adapted to the prevailing climatic conditions. Site selection for peach production should also be enhanced. Even though chilling may be adequate at a particular site, this site may not be acceptable if spring cold hazard is high. Many local conditions have a great influence upon the severity of spring cold, and they should receive adequate consideration.

ACKNOWLEDGEMENT

The authors wish to express their sincere appreciation to Mr. W. O. Johnson, U. S. Weather Bureau, Lakeland, Florida for supplying the seasonal chilling hour totals for all the stations used in this analysis.

LITERATURE CITED

1. Edmond, J. B., T. L. Senn and F. S. Andrews. 1957. **Fundamentals of Horticulture.** 3rd Ed. McGraw Hill, N. Y. 463 pp., p. 321.
2. Johnson, W. O. 1958. Winter minimum temperatures in peninsular Florida, a summary of 20 seasons 1937-1957. Univ. Fla. Agr. Exp. Sta. and U. S. Wea. Bur., Lakeland, Fla. (Mimeo).
3. Lesley, J W. and M. M. Winslow. 1961. Behavior of short-chilling peach varieties in Southern California after the warm winter of 1960-61. Calif. Agr. 15:8-10.
4. Massey, F. J. Jr. 1951. The Kolmogorov-Smirnov test for goodness of fit. Amer. Stat. Assoc. Jour. 46:68-78.
5. Sharpe, R. H. and R. Parker. 1963. Peach production in Florida. Univ. Fla. Agr. Ext. Ser. Cir 264.
6. Swed, F. S. and C. Eisenhart. 1943. Tables for testing randomness of grouping in a sequence of alternatives. Annals Math Stat. 14:66-87.
7. Thom, H. C. S. 1959. The distribution of freeze-date and freeze-free period for climatological series with freezeless years. Mon. Wea. Rev. 87:136-144.
8. Thom, H. C. S. and R. H. Shaw. 1958. Climatological analysis of freeze data for Iowa. Mon. Wea. Rev. 86:251-257.

AVOCADO NUTRITION IN CALIFORNIA

TOM W. EMBLETON AND W. W. JONES

Horticulturists

Department of Horticultural Science

University of California

Riverside, California

Studies relating avocado nutrition to yield have been limited because of the high variability in yield. The variability in avocado yield is several times greater than that of citrus and most other tree crops (10). This means that large numbers of replication and detailed statistical evaluation of data have been necessary to attack the problems with any degree of confidence.

The essential elements which may limit yield in California are N, Zn, and Fe. Chloride is frequently, and Na occasionally, in excess. The source of these excess elements is primarily from the irrigation water.

NITROGEN

Initial detailed studies were with the Fuerte variety (4, 5). These showed that yields could be limited by too low or too high a level of N in the tree (Fig. 1). The most productive range was found to be between 1.6 and 2.0 per cent N in dry leaves. These leaves were sampled in the mid-August to mid-October period and were the youngest fully-expanded and matured leaves from shoots, from all sides of the trees, that were not fruiting or flushing. Normally, under California conditions, these would be spring-cycle leaves.

As the level of N in the leaves was increased above the most productive range, yields were reduced. Trees in this high N range had dense foliage with an abundance of long shoot growth with large, dark-green leaves. As the level of N in the leaves decreased below the most productive range, yields were also decreased. Trees in the low N range were thinly foliated, with a small amount of short shoot growth, with smaller, lighter-green leaves than those in the high N range. Trees in the most productive range were intermediate in density of foliage, size of leaves, amount of shoot growth, and leaf color. The amount of N that has been necessary to apply to adjust the level of N in the leaves to the most productive range has varied depending upon past fertilizer history, amount of cover crop, if any, irrigation and tillage practices, nature of soil, materials used, method of application of nitrogeneous materials, and variety.

The curve shown in Fig. 1 also appears to be applicable for varieties other than the Fuerte, but the amounts of N needed to attain a given leaf level varies greatly among varieties (6). Greater amounts of N are needed to maintain the level in MacArthur leaves in the most productive range than are needed for the Fuerte. Experi-

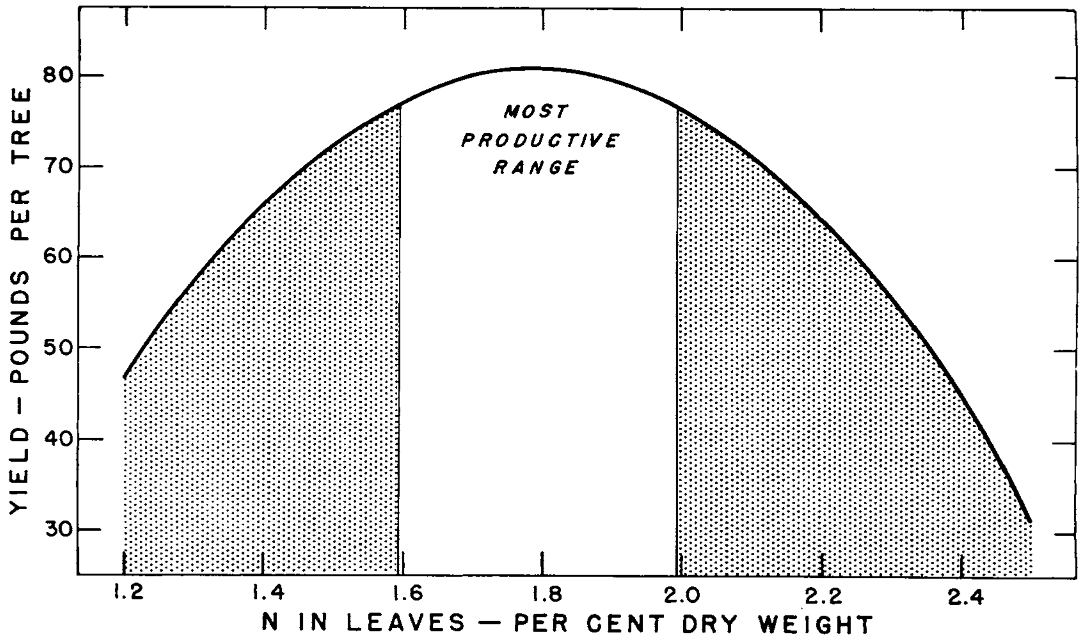

Figure 1.—Fuerte avocado yield as related to the percentage of nitrogen in the youngest, fully-expanded and matured leaves sampled in the August-October period.

mentally, percentages of leaf N above 2.0 in the MacArthur variety have not been achieved even with applications of 5 pounds of N per tree annually. Table 1 shows some typical MacArthur data. High rates of N resulted in larger trees than moderate rates. It is obvious that high rates of N are needed for this variety.

The Jalna variety fruits heavily at a very young age. It was reasoned that, if a well-fertilized tree fruited heavily at 2 years of age, high rates of N would not reduce yield of mature trees. Results of two years' data in an experiment to check on this reasoning appears in Table 2. From this one experiment it appears that it is difficult to get the level of N much above 2 per cent in leaves of this variety. The 4-pound rate did not result in noticeably more vegetative growth than the 2-pound rate of N. The limited evidence available for the Jalna suggests that possibly this variety has some inherent mechanism that restricts the maximum level of N in the leaves. This could explain fruiting at a very young age.

Alternate bearing effects complicate studies on N nutrition relations with yield. An example of this is shown in Table 3. The orchard was planted on virgin, light-textured, well-drained soil in 1955. Prior to the establishment of the experiment in 1961 the trees had received relatively small applications of N. Records for the first experimental yield-response year, 1963, show that there was a marked response to each increment of N. By comparing the levels of N in the leaves with the curve in Fig. 1, this yield response would be predicted. However, the N leaf

Table 1. Nitrogen rate, percentage of nitrogen in leaves, and yield of MacArthur avocado.

Pounds N per tree annually and statistical indices	% N in dry leaves, Aug.-Oct.	Yield, pounds per tree
0.25	1.36_y 1/	35.1_y 1/
0.75	1.46_y	80.1_y
1.50	1.65_z	137.6_{yz}
3.00	1.72_z	216.4_z
C.V., %	6	79

1/ Ranked at the 1% level by Duncan's Multiple Range Test (3). Mean of 4 replications of 4 tree plots for 4 years.

Table 2. Nitrogen rate, percentage nitrogen in leaves and yield for Jalna avocado

Pounds N per tree annually and statistical indices	% N in dry leaves Aug.-Oct.	Yield, pounds per tree
	1960-61	
0	1.69_{y} 1/	27_{y} 1/
2	2.00_{yz}	62_{z}
4	2.06_{z}	61_{z}
C.V., %	6	61
	1961-62	
0	1.60_{y}	88_{y}
2	1.97_{z}	146_{z}
4	2.02_{z}	154_{z}
C.V., %	6	41

1/ Ranked at the 1% level by Duncan's Multiple Range Test (3). There were 20 replications with single-tree plots.

levels in 1963 were not greatly different from those of 1962, but the yields in 1964 were inversely related to the rates of N applied. It appears that the initial strong yield response to N in 1963 started a differential alternate bearing cycle and the alternate bearing influences were more influential on the 1964 crop than were the N levels in the trees. This shows the danger of looking at only one year's data.

Phosphorus

There has been no documented evidence of P deficiency in field-grown avocados in California. However relatively low levels of P in the leaves have been encountered. One such orchard was planted in 1939 where declining navel orange trees were removed because of what is now known to be P deficiency. Valencia orange trees adjacent to this avocado orchard have responded remarkably well to P fertilizers. An experiment was started in 1951 in the avocado orchard and has been maintained to date. Even though differential fertilization with P has resulted in ranges of P in the leaves from 0.070 to 0.130 per cent there was no yield response. To be conservative, the lower limit of the suggested commercial levels (see Table 4) has been set at 0.08 per cent P in the leaves. At the high end of the suggested commercial levels Zn deficiency is more likely to be a problem.

Potassium

Low concentrations of K in the leaves have not been found in field-grown avocados in California. Increasing the concentration of K in the leaves from about 0.9 to about 1.3 had no beneficial effects on yield.

Magnesium

As with K, there is no recorded evidence of Mg deficiency in field-grown avocados in California. All leaf analysis encountered from the field thus far indicate that it is unlikely that Mg deficiency will become a problem in the near future.

Critical levels of Mg in the leaves associated with the growth of the tree and leaf symptoms have been established by use of outdoor sand cultures (1). Concentrations of Mg in leaves, sampled as previously outlined, below 0.20 per cent would be classed in the deficient range.

Table 3. The influence of alternate bearing on the relation between yield and percentage nitrogen in Fuerte avocado leaves.

Pounds N per tree annually and statistical indices		% N in dry leaves, Aug.-Oct.		Yield pounds per tree	
1961, 1962	1963, 1964	1962	1963	1963	1964
0.25	0.50	1.49_{x} 1/	1.48_{y} 1/	76_{x} 1/	59_{z} 1/
0.50	1.00	1.61_{y}	1.53_{y}	107_{xy}	51_{yz}
1.00	2.00	1.67_{y}	1.62_{z}	121_{yz}	44_{yz}
2.00	4.00	1.80_{z}	1.66_{z}	140_{z}	33_{y}
C.V., %		8	6	53	59

1/ Ranked at the 1% level by Duncan's Multiple Range Test (3). There were 32 replications of nitrogen rates with single-tree plots.

Table 4. Tentative leaf analysis guide for diagnosing nutrient status of mature avocado trees.[1/]

Element	Unit (dry matter basis)	Ranges[2/]		
		Deficient: less than:	Suggested commercial levels	Excess: more than:
N	%	1.6	1.6 - 2.0	2.0
P	%	0.05	0.08 - 0.25	0.3
K	%	0.35	0.75- 2.0	3.0
Ca	%	0.5	1.0 - 3.0	4.0
Mg	%	0.15	0.25 - 0.80	1.0
S	%	0.05	0.20 - 0.60	1.0
B	ppm	10-20	50-100	100-250
Fe	ppm	20-40	50-200	?
Mn	ppm	10-15	30-500	1000
Zn	ppm	10-20	30-150	300
Cu	ppm	2-3	5-15	25
Mo	ppm	0.01	0.05 - 1.0	?
Cl	%	?	---	0.25 - 0.50
Na	%	3/	---	0.25 - 0.50
Li	ppm	3/	---	50 - 75

1/ Adapted from Goodall, G. E., T. W. Embleton, and R. G. Platt. Revision of Univ. of Calif. Agr. Ext. Ser. Leaflet 24, Avocado Fertilization. (In preparation.)

2/ Based on the most recently expanded and matured leaves from nonfruiting and non-flushing terminals sampled during the mid-August to mid-October period. Under California conditions these are normally spring-cycle leaves that are 5- to 7-months of age.

3/ Not known to be essential for normal growth of avocados.

ZINC

Specific studies correlating the degree of foliage symptoms of Zn deficiency or the concentration of Zn in leaves with yield have not been reported. However, there is little doubt that moderate to severe foliage symptoms of the deficiency would be associated with a reduced yield. The visual symptoms of the deficiency are usually associated with concentrations of Zn in the foliage that are below 15 ppm.

On the alkaline soils, correction of the visual symptoms of Zn deficiency is commonly achieved by foliar sprays of Zn materials. However, on the acid soils in San Diego and Santa Barbara counties, which are usually nontilled with a volunteer cover crop in the row middles, soil applications of Zn sulfate have given beneficial results. Gustafson (8) recommends from 2 to 10 pounds of Zn sulfate (22-28 per cent metallic Zn) per tree, depending on the age and size of tree. The material should be banded around the drip-line of the tree.

Wallihan *et al.* (11) reported that the injection of ZnEDTA into the irrigation water to give 1 pound of material per 6-year-old Fuerte avocado tree, eliminated the symptoms of Zn deficiency on the fruit and leaves and increased the Zn concentration in the leaves from 15 to 50 ppm. Subsequent observations and leaf analysis showed that this one application of ZnEDTA was effective for at least 4 years. The surface foot of soil in this orchard had pH values that varied between 7 and 8, and the orchard was nontilled.

Subsequent experiments[1] in Fuerte orchards on soils with pH's between 7 and 8 did not indicate effectiveness of Zn chelate soil applications. For example, in one such nontilled, sprinkler-irrigated orchard, with a volunteer sod cover crop, different forms of soil-applied Zn were compared on an economic basis. Treatments, which were replicated 5 times with 3-tree plots, included rates up to 0.1 lb Zn (1 lb material) per tree as HEEDTA, rates up to 0.14 lb Zn (1 lb material) as EDTA, 0.25 lb Zn (5 lb material) as a lignin sulfonate complex, and 1.8 lb Zn per tree as Zn sulfate—all injected into the sprinkler irrigation system. Also included were 1.8 lb Zn as Zn sulfate applied in a 3-inch band at the dripline of the tree and a conventional Zn sulfate-soda ash spray. Three months after treatment the Zn sulfate treatments in irrigation water and in the band treatment had 25 ppm Zn in dry leaves in contrast to 15 ppm in the control treatments, the differences being significant at the 5% level. The spray treatments were not sampled at this time because of questionable procedures for removing spray residues from the surface of the leaves. None of the other treatments had a significant influence on the Zn level in the leaves. One year after treatment the control treatment had 13.1, the Zn sulfate injected into the irrigation system, 20.1, and the Zn sulfate banded, 30.4 ppm Zn in dry leaves, the differences being significant at the 1% level. No other treatments showed significant effects. Two years after treatments only the Zn sulfate band treatment was significantly higher than the control, the values being 16.3 in contrast

[1]Data from files of E. F. Wallihan and T. W. Embleton, University of California, Riverside.

to 29.6 ppm Zn in dry leaves. This difference was significant at the 1% level.

Available evidence suggests that, a) soil applications of Zn chelates up to 1 lb of material per tree are not generally effective; b) soil applications of Zn sulfate to soils with pH's between 7 and 8 may be effective in some orchards; c) if effective, soil applications will probably remain effective for 2 or more years; and d) foliage sprays of Zn are effective for only a short period of time, presumably because Zn is not readily translocated from old to young leaves. Thus, where additional Zn is needed, foliage sprays should be applied annually.

Iron

Iron chlorosis of avocado in California has been observed only on the alkaline soils and is usually associated with free calcium carbonate (lime) in the soil and impaired drainage. Spray application of Fe materials has not been effective. The chlorosis is frequently accentuated by keeping the soil high in available water. In many cases the chlorosis can be reduced by letting the soil dry more between irrigations. Alternate row middle irrigations have been effective in a number of instances. This allows one side of the tree to dry while there is ample water in the soil on the other side. However, control of soil moisture at best is only partially effective. Encouraging results were obtained with a soil application of from ½ to 2 lb of 138-HFe per tree (2). This material is expensive and although it is effective in most cases, there are cases of failure. More effective means of correcting the chlorosis are still needed.

The Guatemalan rootstocks are more susceptible to iron chlorosis than the Mexican rootstocks (9).

Chloride and Sodium Excess

The avocado will show symptoms of excess Cl under conditions where most tree crops will not be noticeably affected. The source of the Cl is primarily from the irrigation water. Usually more tipburn of leaves can be observed with use of manures than with inorganic chemical *fertilizers*. Generally, the use of Guatemalan rootstocks will result in less tipburn and a lower concentration of Cl in the scion leaves than will the use of Mexican rootstocks (7). Reduction of the damage can best be achieved (if higher quality irrigation water is not available) by using an irrigation program that prevents the concentration of Cl in the soil solution around the roots.

Sodium damage is occasionally observed. Manures and irrigation waters are the common source of Na. As with Cl, a good irrigation program is essential to combat Na excess.

Tentative Leaf Analysis Guide

Leaf analysis is an effective diagnostic tool and is being used in California as a guide in planning nitrogen fertilizer programs. Although leaf analysis information for the avocado is limited, there is enough to establish some tentative guidelines (Table 4). These guides are certainly subject to change as more information becomes available, but in the present form they can serve a useful function.

Literature Cited

1. Bingham, F. T. 1963. Magnesium nutrition of avocados under sand culture conditions. Soil Sci. Soc. Amer. Proc. 27: 58-61.
2. Bingham, F. T., and J. A. Beutel. 1957. Iron chlorosis and chelate studies in avocado orchards. California Avocado Soc. Yearbook 41:133-35.
3. Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.
4. Embleton, T. W., W. W. Jones, and M. J. Garber. 1959. Curvilinear relationships between leaf nitrogen and yield of Fuerte avocados. Proc. Amer. Soc. Hort. Sci. 74: 378-82.
5. Embleton, T. W., W. W. Jones, and M. J. Garber. 1959. Leaf analysis as a guide to nitrogen fertilization of avocado. California Avocado Soc. Yearbook 43: 94-95.
6. Embleton, T. W., W. W. Jones, and J. D. Kirkpatrick. 1955. Avocado fertilizer experiments. California Avocado Soc. Yearbook 39: 62-66.
7. Embleton, T. W., Mitsuo Matsumura, W. B. Storey, and M. J. Garber. 1962. Chlorine and other elements in avocado leaves as influenced by rootstock. Proc. Amer. Soc. Hort. Sci. 80: 230-36.
8. Gustafson, C. D. 1957. Zinc soil treatment on avocados. California Citrograph 42: 225-27.
9. Halma, F. F. 1954. Avocado rootstock experiments—a 10-year report. California Avocado Soc. Yearbook 38: 79-86.
10. Jones, W. W., T. W. Embleton, and C. B. Cree. 1957. Number of replications and plot sizes required for reliable evaluation of nutritional studies and yield relationships with citrus and avocado. Proc. Amer. Soc. Hort. Sci. 69: 208-16.
11. Wallihan, E. F., T. W. Embleton, and Wilma Printy. 1958. Zinc deficiency in the avocado. California Agriculture 12(6): 4-5.