November or April Soil-Applied Nitrogen Fertilizer Increases Hass Avocado Yield and Fruit Size

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Abstract. To reduce potential nitrate pollution of groundwater, avocado growers apply nitrogen fertilizer to the soil in several small doses annually. This strategy ignores tree phenology and the possibility that the tree requires more N at some times of the year than others. In a 4-yr-long study, the effect on the yield of 'Hass' avocado trees (*Persea americana* Mill.) of applying 168 kg N (as NH_4NO_3) /ha in six small doses per year was compared to a strategy that supplied 16.7% more N via the soil at one of several key times in the phenology of the tree. Double applications of N (0.56 kg/tree) in November or April increased yield by 85 and 67 kg more fruit/tree/4 years compared to control trees ($P \leq 0.01$). Multiplied by the number of trees/ha, the yield increases are economically significant. Extra N applied to the soil in November significantly increased the cumulative kg of fruit per tree of packing carton sizes 60 ($P \leq 0.05$), 48 ($P \leq 0.01$), and 40 ($P \leq 0.001$) (fruit weighing 178-325 g/fruit) compared to the control trees. The April soil application of extra N increased the cumulative kg of larger fruit per tree, i.e. those weighing 270-325 g/fruit (packing carton size 40) compared to the control ($P \leq 0.001$). For trees receiving 16.7% more N to the soil in January, February or June, yield and fruit size were not significantly different from control trees not receiving extra nitro-

gen. Yield increases were not related to tree nitrogen status. Extra N in April significantly reduced alternate bearing during the four years of the study ($P \leq 0.05$). The results demonstrate that timing of the double dose of nitrogen, not the extra nitrogen, was critical to achieving increased yield and fruit size, and reduced alternate bearing.

Introduction: There are approximately 60,000 acres of bearing avocado trees in California with the majority concentrated in San Diego, Riverside, Ventura and Santa Barbara counties. In an attempt to reduce the potential for nitrate pollution of the groundwater in these counties, avocado growers adopted the strategy of dividing the total amount of nitrogen applied annually into six small applications per year. However, this strategy ignores tree phenology and the possibility that nutrient demand is higher at some times of the year than others. Reports in the literature suggest the likelihood that the time that N fertilizer is applied might effect avocado yield (Kalmer and Lahav, 1976; Kotze, 1982), but no quantitative data are reported. Thus, we undertook a 4-year-long study to test the effect of supplying extra (0.28 kg additional N/tree, +16.7%) nitrogen to the soil at key times in the phenology of the 'Hass' avocado tree. The results of this research demonstrated that the time at which N is applied to the soil, not the extra nitrogen, is the key factor in increasing yield and fruit size and reducing alternate bearing.

Materials and Methods. Commercially bearing 'Hass' avocado trees (Duke 7 rootstock) located in Temecula, California, were used in a 4-year-long study from 1993 to 1996. All trees were fertilized according to the standard orchard practice of 168 kg N/ha as ammonium nitrate in six small doses per year (0.28 kg N/tree/application) as follows:

1. late January to early February,
2. mid-April,
3. mid-June,
4. mid-July,
5. late August to early September, and
6. late October to early November.

Treated trees, but not control trees, received an additional 28 kg N/ha (0.28 kg N/tree) in a single application made at one of the following key times in the phenology of the tree (Salazar et al., 1998) (Fig 1):

1. budbreak and ovule initation – January,
2. beginning of the cauliflower stage, pollen formation – February,
3. anthesis, fruit set, and initiation of the spring vegetative flush – April,
4. end of Stage I of fruit development and beginning of the June drop period – June,
5. beginning of Stage II of fruit development and end of the June drop period – July, or
6. end of the fall vegetative flush and beginning of flower initiation - November.

A randomized complete block design with 20 individual tree replicates per treatment was used.

Tree nutrient status was determined annually in September by collecting 40 spring flush leaves from non-fruiting terminals around each data tree at chest-height. The leaves were thoroughly washed, oven-dried at 60° C for 72 h, and ground in a Wiley mill to pass through a 40-mesh screen (Embleton et al., 1973). Leaf nutrient analyses was performed by Albion Laboratory (Clearfield, Utah) using inductively coupled plasma atomic emission spectrometry (ICP-AES).

At harvest, total kg fruit/tree was determined. Each fruit in random sample of 100 fruit/tree was weighed individually. The percentage of fruit in each size category (standard packing carton sizes) was used to calculate the packout (kg fruit/tree of each packing carton size). External and internal fruit quality was visually evaluated using a scale from 1 to 4 for two randomly selected fruit per tree after the fruit were ripened. Average Alternate Bearing Index (ABI) was calculated by dividing the difference in yield between two consecutive years by the sum of the yield of the two years; the three indices for the four years of the study were averaged. Analysis of variance was by General Linear Model procedure of the SAS statistical program (SAS Institute, Cary, NC).

Results: ***Yield (kg fruit/tree).*** Applying extra N (0.28 kg N/tree, 16.7% additional N) to the soil in November significantly increased cumulative yield of 'Hass' avocado trees for the four years of the study compared to control trees not receiving extra N in November and compared to trees receiving a double dose of N in January, February or June (Table 1). Cumulative yield was significantly greater for trees receiving extra N in April than control trees not re-

ceiving extra N in April and trees receiving a double dose of N in January or February.

Fruit size. Increased yield was not at the expense of fruit size. Extra N applied to the soil in November significantly increased the cumulative kg of commercially valuable fruit per tree (fruit weighing 178-325 g/fruit, packing carton sizes 60, 48 and 40) compared to the control trees (Table 1). Extra N in April significantly increased the kg fruit of packing carton size 40 (270-325 g/fruit) per tree for the four years of the study compared to control trees. Trees receiving double doses of N in January, February or June did not have significantly more large-sized fruit per tree than the control trees despite the fact that these treatments resulted in lower total yield per tree than the November and April N treatments.

Fruit quality. The treatments had no significant effects on external or internal fruit quality in any year of the study with the exception that supplying extra N in November significantly improved internal fruit quality compared to the control in 1994 ($P \leq 0.001$).

Alternate bearing. Supplying extra N (0.28 kg N/tree more than control trees) to 'Hass' avocado trees in April not only increased yield and fruit size, but also significantly reduced alternate bearing compared to the control trees (Table 1). Trees receiving a double dose of N (0.56 kg N/tree, i.e., 0.28 kg N/tree more than control trees) in November had the second lowest alternate bearing index, but it was not significantly different from the control or April-treated trees.

Tree nitrogen status. Yield was not a function of tree N status. Regression analysis of yield as function of tree N status resulted in an R^2 equal to only 0.0067.

Conclusion: Increased production and reduced alternate bearing are goals of California avocado growers. Production has averaged 6,400 kg/ha for the last 25 years. The great difference between crop volumes from year to year (alternate bearing) costs the industry millions of dollars in lost markets during low crop years and from oversupply during heavy crop years (Arpaia, 1998). The results of the research presented here suggest that changes in N fertilization strategy will contribute significantly to meeting these two goals. Specifically, supplying 0.56 kg N/tree in November or April will contribute to increased yield and fruit size and reduced alternate bearing.

Future Research: Based on the results of this study, a new 6-year-long study was initiated to replicate the previous study in a different avocado growing-region and climate (Somis, CA) and to test new strategies identified by the first study. The new study will determine: 1) if combining the double doses of soil-applied nitrogen in April and November will result in additive increases in yield, fruit size and a further reduction in alternate bearing; 2) if alternating soil nitrogen applications in April and November between "off" and "on" years, respectively, will prove a more effective strategy for increasing yield and stabilizing crop load; 3) the effect of a double dose of N in August (time of transition from vegetative to reproductive growth) on flowering, fruit set, and yield; and 4) if a triple dose of soil nitrogen in April is superior to a double dose; and 5) if the triple dose of soil N in April can be replaced with foliar nitrogen (results of our last CDFA FREP-funded project provided evidence that this treatment might provide a viable alternative to soil fertilization, because at this application time, avocado leaves can take up and tolerate high concentrations (2.5-3.0%) of low-biuret urea). The overall goal is to reduce alternate bearing and increase annual and cumulative yield without reducing fruit size and quality.

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Table 1. Effect of timing of soil-applied nitrogen on cumulative yield, fruit size and alternate bearing index of 'Hass' Avocado.

	Cumulative yield (kg/tree/4 years)				
		Fruit size (g/fruit)			Alternate
Treatment[z]	All sizes	178-212	213-269	270-325	bearing index
Standard	220.8 c[y]	48.5 b	64.9 bc	28.8 c	0.90 a
January	218.9 c	50.4 ab	57.2 bc	26.9 c	0.79 ab
February	212.9 c	51.2 ab	52.0 c	23.8 c	0.92 a
April	287.9 ab	66.9 ab	87.8 ab	57.5 a	0.71 b
June	231.5 bc	47.7 b	64.8 bc	36.3 bc	0.85 ab
November	306.1 a	70.0 a	97.8 a	49.1 ab	0.75 ab
P-value	0.01	0.05	0.01	0.001	0.05

[z] All trees received six soil applications of 0.28 kg N (NH_4NO_3)/tree in late January to early February, mid-April, mid-June, mid-July, late August to early September, and late October to early November; standard (control) trees received no additional N; treatments indicate the month trees received an additional 0.28 kg N (NH_4NO_3)/tree.

[y] Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

Table 2.

FLOWERING, FRUIT SET, AND FRUIT DEVELOPMENT OF THE 'HASS' AVOCADO IN CALIFORNIA*