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ANNUAL REPORT TO THE ALMOND BOARD OF CALIFORNIA

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Nitrogen on Drip Irrigated Almonds

by

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Objectives: (1) To evaluate the effects of different nitrogen rates applied at two water levels on growth, nutrient concentrations in leaves and twigs, and nut yields of almonds. (2) To assess the extent of soil acidification from nitrogen application under drip emitters. (3) To evaluate the effects of two rates of potassium on growth, nutrient concentrations in leaves and nut yields. (4) To develop recommendations for nitrogen, irrigation and soil management for use in the establishment and early maturity stages of almond orchards. (5) Evaluate changes in nutrient movement in drip zone as a result of acidification, leaching and nutrient uptake.

Problem and its Significance: Drip irrigation is a unique method of providing water to trees which makes for a number of challenging management situations. Having a relatively small volume of soil being used as the reservoir for water and nutrient uptake which is saturated a high percent of the time during the summer provides a setting for several unusual chemical reactions in the soil. The use of an acidifying nitrogen fertilizer such as urea increases the solubility of toxic elements like manganese and aluminum. Nitrates may be leached below the root zone immediately below the drip emitter if excess water is applied. Denitrification may also be occurring at a rather rapid rate which could result in reduced nitrogen efficiency by the crop. The rapid growth rate and high yields brought about by the high nitrogen applications has resulted in marginal leaf potassium levels. This raises the question, will almonds respond to added potassium applied through the drip system? Almond yields were nearly the same for the three highest nitrogen rates in 1988 and the four highest rates in 1989, 1990 and 1991, even with lower applied nitrogen rates in 1989, 1990 and 1991, pointing out that once the trees reach mature size the requirements for nitrogen are somewhat reduced. Because the answers to a number of these questions are still unknown, this project was initiated and the continuing challenges will allow for the development of solutions so that growers can manage fertilizer application through drip irrigation systems to achieve profitable as well as environmentally sound almond production.

Interpretive Summary: The orchard was planted on the Nickels Soils Laboratory in the spring of 1981 to three almond varieties--Butte, Carmel and Nonpareil on a 12' X 18' spacing (202 trees/A). In the spring of 1982, five-5 tree plots were selected from each of the four-28 tree rows of each variety to which the two replications of the ten treatments were assigned. The ten treatments included two water levels- 0.6 and 1.0 of evapotranspiration (ET) each with five nitrogen rates-0, 0.5, 1.0, 1.5 and 2.0 oz/tree in 1982; 0, 0.8, 1.7, 3.5 and 7.0 oz/tree in 1983;

0, 2, 4, 8 and 16 oz/tree in 1984; 4, 8, 16, 24 and 32 oz/tree in 1985; 6, 12, 24, 36 and 48 oz/tree in 1986; 8, 16, 32, 48 and 64 oz/tree in 1987 and 1988; 6, 12, 24, 36 and 48 oz/tree in 1989; and 4, 8, 16, 24 and 32 oz/tree in 1990 and 1991. Rates planned for 1992 are 4, 8, 16, 24 and 32 oz/tree. Urea is the nitrogen fertilizer source and it is applied on a monthly basis in five (6 in 1986-89) equal increments beginning April 1st. The 1.0 ET irrigation level is based on climatic data and visual observation to maintain active tree growth. The 0.6 ET treatments receive 60% of the water quantity of the 1.0 ET treatments.

Yield results for the 1991 season were slightly higher than in 1990 with five plots having yields greater than 3500 and 11 plots (out of 60) greater than 3000 meat lbs/A. The lowest plot yield was 1429 and the highest was 3954. There was an increase in yield from the lowest nitrogen rate (4 oz) to the third rate (16 oz) with a leveling off or a trend for a decrease at the highest rate (32 oz per tree) at the 1.0 ET irrigation level. Yields for the 0.6 ET irrigation level showed nearly the same or a trend towards lower yields as nitrogen rates increased. The yield differences between the 0.6 and 1.0 ET irrigation levels were nearly 600 meat lbs/A for the three highest nitrogen rates (Figure 14). The Carmel variety which has been more consistent in its yield response to higher rates of nitrogen at the 1.0 ET water level again showed this response in 1991 with equal to slightly declining yields with increasing nitrogen rates at the 0.6 ET water level. The yield difference between the two water levels at the highest nitrogen rate was about 1400 meat lbs/A. The Nonpareil variety showed somewhat the same response as the Carmel except that the yields decreased at the two higher nitrogen rates at the 1.0 ET water level. Yields for the Butte variety were no different for the two water levels and increased from the 4 to 16 oz/tree rate and then declined slightly at the 32 oz/tree nitrogen rate.

Since a review of the work done during the current year is usually included in each annual report and objective 5 addresses a longer time period, a more complete discussion will be presented for "developing recommendations for nitrogen and irrigation during establishment and early maturity stages of almond orchards". During the fourth season of tree growth (1984), excellent meat yields were recorded. Figure 1 indicates average yields of approximately 700 up to 1300 meat lbs/A for the 0 and 16 oz/tree nitrogen rates respectively. An average of about 100 meat lbs/A greater yield was recorded for the 1.0 ET irrigation level. In 1985, the fifth year of growth, yields were from about 700 up to 1900 meat lbs/A for the 4 to 32 oz/tree nitrogen rates (Figure 2). At the three higher N rates the 1.0 ET irrigation level gave approximately 200 meat lbs/A greater yield. The 1986 meat yields were about 700 lbs/A for the 6 oz N/tree rate up to about 1800 lbs/A for the 48 oz N/tree rate (Figure 3). Little if any differences between irrigation levels were observed at the five nitrogen rates. Meat yields in 1987 averaged from about 1700 lbs/A up to 3000 lbs/A for the 8 and 64 oz/tree nitrogen rates respectively (Figure 4). In 1988, meat yields were about 1300 lbs/A for the 6 oz N/tree rate and increased up to about 2200 lbs/A for the 32, 48 and 64 oz/tree nitrogen rates (Figure 5). Very little if any difference between irrigation levels was observed. Figure 6 illustrates the 1989 meat yields which show no increase in meat yield at the 0.6 ET irrigation level as the nitrogen rate is increased from 6 to 48 oz N/tree. At the 1.0 ET irrigation level however, meat yields rose from about 2300 up to about 3200 lbs/A respectively for the lowest (6 oz N/tree) to the higher three nitrogen rates (24, 36 and 48 oz N/tree). In 1990, yields increased from about 2000 up to 2400 and 2900 respectively for the 0.6 and 1.0 ET water levels for the three lowest nitrogen rates (4, 8 and 16 oz/tree) and then leveled off or showed a trend for decreasing yields (Figure 13). The 1991 yields showed a very similar pattern to those of 1989 (Figure 14 versus 6).

The easiest, most effective and economical way for growers to assess the nitrogen status of almonds is by the use of leaf analysis with a July (1st week) leaf sampling for total nitrogen concentration. Figure 7 gives the leaf nitrogen concentration throughout the 1984 growing season for samples taken the first several days of each month. Note that only the 16 oz N/tree rate is above the recommended 2.2% nitrogen level on July 6th and that meat yields increased with more applied N and were the highest at the 16 oz/tree nitrogen rate. The leaf nitrogen levels for 1985 are given in Figure 8 and show that only the highest (32 oz/tree) nitrogen rate is above 2.2% on July 3rd. Note however that both the 16 and 24 oz N/tree rates are very close to the 2.2% level but have significantly lower meat yields. The 1986 leaf nitrogen levels on July 7th for the 24, 36 and 48 oz/tree nitrogen rates are all near or just slightly above 2.2% and the meat yields are likewise very similar (Figure 9). In 1987, the nitrogen levels for the three higher nitrogen rates were again nearly the same and all three significantly greater yields than the two lower nitrogen rates (8 and 16 oz N/tree) which had below 2.2% leaf N levels (Figure 10). Almost the same situation occurred in 1988 (Figure 11) as was observed in 1987. Figure 12 illustrates the changes in leaf nitrogen levels in 1989 where the four higher nitrogen rates had nearly the same yields. The three highest nitrogen rates had leaf levels above 2.3% whereas the 12 and 6 oz N/tree rates were just at or slightly below 2.2%. Figure 15 indicates that leaf N levels greater than 2.5% were required to achieve high yields in 1990 whereas Figure 16 shows levels higher than 2.3% were necessary in 1991. These figures indicate that it is doubtful that yields will increase when leaf nitrogen levels are above 2.5% during the first week in July sampling. A summary of the leaf nitrogen level for the first week in July, the nitrogen rate to achieve that N level and the meat yield (lbs/A) for each year is given in the table below.

Year	Nitrogen Level (%)	Nitrogen Rate (oz/tree)	Optimum Yield (lbs/A)
1984	2.2	16	1375
1985	2.2	32	1850
1986	2.2	24 - 36	1800
1987	2.5	32 - 48	3100
1988	2.3	32 - 48	2300
1989	2.4	24 - 36	3000
1990	2.5	16 - 24	2750
1991	2.4	16 - 24	2800

Discussion: Evaluation of individual year or accumulative yields to arrive at practical nitrogen rates growers could consider applying might at first glance suggest the use of the highest rate utilized in this experiment. This is particularly true for the first two years of meat harvests (1984 - 1985) and the first five years of orchard establishment. More careful study of the yield results for 1986 and later years indicates that the two highest nitrogen rates in 1986 and the three highest rates in 1987 through 1991 (high water level in 1989-91) gave nearly the same yields in each year. Yields results for 1986 through 1988 show nearly the same yield for the two water levels. In 1989, yields were nearly the same for the four highest nitrogen rates. The yield trends in 1990 were similar to those in 1989 with the 0.6 ET water level showing only a slight increase from 4 to 16 oz N/tree rates but decreasing thereafter while the 1.0 ET water level indicated that yields increased from 2000 to 3000 meat lbs/A for the first three rates of applied nitrogen, 4, 8 and 16 oz/tree (50, 100 and 200 lbs N/A) with little or no increase for the two highest rates, 24 and 32 oz/tree. Yields in 1991 were nearly identical to those in 1989 with the only increase in yields for the lowest three rates at the 1.0 ET water level. Note that rates used in 1990 and 1991 are one half those used during 1987 and 1988, a period (along with previous years) when substantial nitrogen was being utilized to grow the trees as well as produce the large meat yields. Yields in the 3000 to 3500 meat lbs/A range would remove approximately 150 to 180 lbs N/A meaning that the recovery of the two highest nitrogen fertilizer rates 24 and 32 oz/tree or 300 and 400 lbs N/A would be about 40 to 50% (150/300 X 100 = 50%, 160/400 X 100 = 40%). For the 16 oz/tree or 200 lbs N/A fertilizer rate the recovery would be of the order of 75 to 80% (150/200 X 100 = 75% or 160/200 X 100 = 80%), thus the yield for this middle rate can be expected to decrease further during the coming years because of the difficulty of maintaining a 70 to 80% nitrogen recovery. Another very interesting tree growth parameter observed last winter was the lack of adequate new shoot growth. In past years the amount, both the number and length of new shoot growth has had a strong relationship to the rate of nitrogen applied, that is, more shoot growth associated with higher nitrogen application rates. The lack of much shoot growth would suggest that excessive rates are not being applied or that slight periods of water stress resulted in this phenomenon.

This suggests that high nitrogen rates can be utilized by almonds during the early growth and development of the tree which also has a varying need for nitrogen to produce large kernel yields. After the tree structure has been developed, the need for nitrogen is not as large with the major portion going into the kernels and a lesser portion going into the development of new fruiting wood. Another very important point to remember is that higher rates of nitrogen fertilizer will not be effectively utilized unless adequate amounts of irrigation water are applied. Note particularly the decrease in 0.6 ET irrigation level yields in 1989 (Figure 6) and 1991 (Figure 14) with higher nitrogen rates. Thus if for any reason water supplies might be limiting such as during a drought year, applying a rate slightly below the "full" rate would be advisable. On the other hand, excessive irrigation water applications should be avoided so that nitrogen in the form of nitrate will not be leached below the tree root zone and potentially reach the groundwater.

The nitrogen source trial initiated in 1986 has ten treatments: (1) calcium nitrate annually, (2) calcium nitrate alternated yearly with urea, (3) urea-ammonium nitrate solution 32 annually, (4) N-phuric (urea-sulfuric acid) annually and (5) through (10) urea annually with different ameliorative treatments such as lime after acidification of the soil. Soil samples taken the summer of 1988 indicated that the degree of soil acidification was nearly the same for all sources of nitrogen fertilizer used. This could be due in part to the earlier use of urea (prior to 1986) which had acidified the soil to a large extent. The soil samples did show that even though considerable acidification had occurred, the $Ca(NO_3)_2$ treatments were showing some ameliorating effect. Plans are to take soil samples to reassess the degree of acidification prior to the application of different lime, gypsum and perhaps potassium hydroxide treatments during 1992.

Plans for 1992 include continuing to take monthly leaf samples, nut yields, relative kernel, shell and hull weights, dormant season twig sampling and trunk diameter measurements. Measurement of any yield response to the potassium applications initiated during 1989 and continued in 1990, 1.5 and 2.0 lbs K_2O/tree respectively, will be of interest. No additional potassium was applied in 1991 nor is any planned for 1992.

The approval of a complimentary proposal from the California Department of Agriculture Fertilizer Research and Education Program in 1992 will provide resources to assess the extent of nitrate leaching for several of the intermediate rates as well as resample the lowest and highest rates of applied nitrogen. Sampling in 1985 and 1989 of the lowest rate revealed very little, if any nitrate movement below the root zone. Nitrate concentrations in the soil under the emitter of the highest nitrogen rate were quite high (>50 ppm at 6.0-6.5 ft depth) in 1989, suggesting considerable nitrate movement below the root zone. Sampling the three intermediate rates of nitrogen after 10 years of known fertilizer application history will provide an understanding of which rate (or rates?) can maximize meat yields and yet not contribute significantly to nitrate movement below the root zone and potentially to the groundwater. It is important to learn at which rate(s) of applied nitrogen significant potential contributions of nitrates to the groundwater might occur.

Suggestions/Recommendations: The easiest, most effective and economical way for growers to assess the nitrogen status of almonds is by the use of leaf analysis with a July (1st week) leaf sampling for total nitrogen concentration. Nitrogen levels in the 2.2 to 2.5% range for leaf samples taken the first week in July have consistently resulted in optimum and near maximum meat yields. After observing the large differences in leaf potassium concentrations during the early growing season followed by nearly the same levels being reached by July 1st, it seems advisable for growers to consider taking leaf samples several times during the year, near April 1 and near July 1 from at least three areas within a field. The three areas should represent low, medium and high producing portions of the field and if leaf analysis indicate large differences in potassium or other nutrients in the early season samples it may indicate an approaching deficient situation.

Another very important point to remember is that higher rates of nitrogen fertilizer will not be effectively utilized unless adequate amounts of irrigation water are applied. Thus if for any reason water supplies might be limiting say during a drought year, applying a rate slightly below the "full" rate would be advisable. On the other hand, excessive irrigation water applications should be avoided so that nitrogen in the form of nitrate will not be leached below the tree root zone and potentially reach the groundwater.

Figure 1. Almond meat yields in 1984 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

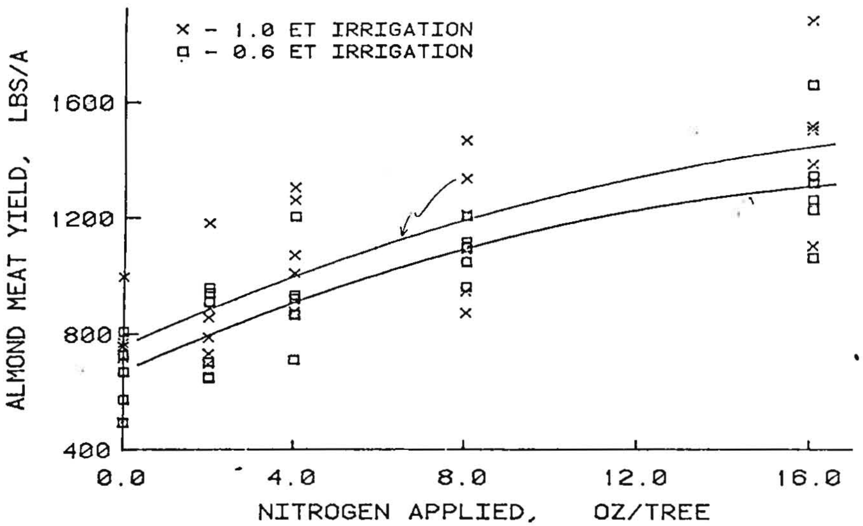

Figure 2. Almond meat yields in 1985 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

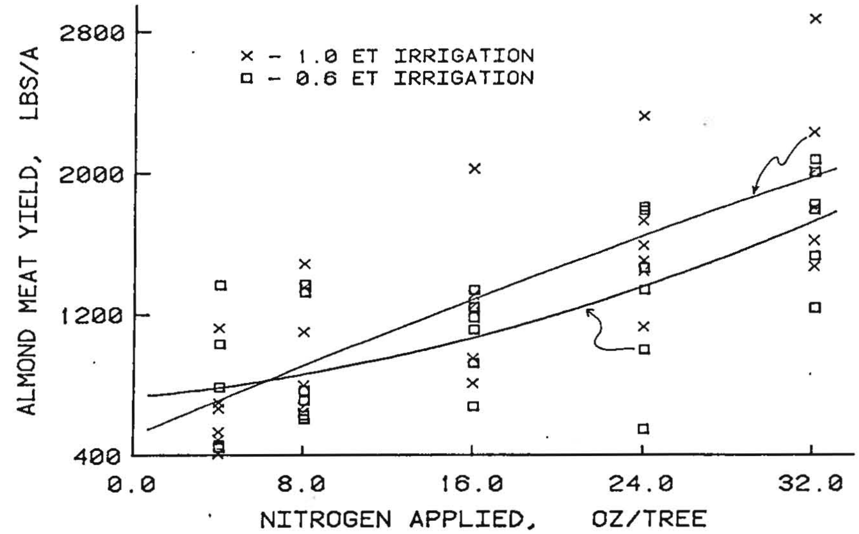

Figure 3. Almond meat yields in 1986 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

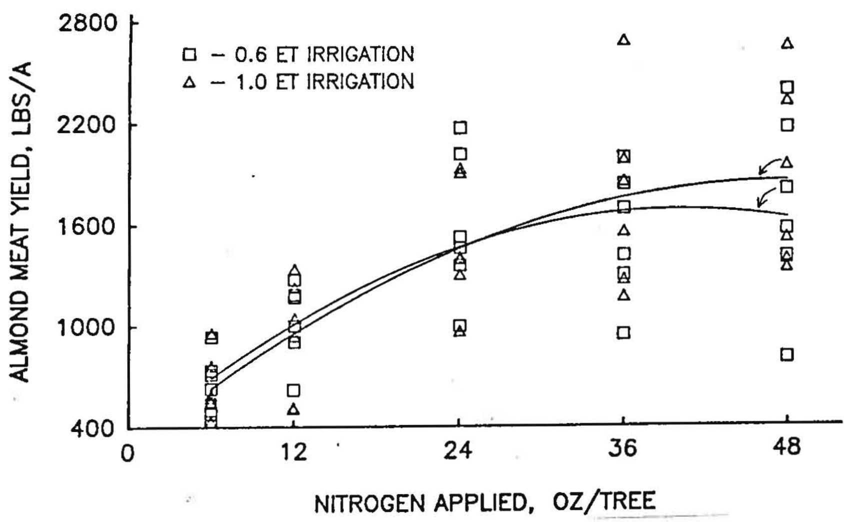

Figure 4. Almond meat yields in 1987 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

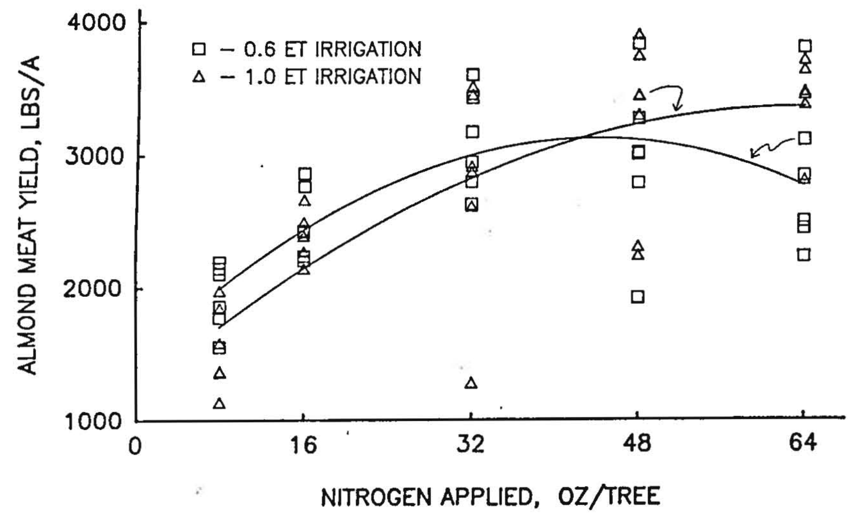

Figure 5. Almond meat yields in 1988 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

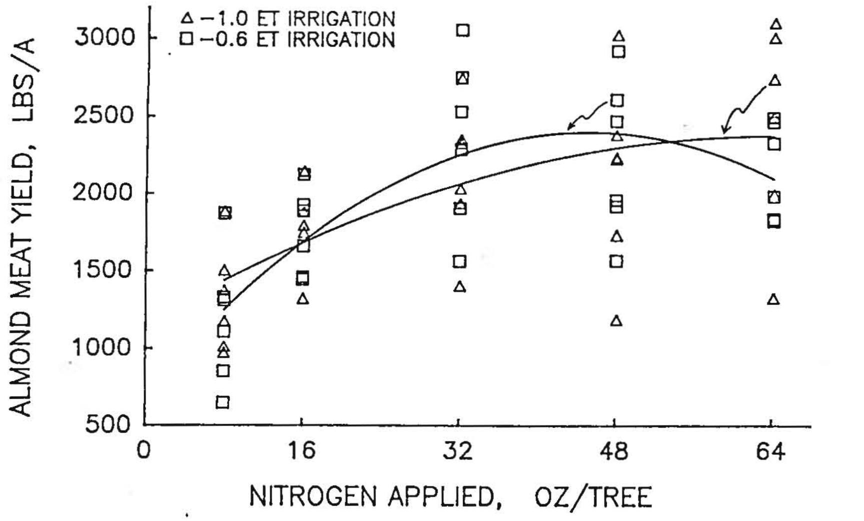

Figure 6. Almond meat yields in 1989 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

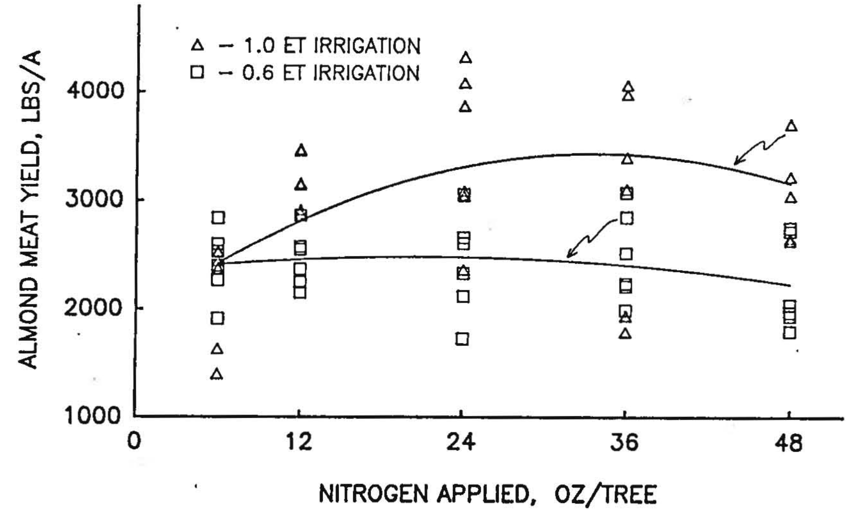

Figure 7. Almond leaf total nitrogen throughout 1984 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

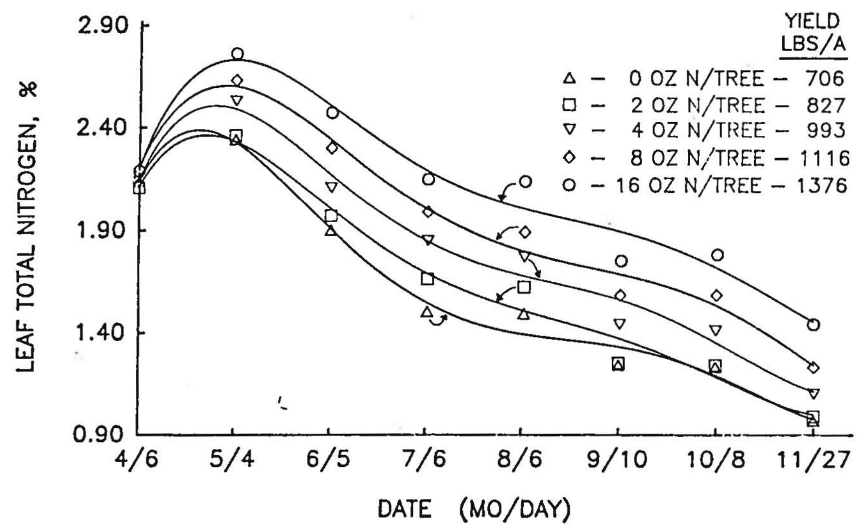

Figure 8. Almond leaf total nitrogen throughout 1985 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

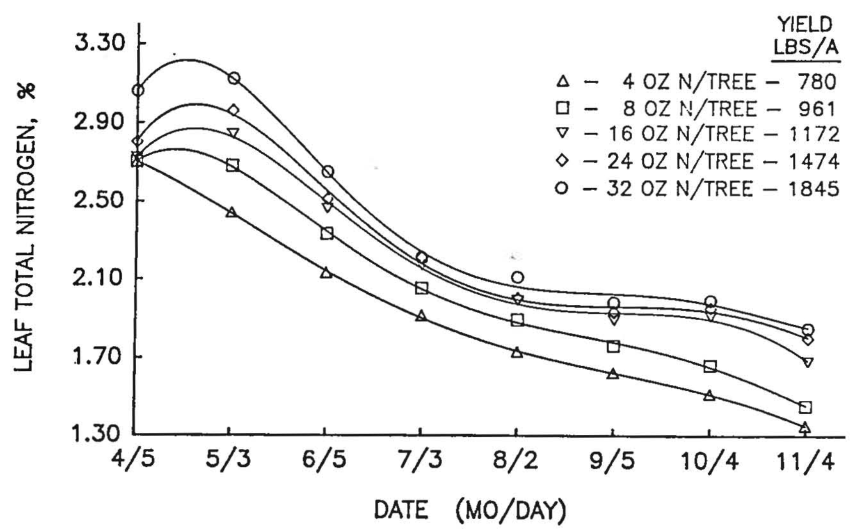

Figure 9. Almond leaf total nitrogen throughout 1986 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

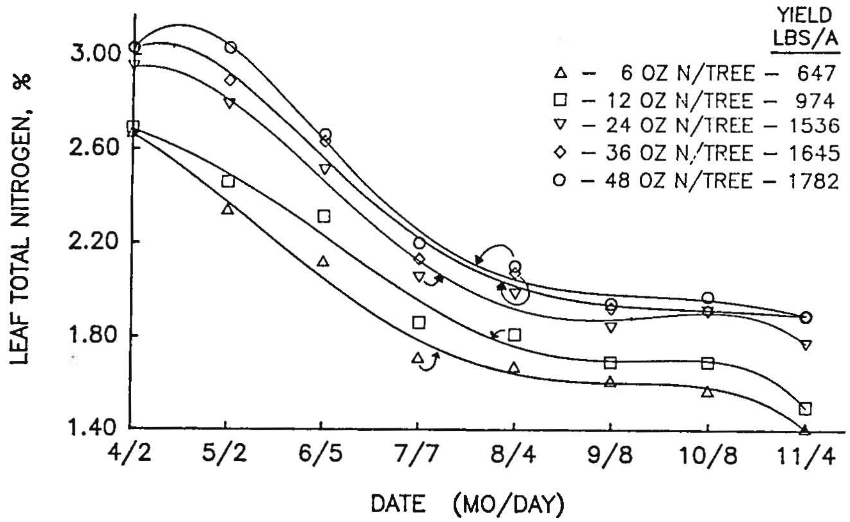

Figure 10. Almond leaf total nitrogen throughout 1987 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

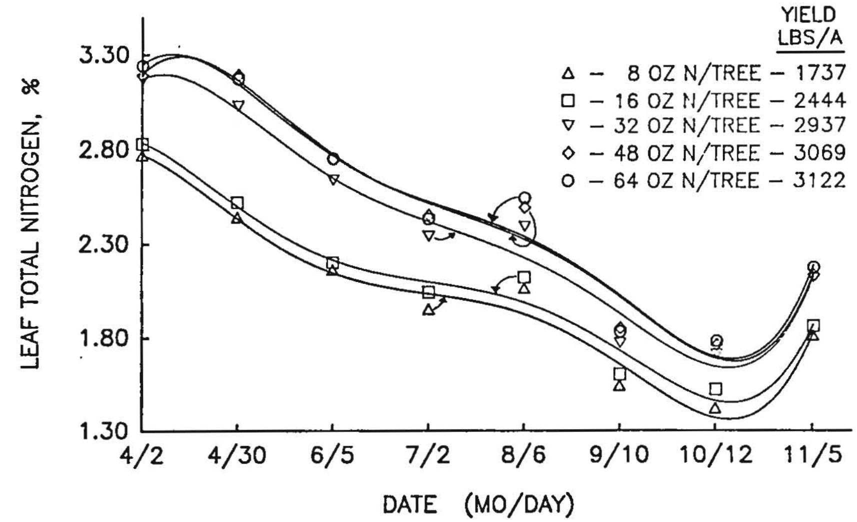

Figure 11. Almond leaf total nitrogen throughout 1988 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

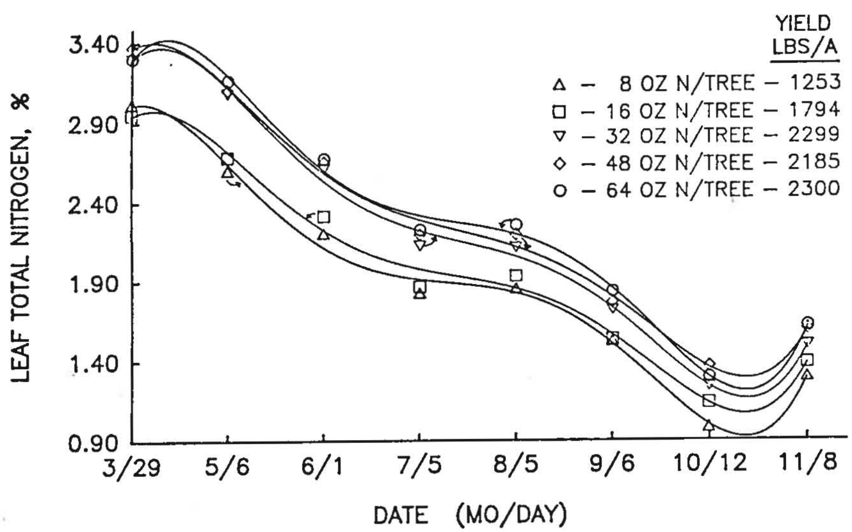

Figure 12. Almond leaf total nitrogen throughout 1989 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

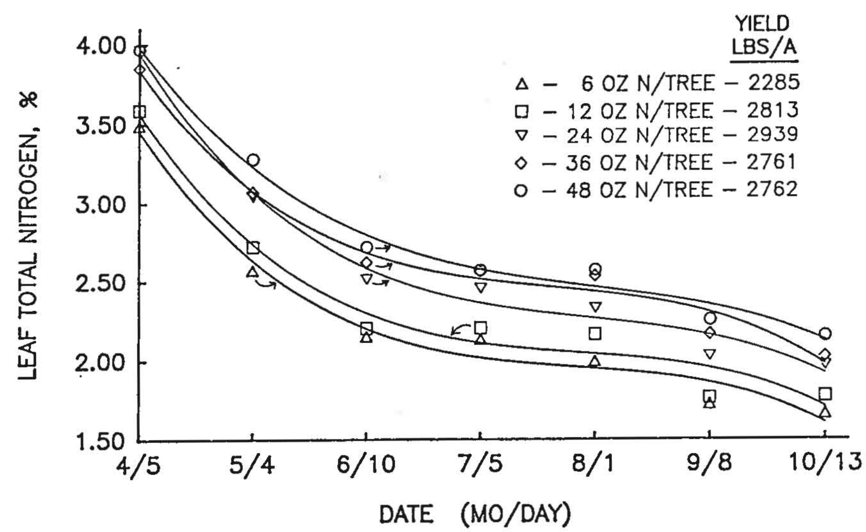

Figure 13. Almond meat yields in 1990 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

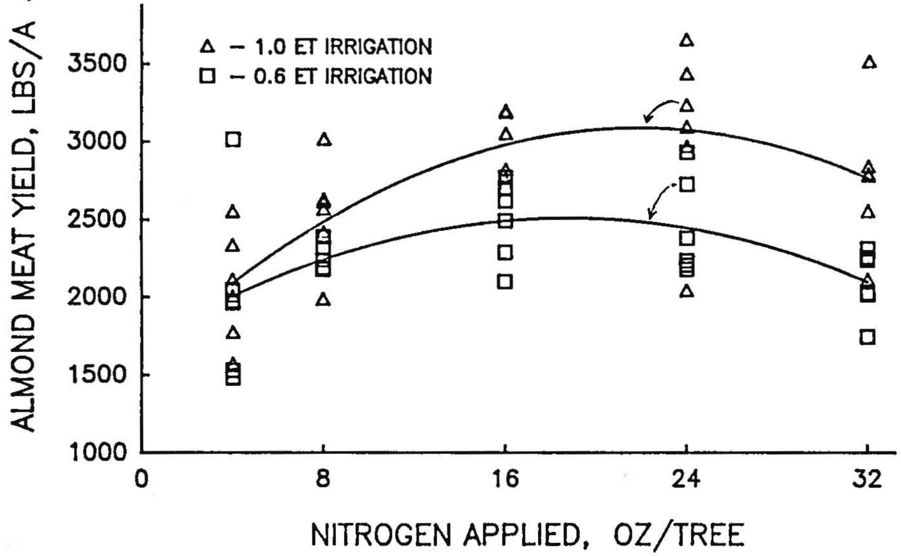

Figure 14. Almond meat yields in 1991 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

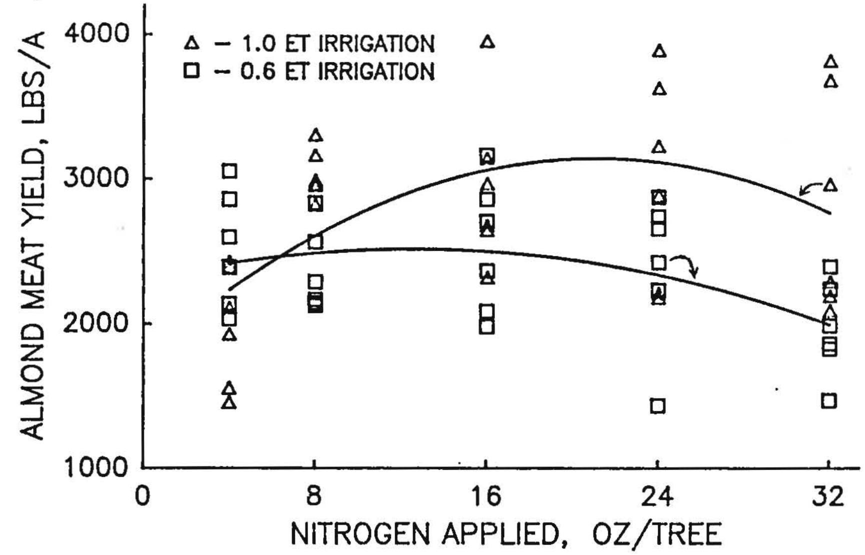

Figure 15. Almond leaf total nitrogen throughout 1990 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

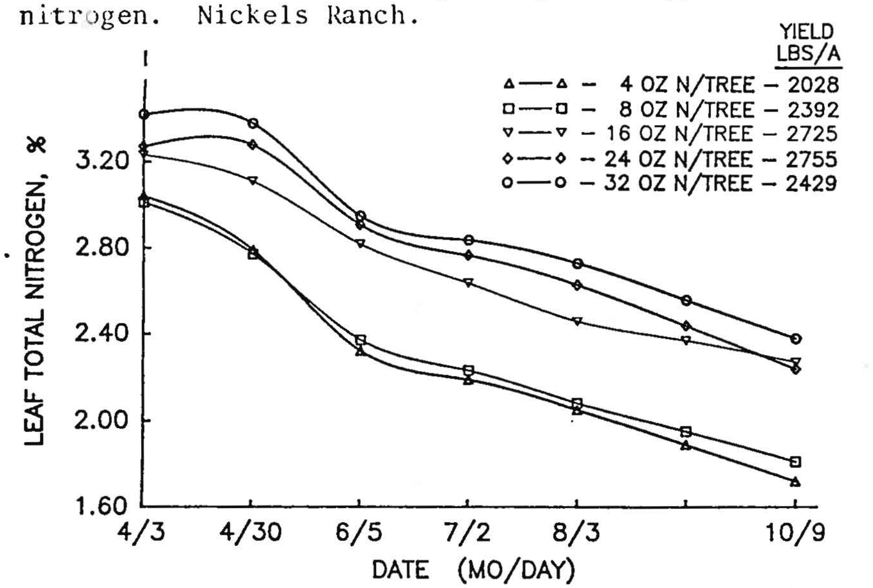

Figure 16. Almond leaf total nitrogen throughout 1991 for five rates of drip irrigation applied nitrogen. Nickels Ranch.