertilizer. The figure 4 shows a consistent yield advantage of +15.3%, +32.8%, +51% and +24%, of the treatment that supplied the ammonium nitrogen together with a nitrification inhibitor, during four successive years, that included also one off-year.

Figure 4. The advantage of accompanying ammonium nitrogen with a nitrification inhibitor, for '*Hass*' avocado yield. Reference: ICL, Nachshonim, 2021.

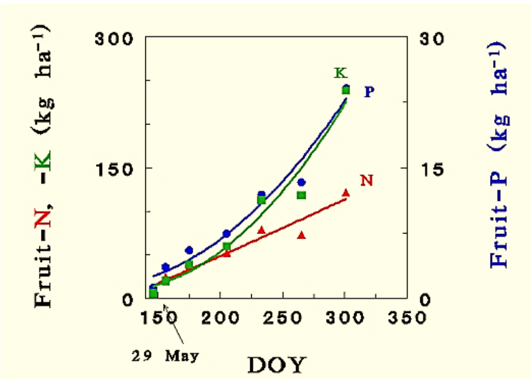


The additional side-effects of combining the nitrification inhibitor were a 28% increase in the share of large (more profitable) fruit size, a considerable increase of nitrogen and manganese and a slight increase of phosphorus in leaf analysis.

Potassium

The potassic cation, K^+, is the main cation that mobilizes anionic amino-acids, fatty acids and sugars, within the plant, from their source, in the leaves, to their sinks in the developing buds, inflorescence, developing fruits, and the root system, feeding them with carbohydrates and amino-acids.
Adequate K content in the avocado fruit is essential for high internal quality during its postharvest life. The balance between the concentrations of K^+, Ca^{2+} and Mg^{2+} is crucial for determining the mesocarp's (pulp) optimal color. By contrast, high (Ca+Mg)/K ratio, was found to greatly increase mesocarp browning of '*Hass*' fruits, due to excessive activity of polyphenol oxidase. K-deficient fruits lose their aesthetic characteristics by discoloration of their vascular system.

Figure 5. Dynamics of N, P, K accumulation by '*Hass*' avocado fruit yield of 30 MT/ha. Reference: Silber, 2018.



(DOY is day of the year, whereby day 150 represents fruit-set stage, while day 320 represents harvest-time at mid-November. Please note that P uptake values are one order of magnitude lower than those of N & K).

Phosphorus

Phosphorus is required for development & stimulation of root growth of young trees. Phosphate is very important in the plant's energy transfer, cell division, photosynthesis, sugar and starch formation. Although being required at relatively very small rates, it should not be ignored, because long-term zero P application can result in gradual crop diminishment.

Table 1. **Nutrients removal by 10 MT of avocado fruit** (calculated on fresh weight basis).
References: Mejía-Jaramillo, 2023; Salazar-Garcia, 2001; http://npk.nrcs.usda.gov; Cutting. 2000. Tamayo, 2018.

Nutrient	Kg		**Nutrient**	g
N	15-26		**B**	2-40
P	2.1-3.8		**Cu**	0.3-11
K	25-35		**Fe**	4.7-212
S	1.3-1.18		**Mn**	0.1-13
Ca	2.0-5.6		**Zn**	1-45
Mg	1.5-2.4			

The NUE (nutrient efficiency value, i.e. nutrient quantity removed by the plant, divided by nutrient applied by fertigation) are 40-50% for N and K, and 20-30% for P (Haneklaus and Schnug 2016; Johnston, 2000). **Considering these NUE values, the annual quantities of N, P & K required for attaining 30 MT/ha of 'Hass' avocado fruit are 250-300, 80-120 and 500-600 kg/ha, respectively**, Reference: Silber, 2018. A comprehensive Nutrient Removal Calculator for '*Hass*' Avocado, in California, is found at: http://www.avocadosource.com/. Reference: Hofshi. 2012.

H. Practical conclusions

Avocado fruits accumulate their nutrients between fruit-set and harvest time. Trees' demand of nutrients during this lengthy period should be satisfied by timely fertilizer applications. To avoid soil depletion, fertilizer applications must, at least, replace the nutrients removed by the fruits. Therefore, the actual values of a specific plot should be compared and verified to the nutrients removal rates, shown on the table 1, and applied accordingly.

N fertilization in Northern Hemisphere's April is critical for fruit-set of the new crop. It enhances fruit growth in terms of individual size and total yield, and reduces the severity of alternate-bearing. April N fertilization also supports growth of the vegetative shoot flushes.

Most **N**, **P**, **Mg**, **S**, **Fe**, and **Zn** should be applied during the Spring, as of full bloom, Summer and Fall seasons. This practice supplies nutrients to the recently pollinated flowers, as well as to the maturing fruits.

K and **B** are accumulated rapidly during the bulking up stage, during Summer and Fall. Therefore, their application rate should depend on fruit load of the maturing fruits.

Ca: Since most of the Ca gets accumulated during Spring and Summer, an abundant supply must be available during these seasons.

N Fertilization of young trees

Young trees are usually fertilized every 4–6 weeks, during the growth season (March–October). Dry or liquid fertilizers can be used. See table 2 for recommended N rates. When mulch is used initially, it may tie up some of the N, so a little extra should be added, to compensate for this loss. As irrigation water can carry nitrogen at considerably rates, water nitrate concentration should be measured, and be considered as part of the total application rate. It is important not to overfertilize, as this can cause root damage. This is why neither manures nor soluble fertilizers should be placed in the planting hole.

Table 2. **Annual N application rates to young avocados, assuming 8 equal monthly applications, during Spring & Summer.**

Tree age (years)	Annual rate of N (g/tree)		Tree age (years)	Annual rate of N (g/tree)
1	48		4	240
2	96		5	476
3	165		6 – 10	717

The fertilizer should be preferably applied by fertigation by mini-sprinklers or by drip irrigation, or applied under the plant canopy, in granular or crystalline formulation, and worked into the soil by irrigation.

N Fertilization of bearing trees (References: Rosecrance, 2012; Mejía-Jaramillo, 2023, Tamayo, 2018)

Avocados remove nitrogen at about 1.5-2.6 kg/1,000 kg of harvested fruit. Nitrogen is taken up by the roots mainly in the nitrate form (NO_3^-), and, somewhat- in ammonium form (NH_4^+). It is a definite fact that no significant increase in total yield can be achieved by increasing the nitrogen status of '*Hass*' tree leaves above 2.0% (see table 3). Avocados are alternate bearing trees, so, applying N, based on an average yield, or on the yield of the previous year's crop, may overstimulate vegetative growth in "off" years, and provide insufficient N in "on" years. So, it's recommended to adjust the N application rate to the upcoming year's on/off prospects, determined after natural fruitlets' drop. Additionally, the N required for canopy growth depends on the crop load, as well as on the size and age of the trees.

Integrated fertilization recommendations

Some common compound fertilizer analysis, for bearing avocados are 18-18-18 (N-P_2O_5-K_2O) for early spring stage; 28-10-10 for vegetative and initial fruitlets growth stage; 17-9-27 for advanced fruitlets growth stage; and 15-5-35 for Summer to Autumn (fruit bulking up) stage. See table 3 for further details. Light-textured soils command the inclusion of micro-nutrients in the applied fertilizers. The optimal way of applying fertilizers in avocado plantations is to inject the fertilizer solution into the irrigation system, by a fertigation device. Hence, applying liquid fertilizers enables ease of application, saving on mechanical distribution labor costs, prevents soil compaction by tractor maneuvers, and delivers the nutrients directly to the tree roots. Applying small rates during the entire irrigation season improves nitrogen use efficiency, and markedly reduces the risk of losing N by volatilization, when it is applied in ammonium or amide form. Fertigation is highly efficient on slopy terrains.

As the aforementioned fertilizers contains nitrogen in the forms of nitrate and ammonium (or urea), specific attention must be paid to avoid nitrate and urea leaching to beneath the trees' shallow root system. This suggests injection of the fertilizer solution at the third part of the irrigation session, hence, avoiding excessive irrigation volume. The annual rates mentioned in table 3 should be divided into 52 weekly annual applications, with special focus on Spring-time applications.

We encourage you, the grower, or your consultant, to get the optimal final fertilization recommendations, adapted to the actual growth conditions from **Gat fertilizers**. It is recommended to apply the fertilizers by fertigation in every irrigation session, at least once a week. The recommendations are mentioned as kg/ha/week.

Please consult Gat-Fertilizers' agronomist, for optimizing the fertilization regime to your local specific conditions, and for adjusting the regime to the expected on/off bearing year.

Table 3. **Detailed nutrients application rates by phenological stages of fruit-bearing Hass avocado plantations**

Growth conditions: Mexico, States of Michoacan & Jalisco.

Soil: Volcanic origin with 6-7.5 pH values.

Temperature range: 15 – 25 °C

Cultivar: Hass.

Yield: 25 MT/ha.

Fertilization using low-chloride fertilizers applied by fertigation, via micro-irrigation.

Phenological Stages:	Stage duration (days)	Macro-nutrients (kg/ha/stage)			Secondary-nutrients (kg/ha/stage)			Micro-nutrients (kg/ha/stage)						Irrigation	
		N (total)	P_2O_5	K_2O	CaO	MgO	SO_4	Fe	Mn	Zn	Cu	Mo	B	Interval (days)	Rate (m^3/ha/day)
Flowering initiation	60	25	55	62	0	0	0	0.01	0.003	0	0	0	0	1	3
Fruitlet: ~5mm	60	33	0	0	0	0	0	0.09	0.043	0	0.003	0.002	0	1	3
Fruitlet: ~12 mm	30	21	50	66	0	0	0	0.12	0.058	0	0.004	0.003	0	1	4
Fruitlet: ~35 mm	30	26	0	0	0	0	0	0.13	0.065	0	0.005	0.003	0	1	4
Fruitlet: ~60 mm	30	23	40	72	0	0	0	0.09	0.045	0	0.003	0.002	0	1	4
Fruitlet: ~3/4 of final size	30	26	0	0	48	13	7.5	0	0	0	0	0	0	1	4
Total	**240**	**154**	**145**	**200**	**48**	**13**	**7.5**	**0.44**	**0.214**	**0**	**0.015**	**0.010**	**0**		

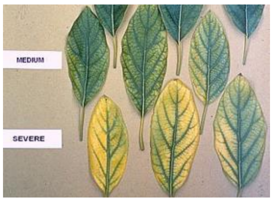
I. Controlling nutrient deficiencies

All plants show their nutritional condition by the look of their leaves, and the educated grower should pay attention to these symptoms, interpret them correctly and control the problem accordingly. Following, please find some clear symptoms of mineral nutrient deficiencies expressed by avocado trees.

Figure 6. **Symptoms of mineral nutrient deficiencies expressed by avocado trees.**

Nitrogen (N)	Phosphorus (P)	Potassium (K)	Sulphur (S)

References: Queensland Government, 2001; Bender, 2016.; https://growabundant.com/

Magnesium (Mg)	Iron (Fe)	Zinc (Zn)	Boron (B)
			
References: Queensland Government, 2001; Bender, 2016.; https://growabundant.com/			

An important additional tool to control nutritional deficiencies, is performing regular leaf analyses.

(Sampling procedure: Leaf samples (~40 leaves per a homogenous block) are taken during late-August – October, from 5-7-month-old spring-flush leaves, 5th or 6th leaf, from the flush tip, on non-fruiting branches).

Reference: Bender, 2016; Joubert, 2016; Bingham & Fenn, 1966.

Leaf nutrient levels (in dry matter) for fruit-bearing *'Hass'* avocado trees

Status / Nutrient	**N** (%)	**P** (%)	**K** (%)	**Ca** (%)	**Mg** (%)	**S** (%)
Deficient	≤0.14	≤0.05	≤0.35	≤0.5	≤0.15	≤0.05
Adequate	2.0-2.2	0.1-0.25	0.75-2.0	1.0-3.0	0.25-0.8	0.2-0.6
High	2.2-2.7	0.26–0.3	≥2.1	≥3.1	≥0.9	≥0.7

Status / Nutrient	**B** (ppm)	**Cu** (ppm)	**Fe** (ppm)	**Mn** (ppm)	**Zn** (ppm)	**Cl** (ppm)	**Na** (ppm)
Adequate	50-100	5-15	50-200	30-500	30-150	≤25	100
Excess **Toxic**	100-250	25	300	1,000	300	**≥2,000**	**≥2500**

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