Mitigation of Reactive N Mobilization (N_2O and NO_3^-) Using Injected, High Frequency Nitrogen Fertigation (HFLN)

Project No: **13-AIR2-Smart**

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Overarching Objective:

This project tests the hypothesis that an easily adaptable means of fertigating micro-irrigated perennial crops with nitrogen can diminish reactive N mobilization (NH_3, NO_3^-, N_2O and NO_x). Reactive N forms have undesirable environmental consequences including NO_3^-, nitrate, contamination of ground water, emissions of the greenhouse gas N_2O and of NO_x, which is involved in production of tropospheric photochemical smog. The adoption of management practices that reduce N mobilization might aide in addressing regulatory mandates of State and Federal agencies. The objective of the project is to test the management practice of high frequency low N applications (HFLN) targeted to tree N demand (root growth, shoot growth and nut development) as a means of diminishing N_2O emissions and NO_3^- movement below the root zone.

The project gathers experimental, ground level information on reactive nitrogen (N) mobilization, mainly NO_3^- leaching and emissions of the greenhouse gas nitrous oxide (N_2O) during 'high frequency' split applications of low N concentration (HFLN, 'spoon feed') to almond. Standard practice is to apply from 20% to 40% of N during each of 4-5 fertigation events that ramp up N concentration during periods of high N demand like nut fill. HFLN applies about 5% of total N during most irrigation sets. Data collection for our two field studies began in February, 2013, in an orchard in Belridge, California, managed by the Paramount Farming Company. An experiment was initiated there by Dr. Patrick Brown's Laboratory (UC Davis) in 2011 in concert with Farm Advisor Blake Sanden and Almond Board of California (ABC) support. The purpose of this experiment was to test the effects of HFLN fertigation (20 per year) against conventional fertigation of 4-5 times per year). The experiment also includes various N sources to be tested within the HFLN practice. Dr. Brown's laboratory is studying effects on yield and on almond root foraging and N uptake. Our work complements theirs by studying the effects of these practices on N_2O emissions and NO_3^- movement below the root zone.

Specific Objectives:

1) Quantify seasonal N_2O-N produced by high frequency N fertigation of approximately 5-10 lbs per acre per application as compared with seasonal N_2O-N emitted during conventional fertigation events of 40-75 lbs per acre per application.

2) Determine the influence of HFLN on yield and water use efficiency so that both yield based greenhouse gas emissions and yield based water use can be gathered.

3) Determine the possible differences in almond yield and N fate caused by two fertilizer formulations representing low nitrate content and high nitrate content.

4) Introduce and validate the concept of adopting continuous nutrient feeding during highest N demand and fine root growth for Californian almond and other nut production systems (e.g. pistachio).

5) Identify controlling factors on soil N_2O production such as water-filled pore space, soil temperature, inorganic N concentration, pH, texture, and soil carbon (organic and inorganic) to develop a greater understanding of the controls on N_2O emissions from arid fertigated soils and almond orchards.

6) Embedded within the experiment, we test a high-ammonium N source (UAN) against a nitrate-only N source ($Ca(NO_3)_2$ + KNO_3, CKN), both under HFLN fertigation.

Interpretive Summary of Work for This Year:

Ground monitoring exercises were used to quantify total N_2O emissions, and soil NH_4^+ and NO_3^- concentrations with soil depth (mobilization) from HFLN applications of 5-10 lbs. acre^{-1} (300 lbs. season^{-1}) as contrasted with the conventional practice of 4-5 applications of 50 to 75 lbs acre^{-1} (also 300 lbs. season^{-1}). Since April 2013 the almond orchards were irrigated almost on a weekly basis during the growing season. Fertilizer for the conventional grower practice was applied to the orchard on five occasions ranging from 50 to 75 lbs acre^{-1}. During fertigation events, the amount of N for the HFLN treatments was ramped up from 5 to 10 lbs acre^{-1} as trees approached the nut fill phenological stage. The HFLN subplots received the same amount of irrigation water during each irrigation event as the conventional treatment on the same irrigation schedule.

Results for the 2014 growing season can be summarized as follows:

1) HFLN fertigation appears to have reduced N_2O emissions per unit of CKN applied by HFLN as compared with HFLN UAN or conventional applied UAN. The difference was nearly 2x.

2) Within the HFLN system, use of CKN significantly reduced N_2O emissions per unit N applied by about 45% compared to UAN.

3) Comparing our data to that of Schellenberg *et al.* (2012), who worked in the same orchard in 2009-2010, it appears that fanjet application of UAN results in approximately 62% lower N_2O emissions than from aboveground drippers. This agrees very well with other work studying drip and fanjet N_2O emissions from an almond orchard in more Northern and cooler climates near Arbuckle, California (Alsina, 2013).

4) Gas sampling at various depths in the soil profile following fertigations suggested that nitrification at shallow depths under UAN leads to higher N_2O emissions than from CKN applications. Results may show that CN+KN locate N lower in the soil profile, where less can be lost to the atmosphere as N_2O through partial denitrification.

5) The assessment of nitrifier and denitrifier microbial enzyme activity were not conclusive with respect to identifying a specific depth where highest N_2O production may occur, but do suggest nitrifier denitrification may play a significant role in N_2O production.

6) We discovered probable “conditioning” of the microbial community under HFLN fertigation, meaning that more denitrifying bacteria may be present in the soil under the HFLN drip zone. Nonetheless, higher competition for the principle substrate of NO_3^- when it is scarce may cause more N to be completely denitrified to N_2 rather than being released as N_2O.

Materials and Methods:

Experimental Design

Experiments were conducted in a 13 year old high productivity orchard in Kern County. The average three-year yield in the orchard is about 4,000 lb/ac/yr. The site has low native K fertility but has received 200 lb/ac K for the past three years as winter banded SOP. Average ammonium acetate extractable K in an adjacent field with identical age, management and soil class has been recorded at 104 ppm in the top 18 inches and 81 ppm in the 18 to 36 inch depth**.** July tissue K levels average 1.2 % and range from 0.7 to 1.8%. Grower standard management consists of 275 lbs N applied as UAN in 4 fertigation events (Feb, April, June and postharvest). K is supplied at 200 lbs K applied as 125 lbs SOP applied as a band in the wetted zone in January and 75 lbs K as KTS applied at the same time as UAN fertigation. The orchard is irrigated by micro sprinkler (static jet, Bowsmith Fanjet®) on a weekly average irrigation cycle of 24 or 48 hour irrigation set as needed to match almond ET over a one to three week interval. A total of 52 to 56 inches of water is applied annually. This is a very low rainfall region (<5 inches) with total effective rainfall (actually stored in the profile) around 2 inches. The soil in the western set of this orchard is very uniform and classed by the USDA Natural Resources Conservation Service soil survey as a Kimberlina sandy loam, but is closer to a hybrid between the Kimberlina and Millham sandy loams with a slight bit of Panoche sandy clay loam (especially below a two foot depth) with respect to texture and fertility. There are no structural limitations/hardpans/layers and infiltration and lateral subbing are excellent with irrigation being extremely efficient with little leaching past the 7 foot depth.

Instrumentation

During 2013, in conjunction with the PH Brown/B Sanden HFLN project, almond orchard trees intended for intensive monitoring were instrumented. In each one of three sites per treatment, five solution samplers, four tensiometers, and five 5TE probes (Decagon, Pullman, WA, USA) were installed (**Figure 1**). All the probes were connected to data loggers (CR1000, Campbell Scientific, Logan, UT, USA; NeoMote, Metronome Systems, Berkeley, CA, USA). Following the installation, the matric potential and the volumetric water content in the subsurface were recorded every 15 min. Both the solution samplers and the tensiometers consisted of polyvinyl chloride (PVC) pipe fitted with ceramic cups. The shallow (<280 cm) sensors monitor the processes in the root zone, while the deep sensors are used to estimate the quantity of mineral-N in the leaching flux and mass of NH_4^+-N and NO_3^--N that percolates below the root zone. In a like manner, arrays of gas sampling tubes were installed spatially within the drip zone at 5, 10, 20, 30, 45, 60 and 80 cm depth. Soil gases sampled from these arrays were analyzed on a Shimadzu Gas Chromatograph with a ^{63}Ni detector.

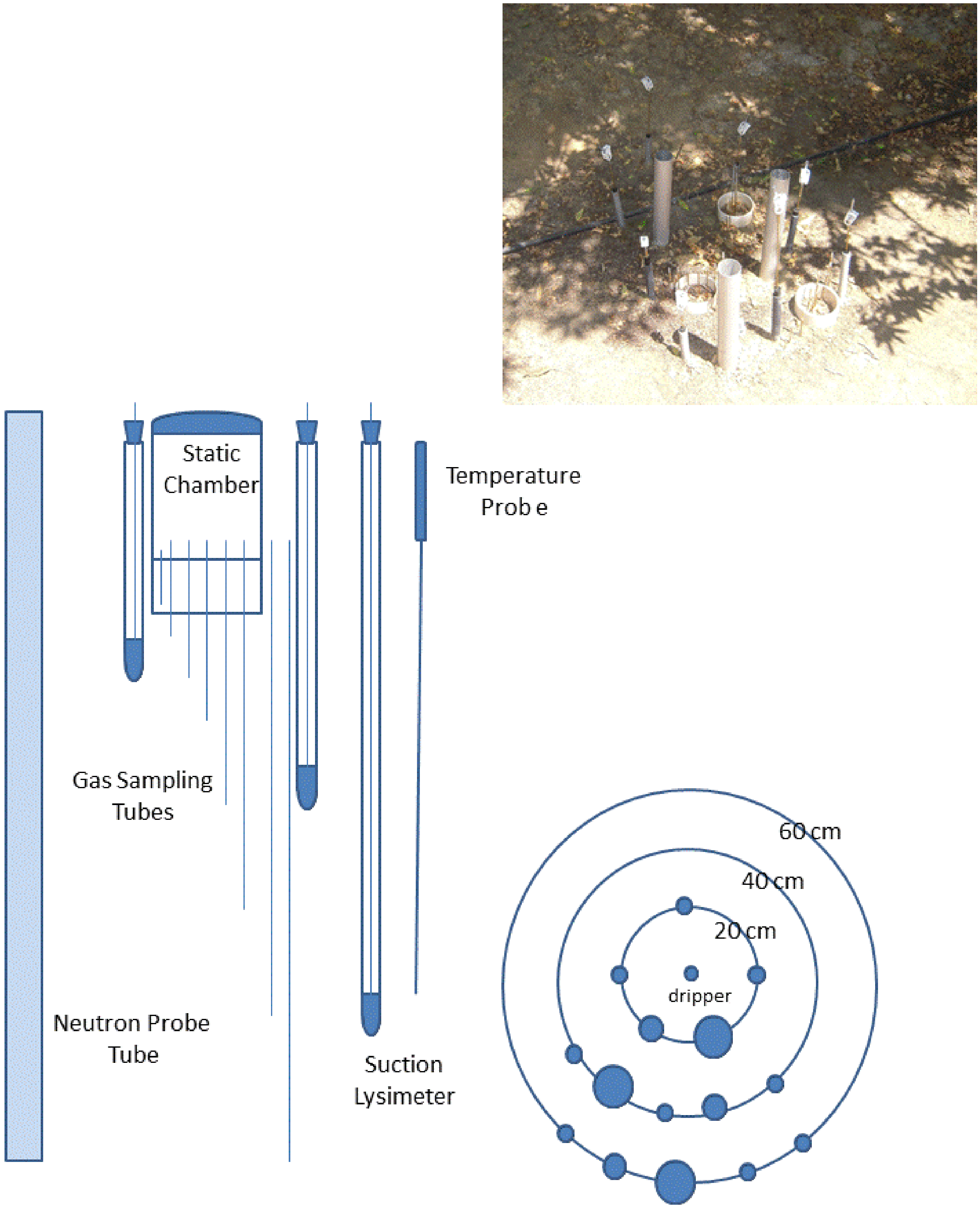


Figure 1. Instrumentation configuration for intensively monitored drip zone areas.

Results and Discussion:

Nitrous Oxide Emissions

Monitoring of growing-season N_2O emissions focused on the three to five days following fertigation. Highest emissions were seen in spring (April-May) and summer (June-July), although the effect was amplified because each of these applications was 30% of yearly total in the Standard UAN treatment (**Figure 2**). Twelve unmonitored high-frequency applications were included in the graphic, as “modeled” averages of the events which they fell between. This approach was undertaken because it was really impossible to have someone on-site for all of the HFLN applications. We are uncertain about the absolute accuracy of these modeled emissions, but given the extensive spatial modeling we have carried out around the drip zone and for stationary microsprinklers means the modeled emissions are our best estimate at this time. We are currently carrying out further measures of N_2O emissions under different soil types and soil temperature conditions and these exercises will be used to better refine the modeling efforts.

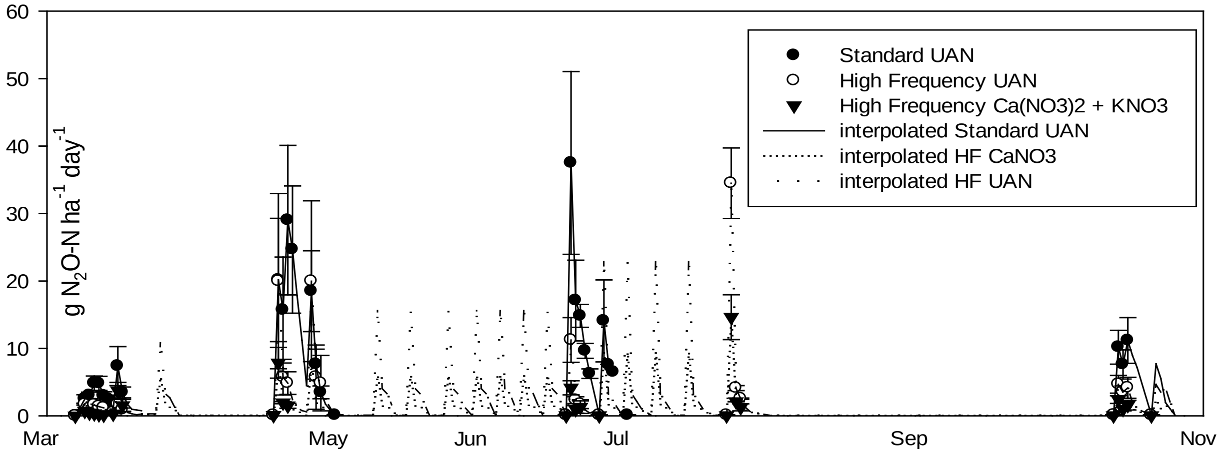


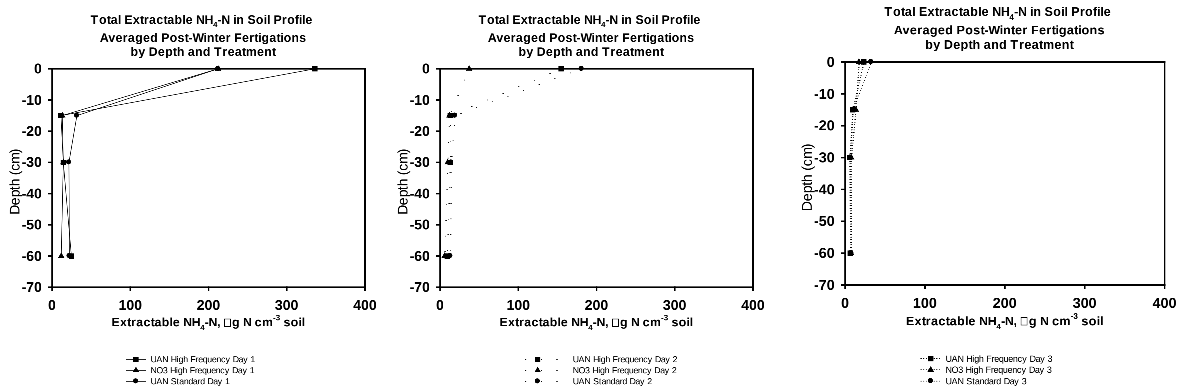
Figure 2. Observed and modeled emissions from three treatments over 2013 growing season.

Concentration profiles of NO_3^-, NH_4^+ and N_2O

Presence of nitrate (NO_3^-) and ammonium (NH_4^+) was monitored at 3-4 depths (to 0.8 m) during the three days following each fertigation (**Figure 3**). The resulting data show distribution patterns helping to predict the fate of N applied through aboveground drip fertigation. Results show high diffusion of NO_3^-, and the appearance of NH_4^+ throughout the soil profile over three days, derived from hydrolysis of urea in UAN applications. These accumulations can be very high and suggest long-term leaching hazards. Values of soil extracts can be more difficult to interpret than soil solution data, but they clearly show the majority of soil-retained N exists in the first 15 cm of these sandy loam soils, 20 cm from aboveground drippers.

Extractable NH_4^+

DAY 1 DAY 2 DAY 3



Extractable NO_3^-

DAY 1 DAY 2 DAY 3

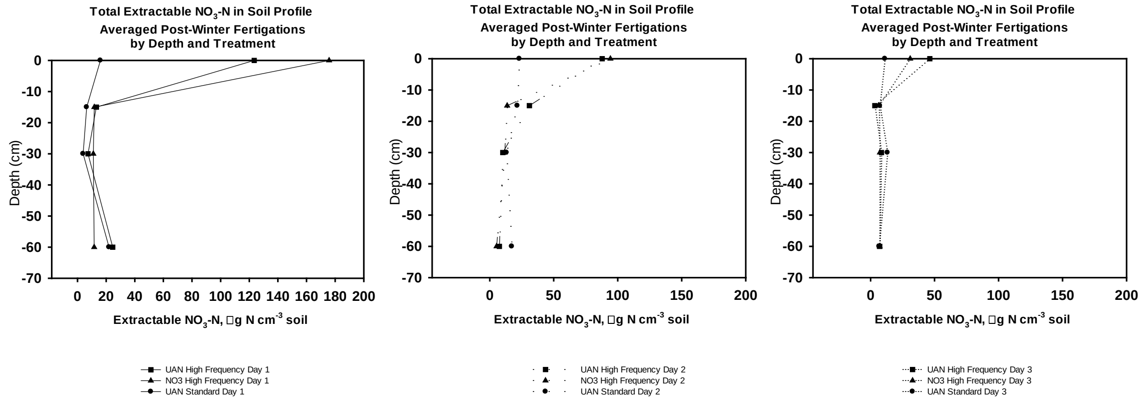
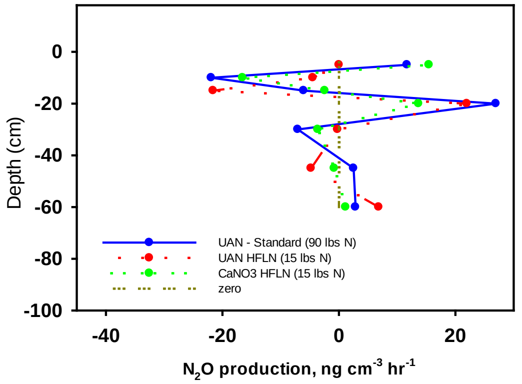


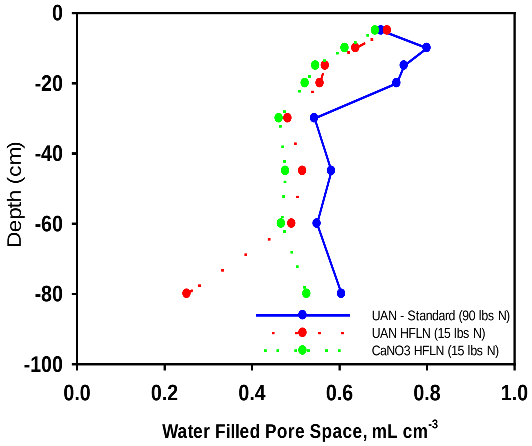
Figure 3. Soil KCl-extractable NH_4^+ and NO_3^- over the first three days following summer and early fall fertigations.

Profiles of N_2O concentration (**Figure 4**, column 1) did not by themselves reveal the depths where N_2O was produced and consumed. They must be combined with soil density and texture information as well as measured moisture throughout the soil profile (column 3) to allow calculations of production and consumption (**Figure 4**, column 2). In general, these studies confirmed that the vast majority of N_2O produced below 20 cm depth is consumed by microbes before it can reach the surface. Also, UAN treatments led to high production of N_2O near surface. These are potentially crucial points in planning aboveground drip fertigation practices to reduce N_2O emissions.

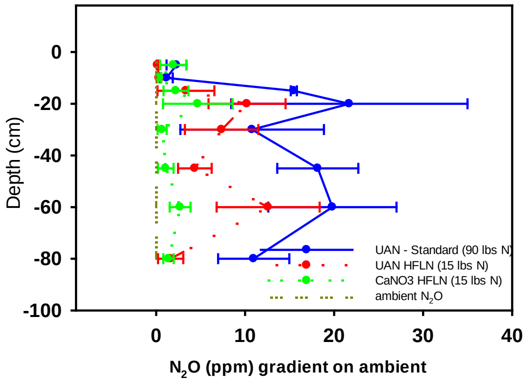
Lost Hills Soil Profile N_2O Production 2013
Winter Day 2
by Depth and Treatment at 20 cm from dripper



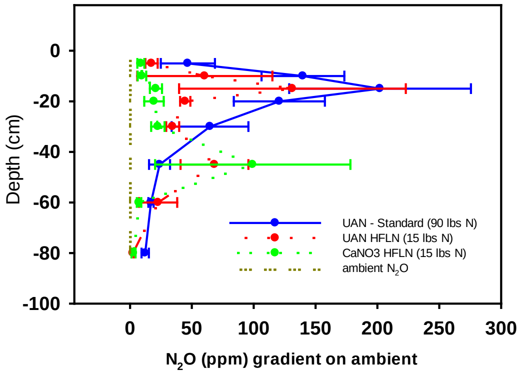
Lost Hills Soil Profile N_2O Production 2013
Winter Day 2
by Depth and Treatment at 20 cm from dripper



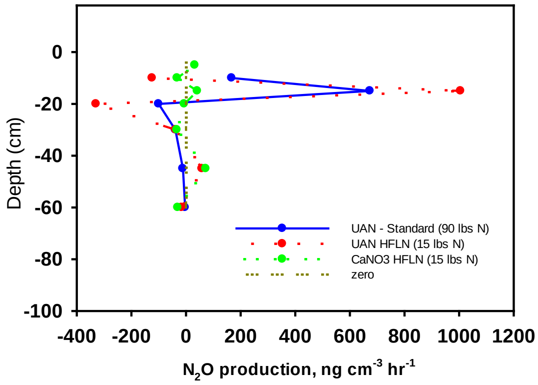
Lost Hills Soil Profile N_2O Concentrations
Winter Day 2
by Depth and Treatment



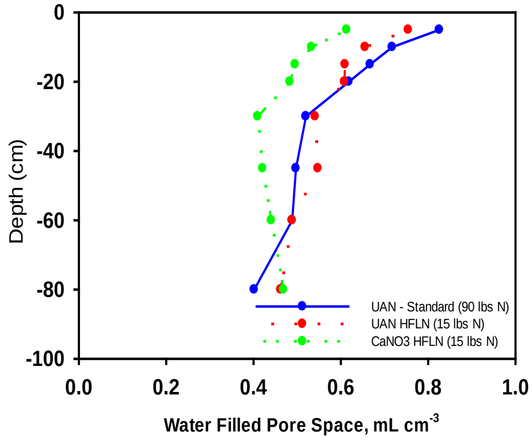
Lost Hills Soil Profile N_2O Concentrations
Spring Day 1
By Depth and Treatment



Lost Hills Soil Profile N_2O Production 2013
Spring Day 1
by Depth and Treatment at 20 cm from dripper



Lost Hills Soil Profile N_2O Production 2013
Spring Day 1
by Depth and Treatment at 20 cm from dripper



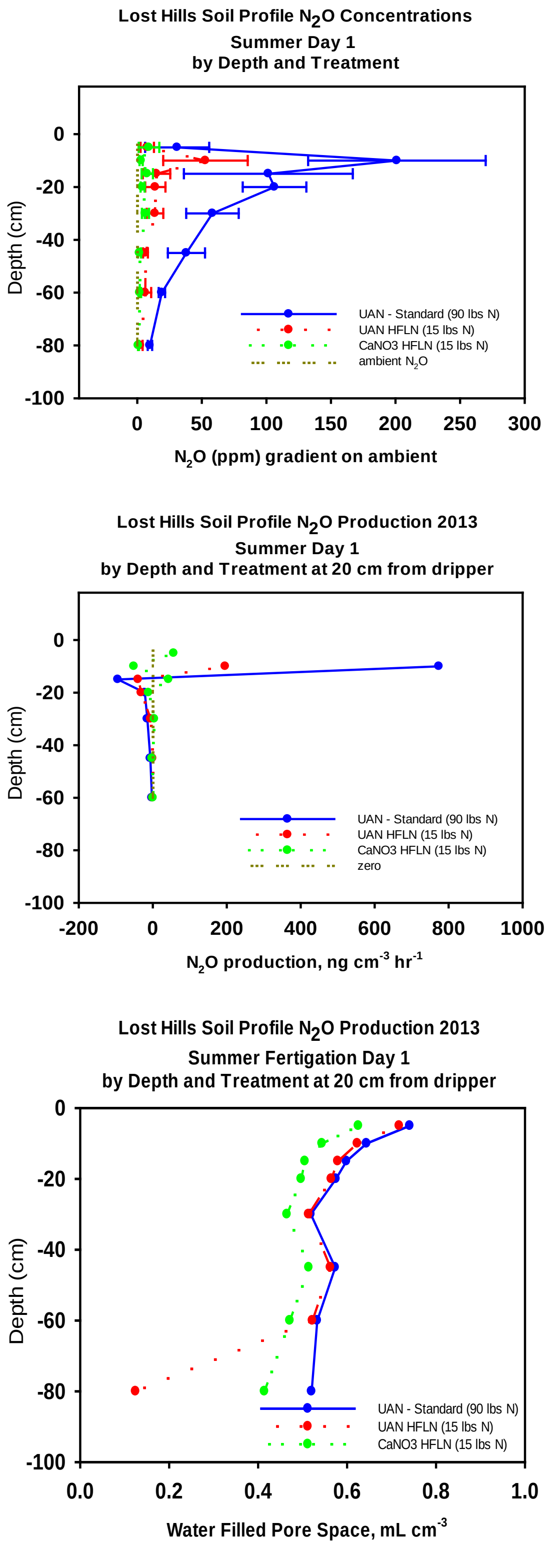


Figure 4. Profiles of N_2O concentration, calculated N_2O production/consumption and WFPS on peak days of major fertigations.

HFLN conditioning of microbial communities in the drip zone

Due to high spatial and temporal variation, differences in N_2O emission between the Standard (4x/year) UAN application and High-Frequency UAN application were not statistically significant (**Table 1**), although data suggested higher total emissions from HFLN. The HFLN consisting of a nitrate formulation (**Table 1**, CKN) cut N_2O emissions to approximately half of those seen with UAN. Overall emission factors were far lower than the 1% assumed by the IPCC, and lower also than those seen by Schellenberg *et al.* (2012) in the same orchard under fanjet (0.23-0.35%) in 2009-2010. Nitrifier denitrification, the simultaneous oxidation of ammonium and coupling of electron transport to the NO_3^- produced (instead of O_2) was hypothesized to be the major source of N_2O emitted from UAN treatments.

Table 1. Growing season emissions of N_2O-N ha^{-1}, using interpolated data.

Treatment	Growing Season Emissions	Emission Factor	Pairwise Significance
Standard UAN	375.81 *g N_2O-N ha^{-1}*	*0.11%*	NS vs. HF UAN
High Frequency UAN	498.86 *g N_2O-N ha^{-1}*	*0.15%*	NS vs. Standard UAN; S vs. HF NO3
High Frequency $Ca(NO_3)_2$ + KNO_3	246.11 *g N_2O-N ha^{-1}*	*0.07%*	S vs. HF UAN

Effects of HFLN treatments which receive N every 1-2 weeks during the growing season are expected to be due in part to improving tree root competition with the microbial community in soils. Anticipated effects were corroborated to some extent by the laboratory results using field soils. High ammonium oxidation rates seen in HFLN UAN soils may contribute to greater production of N_2O, but higher denitrification rates under both HFLN treatments (UAN and CKN) have been expected to reduce N_2O emitted, as suggested here for our results with HFLN CKN. But results for HFLN UAN suggest HFLN in this case may actually condition the microbial community (increase population density and diminish turnover rates), thus slightly decreasing tree root competition for N. One further round of microbial enzyme potential assays remains to be done this year. At this point such microbial studies are of great scientific interest and might help to explain the field results of this project, but more importantly in providing information for hypotheses to further best management practices for N applications

Table 2. Soil conditioning effects in samples taken at 0-20 cm depth on Aug. 23, after at least 3 weekly irrigations without fertilizer.

Treatment	Ammonium Oxidation	Denitrification Enzyme Activity		Soil pH
	µg NO_2-N g^{-1} soil 5 h^{-1}	*ng N_2O-N g^{-1} soil min^{-1}*	*ng (N_2O-N + N_2-N) g^{-1} soil min^{-1}*	
UAN - Standard	2.67 ab	0.040 b	0.018 b	7.23 ab
UAN - High Frequency	3.13 a	0.071 a	0.043 a	7.09 a
NO_3 - High Frequency	2.15 b	0.067 a	0.040 a	7.52 b

References:

Alsina, M del Mar, AF Borges and DR Smart (2013) Spatiotemporal variation of event related N_2O and CH_4 emissions during fertigation in a California almond orchard (*Prunus dulcis* Batsch). *Ecosphere* 4:1-21.

Schellenberg, D, M del Mar Alsina, S Muhammad, CM Stockert, BL Sanden, PH Brown and DR Smart (2012) Yield-scaled global warming potential from N_2O emissions and CH_4 oxidation for almond (Prunus dulcis) irrigated with nitrogen fertilizers on arid land (*Prunus dulcis*). *Agricultural Ecosystems and Environment* 155:7– 15.