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Avocado Fertilisation

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1. Introduction

The avocado is a relatively new crop in areas of the world outside its native range in the American tropics. Its total production, 93% of which is from the Western Hemisphere, was estimated (in 1976) to be close to 1 million metric tons and is thus less than that of grapes, citrus, bananas, apples, and even of mangoes and pineapples. It has proved to be a profitable commercial crop, both for local sale and for export. Its importance, as expressed in the establishment of avocado industries, is steadily increasing (Table 1). The main countries of commercial avocado industry are Mexico, the U.S.A., South Africa and Israel.

The avocado, *Persea americana* Mill., belongs to the family Lauraceae. It has developed three horticultural races (West Indian, Guatemalan and Mexican), which are adaptable to a wide range of soil and climatic conditions.

2. Climatic requirements

The avocado is a subtropical evergreen tree which is never dormant, although its activity is reduced during the winter as compared with spring and summer. Temperatures at, or somewhat below, freezing point harm the fruit, buds and foliage of young trees. Temperature below freezing for only a few hours, can cause serious injury to mature trees. Of the three horticultural races, the West Indian is most susceptible to low temperatures while the Mexican race is the most cold hardy. It is preferable to plant trees in frost-free areas, such as on slopes with good air drainage.

3. Soil requirements

Avocado trees can be planted on a great variety of soils, ranging from light to heavy. However, to ensure a suitable soil type the following conditions should be considered.

3.1 Aeration

Avocado roots are particularly sensitive to poor aeration. It is not recommended to plant on excessively heavy, compact soils, with poor permeability. It is desirable to carry out field and laboratory tests to determine the

Table 1: *Avocado growing by country, cultivated area and production in 1976* (based on *Gustafson [18]*)

	Cultivated area (ha)			
	Bearing	Non-bearing	Total	Production (metric tons)
North America				
California	10 282	5 182	15 464	91 000
Florida	2 240	912	3 152	28 000
South America				
Argentine	600	600	1 200	9 000
Brazil	—	—	17 000	110 000
Chile	4 000	2 000	6 000	21 000
Columbia	—	—	—	70 000
Ecuador	—	—	5 248	32 000
Paraguay	—	—	—	21 000
Peru	3 500	300	3 800	26 000
Venezuela	—	—	12 240	56 000
Central America and Caribbean Islands				
Costa Rica	—	—	—	21 000
Cuba	—	—	—	21 000
Dominican Republic	—	—	—	21 000
El Salvador	—	—	—	28 000
Guatemala	—	—	—	23 000
Haiti	—	—	—	9 000
Honduras	—	—	—	6 000
Jamaica	—	—	—	3 000
Martinique	700	1 500	2 200	4 000
Mexico	37 453	13 981	51 434	276 000
Panama	—	—	—	2 000
Puerto Rico	—	—	—	5 000
St. Lucia	70	52	122	312
Africa				
Cameroon	—	—	130	363
Egypt	20	20	40	181
Kenya	—	—	40	318
South Africa	4 735	2 000	6 734	16 000
Zaire	—	—	—	10 000
Mediterranean Region				
Cyprus	4	32	36	1
Israel	2 500	2 500	5 000	24 000
Spain (incl.. Canaries)	160	280	440	1 300
Australia	414	297	711	445
New Zeeland	—	—	40	—
Philippines	—	—	5 210	21 000

The avocado is grown also in: Hawaii, Texas, Nicaragua, Guadeloupe, Trinidad, Greece, Morocco, Tunisia, Algeria, Ghana, Ivory Coast, Mozambique, Malagasy Republic, Malaysia and Indonesia.

suitability of the area for planting. Important parameters to be considered are: clay percentage, structure of soil profile, free pores at field capacity, and drainage of water under field conditions. In marginal cases, and in areas distinguished by heavy precipitation, it is advisable to plant on ridges, to allow draining of excess water.

3.2 Lime

It is customary to determine total lime in the soil, although some prefer the determination of «active lime». Avocado trees show considerable variation in their tolerance to lime, in conjunction with the size of lime particles. It appears that the larger the lime particles, the greater the tree's tolerance to lime. As a general guide line, the maximum total soil lime content for the Guatemalan rootstock (*cv.* Nabal) is estimated at 4—5%, for the Mexican rootstock at 20—25%, and some West Indian stocks can withstand even above 40%.

4. Water requirements

4.1 Irrigation

During the early growing years and in its bearing stage, the avocado is most sensitive to the amount of water in the soil. Great attention is therefore paid to the irrigation regime in relation to tree development and fertility. Irrigation planning is also closely connected with mineral nutrition. An irrigation experiment carried out in Israel *[30]* showed that on heavy soils, longer irrigation intervals combined with smaller water allocations, slowed down the rates of development of trunk and canopy. Nevertheless, the drop in yield remained insignificant, even with irrigation intervals of 21 days. Sprinkling and trickle irrigation are the main methods practised.

4.2 Salinity of irrigation water

is an important factor. Irrigation water containing above 120—150 ppm Cl generally causes leaf burn, often in severe form, along margins and tips of blades *(Figure 4)* on trees grafted on Mexican rootstocks. However, no signs of damage are found on trees grafted on some West Indian stocks even when the water contains 230—300 ppm Cl *[24]*. It should not be overlooked that salts which accumulate in the soil during the irrigation season can be partially leached with water allocations increased by 25—35 %, provided good drainage conditions prevail. According to *Bernstein [2],* Mexican root-stocks can be used with Cl concentration of up to 5 me/1. The salt tolerance of selected West Indian rootstocks seems to be higher than 10 me/1 *[24]*.

5. Avocado nutrition and fertilizer requirements

The avocado tree is known for its superficial root system, a fact to be considered in agricultural practices such as irrigation, cultivation and fertilization. The use of inorganic sources of fertilizer materials is practised trough-out most of the avocado-growing countries, but it is not always based on experimental data. The demand for mineral nutrition is higher in places where the avocado is grown on shallow, light or rocky soils, as in Florida. Differences exist in the results of fertilizer experiments carried out in different parts of the world. In some places a marked increase in tree growth was found after fertilization, while in others no response was observed. In most places no relationship was found between the level of most nutrients in the leaves, and yields *[1, 36, 43]*. Moreover, it seems that the great variability among trees in the same plot, causes a deviation of the average, resulting in an inaccurate sampling. In fact, the understanding of the difference between levels of elements in leaves of trees sampled in «on» years (heavy crop) and those sampled in «off» years, is still insufficient. The response of the tree to fertilization applied in an «off» year is likewise still unclear. Consequently, the effectiveness of the sampling method practiced at present for the determination of the nutritional status of the avocado is sometimes insufficient. However, in spite of its limitations, foliar analysis remains a useful auxiliary tool for fertilizer recommendations. These analyses enable one to uncover any extreme deficiency or excess which demands special fertilizer treatment.

5.1 Nitrogen

This element is considered to have a great influence on the growth of the avocado tree and is therefore commonly used. Nitrogen 'deficiency symptoms are expressed by restricted growth, pale, small-sized leaves, and early leaf shedding. In cases of acute lack of N, the veins turn yellow. In Florida yields were markedly decreased when trees were not fertilized for several years *[41]*. Research carried out in California *[9, 10, 12]* on N consumption of avocado trees over a five-year period, led to the conclusion that there is a curvilinear relationship between yield and N level in leaves. The optimal level for *cv.* Fuerte was found to be 1.6-2.0%, below and above which there was a decrease in yield. The upper level for *cv.* Hass was above 2.0 % N. On the other hand, results of work carried out in Israel *[43, 45, 46]* showed no clear relationship between yield and N level in leaves. Variable effects of N levels within and between cultivars, caused by different amounts of N in irrigation water, competition between vegetation cover in the plantation, and remnants of previous fertilizations - render fertilizer recommendations based on N quantities in the leaves difficult. It is impossible to understand the relationship between N fertilization, foliar analysis, and avocado yields without taking into consideration the carbohydrate reserves (no refernce)in the tree. In particular, one should keep in mind alternate bearing, in consequence of which N level in leaves is ascribed to yields of «on» or «off» years. In some cases the carbohydrate reserve in the trees is so low that it becomes a limiting factor in flowering and fruit setting. The factor accountable for the negative ratio of high N content to yield may possibly be related to growth substances regulated by factors responsible for carbohydrate reserves. Correlation between N levels in leaves and yields may in any event be influenced by other, more limiting factors. Until root systems of young plants are fully developed, no fertilization is necessary. Subsequently, to achieve speedy development of plants, abundant fertilization is essential, especially on light soils. The yearly amount to be applied in the first year is 30—40g N/tree, 80g in the second year, 160g in the third year, and 200g in the fourth year.

It is advisable to fertilize each cultivar selectively. Cultivars distinguished by high fertility require higher N applications prior to an «on» year, and lower amounts prior to an «off» year. The rates recommended in Israel for a plantation of bearing age are given in Table 2.

Table 2: Fertilizer recommendations for bearing avocado trees, based on percent nitrogen in leaves.

Cultivar	N in leaves (% of dry matter)	Recommended N application (kg/ha)
Ettinger and Fuerte	< 1.6	200
	1.6–2.0	100
	> 2.0	0
Nabal and Hass	< 1.8	250
	1.8–2.2	150
	> 2.2	0

The fertilizer can be divided into two parts, about a third to be applied in the early spring and the remainder in mid-summer. It should be noted that, because of flush and fruit-set competition, it is recommended to start N application after fruit-set. Fertilizers are generally not applied in winter. When the fertilizer is applied through the irrigation system, the summer application is divided into several portions. If irrigation is applied at frequent intervals by micro-jets or the drip method, it is advisable to subdivide the fertilizer into more numerous portions. In instances of suspected deficiency symptoms, such as pale leaves, N fertilizer is to be applied without delay, even when the most recent leaf analysis did not show a low N level. Nitrate level in the irrigation water must be considered when determining the amount of N fertilizer to be applied *[43]*. It is therefore advisable to include water analyses before making fertilizer recommendations.

5.2 **Phosphorus**

Symptoms of P deficiency in sand culture are expressed by decreased vegetative growth, small round leaves, early leaf shedding, and branch dieback. Leaves are brownish-green in color and burnt.

Avocado plantations have not shown any definite P deficiency symptoms. In cases of low P level in the leaves and its successful raising by fertilization, the effect on yield was nil. Still, the practice continues of supplying P fertilizer to avocado plantations growing on poor soil. It has been shown that excess amounts of P are likely to cause Zn deficiency symptoms *[9]*.

5.3 Potassium

Deficiency symptoms appeared, only after 8 years, in trees grown in sand culture and not receiving any K. The leaves were small and narrow. In autumn, brownish-red necrotic spots began to appear on older leaves, subsequently, the spots spread over the whole leaf blade between the large veins. On severely deficient trees, the twigs were very thin and some dieback occurred *[14]*. However, in another research work, deficiency symptoms began to appear on the leaf base and petiole and advanced through the central and secondary veins towards the tip *[6]*. It is of interest to note that intraveinal necrosis was also a symptom of KC1 excess *(Figure 1).* As with P, there have been no reports of K deficiency in avocado plantations. A survey conducted in Israel showed a relationship between K concentration in the leaves and soil type. On high-lime soils, K percentage was much lower than on other soils *[44]*. Reducing the K level in the leaf to 0.8 % in Florida, or increasing it from 0.9 to 1.3 % in an experiment conducted during

12 years in California, had no effect on yield *[9]*. Experiments in South Africa showed a slow response to K fertilization. Only after 8 years oí KC1 application was an increase in yields recorded. In fertilization experiments in Israel, KNO_3 increased K levels in the leaves on light soils only; tree growth, yields and fruit quality were all unaffected *[36]*. It is interesting to note that an increase in the rate of KNO_3 fertilization resulted in a slight decrease in fruit drop of *cv.* Hass following frosts *[36]*. Further research is needed to clarify the question of K effect on cold tolerance of the avocado tree. Potassium fertilization is recommended in Florida and in other areas where the avocado is grown on soils of volcanic origin. In Florida, KNO_3 is provided by soil or aerial application but more often KC1 or K_2SO_4 is being used.

5.4 Calcium

The symptoms of Ca deficiency in sand culture are scorched leaf tips and small-sized leaves. Calcium deficiency or excess in leaves may point to interference in uptake of other elements. However, no Ca deficiency has been reported in commercial plantations. Calcium deficiency symptoms are sometimes similar to those of *Phytophthora cinnamomi.* Both cause the root system to collapse and disintegrate *[16]*. However, in Ca deficiency the roots regenerate, whereas in the plants affected by *Phytophthora* root disintegration was followed by loss of leaf turgor, and a much faster dieback. In another work, the maintenance of high Ca levels in soils was supposed to reduce the severity of root rot by soil structure /5/.

5.5 Magnesium

Deficiency symptoms were reported as intra-veinal chlorosis in mature leaves which produces scorch of the leaf margins *[14, 48]*. In California a substantial application of dolomite to avocado trees (about 75 kg/tree) raised only very little the Mg content in leaves. Trees sprayed with a solution of $Mg(NO_3)_2$ hardly responded to treatment. A fertilization experiment carried out in Israel did not affect yields nor the amount of Mg in the leaves *[1]*. Magnesium fertilization is recommended in Florida with formulas of N-P_2O_5-K_2O-MgO in a 1-0-1-0.5 ratio *[40]* and in South Africa at 2.0 kg/ tree $MgSO_4$ *¡31]*.

5.6 Iron

Deficiency symptoms are distinct and widespread in most regions of the world where avocado is cultivated. Commonly, one finds deficiency symptoms

Fig. 1 Interveinal and marginal necrosis due to KCl excess, *cv.* Fuerte.

Fig. 2 Mottled leaves due to zinc deficiency, *cv.* Benik.

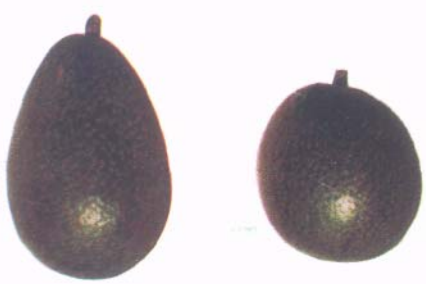

Fig. 3 Rounded fruit as a result of severe zinc deficiency. Normal fruit, left, *cv.* Ettinger.

also in locations where Fe is present, though in an unavailable form. Lack of Fe is associated mainly with calcareous soils. Often, deficiency is caused by inadequate aeration as a consequence of poor drainage or excess irrigation. Deficiency symptoms in leaves of the spring flush are expressed by inter-veinal yellowish color and narrow dark-green strips along the veins. With progressive deficiency, leaves of the summer flush become smaller, more delicate and, while young, have a pale yellow to white color. Later, severely chlorotic leaves show scorch symptoms at their tips and along margins and in extreme cases are shed. In extreme deficiency, desiccation of branches follows, and the fruit turns from dark green to a light color. In California, chlorosis occurred at a level of below 40 ppm Fe in mature leaves and at less than 30 ppm the trees were severely affected. Leaves of healthy trees sampled in spring or in autumn, contained above 50 ppm iron *[4, 44]*. Generally, there is no correlation between Fe content in leaves and Fe deficiency symptoms.

Chlorosis can sometimes be controlled by improving drainage and decreasing water duties, or by lowering soil temperature by means of mulching. Iron chelate is the best way of curing Fe-chlorosis of the avocado tree. Applications by foliar spray have not been successful *[28]*. This material contains Fe in an available form and therefore the response is immediate. The usual rate is 50-400 g of FeEDDHA per tree, depending on size, the degree of chlorosis and the soil type. Direct pressure injections of Fe-chelate solution into the trunk or main branches proved effective in attempts to save severely affected trees from complete decline. The cure is achieved within a few days *[27]*. Trickle irrigation is perhaps the most convenient and efficient way to apply FeEDDHA, because the material goes directly to the area where there is a proliferation of roots. With this method, the amount of FeEDDHA applied can be less than by other means.

5.7 Zinc

Zinc is considered an important element to the avocado tree. Symptoms of deficiency are observed in acid soils from which it is easily leached, and in calcareous soils in which it is fixed in unavailable forms. Early symptoms of deficiency are mottled, narrow, small leaves at the terminal branches, usually with a light green or chlorotic color *(Figure 2)*. Leaf margins are necrotic and internodes are shortened in advanced cases. In California, Fuerte trees affected by Zn deficiency bore small spherical fruits *(Figure 3)* instead of the normal pear-shaped fruit *[50]*. Surveys conducted in avocado orchards in California and Israel *[12, 32, 44]* showed that the critical level in the leaves is 20 ppm. In California, Florida and Israel, it is customary to treat avocado plantations suspected of Zn deficiency with Zn fertilizer. However, no beneficial effect was obtained when healthy trees were treated *[1, 29]*. *Gustafson [17]* showed that applications of $ZnSO_4$ to soil at rates of 1-5 kg/tree, depending on age, brought about an improvement in trees affected by zinc deficiency. Usually, $ZnSO_4$ is preferable to Zn-chelate. *Wallihan et al. [50]* found that addition of Zn-chelate to irrigation water applied to 6-year-old Fuerte trees at a rate of 0.5 kg per tree, alleviated Zn deficiency symptoms in fruits and leaves, and raised the Zn level in leaves from 15 to 50 ppm. The lasting effect continued for at least four years.

The value of aerial spraying of Zn-deficient avocado trees is questionable *[29]*. In Florida *[49]* and California *[39]* spraying with $ZnSO_4$was found to improve Zn-deficient trees. Experiments conducted in Israel with absorption of salts through foliage showed that the capacity of mature avocado leaves to absorb and transport salts is extremely limited. It is agreed, however, that better penetration occurs when the young flush is sprayed. The use of Zn spray on foliage is effective, if at all, only for a short period of time, apparently as a result of low penetration and of slow translocation from mature to younger leaves, which necessitates a repetition of the operation each season.

5.8 Manganese

The deficiency symptom in sand culture is intraveinal chlorosis, similar to that occurring in cases of Zn and Mg deficiency *[14]*. No Mn deficiency has been observed in commercial avocado plantations and no response to fertilizer treatment has been reported. Nevertheless, Mn application is recommended in Florida.

5.9 Copper

This element is reported to accumulate in toxic amounts after fungicidal sprays in Florida. High amounts of Cu have been found on the exterior surfaces of «Lula» avocado roots *[42]*. Earlier reports from Florida indicate dieback in avocado trees caused by Cu deficiency *[49]*

5.10 Boron

Symptoms of B deficiency in sand culture are short and thick branches and scorched leaf blade margins, followed by early leaf shedding. At a later

stage, internodes become very short and the leaves scale-like. Boron deficiency in avocado plantations is unknown in the U.S.A. and Israel. However, in South Africa, avocado trees deficient in B responded quickly to B application.
Symptoms of excess include scorching of the whole blade, especially at the margins. No damage has been observed in regular plantations, with the exception of a single experimental orchard in Florida when trees supplied with large amounts of borax had their boron level in the leaves raised to over 100 ppm. In general, avocado trees are much more resistant to excess of B than are citrus trees.

5.11 Chlorine

The avocado is particularly susceptible to an excess of Cl. Symptoms of Cl toxicity are expressed in leaf burn — tips and margins *(Figure 4)* — aggravated during the summer and autumn to the point of leaf shedding. There is a distinct correlation between the extent of the burn and the Cl concentration in the leaves *[22]*. Chlorine concentration in normal leaves was recorded by *Cooper and Gorton [7]* to be between 0.23 and 0.7 %, compared with the 0.22-1.48 % found in burnt leaves. In analysis carried out with leaves of various avocado rootstocks, above 2 % Cl was found in severely scorched leaves of Mexican stock *[22]*.
Observations in avocado orchards showed that hot, dry winds intensify leaf burn. Thus, results of experiments conducted with avocado plants under controlled conditions showed a positive correlation between increased transpiration and a higher rate of absorption and accumulation of Cl in leaves *[25¡*. An increased accumulation of Cl in leaves was observed also in a case of root injury by *P. cinnamomi [35]*, (see Table 5). Intensification of Cl damage is attributed among other factors to a rise in Cl concentration in the vicinity of the roots. Consequently, one should take care while irrigating with saline water to follow a procedure preventing accumulation of Cl in the root zone by rinsing the soil once every few irrigations with excess water, exceeding by 30-50 % the regular water duties allocated.

5.12 Sodium

The avocado is highly susceptible to Na excess, as expressed by interveinal necrotic spots, which spread with the increase in Na concentration in the leaves *(Figure 5)*. In the course of time, leaf buds are affected and

Fig. 4 Increasing degrees of tip and margin necrosis due to chlorine excess. Normal leaf, left.

Fig. 5 Interveinal necrotic spots due to sodium excess.

branches - young and mature - dry up to the point of complete degeneration *[23]*. Sodium, being adsorbed to the soil complex, is more difficult to leach than Cl. It is advisable, therefore, to avoid irrigation with water containing excessive Na concentration. In a series of experiments set up to test the behavior of various rootstocks under saline conditions, resistant stocks (West Indian) were found to prevent translocation of Na from roots to canopy, while susceptible ones (Mexican) translocated appreciable quantities *[25]*. It was likewise established that leaves of sensitive stocks, severely affected by excess Na, contained 1.0%> and more Na *versus* the 0.01-0.02% found normally *[23]*. In another research work, increased translocation from roots to leaves resulted from root injury by *Phytophthora cinnamomi [35]*.

5.13 Organic manure

Manuring practices are not based on any comparative tests. Even though some groves are treated regularly with manure, organic manure appears to be superfluous. When an orchard under cultivation was supplied with equal amounts of N by various kinds of fertilizers, it was found that organic manure and ammonium nitrate supplied N to the tree in equivalent amounts. However, when the organic manure was applied to the surface of the soil of an orchard under non-cultivation condition, its effect was less *[8]*. Thus, it would appear that part of the N was lost to the air while the manure decomposed on the soil surface. In some cases, organic manure can improve the tree growth and increase yields, but in other cases no response was found. A high level of organic matter in the soil is sometimes associated with low activity of *Phytophthora cinnamomi [5]*. It is accepted that the high content of P in chicken manure might give rise to Zn deficiency symptoms. It is therefore suggested that research on the effect of organic manure on the avocado tree should be expanded.

6. Nutrient removal by the crop

The relatively low demand of the avocado tree for nutrients is demonstrated by the tree's low removal of nutrients by the crop (Table 3). Compensation of N removal will demand fertilization of 55 kg/ha of $(NH_4)_2SO_4$ and K removal will be compensated by the addition of 33 kg/ha of KC1.

Table 3: Nutrients removed from an avocado plantation by the crop*

Nutrient	% of dry weight	kg/ha	Nutrient	ppm of dry weight	kg/ha
N	0.54	11.3	Na	400	0.8
P	0.08	1.7	B	19	0.04
K	0.93	19.5	Fe	42	0.09
Ca	0.10	2.1	Zn	18	0.04
Mg	0.24	5.0	Mn	9	0.02
Cl	0.07	1.5	Cu	5	0.01
S	0.30	8.0			

* Based on a yield of 10 t/ha.

7. Leaf analysis

Foliar analysis provides at present the basic knowledge concerning avocado nutrition. The main work in this field has been performed in California *19, 12, 33, 34]*, Florida *[20, 47]* and Israel *[44, 45, 46]*. Leaf sampling must be precise and uniform in order to ensure that only nutritional factors influence the composition of the leaves.

7.1 Factors influencing concentration of elements in leaves

Research done in various parts of the world has proved that many factors influence the concentration of elements in avocado leaves. The most important of them are: age of leaf, season of the year, position of the leaf on the tree, variety and rootstock, yield, girdling, avocado root rot, and washing techniques.

7.1.1 Age of leaf and season of the year

Many researchers have reported considerable differences in the content of elements in leaves sampled at different ages and different seasons *[3, 11, 34,* 44]. Contents of Ca, Mg and Cl definitely increase with age of leaf from spring to autumn, whereas N, S, and K contents tend to decrease.

7.1.2 Position of leaf on the tree

Small differences in element concentration were recorded in leaves sampled from different sides of trees *[3]*. In a survey carried out in Israel, leaves sampled from the northern side of the tree were found to have the best correlation with the average level of most elements analyzed in leaves sampled from the other sides *[46]*. It seems, therefore, that sampling leaves from the northern side should generally prove sufficient to represent reliably the tree's element concentration.

7.7.3 *Varieties and rootstocks*

In a nitrogen fertilizer experiment carried out in Israel, the levels of N, P, K and Fe in leaves of the Guatemalan cultivars - Nabal, Benik and Anaheim -were higher than those found in Ettinger and Fuerte leaves *[46]*. In another nitrogen fertilization experiment, performed in California, the highest N level was found in Hass leaves, medium in Fuerte and lowest in MacArthur *[12]*.

Avocado trees grafted on Guatemalan rootstocks were reported in California to be more susceptible to iron chlorosis than those grafted on Mexican stocks *[19]*. In Israel, trees grafted on West Indian stocks proved more resistant to chlorosis than those on Guatemalan stocks *[21]*. In California as well as in Israel, West Indian stocks were found to be much more resistant to salinity than the Mexican and Guatemalan rootstocks; this was expressed in lower concentrations of Cl and Na and in less leaf burn *[13, 22]*. In leaves of trees grafted on West Indian rootstocks, the concentration of Zn was higher and that of N lower than in leaves grafted on Mexican stocks *[45]*. Two studies of comparative effect of different rootstocks on the leaf nutrient content is summarized in Table 4.

Table 4: The relative effect of rootstock on the scion leaf nutrient content

Rootstock: / Element	Mexican	West Indian	Guatemalan
N	M*	L*	H*
P	M	H	L*
K	H	M*	L*
Ca	L*	M*	H
Mg	L	M	H
Na	H	L	L
Cl	H	L	L
Fe	M*	H*	L*

Data obtained from several years of leaf analysis in two field trials (*A. Ben-Ya'acov:* personal communication)
* Data from one experiment only.
H - High M - Medium L - Low

7.1.4 Influence of yields

In a leaf analysis survey carried out in Florida avocado groves, heavy crops resulted in low S and K contents in leaves of *cv.* Fuerte *[47]*. Similar observations were made in Israel with leaves of *cv.* Nabal *[45]*.

7.1.5 Girdling

This is a commonly used practice in some countries and therefore should not be disregarded. In many cases girdling is followed by chlorosis and low mineral content as a result of depletion caused by higher yields and from disruption in translocation caused by the girdle *[37]*.

7.1.6 *Effect of root rot*

This disease, which is of greatest importance in most avocado growing countries, is caused by *Phytophthora cinnamomi*. The presence of the fungus in the roots of avocado seedlings caused drastic changes in the nutrient concentrations found in the leaves and a marked decrease in the total amount of nutrients taken up by the plant *[35]*.
Infected plant leaves showed an increase in N, Na, Cl and Cu and a decrease in P, Mn and Fe concentrations as compared with leaves of uninfected plants (Table 5).

Table 5 Effects of root infection by *P. cinnamomi* on nutrient concentration in leaves and total amount of nutrients per avocado seedling (after *Labanauskas et al. [35]*).

	Concentration (% d. w.)				Total uptake((% of plant)			
	(—) Phyt.	(+) Phyt.	Sign.	C.V.	(—) Phyt.	(+) Phyt.	Sign.	C.V
Dry wt (g)	40.87	7.36	**	26	91.56	13.46	**	27
N	2.07	2.22	**	8	1.30	0.23	**	22
P	0.174	0.135	**	9	0.166	0.021	**	26
K	0.91	1.00	N.S.	17	0.70	0.11	**	24
Ca	1.75	1.74	N.S.	15	0.90	0.15	**	26
Mg	0.56	0.49	N S.	14	0.35	0.4	**	26
Na	0.013	0.163	**	76	0.078	0.018	**	21
Cl	0.122	0.149	**	48	0.147	0.021	**	26
	in ppm				in mg/plant			
Zn	34	35	N.S.	23	2.75	0.39	**	30
Mn	94	51	**	32	3.99	0.57	**	26
Fe	77	51	**	29	28.64	3.96	**	57
Cu	4.9	6.2	**	20	0.39	0.08	**	29

7.7.7 *Preparation of leaves for analysis*

Washing procedures might affect nutrient concentrations in avocado leaves. It was found that some detergents contain P und Cu and therefore increase the levels of these elements found in the tissues *[26]*.

7.2 Methods of sampling

The following practices are recommended for sampling avocado leaves. Preferably the main cultivars (Fuerte, Hass and in some cases Nabal) should be sampled. Bearing groves, at least seven years old, are customarily sampled. Groves which entered the regular fruiting stage at a younger age may also be included. Autumn is the preferred time.

It is advisable to avoid sampling immediately after rain. The size of a unit sample should not be over 2 hectares. The plot should be as uniform as possible, in respect to age, soil, cultivation and development. Healthy, unimpaired mature leaves of first growth of the present year are sampled, namely, leaves of the present spring's growth. Branches selected for sampling should not bear fruit nor should they exhibit a profuse outbreak of flush. Trees should be sampled prior to being girdled, excluding branches still showing the effects of preceding years' girdling, such as defective callusing, paleness of leaves, etc. Trees showing leaf burn should not be sampled (or sampled separately). Sampled leaves include blade and petiole. Leaves are sampled from the northern side at a height of 1.5-2.0 m. When working a Fuerte plot, it is preferable to take two separate samples, one of fertile, the other of poorly cropping trees. With all other cultivars, a single sample is taken of trees with typical yield level for the particular year, with an indication of an estimated average yield for each cultivar. The sampled trees should be marked for future use. Six to eight leaves are collected from each of ten trees. Each sample therefore comprises 60-80 leaves.

Under normal conditions, a good rinse with tap water and washing with deionized water may be sufficient to obtain reliable results. Special care should be taken in the washing procedure when highly accurate results are needed for a study of microelements, such as iron.

7.3 **Leaf analysis standards**

Table 6 gives the nutritional leaf composition of avocado trees as summarized in California *[15]*.

Table 6: *Standards of avocado leaf analysis*

Element	Unit	Ranges: Deficient, less than	Adequate	Excess, more than
Nitrogen (N)	%	1.6	1.60—2.0	2.0
Phosphorus (P)	%	0.05	0.08—0.25	0.3
Potassium (K)	%	0.35	0.75—2.0	3.0
Calcium (Ca)	%	0.5	1.0—3.0	4.0
Magnesium (Mg)	%	0.15	0.25—0.80	1.0
Sulphur (S)	%	0.05	0.20—0.60	1.0
Boron (B)	ppm	10—20	50—100	100
Iron (Fe)	ppm	20—40	50—200	?
Manganese (Mn)	ppm	10—15	30—500	1000
Zinc (Zn)	ppm	10—20	30—150	300
Copper (Cu)	ppm	2—3	5—15	25
Molybdenum (Mo)	ppm	0.01	0.05—1.0	?
Chloride (Cl)	%	?	0.07—0.23*	0.25
Sodium (Na)	%	—	0.01—0.02*	0.25

* After *Cooper and Gorton [7]*

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