Completed

A. Project Title: NITROGEN EFFICIENCY IN DRIP IRRIGATED ALMONDS
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B. OBJECTIVES

This research is designed to determine the fate of fertilizer N applied to a drip irrigated almond orchard under acidified soil conditions. This information does not currently exist for finer textured soils nor for sandy soils. The use of stable isotopes will allow us to directly measure whole plant uptake (tops, roots and the crop). Knowing uptake, N efficiency in drip systems can then be calculated.

C. EXECUTIVE SUMMARY

Three replications of drip irrigated Nonpareil almonds on Lovell peach root were pre-treated (fertilized) with ammonium sulfate or calcium nitrate to produce different pH levels in the wetted soil volume. Fertilizer application rate for two years prior to treatment was 800 lbs per acre in split monthly or bimonthly applications for 1989 and 1990 respectively. Beginning in April 1991 ^{15}N-depleted ammonium sulfate (at a rate of 200 lbs acre) was applied to the

ammonium sulfate and calcium nitrate treatments. On January 21 and 22, 1992 six treated trees were extracted, chipped and weighed to determine the biomass in branches, stems, medium roots and coarse roots. Subsamples of these components were analyzed for total and isotopic N ratio in order to determine total N uptake and recovery of the applied label. Core samples from treated trees were obtained in April to determine root distribution and fine root mass as well as nitrogen distribution around the treated trees. Vacuum soil solution samplers and platinum electrodes have were installed to measure soil solution composition and aeration status of the drip zone.

Before the ^{15}N-depleted ammonium sulfate was applied the ammonium sulfate treatments were distinctly more acid than the calcium nitrate plots. In the surface two feet, pH measured in 1:2.5 $CaCl_2$ averaged 5.59 for the calcium nitrate plots and 4.23 in the ammonium sulfate plots. In spite of the differences in pH, there were no differences in the total soil nitrogen. However, extractable ammonium and nitrate distribution was different between the treatments. With this pretreatment, soils in the calcium nitrate plots were less acidity and lower in extractable nitrogen than soils of the ammonium sulfate pre-treatments prior to application of the ^{15}N-depleted material. A higher N status in the ammonium sulfate plots was associated with higher foliar N in previous years.

Extraction and measurement of whole trees found the majority of the biomass is associated with the tree stem and branches, which averaged 264 lbs per tree. None of the component biomasses were significantly different between the calcium nitrate and ammonium sulfate pre-treatments. Likewise for the total nitrogen content there were no significant differences between pre-treatments. The roots greater than 1/4 inch in diameter accounted for 16% of the total measured biomass but contained 36% of the nitrogen in these components. Average above ground biomass plus the coarse and medium roots was 33.9 tons of dry material per acre. About 360 lbs of N are need to construct the above ground structures plus the coarse and medium roots in this orchard. Additional N is cycled into the foliage and fine roots. This additional N is retained in the orchard, while some N is removed in the crop.

In the calcium nitrate plots a greater fraction of the total N for all components was derived from the ^{15}N-depleted fertilizer source. Using the crop values for 1991 and the 1992 biomass data total uptake derived from the ^{15}N-depleted material was 42 lbs per acre for the ammonium sulfate plots and 63 lbs per acre for the calcium nitrate plots. This accounts for 21 and 31% of the N applied (200 lbs per acre) during the 1991 season. The reason for this greater utilization in the calcium nitrate plots is not known. Since there was less available N in the calcium nitrate plots prior to ammonium sulfate addition, the fertilizer would have been a greater fraction of the available N pool in the calcium plots. Analysis of extracted soil solutions shows that ammonium treated plots are more acidic, but have high levels of soluble N. The nitrate appears to be more mobile. However, further analysis is necessary to elucidate the reasons for this substantial difference between treatments in the total N labeling.

D. Work description

Task 1. Determination of nitrogen in the tree and soil.

Samples of foliage, tree components and soils have been collected. Whole trees were excavated, subsampled and dried. Samples of roots and above ground materials were collected in January 1992. These materials were ground and analyzed for N and isotopic N content. For logistic reasons, it was not possible to collect fine roots at the same time as the tree samples. Therefore, ammonium sulfate and calcium nitrate treatments. On January 21 and 22, 1992 six treated trees were extracted, chipped and weighed to determine the biomass in branches, stems, medium roots and coarse roots. Subsamples of these components were analyzed for total and isotopic N ratio in order to determine total N uptake and recovery of the applied label. Core samples from treated trees were obtained in April to determine root distribution and fine root mass as well as nitrogen distribution around the treated trees. Vacuum soil solution samplers and platinum electrodes have were installed to measure soil solution composition and aeration status of the drip zone.

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Extraction and measurement of whole trees found the majority of the biomass is associated with the tree stem and branches, which averaged 264 lbs per tree. None of the component biomasses were significantly different between the calcium nitrate and ammonium sulfate pre-treatments. Likewise for the total nitrogen content there were no significant differences between pre-treatments. The roots greater than 1/4 inch in diameter accounted for 16% of the total measured biomass but contained 36% of the nitrogen in these components. Average above ground biomass plus the coarse and medium roots was 33.9 tons of dry material per acre. About 360 lbs of N are need to construct the above ground structures plus the coarse and medium roots in this orchard. Additional N is cycled into the foliage and fine roots. This additional N is retained in the orchard, while some N is removed in the crop.

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Task 2. Installation of solution samplers and redox probes.

Soil solution samplers and redox probes were installed. Unfortunately, the components for these probes were back ordered and installation was delayed. Consequently, preliminary solution sampling was carried out in 1991 amd further sampling was continued into 1992 and 1993 as a no cost extension of the first year's work on this two year contract.

Task 3. Determination of the nitrogen budget for the labeled material.

The nitrogen budget for the labeled material is completed. Six whole trees were extracted, ground and analyzed for total N and isotopic composition.

E. Results, Discussion and Conclusions.

Table 1 presents data for soil pH and nitrogen status prior to addition of the depleted nitrogen source. Before the ^{15}N-depleted ammonium sulfate was applied the ammonium sulfate treatments were distinctly more acid than the calcium nitrate plots. In the surface two feet, pH measured in 1:2.5 $CaCl_2$ averaged 5.59 for the calcium nitrate plots and 4.23 in the ammonium sulfate plots. In spite of the differences in pH, there were no differences in the total soil nitrogen after two years of an 880 kg N ha^{-1} fertilization. However, extractable ammonium and nitrate distribution was different between the treatments. Nitrate extracted by KCl averaged 5.5 $mgkg^{-1}$ while extractable ammonium was 1.1 $mgkg^{-1}$ in the upper 36 inches of the calcium nitrate plots. In comparison the average nitrate was 12.5 $mgkg^{-1}$ and extractable ammonium averaged 38.8 $mgkg^{-1}$ in ammonium sulfate plots. In the calcium nitrate pre-treatments extractable nitrate at 120 cm was greater than at shallower depths. Some nitrate is penetrating the clay lenses at the 60 cm depth.

As planned, prior to application of the ^{15}N-depleted material, soils in the calcium nitrate plots were less acidic and lower in extractable nitrogen than soils of the ammonium sulfate pre-treatments. In previous years foliage from the ammonium sulfate plots had been higher in total nitrogen than foliage from the calcium nitrate plots. This data is presented in Table 2. In 1992 the level of foliar N in both the ammonium and nitrate treated plots were not significantly different, however the nitrate plots received 200 kg/ha of ^{15}N-depleted ammonium sulfate in 1991. Nitrogen content of the fruit (hulls, shells and meats) in 1991 are presented in Table 3.

Biomass contained in the tops, coarse and medium roots is presented in Table 4. The majority of the biomass is associated with the tree stem and branches, which averaged 264 lbs per tree. None of the component biomasses were significantly different between the calcium nitrate and ammonium sulfate pre-treatments. When these trees were extracted, it was obvious that the clay lenses at about 60 cm was a barrier to root growth into deeper soil layers. Consequently most of the roots are in the upper 60 cm and sampling for fine roots was confined to the upper 60 cm.

As was the case for biomass, total nitrogen content was not significantly differences between pre-treatments (Table 5). The roots greater than 1/4 inch in diameter accounted for 16% of the total measured biomass but contained 36% of the nitrogen in these components (Table 5). This reflects the fact that the woody tissue such as stem and branch wood is generally low in nitrogen. Average above ground biomass including the coarse and medium roots is 336 lbs per tree. This calculates to be 33.9 tons of dry material per acre. Another way to view this data is to consider that about 360 lbs of N are need to construct the above ground structures plus the coarse and medium roots in this orchard. Additional N is cycled into the foliage and fine roots. This additional N is retained in the orchard. Some N is removed in the crop (around a 100 lbs acre).

Table 6 contains the data for nitrogen in the various tree and crop components which has been derived from the ^{15}N-depleted source. In the calcium nitrate plots a greater fraction of the total N for all components was derived from the ^{15}N-depleted fertilizer source. These differences were statistically significant for all of the components except the tops which is affected by one replication that is substantially lower than the other two in the calcium nitrate treatments. Using the crop values for 1991 and the 1992 biomass data total uptake derived from the ^{15}N-depleted material was 42 lbs per acre for the ammonium sulfate plots and 63 lbs per acre for the calcium nitrate plots. This accounts for 21 and 31% of the N applied (200 lbs per acre) during the 1991 season. The reason for this greater utilization in the calcium nitrate plots is not known. Since there was less available N in the calcium nitrate plots prior to ammonium sulfate addition, the fertilizer would have been a greater fraction of the available N pool in the calcium plots. However, further analysis is necessary to elucidate the reasons for this substantial difference between treatments in the total N labeling. Samples collected in the spring of 1992 again show that the total extractable soil N was greater in the ammonium sulfate plots than in the calcium nitrate plots. At the beginning of the growing seasons in 1991 and 1992 more nitrogen was available to the ammonium treated plots. A greater root mass was associated with this greater N in the ammonium plots (Table 7).

Data for fine root biomass and nitrogen content as well as soil solution N and extractable N were recently completed. Samples were taken on arcs 1, 3, 4.5 and 6 feet from the tree in one quadrant. Samples 1-4 were in the tree row, while samples 5-8 were located 1 foot toward the row center. Similarly, samples 9-11 were 3.5 feet into the row. Sample 12 was 4.5 feet from the row and samples 13 and 14 were 6 feet from the row and site of nitrogen fertilization. For comparison purposes, sites 1-4, 5-8, 9-11, and 12-14 have been grouped to give averages 0, 1, 3, and 6 feet away from the tree row. Nitrogen and water was applied to the trees in basins located at sampling site 4 and between site 1 and 2. Data for average KCl extractable nitrate, ammonium, pH and fine root biomass are given in Table 7. Extractable N decreases as distance from the tree and N source increases. The ratio of ammonium to nitrate also decreases with distance and is strongly correlated with soil pH. In all cases the soil pH is greater in the calcium nitrate treatments compared to the ammonium sulfate treatments. In both treatments pH increases with distance from the tree. Fine root biomass was greater in the ammonium treatments is spite of lower pH levels. It appears that the higher N is more influential than the low pH in determining fine root growth.

Data for extractable N show only a static picture for one point in time. In order to determine more about the dynamics of applied N in the drip basins, solution samplers were installed at various depths below the emitters. Samples of solution were collected over time and solution pH, nitrate and ammonium level and Eh were determined. Data for solutions sampled in 1991 and 1992 are presented in Tables 8, 9 ,10, 11 and 12. Solution levels of nitrate and ammonium varied with depth time and nitrogen source. For many of the sites a dense clay lenses occurs at about 60 cm. In the case of nitrate treatments, little N is found in solutions below this layer and levels in the ammonium treatment are also lower in the 60 cm samples. The trends with time are difficult to explain as levels of both nitrate and ammonium increase after fertilization in the calcium nitrate plots. This 1991 data is not replicated. Replicate samplers were available for collections in 1992. Data from these solution probes (Table 9) show a trend of increasing solution N following fertilization and decreasing N levels with depth. In the ammonium treatments, both nitrate and ammonium are found below the 60 cm depth. Nitrate predominates and ammonium decreases with time. In the Nitrate-treated samples, ammonium levels are low and nitrate increases to high levels. Solution acidity varies considerably over the fertilization cycle in both 1991 and 1992. Tables 10 and 11 present soil pH data. Solution pH varies as much as 3 units during a period of several days. As was found for soil pH, soluton pH is more acidic in the ammonium sulfate treatments. The irrigation water (Table 10) has a pH of 8.3. Continual addition of this higher pH and higher Ca water will neutralize some of the soil and solution acidity and may explain why the soil is more acidic at depth in some treatments. As mentioned above, in spite of the lower pH in the ammonium treatment fine root mass is larger than in the nitrate treatments. As shown in Table 9, solution N tends to be greater in the ammonium treatments. Thus both extractable and soluble N is lower in the calcium nitrate plots. Nitrate is more mobile than ammonium and may be subject to a greater leaching loss. Redox measurements suggest that denitrification could take place in some treatments and nitrate could be lost by denitrification. We are currently looking into this possibility. Since sulfate can be adsorbed on acid soils, salt migration could be limited by the lack of a mobile anion in ammonium sulfate treatments.

In summary it can be concluded that ammonium sulfate is strongly acidifying when concentrated in the small area utilized by drip systems. This can happen in a short time (on the order of a few years) with high N rates and values as low as 3.6 have been found in the soil and in solution. However, ammonium sulfate does appear to supply more N to the plant and maintain a higher extractable and soluble soil N level. Fine root biomass is greater in the ammonium sulfate treatments than in the calcium nitrate treatments. A greater N supply is the most probable reason, but other interactions with pH can not be ruled out. Soil N and soil acidity are very dynamic. Between monthly fertilizations, pH may vary as much as 3 units and levels of soluble N fluctuate several hundred mg L^{-1}. The strong acidification associated with ammonium sulfate may have significant long term consequences and needs to be followed.

Table 1. Soil nitrogen and pH data for samples collected in April 1991. Samples are averaged over locations. N_T is percent total soil N for samples collected in April 1989 and 1990.

Treatment	Depth (cm)	pH	NH_4	NO_3	% N_T 1991	1989
			(mg/kg)			
Calcium Nitrate	0-30	5.78	2.09	0.33	0.06	0.06
	30-60	5.40	0.89	9.14	0.03	0.037
	60-90	6.06	0.34	6.95	0.03	0.034
	90-120	6.31	0.35	21.05	0.02	0.021
Ammonium sulfate	0-30	4.06	57.3	10.91	0.06	0.06
	30-60	4.39	56.8	14.61	0.04	0.037
	60-90	5.79	2.32	12.61	0.02	0.034
	90-120	6.13	1.61	9.24	0.02	0.021

* pH was measured in 1:2.5 soil: 0.01 M $CaCl_2$

Table 2. Nitrogen content of almond leaves, hulls, meats and shells collected at harvest in August 1990. Nitrogen is reported as percent on a dry weight basis.

Treatment	Hulls	Shells	Meats	Leaves
Ammonium sulfate				
Plot 1	0.76	0.42	3.10	2.16
Plot 2	0.72	0.41	3.03	2.02
Plot 3	0.90	0.51	3.17	2.41
Average	0.76	0.45	3.10	2.20
SDV	0.07	0.03	0.04	0.11
Calcium nitrate				
Plot 4	0.65	0.49	3.12	1.72
Plot 5	0.67	0.47	3.00	1.86
Plot 6	0.64	0.43	3.15	2.02
Average	0.65	0.46	3.09	1.87
SDV	0.01	0.02	0.05	0.09

Table 3. Nitrogen content of almond, hulls, meats and shells collected at harvest in September 1991. Nitrogen is reported as percent on a dry weight basis.

Treatment	Hulls	Shells	Meats
Ammonium sulfate			
Plot 1	0.78	0.40	2.4
Plot 2	0.92	0.33	2.43
Plot 3	0.68	0.38	2.60
Average	0.79	0.37	2.47
SDV	0.12	0.04	0.11
Calcium nitrate			
Plot 4	0.78	0.34	2.38
Plot 5	0.56	0.45	2.72
Plot 6	0.58	0.37	2.54
Average	0.64	0.39	2.54
SDV	0.12	0.06	0.17

Table 4. Dry weights of tops, coarse roots, medium roots and stumps of trees extracted in late January 1992. (Pounds of dry weight per tree)

Treatment	Tops	Coarse Roots	Medium Roots	Stump	Total
Ammonium sulfate					
Plot 1	284	39	27	21	350
Plot 2	241	30	19	18	308
Plot 3	238	22	25	26	311
AVERAGE	254	30	24	22	323
SDEV	25	8.5	4.2	4.0	23
Calcium Nitrate					
Plot 4	290	26	30	21	367
Plot 5	300	25	33	17	375
Plot 6	228	21	31	22	302
AVERAGE	273	24	31*	20	348
SDEV	39	2.6	1.5	2.6	40

* significantly different at the 10% probability level.

Table 5. Total nitrogen contained in the tree components (lbs per acre).

Treatment	Top	Coarse Roots	Medium Roots	Stump	Total
Ammonium sulfate					
Plot 1	212	88	82	10	392
Plot 2	214	57	49	12	332
Plot 3	207	41	60	12	320
AVERAGE	211	62	64	11	348
SDEV	4	23	17	1	39
Calcium nitrate					
Plot 4	240	51	78	7	376
Plot 5	212	58	101	10	381
Plot 6	212	44	80	14	350
AVERAGE	221	51	86	10	369
SDEV	16	7	13	3.5	17

Table 6. Nitrogen (% of total N) derived from ^{15}N-Depleted fertilizer in 1991 and 1992. Component means with an *,** or *** are significantly different at the 0.05, 0.01 and 0.001 level respectively between treatments.

		Component				
Treatment	Tops	Fine Roots	Coarse Roots	Stump	Kernel	Husk & Shell
Ammonium sulfate						
Plot 1	9.36	12.20	9.92	10.70	5.02	3.51
Plot 2	9.43	15.12	11.39	13.26	6.96	4.70
Plot 3	8.50	15.40	11.07	13.56	4.31	4.28
AVERAGE	9.09	14.24	10.79	12.50	5.34	4.16
SDEV	0.51	1.77	0.77	1.57	1.22	0.60
$Ca(NO_3)_2$	12.44	21.32	14.85	16.44	9.69	6.72
	16.28	19.92	14.17	19.68	8.06	7.97
	9.85	21.38	17.44	17.60	8.03	6.03
AVERAGE	12.85	20.87***	15.48**	17.91**	8.59**	6.91**
SDEV	3.23	0.84	1.72	1.64	0.95	0.98

Table 7. Ammonium, nitrate, pH and fine root biomass for found in core samples taken in April 1992.

	Location	Core 1-4	Core 5-8	Core 9-11	Core 12-14
pH					
	Ammonium Sulfate	3.8	4.37	5.08	5.56
	Calcium nitrate	4.75	5.29	5.45	5.48
NO_3			mg/kg		
	Ammonium Sulfate	7.1	5.6	5.6	7.8
	Calcium nitrate	4.0	3.2	7.8	6.5
NH_4			mg/kg		
	Ammonium Sulfate	57.3	10.6	4.7	1.3
	Calcium Nitrate	21.9	6.6	3.2	2.6
Root Mass			g/core*		
	Ammonium Sulfate	2.6	1.9	0.37	0.49
	Calcium Nitrate	1.5	1.2	0.45	0.29

* cores were 2 inches in diameter and 2 feet deep (1.197 liter of volume).

Table 8. Nitrate and ammonium in solutions (mg N L^{-1}) collected beneath the emitters during a fertilization cycle in July-August 1991. Days are the time since fertilization.

	Time zero		Day 3		Day 8		Day 14		Day 23		Day 26		Day 30	
	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
Depth (cm)	Ammonium sulfate Treatment													
10	26	56	160	34	34	26	19	19	11	17	134	19	79	25
20	300	145	146	41	50	15	28	20	11	10	184	19	145	15
30														
40	56	13	159	31	51	13	15	12	7	8	49	22	37	25
60			51	17	17	7	7	5	5	9	93	12	0	0
	Calcium Nitrate Treatment													
5	6	5	172	21	80	22	33	21	16	17	361	28	455	28
20	7	9	239	24	25	4	20	22	13	22	78	12	46	16
30	6	5	218	23	42	15	34	28	21	22	294	22	202	22
40	1	8	97	7	42	15	19	38	10	45	36	36	61	25
60	0	0	2	1	1	0	1	0	2	0	1	1	0	1
Irrigation Water	0	0												

Table 9 . Solution pH values for samples collected beneath the drip basin during a fertilization cycle beginning in late July 1991.

Treatment	Depth	Time Since Fertilization (Days)						
	(cm)	0	3	8	14	23	26	30
				Solution pH				
Ammonium	10	3.90	3.67	5.42	4.55	4.35	3.75	4.08
sulfate	20		3.60	4.26	4.10	4.43	3.58	4.45
	30		-	- -	- -	-		
	40		3.61	3.98	4.44	4.76	5.09	6.07
	60		3.99	5.73	5.46	4.25	3.86	-
Calcium	5	5.60	4.37	5.11	4.94	5.09	3.97	-
nitrate	20	5.29	4.43	5.93	5.12	5.49	4.41	6.04
	30	6.63	4.65	6.07	5.15	6.41	4.20	5.61
	40	4.35	4.10	5.86	4.25	4.55	4.12	3.77
	60	7.85	7.28	7.79	7.14	7.65	7.62	7.64
Irrigation Water			8.28					

Table 10. Solution pH in samples collected from porous cup samples following fertilization with calcium nitrate or ammonium sulfate in 1992.

		Day 0	Day 1	Day 4	Day 8	Day 15
Ammonium sulfate treatments						
	Depth (cm)					
Rep 1	15	5.59	4.46	4.70	4.46	6.09
	30	4.16	3.74	4.04	3.97	
	45	6.29	3.89			
	60	6.14	4.50	5.73		4.38
	60+	6.64	5.31	6.51	6.89	5.98
Rep 2	15	4.18	3.72	4.23	4.23	5.96
	30	4.13	3.64	4.37	4.48	5.02
	45	4.46	4.33	5.31		4.19
	60	4.41	4.50	5.72	5.09	4.36
	60+	7.12	7.00	7.03	6.65	7.63
Calcium nitrate treatments						
Rep1	15	6.92	6.71			7.20
	30	6.58	6.69			
	45	6.74	6.65	7.35		
	60	6.00	5.58			
	60+		6.94	6.78		
Rep 2	15	6.68	6.63	6.33	5.92	6.82
	30	5.27	4.43	4.50	4.14	
	45	6.12	5.92	6.61	6.35	
	60	6.46	6.24	7.04		
	60+	7.12	7.25			

Table 11. Redox readings (Eh) for probes buried beneath emitters over time since fertilization.

	Days since fertilization				
	14	23	26	30	
Depth (cm)		Ammonium sulfate Treatments			
10	637	671	645		702
20	718	642	644		508
30	396	375	349		437
40	499	524	374		600
60	700	639	704		686
		Calcium nitrate Treatments			
5	383	437	479	573	
20	565	575	534	642	
30	607	622	592		671
40	660	695	631		729
60	-190	-183	-168		-8