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Optimum Leaf Nutrient Concentration Ranges for the 'Hass' Avocado in California

It has long been recommended that growers use fall leaf analyses as a guide for making fertilizer decisions for their avocado trees. Specifically, samples should be collected from 5- to 7-month-old (spring flush) leaves from non-fruiting, non-flushing terminal spring shoots from August to October. Research has shown that these are the leaves and time during which nutrient pools are the most stable and provide the most consistent results from year to year. But what are the optimum levels of nutrients that should be in your leaves for maximum production?

Believe it or not, most of the values reported by Dr. Tom Embleton were not empirically determined for commercial avocado trees in California, like they had been for citrus and other tree crops. Rather, early avocado researchers like Embleton, "borrowed" values from citrus and tweaked them based on their research knowledge (see "Embleton's Ranges" in Table 1). Some studies were conducted to specifically look at nitrogen (N), iron (Fe), and zinc (Zn) levels, but not the other 11 mineral nutrients essential for plant growth and productivity. Over the years, modifications to the recommendations of Embleton were made by analytical labs offering avocado leaf testing, resulting in various laboratories recommending different leaf nutrient concentrations as optimal. Thus, we were left with a variety of optimum leaf nutrient concentrations, none of which had been developed based on avocado yield, fruit size, or fruit quality data. As a result, optimum leaf nutrient concentration ranges, especially for most micronutrients, were broad and imprecise.

Table 1. Old and new optimum leaf nutrient concentration ranges for 'Hass' avocado leaves sampled as 5- to 7-month-old leaves from non-fruiting, non-flushing terminal spring shoots from August to October.

Nutrient (conc.)	Embleton's Ranges[1]	New Optimum Ranges[2]	Highest Grower Frequency[3]
N (%)	2.0–2.6	2.2–2.5	2.25–2.7 ✓–X+
P (%)	0.10–0.25	0.10–0.15	0.15 ✓
K (%)	0.75–2.0	0.7–1.0	0.9 ✓
Ca (%)	1.0–3.0	1.8–2.0	1.4 X-
Mg (%)	0.25–0.80	0.6–0.9	0.5–0.6 X-
S (%)	0.2–0.6	0.45–0.53	0.3–0.37 X-
Zn (ppm)	30–150	50–80	34 X-
Mn (ppm)	30–500	110–145	75 X-
Fe (ppm)	50–200	55–80	55 ✓
B (ppm)	50–100	40–65	25 X-
Cu (ppm)	5–15	4–7	9 X+
Cl (%)[4]		0.3–0.5	

[1] Embleton, T.W., Jones, W.W., Labanauskas, C.K., and Reuther, W.J. 1973. Leaf analysis as a diagnostic tool and guide to fertilization, p. 183–211. In: W.J. Reuther (ed.). The citrus industry. Univ. California Div. Agr. Sci., Berkeley.

[2] Developed by D. Crowley, S. Campisi-Pinto, P. Rolshausen and C. J. Lovatt.

[3] The leaf nutrient concentrations that occurred most frequently in the research orchards used in developing the new avocado leaf optimum concentration ranges. ✓ = values within the new optimum range; X- = values below the new optimum range; X+ = values above the new optimum range.

[4] Crowley, 2017. Index Fresh Seminar Series.

In 2012, the California Avocado Commission (CAC) began funding a research project with Dr. David Crowley, professor and soil scientist at UC Riverside, which had among its objectives to identify "optimal ranges of leaf tissue concentrations in avocado that are associated with high yields." Dr. Crowley's project had more than 400 'Hass' trees in groves in all growing regions, for which all inputs — water, fertilizer and

yield — were monitored on an individual tree basis. In 2015, Dr. Carol Lovatt, professor and plant Physiologist, was brought on to the project. Dr. Lovatt brought to the project a comprehensive data set collected over a 20-year period that included leaf analyses (N, P, K, Ca, Mg, S, Fe, Zn, Mn, B, and Cu), total yield and fruit size distribution (packing carton sizes <84, 84, 70, 60, 48, 40, 36, 32 and >32), and fruit quality data from about 3,000 trees in commercial coastal and inland valley orchards (Pauma Valley to San Luis Obispo). A subset of the trees also included chloride in the leaf analyses.

The data sets were subjected to extensive statistical analysis to determine the relationships between leaf content of various nutrients and yield. For a detailed explanation of these analyses, see "Decision Support Tools For Management of Avocado Nutrition and Chloride Toxicity: Final Report," available at californiaavocadogrowers.com. Based on these analyses, preliminary optimum ranges for leaf nutrients were published in the Fall 2015 issue of *From the Grove*. In the intervening time, many iterations of the results have been presented at seminars and have made their way onto various websites. To prevent confusion, Dr. Lovatt and I have sorted through the analyses in an attempt to clarify the results and provide a basic definitive set of optimum leaf nutrient concentration ranges for the 'Hass' avocado in California (see "New Optimum Ranges" in Table 1).

Since the new 'Hass' avocado optimum leaf nutrient concentration ranges were developed using the same leaf tissue recommended by Embleton — 5- to 7-month-old leaves collected from non-fruiting, non-flushing terminal spring flush shoots in August to October — they can be compared directly with the old standards. The leaf nutrient concentrations that occurred most frequently in the research orchards used in developing the new optimums are shown in the last column of Table 1. The research revealed that leaf concentrations of nitrogen (N), phosphorus (P) and potassium (K) were high in the majority of orchards, (above or at the upper end of the new optimal ranges), with magnesium (Mg) and iron (Fe) at the low end of the new optimal ranges, respectively. Note that negative effects on yield result from excess N, P and K.

As reported in the Fall 2015 issue of *From the Grove*, the most significant result of these analyses was likely the discovery that leaf concentrations of calcium (Ca), sulfur (S), zinc (Zn), manganese (Mn) and boron (B) were well below the new optimum ranges (Table 1). The results documented that nutrient deficiencies in Ca, S, Zn, Mn and B are widespread throughout the California avocado industry. In addition, avocado trees in a high percentage of orchards had excessive levels of copper (Cu) in their leaves. Correcting these deficiencies and Cu toxicity, which limit avocado tree productivity, will contribute to increasing yield and fruit size of 'Hass' avocado trees in California. Please note: In her doctorate research on water management of 'Hass' avocado orchards in California, Julie Reints discovered that Mn accumulates in avocado leaves in response to episodes of hypoxia (saturated soil). Based on Dr. Reints' work, care must be taken in interpreting Mn results from avocado leaf tissue analysis.

In all cases, the new avocado leaf optimal nutrient concentration ranges that are best for greatest total yield per tree also are optimal for greatest yield of commercially valuable size fruit (packing carton sizes 40, 48 and 60). The data set revealed that in California, the greatest proportion (majority) of total yield is fruit of packing carton size 48 over a broad range of yields (22 to 420 pounds per tree; up to 46,200 pounds per 110 trees per acre). Over that range in total yields, the pounds and number of fruit of packing carton sizes 40, 48, and 60 per tree continued to increase and remained 65% to 75% of the total yield. Whereas fruit of packing carton size 70 increased gradually from 12% up to 30% of total yield. Yield of fruit of packing carton size 84 did not exceed 6% of total yield.

'Hass' avocado trees yielding greater than 285 pounds per tree (> 31,350 pounds per 110 trees per acre) had leaf N concentrations between 2.09% to 2.6%; as N increased to greater than 3.0%, yield decreased. The highest yields were associated with N at 2.5%, P between 0.12% to 0.15% and K at 0.9%; low yields were associated with N > 3.0%, P > at 0.2%, and K > 1.2% (see Crowley's Final Report).

In the Fall 2015 issue of *From the Grove*, the optimum range for N was reported as 2.25% to 2.9%. An upper value of 2.9% leaf N is too close the threshold value of 3%, above which yields decline. If the average value for N is 2.9% for leaves in a representative sample collected from trees throughout the orchard, then some trees will have leaf N levels > 3% and concomitantly have reduced yields. Moreover, in orchards with high chloride levels, leaf N needs to be between 2.0% to 2.5% as leaf chloride concentrations increase above 0.6%. Interestingly, higher yielding trees had leaf Cl concentrations between 0.3% to 0.5%; trees having < 0.2% Cl or > 0.6% had reduced yields (see Crowley's presentation "Decision Support Tools for Fertilization of Avocados" available at indexfresh.com/seminar-series).

It is recommended that growers utilize these new optimum avocado leaf nutrient concentration ranges to help determine their trees' nutrient needs.