CALIFORNIA DEPARTMENT OF FOOD AND AGRICLUTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)
FINAL REPORT

Project Title: **Development of Nitrogen Best Management Practices for the 'Hass' Avocado**

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Statement of Objective:

To protect the groundwater from potential nitrate pollution, 'Hass' avocado growers in California divide the total annual amount of nitrogen (56-168 kg/ha) into six small soil applications made during the period from late January to early November. The lack of research data raised the question of whether 'Hass' avocado yield was being compromised by this fertilization practice. In an earlier study we identified two phenological stages for which N application at 56 kg/ha in a single application (double dose of N) significantly increased the 4-year cumulative yield (kilograms fruit per tree) 30% and 39%, respectively, compared to control trees ($P \leq 0.01$) and increased the number of commercially valuable large-size fruit. A double dose of N at one phenological stage also reduced alternate bearing. This research addresses the concerns of the avocado industry that using double or triple doses of soil-applied N to increase yield and fruit size and to reduce alternate bearing will increase the potential for nitrate groundwater pollution.

Project Objectives:

1) Quantify the nitrate pollution potential of the various nitrogen fertilization strategies.
2) Identify the threshold rate of nitrogen fertilization above which the pollution potential increases.
3) Evaluate the potential for replacing the April double dose or triple dose of soil nitrogen with foliar nitrogen.

4) Provide a ratio of enhanced-yield benefit to environmental cost for each nitrogen fertilization strategy.

5) Identify BMP's for nitrogen fertilization for the 'Hass' avocado in California.

Executive Summary:

Results of the first harvest (1998) indicated that the time of N fertilizer application was more important than the amount of N that was applied ($P \leq 0.06$). The freeze of December 1998 resulted in very low yields in 1999 and 2000. The N treatments had no effect on yield either year. Time of N application had a significant effect on yield for the harvest of 2001 ($P \leq 0.01$). The better treatments were all due to extra N applied to the soil in November or April, despite the fact that all trees in this study received 140 kg/ha total annual N. However, these treatments were not significantly better than trees receiving extra N in November and April, August, Ranch Practice or the control, which also received N in November, April and August. Time of N application had a significant effect on yield for the harvest of 2002 ($P \leq 0.10$). However, the better yielding trees in 2002 were those with the lowest yields in 2001 (this included the control). Trees receiving 3x N (84 kg/ha) in April had the highest 2-year (2001 plus 2002) cumulative yield. For the five years of the study, treatments that significantly increased yield had the greatest number of large-size fruit. Nitrogen treatments significantly ($P \leq 0.05$) affected tree N status as indicated by standard leaf analysis. However, there was no significant correlation between tree N status and yield. Each spring approximately 3-fold more proleptic, less productive, shoots developed compared to sylleptic shoots. N treatments did not affect on the proportion of proleptic to sylleptic shoots produced.

The total annual amounts of nitrate leaching past the root zone were not significantly affected by the treatments on any sampling date or in any year. All trees received some portion of their annual N during the month being sampled and all trees received the same total amount of N annually. However, it was clear that when higher doses of N were applied in a given month, higher amounts of N leached passed the root zone for that sampling date, and that dividing the total amount of annual N into five small doses results in a numerical, but not statistically significant, reduction in the amount of N leaching past the root zone. Ammonium leaching past the root zone was low and not significantly affected by N teatment.

Treatments producing the three numerically, but not statistically greater cumulative yields for 2001 plus 2002 were soil applications of 3x N in April > the control > application of 2x N in November. Phenological stages producing numerically greater yields in response to N fertilization in this study are those identified in our previous study. In this study we incorporated these application times into the control, so the control in this study received single doses of N at optimal stages of avocado tree phenology. Due to the effect of the freeze on the 1999 and 2000 yields and the effect of the resulting alternate bearing on the 2001 and 2002 yields, two additional years of yield data are required to determine if the Ranch Practice of applying only 45 kg N/ha split in July and August will sustain yields equal to that of the control, or whether maximum yield requires 3x N in April, 2x N in November or simply timing the five single doses of N to key stages of 'Hass' tree phenology as in the control. At present, without additional data, growers should be encouraged to split their total amount of N fertilizer applied each year into five doses applied in August, November, late January, April and July. The control treatment numerically, but not statistically, reduced the potential nitrate pollution of groundwater.

Work Description:

TASK 1: Quantify the Relative Amount of Nitrate and Ammonia Leaching Past the Root Zone of 'Hass' Avocado Trees

The purpose of this task is to quantify the nitrate pollution potential of five nitrogen fertilization strategies in order to identify a BMP for nitrogen fertilization for the 'Hass' avocado in California. The product of this task will be a report summarizing the result of the task.

Subtask 1.1: Quantify the relative amount of nitrate and ammonia leaching past the root zone of 'Hass' avocado trees.

The experimental design was a randomized complete block with 20 individual tree replicates per treatment. There were nine treatments (see Treatment Key below). The application times for extra N were based on the following phenological events: 1) April – anthesis, fruit set and initiation of the spring vegetative flush; 2) August – transition from vegetative to reproductive development, i.e., inflorescence initiation; and 3) November – end of the fall vegetative flush and beginning of flower initiation (Salazar-Garcia et al., 1998). The orchard (17-year-old 'Hass' on Duke 7) was located in Somis, Calif. For nutrient analysis, 40 spring flush leaves from nonfruiting terminals were collected at chest height around each data tree in September of each year. Leaves were immediately taken to UCR, washed thoroughly, oven-dried, ground, and sent to Albion Laboratories or the DANR Analytical Laboratory at UC-Davis for analysis. Harvest data included total kg fruit per tree and kg fruit of each packing carton size per tree. All data were analyzed for statistical significance at $P \leq 0.05$ using SAS.

Treatment Key
N fertilizer rates – N fertilizer was applied to the soil as NH_4NO_3.
(1) Nov. 1996 to Dec. 1998: control trees received four applications at 22.5 kg/ha in August, November, April, and July; trees in the Ranch Practice received 45 kg/ha split in July and August; trees receiving 2x N in August, November in the on year and April in the off year, November or April all received 45 kg/ha total N; trees receiving 3x N applied to the soil received 67 kg/ha; and trees receiving 3x N to the foliage received 112 kg/ha.
(2) Starting Jan. 1999: control trees received five applications at 28 kg/ha in January, April, July, August, and November. Trees in the treatments listed below received 2x N=56 kg/ha or 3x N=84 kg/ha in the months indicated. The amount of N applied in other months was reduced to compensate for the extra N applied so that all trees received 140 kg/ha, except trees in the Ranch Practice, which received only 45 kg/ha split in July and August.
N application time(s) –
1. Ranch Practice, 1.6x N split in July and August
2. 2x N in August
3. 2x N in November (prior to "on" years) and April (during "off" years)
4. 2x N in November
5. 2x N in April and November
6. 2x N in April
7. 3x N in April
8. 3x N in April applied foliarly as low-biuret urea
9. Control

Treatments 1, 3, 5, 7, and 8 listed above were sampled to quantify the amounts of nitrate and ammonium leaching past the root zone. In this case, 10 individual tree replicates per treatment were sampled.

Bags of Dowex 1-X8 anion exchange resin and Dowex 50-W-X8 cation exchange resin were constructed of nylon material. Each bag contained 5 g (dry wt.) resin. The anion and cation resin bags were charged by three successive washes with 0.5 M $NaHCO_3$ or 0.5 M HCl, respectively, centrifuged in a salad spinner, placed in individual Ziploc plastic bags to prevent contamination, and refrigerated at 3-5 ºC until used. Just prior to soil fertilization/irrigation, resin bags (one each of Dowex 1-X8 anion exchange resin and Dowex 50-W-X8 cation exchange resin) were placed at the intersect of the drip-line of the tree and the wetting pattern of the mini-sprinklers on two sides of each of 10 trees by lowering the bags down a PVC pipe (60 mm in diameter, at a 45° angle with the ground) to a depth of 0.9 m. The bags were collected 7 days after N fertilizer application. Each time resin bags were put in place for the treatments, resin bags were placed in the same manner for a set of 10 trees receiving no nitrogen fertilizer at that time. These samples will serve as our field blanks. Collected resin bags were placed in individual, labeled Ziploc plastic bags and taken immediately back to the lab in a coolbox. Collected resin bags were rinsed with deionized water to remove adhering soil and then excess water removed by centrifugation in a salad spinner. Ions were removed by submerging intact bags in 100 ml 2.0 M KCl overnight with shaking followed by filtration through Whatman no. 42 filter paper. Samples of the filtrates were originally sent to Albion Laboratories, Clearwater, UT, for analysis of NH_4^+-N (by combustion followed by infra-red analysis) and NO_3^--N (by automated cadmium reduction, followed by spectrophotometric analysis at 540 nm). However, the sensitivity of these methods were approximately 1.0% (w/w) and 100 mg/L (w/v), respectively, and inadequate for our samples. The samples were then sent to the DANR Analytical Laboratory at UCD and analyzed for NO_3^--N and NH_4^+-N (Wendt, 1999; Switala, 1999). Nitrate is determined by reduction to nitrite via a copper-cadmium column. The nitrite is then determined by diazotizing with sulfanilamide followed by coupling with N-(1-naphthyl)ethlyenediaminie dihydrochloride. The absorbance of the product is measured at 520 nm. Ammonia is heated with salicylate and hypochlorite in an alkaline phosphate buffer. The presence of EDTA prevents precipitation of calcium and magnesium and sodium nitroprusside is added to enhance sensitivity. The absorbance of the reaction product is measured at 630 nm and is directly proportional to the original ammonia concentration. The sensitivity of the method is approximately 0.05 mg/L (w/v) for nitrate and 0.01 mg/L (w/v) for ammonium and is generally reproducible within 7%.

Filtrates analyzed for NH_4^+-N were also be analyzed for total nitrogen and carbon by combustion analysis to quantify the amount of organic matter trapped on the resin bags which would contribute N not originating from the fertilizer applications. This analytical method quantitatively determines the total amount of nitrogen and carbon in a solid sample using a dynamic flash combustion system coupled with a gas chromatographic (GC) separation system and a thermal conductivity detection (TCD) system. The analytical method is based on the complete and instantaneous oxidation of the sample by "lash combustion" which converts all organic and inorganic substances into combustion gases (N_2, NO_x, CO_2, and H_20). The method has a detection limit of 0.02% and is generally reproducible within 5% (Pella, 1990).

Subtask 1.2: Analyze data.

Results of the nitrate and ammonium analyses were used to calculate the amount of nitrate and ammonia leaching past the root zone as a result of the fertilization treatment (corrected for organic matter N) for each year of the experiment. The nitrate and ammonia leaching past the root zone due to each fertilization strategy was determined by comparison to the field blank which was the measurement of endogenous soil nitrate and ammonia (these samples were also analyzed for organic matter N) leaching past the root zone of the avocado trees.

Subtask 1.3: Submit the interim report, interpretative summary and invoice by 6/30/99.

Subtask 1.4: Outreach.

Subtask 1.5: Annual report submitted to CDFA by12/31/99.

TASK 2: Quantify the Relative Amount of Nitrate and Ammonia Leaching Past the Root Zone of 'Hass' Avocado Trees

The purpose of this task is to quantify the nitrate pollution potential of five nitrogen fertilization strategies in order to identify a BMP for nitrogen fertilization for the 'Hass' avocado in California. The procedures used to meet the subtasks in year 1 were used to meet the subtasks in year 2 and thus, are not repeated below. The product of this task will be a report summarizing the result of the task. The report will be submitted to CDFA by 12/31/00.

Subtask 2.1: Quantify the relative amount of nitrate and ammonia leaching past the root zone of 'Hass' avocado trees.

Subtask 2.2: Analyze data.

Subtask 2.3: Submit the interim report, interpretative summary and invoice by 6/30/00.

Subtask 2.4: Outreach.

Subtask 2.5: Final report submitted to CDFA by 12/00. This date was extended to 9/30/02.

Results, Discussion and Conclusions:

Results of the first harvest (1998) indicated that the time of N fertilizer application was more important than the amount of N that was applied ($P \leq 0.06$) (Table 1). The numerically, not statistically, greater yields were obtained for the treatments receiving the lowest rate of N (45 kg/ha), potentially due to proper timing: 2x N in August, Ranch Practice, and 2x N in November (on-year) and April (off-year). Trees receiving the highest rate of N (112 kg/ha as low-biuret urea) to the foliage had the lowest yield. N treatments had no effect on the kg per tree of large-size fruit (packing carton sizes ≥ 60; fruit weighing ≥ 184 g/fruit) (Table 2) but significantly affected the kg of small-size fruit per tree (packing carton sizes 84 and 70; fruit weighing 135 to 163 g/fruit) ($P \leq 0.09$) (Table 3). Supplying N at 45 kg/ha in August significantly increased the kg of small-size fruit per tree compared to trees receiving the same total amount of N split in July and August (Ranch Practice) or applied to the soil once in April and compared to trees receiving urea-N at 112 kg/ha in April to the foliage. The application of different annual amounts of N continued through December 1998 at the request of the California Avocado Commission in order to obtain two years of yield data. The N fertilization rates proposed in the CDFA-FREP project were initiated in January 1999, which was the start of this CDFA-FREP project. Trees in all treatments received N at 140 kg/ha (see Treatment Key, N Fertilizer Rates (2) above). Unfortunately, a freeze occurred in December 1998 resulting in very low yields in 1999 and 2000. N treatments had no effect on yield or fruit size in either year. Time of N application had a significant effect on yield for the harvest of 2001 ($P \leq 0.01$) (Table 1). The better treatments were all due to extra N applied to the soil in November or April. However, these treatments were not significantly better than trees receiving extra N in November and April, August, Ranch Practice or the control, which also received N in November, April and August. N treatments had no effect on the kg per tree of large-size fruit (Table 2). However, 2x N in April significantly increased the kg per tree of small-size fruit compared to trees receiving the Ranch Practice, 2x N November, 2x N in April and November or foliar 3x N (low-biuret urea) in April ($P \leq 0.01$) (Table 3). Other N treatments were intermediate in their effect on the kg per tree of small-size fruit. Time of N application had a significant effect on yield for the harvest of 2002 ($P \leq 0.10$) (Table 1). However, the better yielding trees in 2002 were those with the lowest yields in 2001 (this included the control). N treatments had no effect on fruit size in 2002.

Trees receiving 3x N (84 kg/ha) in April had the highest 2-year (2001 plus 2002) cumulative yield. For the five years of the study, treatments that significantly increased yield had no significant effect on fruit size. In general, trees with the most fruit had the greatest number of large-size (Fig. 1) and small-size fruit (Fig. 2).

Due to the effect of the freeze on the yields for 1999 and 2000 and the effect of the resulting alternate bearing on the yields for 2001 and 2002, two additional years of yield data are required to identify the best N fertilization strategy for maximizing yield of commercially valuable large-size fruit and reducing alternate bearing of the ‘Hass’ avocado. Additional years of yield data are also necessary to determine if the Ranch Practice of applying only 45 kg N/ha split in July and August will sustain yields equal to that of the control and to determine the utility of foliar applied 3x N as low-biuret urea. This treatment had the lowest yield in 2001 and the highest yield in 2002. It might simply be out of synchrony with regard to alternate bearing.

Time of N application had no significant effect on the number of sylleptic or proleptic shoots produced annually (Table 4). The proleptic shoot type, a generally less productive shoot, dominated the new shoots produced each spring by more than 3-fold. N treatments had no effect on the productivity of sylleptic or proleptic shoots. N treatments had a significant effect ($P=0.06$) on the number of inflorescences produced by sylleptic shoots but inflorescence number was not consistently related to yield. The proportion of proleptic versus sylleptic shoots produced was not related to alternate bearing. Nitrogen treatments significantly ($P \leq 0.05$) affected tree N status in some years as indicated by standard leaf analysis of spring flush leaves collected in September. However, there was no significant correlation between tree N status and yield the following year (Fig. 3) or tree N status and yield the same year (Fig. 4).

The failure of leaf N to correlate with yield has been reported previously (Embleton et al., 1968; Embleton and Jones 1972; Lovatt, 2001). There are several reasons why leaf N may not correlate with yield. Another nutrient might be in low supply and thus, limit yield at the higher rates of N fertilization. Another possibility is the time of leaf sampling for nutrient analysis relative to the time of the last fertilizer application. If fertilizer was applied in July and/or August before leaves were collected in September, one would expect these trees to have high leaf N concentrations relative to those trees receiving their last application of N fertilizer earlier in the year, independent of yield. Moreover, the N fertilization experiments to date have all been conducted in alternate bearing orchards

(Embleton et al., 1968; Embleton and Jones 1972; Lovatt, 2001). Any treatment that affected yield in a given year altered the degree of alternate bearing of the trees receiving that treatment relative to other treatments. Not only yield was affected. The amount of vegetative growth the tree produced and the amount of stored N the tree used or conserved was affected. Thus, it is not unexpected that yield is not related to leaf N concentration.

The amounts of nitrate leaching past the root zone were not significantly affected by the treatments on any sampling date or in any year (Table 5), despite the fact that yields were very different in 2000 vs. 2001. The results suggest that 'Hass' avocado trees do not take up sufficiently more N when producing a heavy on-year crop to significantly impact the amount of nitrate leaching past the root zone, at least for the N fertilization rate used in this research. All trees received some portion of their annual N during the month being sampled and all trees received the same amount of total N annually. However, it is clear that when higher doses of N were applied in a given month, higher amounts of N leached passed the root zone for that sampling date. Moreover, dividing the total amount of N applied annually into five small doses resulted in a numerical, but not statistically significant, reduction in the amount of N leaching past the root zone, reducing the potential for nitrate pollution of the groundwater. The amounts of ammonium leaching past the root zone were low and not significantly affected by the N treatments (Table 6).

The treatments producing the three numerically, but not statistically, greater cumulative yields for the 2001 plus 2002 were the soil application of 3x N in April > the control > application of 2x N in November. No treatment significantly affected potential nitrate pollution of groundwater. The phenological stages producing numerically greater yields in response to N fertilization in this study are those identified in our previous study (Lovatt, 2001). The optimal application times for extra N corresponded to the following phenological events: 1) April – anthesis, fruit set and initiation of the spring vegetative flush and 2) November – end of the fall vegetative flush and beginning of flower initiation (Salazar-Garcia et al., 1998). In this study we incorporated these application times into the control, so the control in this study was receiving single doses of N at the optimal stages of avocado tree phenology. The control treatment numerically, but not statistically, reduced the potential for nitrate pollution of groundwater. Due to the freeze and resulting alternate bearing, no treatment was significantly better than another. A minimum of two additional years of yield data is required before an N fertilization recommendation can be made for the 'Hass' avocado in California. The additional years of yield data are necessary to calculate the benefit of the individual fertilization strategies relative to their cost to the environment. At present, without additional data, growers should be encouraged to split their total amount of N fertilizer applied each year into five doses applied in August, November, late January, April and July. These application times correspond to the following phenlogical stages: (1) August – transition from vegetative to reproductive development, i.e., inflorescence initiation; (2) November – end of vegetative shoot growth, shoot apices have approximately four of the 10 secondary axes of the inflorescence present, additional secondary axes are being initiated early; (3) January – "bud swell" – the total number of secondary axes (10) of the inflorescence are formed, the oldest are beginning to elongate and to initiate flower organs; (4) anthesis-early fruit set and initiation of the spring vegetative flush at the apex of indeterminate floral shoots (April); and (5) July – beginning of Stage II of fruit development (rapid increase in fruit size) and end of the June drop period (Salazar-Garcia and Lovatt, 1998). This treatment had the lowest potential for nitrate pollution of groundwater.

Project Evaluation:

There is no impediment to adoption of the control treatment, which incorporates the best phenological stages for providing nitrogen to the 'Hass' avocado and numerically, but not statistically, reduces the potential for nitrate pollution of groundwater. Avocado growers in California are use to dividing their total annual amount of N into small doses and have been seeking guidance as to the best time with regard to the phenology of the tree to apply their N. Since in this experiment applying double doses of N at key stages in the phenology of the 'Hass avocado tree was not significantly better than applying a single dose of N at key phenological stages in increasing yield and fruit size or in reducing alternate bearing, growers will likely cease applying double doses of N in April, August or November. We have always been reluctant to advise avocado growers to applying 2x N in April. This trepidation is reinforced by this research since the data from this study suggests that 3x N in April might be required in some orchards. Furthermore, a statement was made by Dr. Ben Faber at the UCR-CAC Annual Symposium on October 25, 2002, that the November 2x N application might increase the fall vegetative shoot flush and thus, increase the over-wintering population of avocado thrips, resulting in a greater population of thrips in spring and more damage and economic loss. This needs to be investigated further.

It is unfortunate that the freeze reduced yield dramatically for two of the five years of the study and left the trees in alternate bearing for the final two years of the study. This situation makes it impossible to know whether or not the Ranch Practice of providing 45 kg/ha split in July and August provides sufficient N to sustain yields equal to the control over a five year-period or whether foliar application of low-biuret urea can replace a significant portion of soil-applied N to sustain avocado yield and fruit size. At present it is unclear if this treatment reduces yield in some years or if the trees in this treatment are simply out of synchrony from other trees in the experiment, except the control trees, with regard to alternate bearing.

We are dedicated to obtaining useful information from this project. To that end we continued this research this past year without funding in order to obtain yield data for a second "normal" crop after the freeze. Because the results of an additional two years of yield data are needed to confirm the N best management fertilizer practice for the 'Hass' avocado in California, we will seek funding from other sources. We thank the CDFA-FREP for the no cost extension that enabled us to obtain the yield data for the 2001 and enabled us to include the yield data for the 2002 harvest at the end of August in this report.

Outreach activities summary:

The PI presented talks to avocado growers and the California Avocado Commission and California Avocado Society Production Committee in July 1999, 2000, and 2001; to avocado growers in Temecula on June 29, 2000, and to Mission avocado growers in Pauma Valley on June 28, 2002. A poster with the final results of this research was presented to avocado growers at the UCR-CAC Annual Avocado Symposium at UCR on October 25, 2002. These outreach presentations were to introduce industry people and growers to both the potential nitrate pollution problem associated with the nitrogen fertilization strategies and research we were conducting as part of this CDFA-FREP project to address the problem. Over the past years, results were presented as they become available. The PI's graduate student presented the results at the International Horticultural Congress in Toronto, Canada, in August 2002. The results will be presented at the California Department of Food and Agriculture's 2002 Fertilizer Research and Education Program Conference, Tulare, CA, November 19, 2002.

Literature cited:

Embleton, T.W. and W.W. Jones. 1972. Development of nitrogen fertilizer programs for California avocados. Calif. Avocado Soc. Yrbk. 56:90-96.

Embleton, T.W., W.W. Jones, M.J. Garber, and S.B. Boswell. 1968. Nitrogen fertilization of the Hass avocado. Calif. Avocado Soc. Yrbk. 52:131-134.

Lovatt, C.J. 2001. Properly timed soil-applied nitrogen fertilizer increases yield and fruit size of ‘Hass’ avocado. J. Amer. Soc. Hort. Sci. 126:555-559.

Pella, E. 1990. Elemental organic analysis: part 2: state of the art. American Laboratory. Aug. 22:28-32.

Salazar-Garcia, S., E.M. Lord, and C.J. Lovatt. 1998. Inflorescence and flower development of the ‘Hass’ avocado (*Persea americana* Mill.) during “on” and “off” crop years. J. Amer. Soc. Hort. Sci. 123:537-544.

Switala, K. 1999. Determination of Ammonia by Flow Injection analysis. QuikChem Method 10-107-06-1-A. Lachat Instruments, Milwaukee, WI.

Wendt, K. 1999. Determination of Nitrate/Nitrite by Flow Injection Analysis (Low Flow Method). QuikChem Method 10-107-04-1-A. Lachat Instruments, Milwaukee, WI.

Table 1. Effect of nine nitrogen fertilization strategies on the yield of 'Hass' avocado trees harvested from 1998 to 2002.[z]

	Year[y]				
Treatment[y]	1998	1999	2000	2001	2002
	kg/tree				
1.6x N Ranch practice	32.1 a	18.2	13.1	85.2 ab	46.1 ab
2x N in August	33.4 a	17.1	13.0	81.1 ab	31.5 b
2x N in November (on), April (off)	30.9 a	18.4	11.4	91.0 a	39.8 ab
2x N in November	28.3 ab	20.2	7.7	91.8 a	35.9 ab
2x N in April/November	26.7 ab	16.9	12.7	80.7 ab	37.7 ab
2x N in April	25.8 ab	19.1	12.3	98.4 a	31.0 b
3x N in April	26.6 ab	22.0	13.1	94.6 a	41.4 ab
3x N in April, foliar	19.2 b	20.2	8.5	67.8 b	58.6 a
Control	26.7 ab	22.4	17.7	79.4 ab	55.0 a
P-value	0.06	NS	NS	0.01[x]	0.10

[z] Values in a vertical column followed by different letters are significantly different at specified *P* levels by Duncan's Multiple Range Test.

[y] Grower's fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. From November 1996 to December 1998 trees received N as NH_4NO_3 at 45 kg/ha (for treatments 2x N in August; 2x N in November on-year and April off-year; 2x N in November; and 2x N in April); 67 kg/ha (3x N in April); 90 kg/ha (2x N in April and November; and Control); or 112 kg/ha (3x N in April, foliar). Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

[z] Removal of trees that did not recover from the freeze until 2002 resulted in a *P*-value different from that reported previously.

Table 2. Effect of nine nitrogen fertilization strategies on the yield of large-size fruit (carton sizes 60+48+40+36+32) of 'Hass' avocado trees harvested from 1998 to 2002.[z]

	Year[y]				
Treatment[y]	1998	1999	2000	2001	2002
	kg/tree				
1.6x N Ranch practice	29.7	9.7	12.1	59.6	45.0
2x N in August	28.2	9.4	12.0	52.0	30.9
2x N in November (on), April (off)	27.0	11.3	10.2	57.9	39.2
2x N in November	25.0	11.3	7.4	65.7	35.3
2x N in April/November	23.5	10.3	11.2	53.4	36.8
2x N in April	22.4	11.2	10.8	55.2	29.9
3x N in April	23.2	13.4	12.1	64.5	40.7
3x N in April, foliar	17.9	11.2	7.8	58.3	57.3
Control	23.9	13.7	15.7	49.5	52.3
P-value	NS	NS	NS	NS	NS

[z] Values in a vertical column followed by different letters are significantly different at the specified *P* level by Duncan's Multiple Range Test.

[y] Grower's fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. From November 1996 to December 1998 trees received N as NH_4NO_3 at 45 kg/ha (for treatments 2x N in August; 2x N in November on-year and April off-year; 2x N in November; and 2x N in April); 67 kg/ha (3x N in April); 90 kg/ha (2x N in April and November; and Control); or 112 kg/ha (3x N in April, foliar). Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

Table 3. Effect of nine nitrogen fertilization strategies on the yield of small-size fruit (carton sizes 84+70) of ‘Hass’ avocado trees harvested from 1998 to 2002.[z]

	Year[y]				
Treatment[y]	1998	1999	2000	2001	2002
	kg/tree				
1.6x N Ranch practice	2.4 b	8.4	1.0	25.7 b	1.0
2x N in August	5.2 a	7.7	1.0	29.1 ab	0.7
2x N in November (on), April (off)	3.9 ab	7.8	1.2	33.1 ab	0.6
2x N in November	3.3 ab	9.0	0.3	24.4 b	0.5
2x N in April/November	3.2 ab	6.6	1.5	26.0 b	0.9
2x N in April	2.0 b	8.3	1.2	43.2 a	1.0
3x N in April	3.4 ab	8.6	1.0	30.1 ab	0.6
3x N in April, foliar	1.4 b	9.0	0.7	9.5 c	1.3
Control	2.8 ab	8.7	1.9	29.9 ab	2.7
P-value	0.09	NS	NS	0.01	NS

[z] Values in a vertical column followed by different letters are significantly different at specified *P* levels by Duncan’s Multiple Range Test.

[y] Grower’s fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. From November 1996 to December 1998 trees received N as NH_4NO_3 at 45 kg/ha (for treatments 2x N in August; 2x N in November on-year and April off-year; 2x N in November; and 2x N in April); 67 kg/ha (3x N in April); 90 kg/ha (2x N in April and November; and Control); or 112 kg/ha (3x N in April, foliar). Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

Table 4. Effect of nine nitrogen fertilization strategies on the percentage of sylleptic and proleptic shoots of 'Hass' avocado trees in 2001 and 2002.[z]

	2001		2002	
Treatment[y]	Sylleptic	Proleptic	Sylleptic	Proleptic
	%			
1.6x N Ranch practice	21.1	78.9	24.7	75.3
2x N in August	24.0	76.0	23.7	76.3
2x N in November (on), April (off)	34.0	66.0	23.0	77.0
2x N in November	25.3	74.7	25.2	74.8
2x N in April/November	24.2	75.8	28.2	71.8
2x N in April	28.0	72.0	22.8	77.2
3x N in April	25.6	74.4	23.3	76.7
3x N in April, foliar	23.0	77.0	25.7	74.3
Control	20.0	80.0	22.9	77.1
P-value	NS	NS	NS	NS

[z] Values in a vertical column followed by different letters are significantly different at the specified *P* level by Duncan's Multiple Range Test.

[y] Grower's fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

Table 5. Effect of application time for the double dose of N vs. control on nitrate leaching past the root zone from April through November in 2000 and 2001.[z]

Treatment[y]	2000 Apr.	2000 Aug.	2000 Nov.	2000 Cumulative total	2001 Apr.	2001 Aug.	2001 Nov.	2001 Cumulative total	2-year cumulative total
	µg NO_3^-/5 g resin								
2x N in August	1185	n/a	3833	5018	7339	776	544	8655	13673
2x N in November	4808	n/a	1043	5850	2051	10148	2449	14648	20498
Control	1064	n/a	1465	2530	1050	1250	2405	4701	7231
3x N in April	1789	n/a	7868	9656	2693	2899	1688	7277	16933
2x N in April	7920	n/a	619	8539	1009	1485	551	3047	11586
P-value	NS	n/a	NS	NS	NS	NS	NS	NS	NS

[z] Values in a vertical column followed by different letters are significantly different at the specified *P* level by Duncan's Multiple Range Test.

[y] Grower's fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

Table 6. Effect of application time for the double dose of N vs. control on ammonia leaching past the root zone from April through November in 2000 and 2001.[z]

Treatment[y]	2000 Apr.	2000 Aug.	2000 Nov.	2000 Cumulative total	2001 Apr.	2001 Aug.	2001 Nov.	2001 Cumulative total	2-year cumulative total
	µg NH_4^+/5 g resin								
2x N in August	633	n/a	84	717	236	330	102 ab	669	1386
2x N in November	412	n/a	71	483	331	95	119 a	544	1027
Control	1226	n/a	65	1290	235	67	101 ab	402	1690
3x N April	401	n/a	99	500	201	162	75 b	438	939
2x N in April	416	n/a	118	533	257	95	119 a	471	1004
P-value	NS	n/a	NS	NS	NS	NS	0.08	NS	NS

[z] Values in a vertical column followed by different letters are significantly different at the specified *P* level by Duncan's Multiple Range Test.

[y] Grower's fertilization (Ranch) practice is N as NH_4NO_3 at 45 kg/ha applied to the soil as a split application in July and August for all years of the experiment. Starting in January 1999 control trees received N as NH_4NO_3 at 140 kg/ha annually, divided into five applications of N at 28 kg/ha in August, November, January, April, and July. Trees in all other treatments received NH_4NO_3 applied as 2x N= N at 56 kg/ha or 3x N=N at 84 kg/ha in the months indicated. The total N applied in any treatment is 140 kg/ha; the amount of N applied in other months is reduced to compensate for the extra N applied in the month(s) specified for the treatment.

Figure 1. Effect of nine nitrogen fertilization strategies on the yield of large-size fruit (carton sizes 60+48+40+36+32) of ‘Hass’ avocado trees for 4 years of the study.

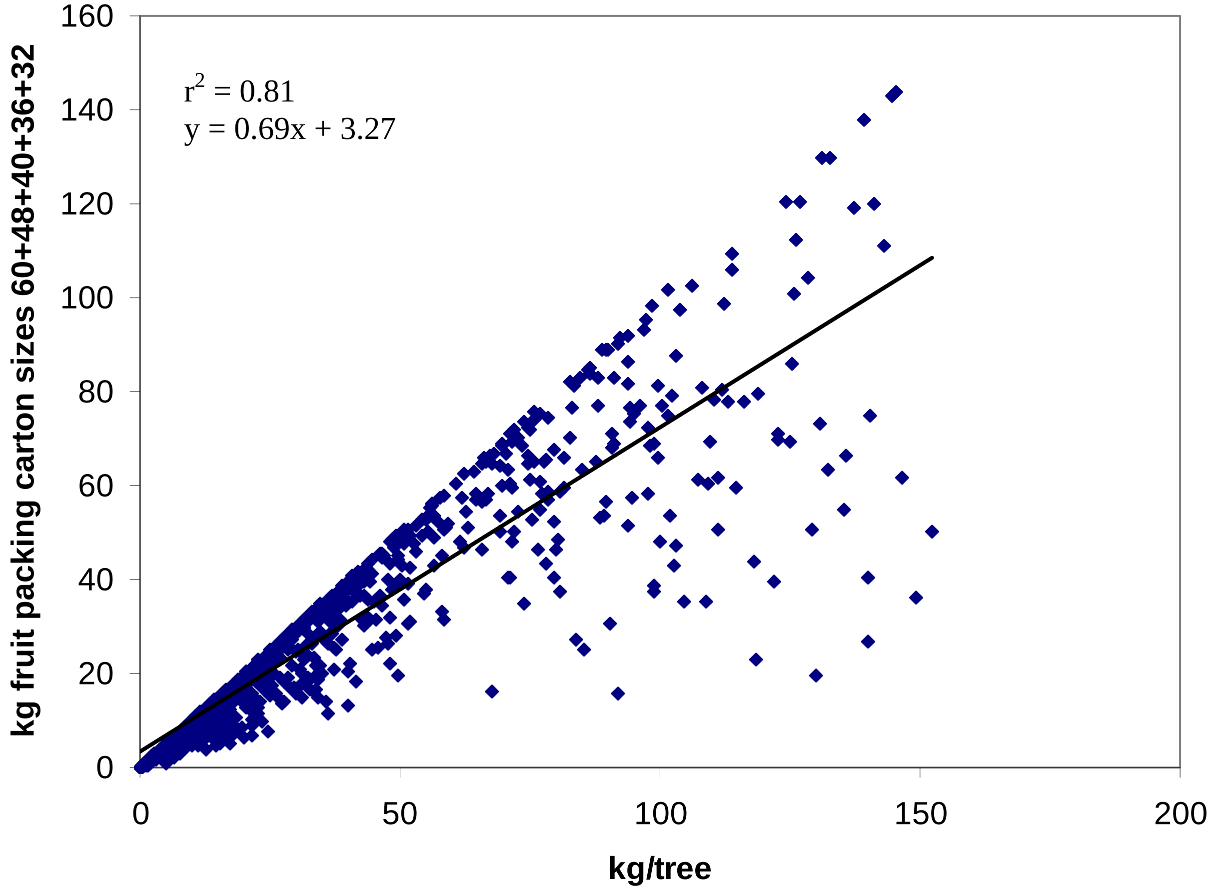

Figure 2. Effect of nine nitrogen fertilization strategies on the yield of small-size fruit (carton sizes 84+70) of ‘Hass’ avocado trees for 4 years of the study.

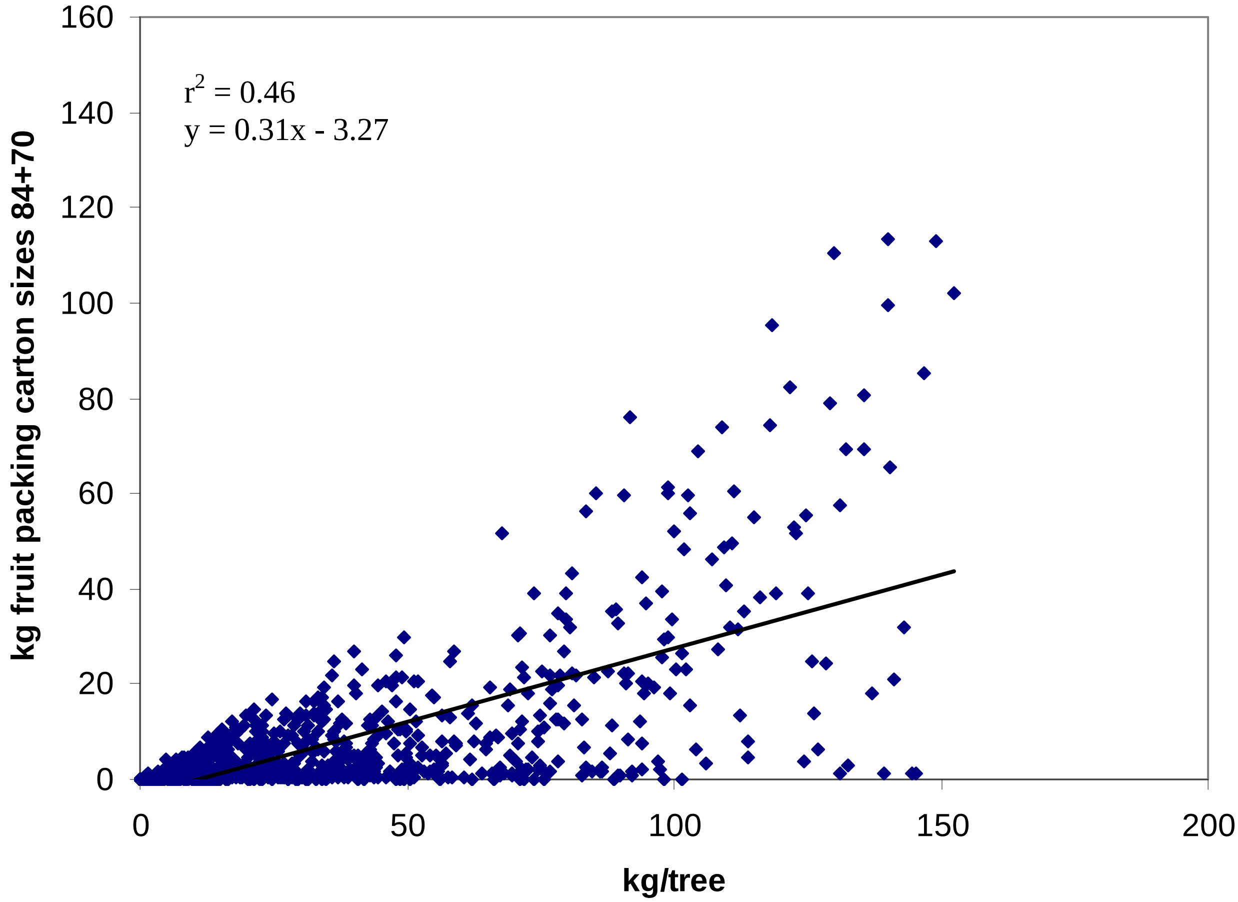

Figure 3. Leaf nitrogen concentration (%) vs. total kg fruit/tree harvested the year following the September leaf analyses for 4 years of the study.

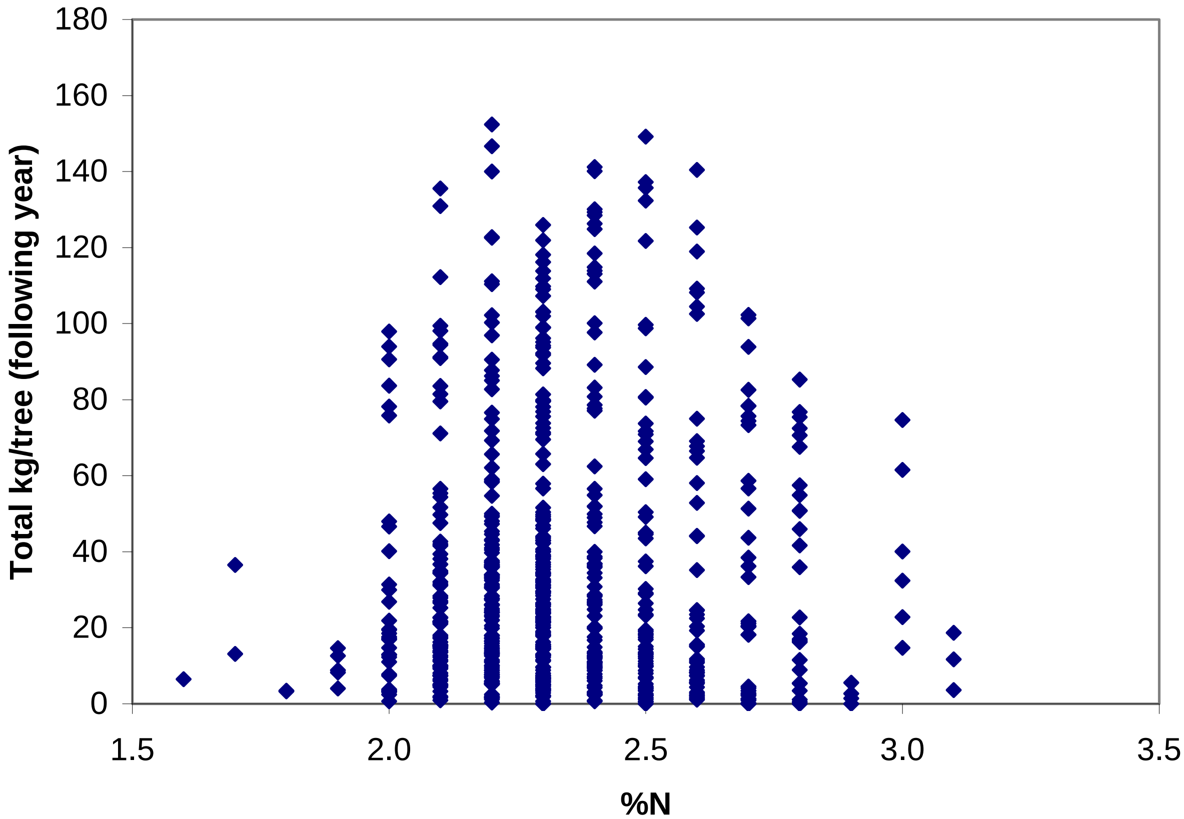

Figure 4. Leaf nitrogen concentration (%) vs. total kg fruit/tree harvested the same year as the September leaf analyses for 3 years of the study.