Evaluating HFLC Nitrogen Management Strategies to Minimize Reactive Nitrogen Mobilization from California Almond Orchards

Project No.:   **18-PREC6-Smart**

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Objectives:

The overarching goal of our work is to provide economically effective solutions for improved nitrogen fertilizer and water use in almond orchards that demonstrably meet emerging environmental compliance requirements under the Central Valley ILRP and under California's 2030 GHG targets. Results will provide scientifically defensible data and assessment tools necessary to support the compliance efforts of the agricultural coalitions representing almond growers in the Central Valley ILRP, substantially contributing to the coalition's Management Practices Evaluation Program (MPEP), and for documenting the industry's contribution to California's 2030 GHG targets.

The specific objectives of the proposal are:
1) Assess annual GHG emissions (N2O, CH4 and CO2) at the orchard scale under HFLC management relative to standard practices. **Milestones**: annual GHG emission budget.
2) Evaluate temporal dynamics of GHG emissions with an emphasis on measuring spring time peak flux; determine relationship to environmental factors, including soil moisture content, temperature, soil mineral N, and irrigation emitter type. **Milestones**: statistical analysis to assess environmental and management controls on the temporal GHG emission variations. Annual progress report.
3) Measure and assess the recharge rate and NO3- movement to below the root zone. **Milestones**: quantify monthly and annual water and NO3- losses from the root zone to the deeper vadose zone and assess travel time to groundwater. Annual progress report.
4) Determine groundwater quality impacts and their spatio-temporal dynamics using a conventional regulatory groundwater monitoring programs, determine nitrate discharge to groundwater from the orchard, and inform ILRP approach. **Milestones**: statistical analysis of spatio-temporal variability of nitrate in shallow groundwater; hydrogeological and modeling analysis of relationship between orchard N mass balance, root-zone NO3- losses,

and groundwater NO3- and NH4+; inform ILRP regulatory process on usefulness and limitation of N mass balance as a practical, readily available tool to estimate actual long-term average N discharge to groundwater.

5) Assess the potential for regional application of Best Management Practices to minimize NO3- leaching to groundwater, improve groundwater quality, and reduce GHG emissions by performing DNDC and HYDRUS modeling. **Milestone**: BMP recommendations for final report in 2020.

Interpretive Summary:

This is our second project year at the Bowman almond orchard. Instrumentation, including monitoring wells, were installed during year 1 and initial measurements taken, which has led to some adjustments in equipment and monitoring protocol. In year 2, we achieved the main goal of A) implementing consistent High Frequency Low Concentration (HFLC) fertigation and B) obtaining a full year of consistent monitoring records describing nitrogen fluxes into and out of the orchard with our network of instruments and through regular monitoring campaigns. This lays the ground work for a replicate monitoring year in Project Year 3 and extensive analysis of the data collected.

Materials and Methods:

Experimental design for all objectives: In 2016/2017, the project consists of a 56 ha research platform to simultaneously monitor GHG emissions, soil nitrogen, and nitrate leaching from almond orchards under improved grower practices (**Figure 1**). The site combines several tiers to measure the fate of nitrogen: Measurements of GHG emissions that can be scaled to estimate orchard scale emission rates; orchard scale water and nitrogen mass balances to constrain and estimate potential nitrate losses to groundwater (Rosenstock et al., 2013), a tool that is also employed in the Nutrient Management Plans (NMPs) required under the ILRP of Central Valley growers; monitoring the fate of root zone water and nitrogen using an intensive vadose zone monitoring network installed at depths of 3 m to assess water and estimating nitrate losses to below the orchard root zone on a continuous basis (Harter et al., 2005, Botros et al., 2009, Baram et al., 2016); and monitoring first encountered groundwater for NO3- and NH4+ to determine actual discharge to groundwater in accordance with monitoring systems typically employed for site evaluation and WDR compliance by Regional Water Boards (e.g., Harter et al., 2002, 2014).

We have shown in prior work that such a monitoring well design, applied in an irrigated agricultural setting, will capture recharge from a "source area" of the monitoring well. The source area is estimated to extend from the monitoring well to several hundred feet upgradient (VanderSchans et al., 2009). Because of the extended and uncertain location of the source area of water sampled in a monitoring well, research sites are needed where practices are employed over several 10s of hectares rather than on a single small plot. Our selected study site is therefore a 56 ha almond orchard in a region near Modesto, California (**Figure 1**) that is vulnerable to nitrate contamination (Ransom et al., 2017). Soils are predominantly loamy sand and sandy loam with relatively shallow (7 m) depth to groundwater suggesting a relatively quick transport of nitrate to groundwater. In the initial project phase, a monitoring well network with 20 wells to 13 m depth was installed in 2017 (ABC Project #16.Water8.Harter).

The orchard irrigation system is an arrangement of micro-sprinklers and drip emitters varying between four orchard blocks, suitable for implementation of High Frequency Low Concentration (HFLC) fertigation regime. To meet grower's needs, a computer controlled HFLC fertigation program was provided by PH Technologies that significantly reduces labor requirements for implementation of the high frequency 'spoon feed' fertigation strategy. This system is key to achieving effective BMPs yet provides significant flexibility in fine-tuning the irrigation and nutrient scheduling. The system was installed at our site in early 2018.
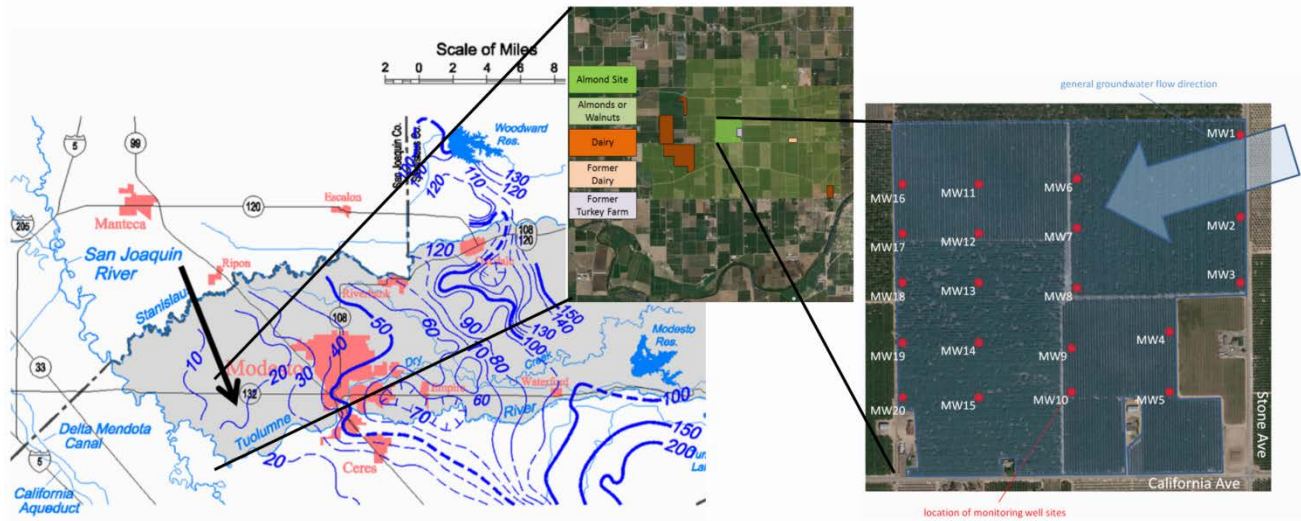
Figure 1. Location in the Modesto Groundwater Basin (grey area, left) with depth to groundwater, spring 2010 (map from DWR). Land use patterns in the vicinity of the 56 ha orchard (center), and groundwater monitoring well network on the 56 ha orchard for long-term assessment of groundwater nitrate leaching from continuous high frequency fertilizer N management relative to prior management (right).

Objectives 1 and 2:
Task 1: Collect one year of baseline data (2017) and two years of HFLC management data (2018, 2019).

Task 2: Weekly soil N monitoring; continuous climate monitoring; 2017: instrument setup and calibration; 2018-2019: HFLC monitoring.

GHG emissions samples were collected weekly by the static chamber method and analyzed on a GC. Intensive gas sampling was conducted during a week at the end of May to elucidate the peak increase in cumulative emissions following fertigation. Chamber collars were installed in four blocks (experimental units) in the orchard with three subsample transects in each block. Additionally, soil samples were collected for chemical analysis and measured for soil temperature and soil moisture content. Other environmental variables (air temperature, air vapor pressure, solar radiation, wind velocity, precipitation amounts etc.) were gathered using weather stations and a surface renewal system.

Objective 3:

Task 3: Weekly soil solution N monitoring; continuous soil moisture monitoring; 2017: instrument setup and calibration; 2018 and 2019: HFLC monitoring, development and implementation of statistical analysis

Seven locations were equipped with two arrays of soil water and nitrogen monitoring equipment: solution samplers at approximately 30 cm, 60 cm, 90 cm, 180 cm, 300 cm, as well as 4 tensiometers, two each at depths of 280 cm and 300 cm. Soil water samples were collected from porous cup solution samplers once a week, after each fertigation even to measure nitrate movement throughout the soil profile at the specified depths. Tensiometers allow for real time recording of soil water potential, and were recording measurements every 15 min. Additionally, a neutron probe was used at each sampling event to monitor soil moisture to 3 m depth throughout the growing season.

Tensiometers readings are recorded every 15 minutes in mV and converted to matric potential (cm) using a calibration curve, and then adjusted for the pressure transducer height above ground. The matric potential h (here positive when unsaturated) readings for 280 cm and 300 cm were averaged, and a gradient (J) for each station was calculated by:

1
$$J = \frac{dh}{dz} = \frac{h(300cm) - h(280cm)}{\nabla z}$$

where ∇z = 20 cm, the height difference between the two tensionmeter depths.

The rate of water flow is determined by calculating the Darcy flux, q, using:

2
$$q = -K(h)J$$

Darcy's law is the basic equation that describes fluid flow through porous media. Where J is the calculated gradient from eq.1 and K(h) is the hydraulic conductivity. A functional relation between the hydraulic conductivity (K(h)) and matric head (h) is required to solve this equation. K(h) was evaluated using the van Genuchten - Mualem (van Genuchten, 1980):

3
$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + (\alpha)|h|^n\right]^m}$$

4
$$K(h) = K_s (S_e)^{0.5} \left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$

where α and n are empirical parameters and $m = 1 - 1/n$, θ_r is the soil's residual volumetric water content, θ_s the soil's saturated volumetric water content and K_s is the saturated hydraulic conductivity.

The constants- α, n, m and K_s for now were assumed (**Table 1**), according to the closest two well profiles description at depth of 266-333 to each site. Due to the great variability in soil properties found at the wells (e.g. well 20 and 18 showing sandy loam vs. silty clay for site 3), it is not accurate to use the closest well profile. Therefore, during the upcoming winter we will core at each site to determine soil properties and make more accurate measurement of the texture parameters in equations 3 and 4. For now, a general assumption was made to have one constant for all sites. The soil description at the nearby monitoring well sites, where continuous soil cores were obtained, are used this year to determine the hydraulic properties from the Rosetta-lite pedotransfer function database in HYDRUS (Šimůnek et al., 1998). These properties will be calibrated in the future more accurately.

	1		7		3		4		2		8		6
Depth (cm)	BWN1	BWN2	BWN10	BWN9	BWN20	BWN18	BWN19	BWN17	BWN6	BWN5	BWN7	BWN8	BWN11
0-33	silty clay	loam	silty clay	loam	sandy loam	loamy clay	silty clay	silty clay	silty clay	silty clay	loam	sandy loam	silty clay
33-66	silty clay	loam	silty clay	loam	silty clay	loamy clay	silty clay	silty clay	silty clay	silty clay	loam	sandy loam	silty clay
66-100	silty clay	sandy loam	silty clay	loam	silty clay	loamy clay	loam	silty clay	loam	loam	loam	sandy loam	silty clay
100-133	silty clay	sandy loam	silty clay	loam	loam	loamy clay	loamy clay	silty clay	silty clay	silty clay	silty clay	sandy loam	silty clay
133-166	loam	loam	silty clay	loam	silty clay	silty clay	silty clay	loamy clay	sandy loam	sandy loam	sandy loam	silty clay	loam
166-200	loam	loam	sandy loam	sand	silty clay	sandy loam	loam	loamy clay	silty clay	sandy loam	sandy loam	sand	sand
200-266	silty clay	loam	silty clay	sandy loam	sandy loam	silty clay	silty clay	silty clay	sandy loam	sandy loam	sandy loam	silty clay	sand
266-333	silty clay	sandy loam	silty clay	loam	sand	silty clay	loam	silty clay	sandy loam	sand	sand	sandy loam	sand

Figure 2. Soil profile description at the well sites arranged in groups according to location by to each of the monitoring sites (1-8).

Table 1. Assumed soil hydraulic properties according to HYDRUS

Assumed soil	site	K_s [cm/day]	n	α
Silty clay	4,3	1.68	0.01	1.23
loam	1,7	24.9	0.036	1.56
Sandy loam	2,8	106	0.075	1.89
sand	6	712	0.145	2.68

Objective 4:
Task 4: In 2017, a shallow groundwater monitoring well network has been completed (ABC Project #16.Water8.Harter). Beginning in the Fall of 2018 and continuing over the remainder of the project we perform regular groundwater sampling for NO3-, NH4+, and salinity monitoring, initially twice per quarter (through July 2019), then quarterly thereafter for at least 5 years. Once per year, samples are analyzed for complete major constituents. Future tasks under this objective (Spring 2019-Spring 2020) will perform initial modeling and hydrogeological analysis.

Groundwater samples were collected on 10/29/2017, 5/7/2018 and 7/23/2018 from each of 20 shallow groundwater monitoring wells. Water samples were collected in the field with our groundwater sampling equipment following standard operating procedures (Harter et al., 2002). Field analysis of water samples included temperature, pH, and electrical conductivity.

After each sampling, the samples were submitted to UC ANR Analytical Laboratory for analysis of nitrate and ammonium. At each sampling event, water samples were analyzed for at least the minimum of pH, salinity and nitrate. For each sampling event, we will also submit 5 QA/QC samples (duplicates and blanks; 25 samples in total per sampling event). Data will be evaluated for temporal trends, spatial variability, and compared to hydrogeologic conditions and results from the vadose zone monitoring program and from the water and nitrogen mass balance monitoring.

Objective 5:
Task 5: Develop HYDRUS model to simulate fate of nitrate at the orchard site; develop DNDC model for various almond site conditions (soil, irrigation, nutrient management) and provide specific emission / discharge performance reports for HFLC under a range of soil and irrigation conditions relative to other practices under the same range of conditions.

GHG data will feed into the DNDC model to simulate annual budgets according to daily environmental conditions. The data collected in the field for objectives 2 and 3 will be utilized in computer simulation using a hydrologic process-based model, HYDRUS model (Šimůnek et al., 1998). Data on the hydraulic conditions below the effective root zone (i.e. water content and matric potential), will be used to enable better nitrate leaching simulations while accounting for the daily water balance (irrigation vs. transpiration) and for soil layering.

Data collected will provide growers with information needed to quantify and optimize management of water, nitrogen fertilizer, GHG emissions, and groundwater nitrate for nut crops. The research performed will provide critical information to the Central Valley Regional Water Quality Control Board under the current waste discharge requirements for their Irrigated Lands Regulatory Program. The monitoring wells may potentially serve as part of a trend monitoring program. We are working closely with the agricultural water quality coalitions to ensure that our research design meets their needs for implementing the MPEP. The site used in these experiments will be principle demonstration sites for the almond industry field days demonstrating new applications of nutrient budget management and leaf sampling, and as demonstration site for new technologies. The developed nitrogen recommendation models will help to control N losses to the atmosphere and groundwater, contribute to climate change mitigation and to the restoration of degraded groundwater quality.

Results and Discussion:

Objectives 1 and 2: **N$_2$O Emissions**
Soil gas emissions were collected following fertigation events (almost weekly) from spring through harvest of the 2017 growing season and continued post-harvest up to date for the 2018 season. We conducted gas sampling in each of the four blocks during the 2017 campaign and added a new collection site on a compost trial portion of Block 2 for 2018. The four orchard blocks are planted with the same almond varieties, however orientation, tree spacing, and irrigation systems differ between the blocks (**Table 2**).

Table 2. Planting characteristics of orchard blocks

Block #	Tree spacing (feet)	Irrigation system	Row orientation
Block 1	14	Fan jet	North-south
Block 2	14	Drip	North-south
Block 3	18	Fan jet	East-west
Block 4	14	Fan jet subterranean hose	North-south

The N_2O emissions starting in April of the 2017 growing season show a seasonal pattern of flux with a peak during the spring and subsequent peaks generally following fertilization and irrigation events (**Figure 3**). Generally, Block 4 irrigated by fan jet with subterranean hose produced the highest flux per event, although Block 1 (fan jet with smaller spacing) resulted in the highest peak measured flux during April. This could be attributable to irrigation scheduling; further analysis and modeling will attempt to evaluate these details.

Nitrous oxide emissions from 2018 growing season through early summer (post-harvest in October 2017 through June 2018) show a seasonal pattern as well, with all blocks peaking during the spring season (**Figure 3 B**). We also see a few peaks after 2017 harvest due to rain and post-harvest fertilizer applications. The same block shows the highest peak emissions (Block 1) as occurred in the spring of 2017.
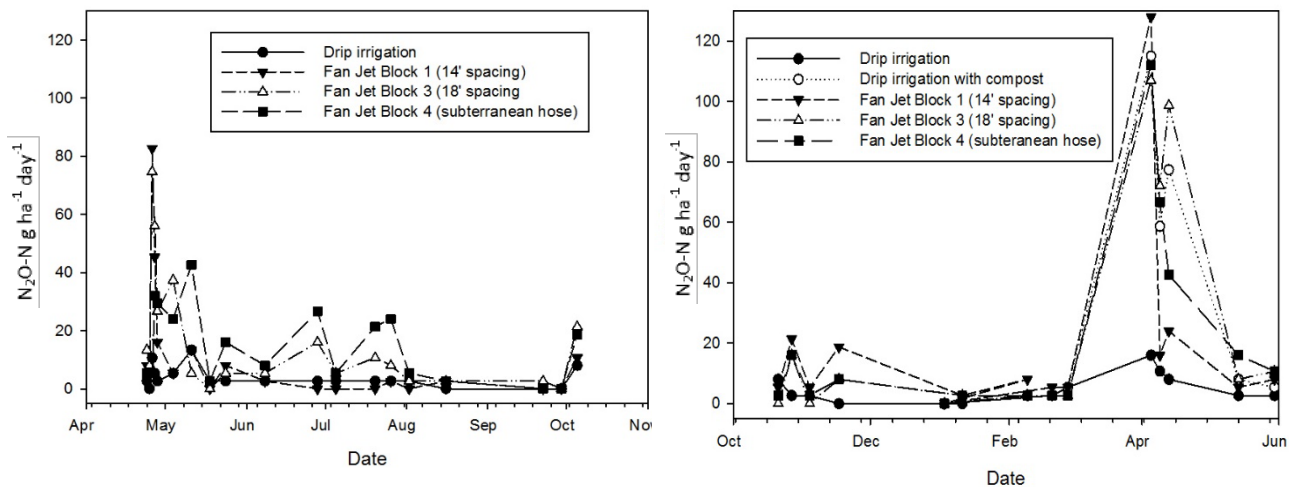
Figure 3. N_2O flux (g N_2O-N ha^{-1}) for 2017 (left) and 2018 (right) season.

Comparing the spring (April-May) peak emissions in each season, peak flux is higher during the 2018 season than 2017 season (**Figure 4 A and B**). Although 2017 season had a lower spring peak, it was followed by subsequent peaks at higher fluxes than seen in the 2018 season. Spring 2018 has only three data points as additional sampling during that time has not yet completed analyses; however, this data does represent the spring peak time. Additional explanation to the differences between the two seasons could be the sampling time in relation to the fertigation/ irrigation times. More gas sampling data is needed to be able to compare the two seasons.
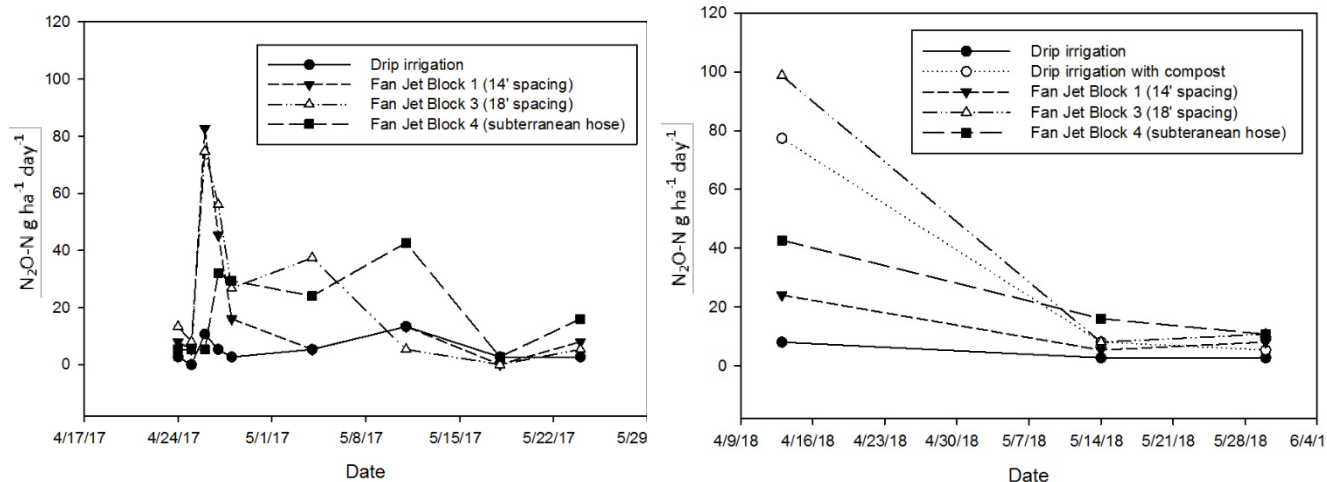
Figure 4. Spring peak fluxes during A. 2017 and B. 2018 season.

Cumulative N₂O emissions for 2017 and 2018 season indicate the drip irrigation block had lower total emissions for both seasons (**Figure 5 A and B**). The fan jet irrigation system with larger tree spacing (Block 3) resulted in the highest cumulative emissions during both seasons. (**Figure 6 A and B**).
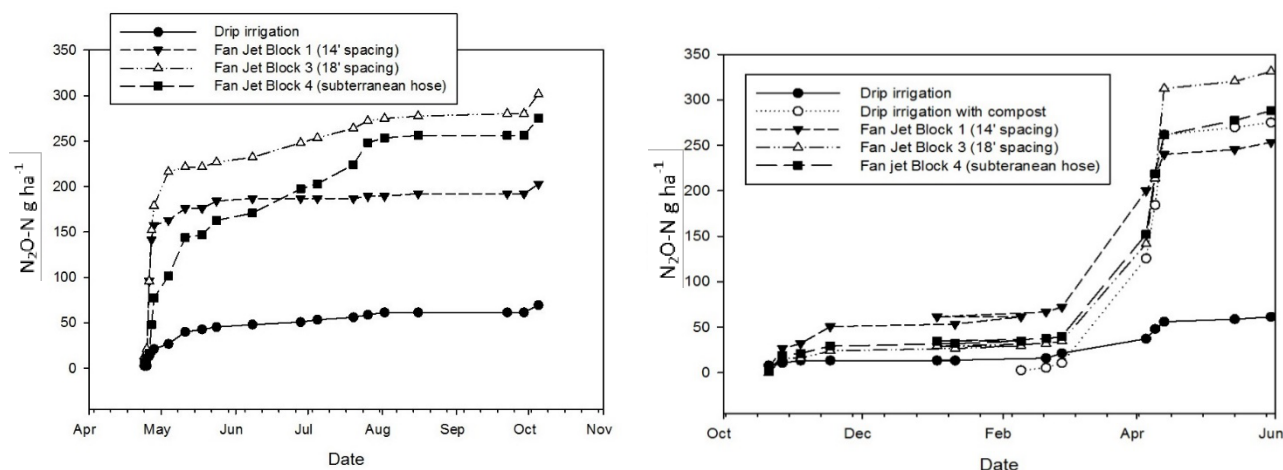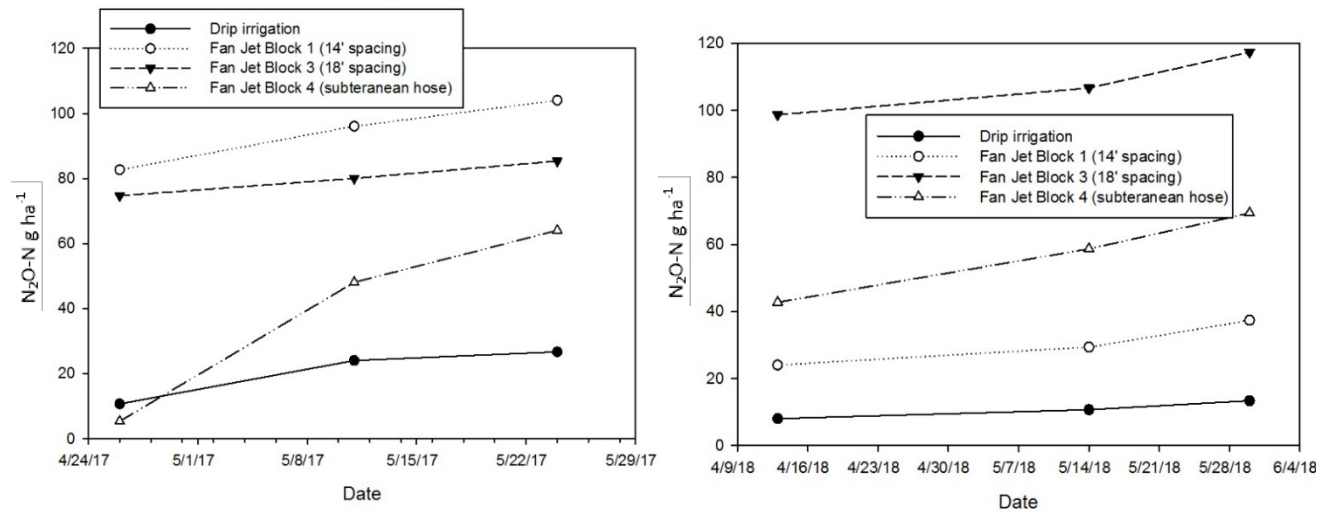

Figure 5. Cumulative N₂O emissions in g N₂O-N ha⁻¹ for A.2017 and B. 2018 growing season

As expected from our previous results, N2O flux increased in Spring. However, N2O flux rates peaked earlier and ended earlier in 2018 than in 2017 during April and May. Cumulative emissions during the spring in both seasons show similar patterns (**Figures 6 A and B**). Drip irrigation resulted in lowest cumulative emissions for both years with 2018 slightly lower than 2017. The cumulative N₂O emissions for fanjets with narrower 14' tree spacing decreased with HFLC treatments in 2018 compared to 2017. Fanjets with 18' tree spacing generally resulted in the higher cumulative N₂O emissions for both years compared to the other fan jet systems. Subterranean hose fan jet systems had lower cumulative N₂O emissions than the other fan jet systems.

Figure 6. Cumulative N_2O emissions in g N_2O-N ha^{-1} for April and May of A. 2017 and B. 2018 growing season.

Objective 3:

Porewater quality samples and soil moisture data was collected from the five depths at each of seven monitoring sites immediately following each weekly fertigation event during 2018 growing season. The pore water samples were analyzed for ammonium and nitrate+nitrite using a colorimetric method. The pore water results, soil moisture and the tensiometer readings were used to calculate the nitrate flux from each site to below the root zone, using the equations described in the methods section.

Soil hydraulic conductivity - K(h) was calculated for tensiometers at 280, and 300 cm by using equations 3 and 4 and then used in equation 2 to calculate Darcy flux, the amount of water [cm] leaching from below the root zone profile. Cumulative water flux between February and mid-July varied by more than double between sites (**Figure 7**). Three of the seven sites had significant leaching rates: Sites 1 and 7 leached 22 cm, while Site 3 leached the most - more than 80 cm, of which more than 60 cm of all leaching occurred over a two-week period in early May. Site 6 had a lower and constant leaching during this period cumulating to 12 cm. In contrast, Site 4 showed an opposite – upward - flow during most of the season. Site 2 showing a cumulative flux of around zero, first a leaching of 5 cm at the end of March in one event, and then no flux during the rest of the season.

It is unclear, why some sites recorded significant leaching. Relating the leaching at the sites to the assumed soil texture in **Figure 2**, Sites 2,6 and 8, which show the lowest leaching are sandy profiles, while the other sites at which the leaching was recorded have assumed profiles of silty clay texture (Sites 3 and 4) or loamy texture (Sites 1 and 7). Lower leaching at the light soil texture sites might be due to preferential flow (Hillel, 1998). With preferential flow, the water flow may have bypassed the tensiometers. The one week leaching increase at Site 3 during May might be due to a technical problem in the data analysis (a similar issue may drive the increase at Site 2). In the silty profiles we would expect a lower leaching flux, or even an upward flux as we see at Site 4
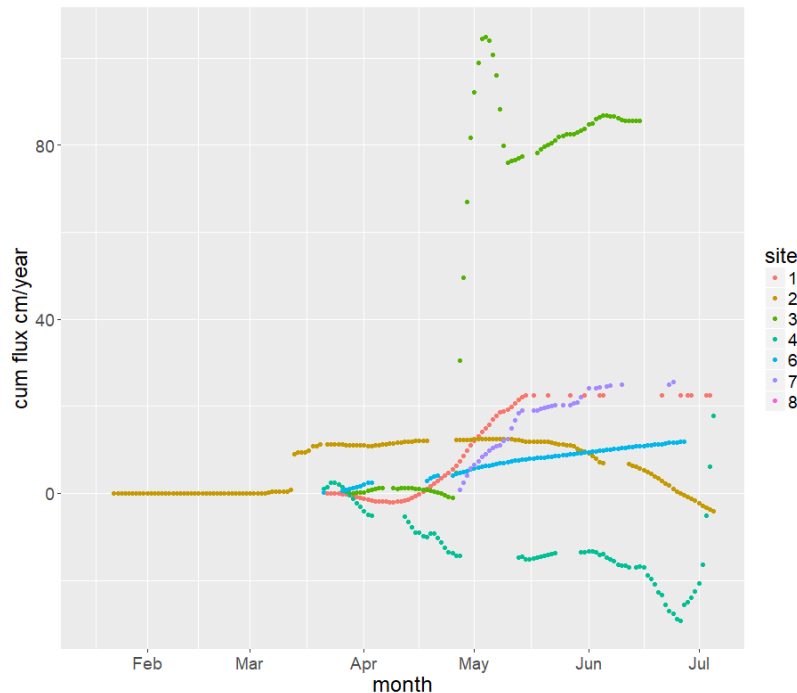
**Figure 7.** Cumulative water flux for each site during 2018 growing season

For each site, the nitrate concentration at each depth was averaged by season: winter (December, January, February), spring (March, April, May), and summer (June, July, August). Fall (September, October, November) has not yet been recorded. Measurements during the 2018 growing season started in March (**Figure 8**). During the summer most of the 30, 60 and 90 cm pore water started to fail due to dry conditions.

Nitrate+nitrite N concentrations are highly variable, but rarely exceed 100 mg/L. Soil nitrate+nitrite profiles during the winter season indicate downward leaching from winter rains: Concentrations in the winter profiles are lowest in the first 30 cm, then generally (with some variability) increase with depth to 300 cm. In the spring, nitrate+nitrite N concentrations begin to increase near the surface as fertigation begins but decrease in the deepest portion of the soil profile as nitrate leaches deeper. Only at Site 8, large concentration increases are observed in the spring at 200 cm and 300 cm depth (**Figure 8**). As the summer dries out the soil profile, Sites 1, 2, 6, and 7 see further increases throughout most of the profile. Except for Site 7, increases at depth are not large enough to exceed concentrations observed during the winter leaching period. At Sites 3 and 4, summer concentrations are generally lower throughout the profile than in the spring.
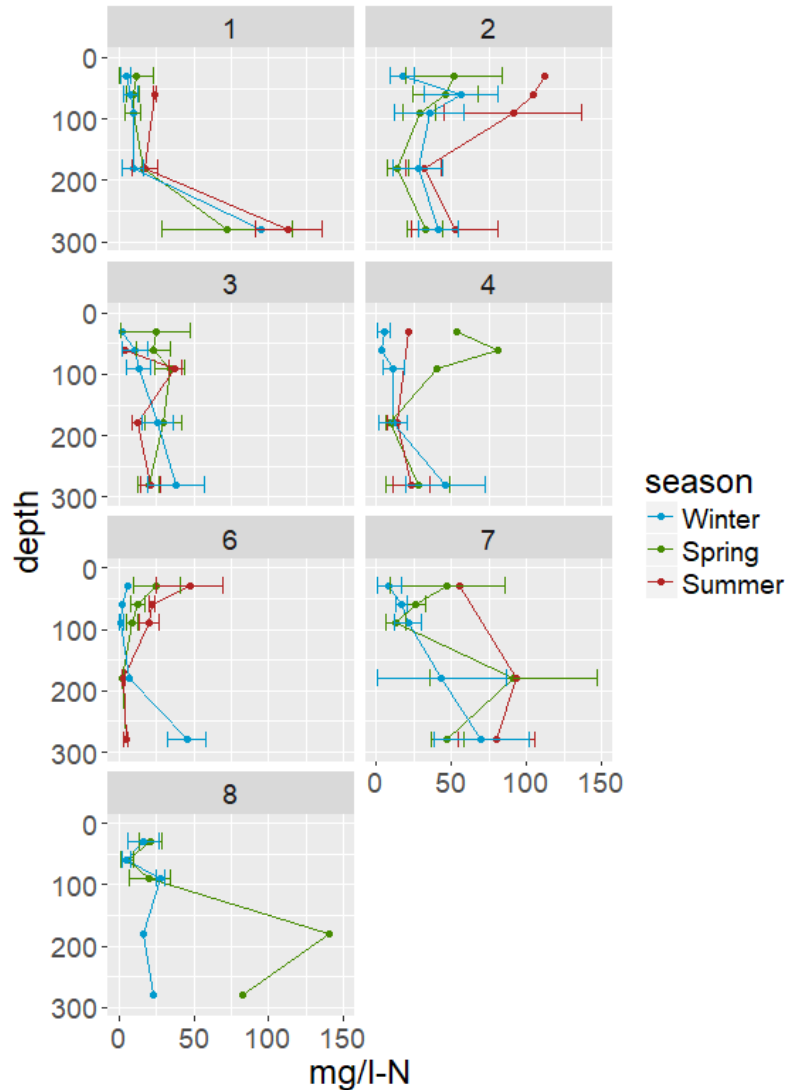
Figure 8. Nitrate+nitrite-nitrogen content by depth at each site averaged by season, with in-season standard deviation. Data points without standard deviation did not have enough data to average.

When averaging across all sites to obtain representative N and water profiles for the orchard, these trends are more obvious: The soil profile dries out throughout. Much more drying is observed near the top than toward the bottom of the 300 cm profile (**Figure 9 B**). Over time, nitrate concentrations increase everywhere in the upper 180 cm. Highest concentration increases are seen in the driest part of the soil, at the top. At 280 cm, below the root zone, water content decreases only slightly. There, average concentrations decrease from 56 mg/L in the winter to 32 mg/L in the spring, then increase again to 47 mg/L in the summer. However, only Site 4 would have measurable downward flux in the summer, but summer concentrations at Site 4 (280 cm depth) are among the lowest, at 24 mg/L (**Figure 7**).
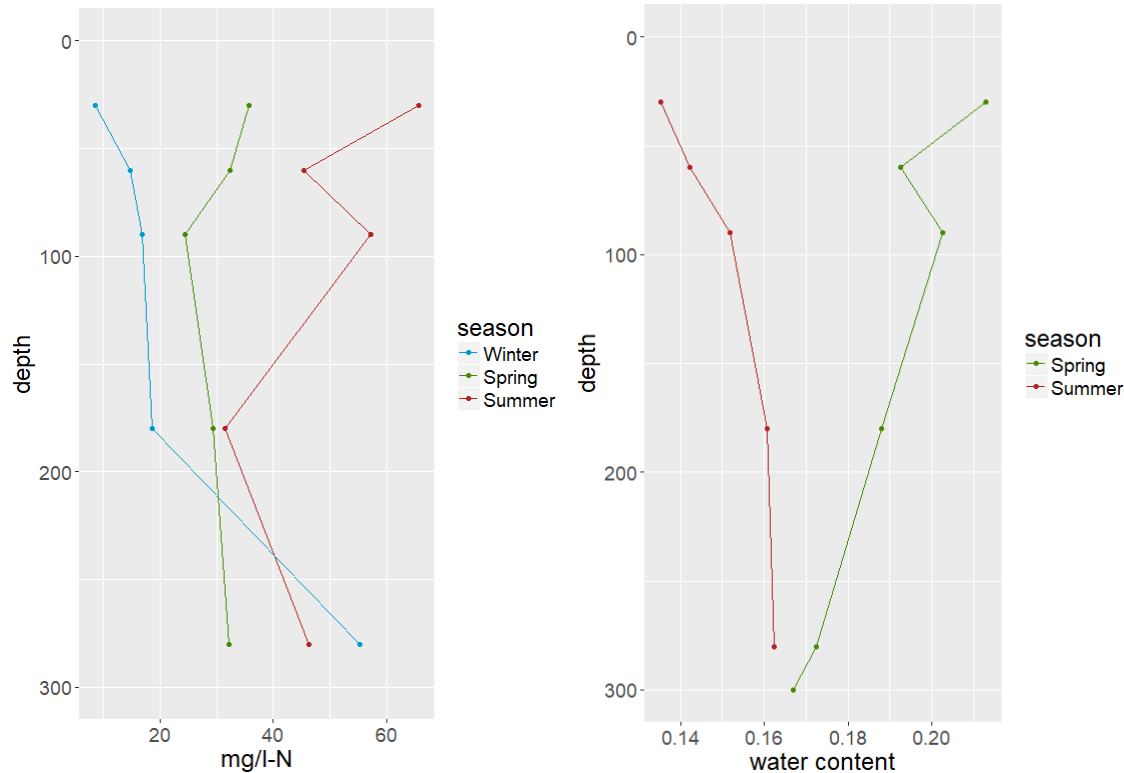
Figure 9. Average of nitrate +nitrite-nitrogen (A) and water content (B) for each season for all the sites

Nitrate flux out of the bottom of the root zone

Daily nitrate flux out of the root zone, at 280 cm below ground surface, was determined by totaling the 15-minute water flux estimates over a 24-hour period to obtain the daily flux. The daily flux was multiplied by the nitrogen concentration relevant for that day, interpolated between measurement days, and summed for a cumulative flux for the year (**Figure 9)** for each site

$$Q_N = \sum C_N(mg/l) \times q(cm/day) \times A(cm^2).$$

where summation is over the growing season, Q_N is the cumulative flux of nitrate over the growing season, C_N is the nitrate concertation measured in pore water at 280 cm, q is the daily flux and A is the wetted area of the sprinkler, assuming there is about 130 sprinklers per acre.

Sites 1 and 7 show a similar leaching of around 20 kg-N/year/acre, both sites consist with similar soil texture (loam, **Table 1**). Site 3 shows the greatest cumulative nitrate flux of about 25 kg-N/year/acre, most of which is associated with a very short leaching event in late April, which may be due to sensor malfunction at this time period. If this one-week event is ignored (assuming instrument failure), the site's nitrogen leaching reduces to 5 kg-N/year/acre. Cumulative N leaching at Site 6 appears to also be negligibly small during the growing season, given the absence of significant water flux. Ignoring the largest event in Site 2 indicates leaching rates that are similarly low as at Site 6 (both these sites have a light soil texture).

Continuous data collection started in April after solving most of the technical problems. Some leaching before April may have been missed in our data collection. Therefore, it looks like most

of the leaching occurred during April-May after the rains stopped and a more intensive irrigation began (**Figure 10**). **Figure 10** is missing data points from the beginning of the season when some of the equipment was having problems. The leaching does not continue past June, after the fertigation stopped.
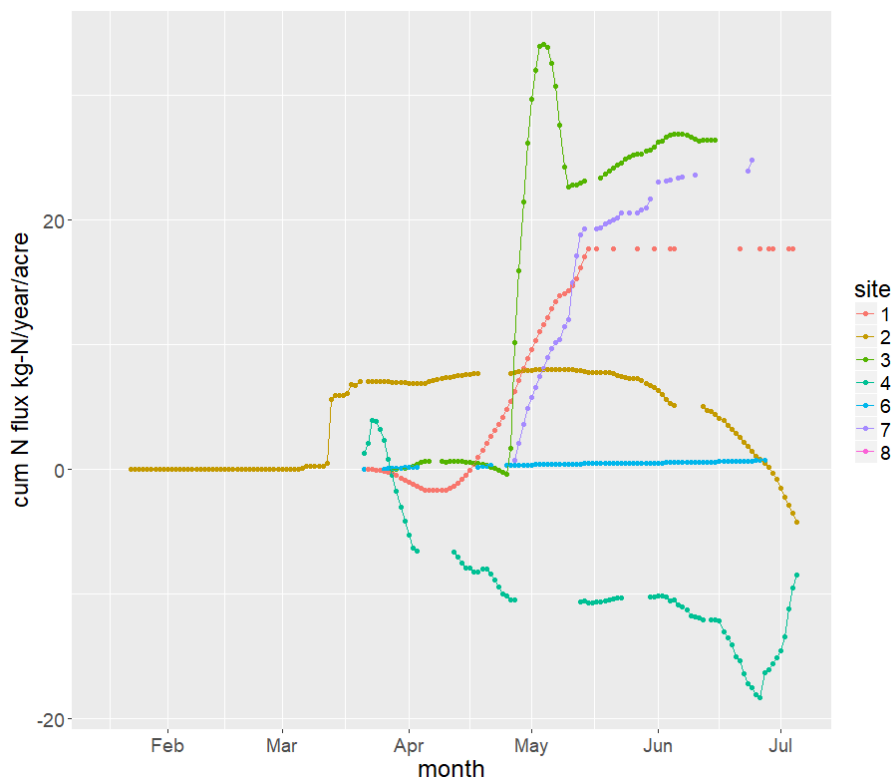
Figure 10: Cumulative N flux over the growing season, at the 7 root zone monitoring sites in the orchard. Some data were not collected in February and March. The graph may therefore miss some leaching events.

These results will be refined after fieldwork season slows and more elaborate computations can be performed in the lab.

Objective 4:
Ground water
A new well pump and tubing was purchased to replace a 23-year-old pump that could not be repaired after several attempts. Prior to sampling, water levels were monitored and each well was purged: at least 25 gallons of water were evacuated before samples were collected to ensure that fresh aquifer water is sampled, not stagnant water from the well casing. Field analysis of water samples included temperature, pH, and electrical conductivity after each 5 gallons purged. After each sampling, the samples were submitted to UC ANR Analytical Laboratory for analysis. At each sampling event, water samples were analyzed for nitrate, and ammonium, however, since ammonium was not detectable, future bi-quarterly samples will be analyzed for nitrate only (**Figure 11**) The annual comprehensive groundwater samples taken on May 7-8 were submitted to the analytical lab for all major anions and cations, nitrate, and ammonium (**Table 3**).

Depth (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Oct-17	4.5	6.0	9.7	25.1	16.3	18.3	19.2	23.0	6.8	16.7	23.4	27.1	56.9	31.2	42.6	20.8	33.9	16.0	8.4	27.1
May-18	4.7	3.5	10.3	33.1	20.6	23.9	21.3	10.7	5.5	17.1	22.3	24.9	49.4	36.6	55.9	20.3	25.5	18.9	19.0	20.4
Jul-18	13.4	9.5	10.1	37.3	19.2	19.7	19.2	25.5	6.7	17.2	23.1	28.7	56.4	32.3	53.7	26.4	31.9	22.7	18.4	36.1

Legend: sand | sandy loam | sandy clay | loam | silty clay | loamy clay | clay
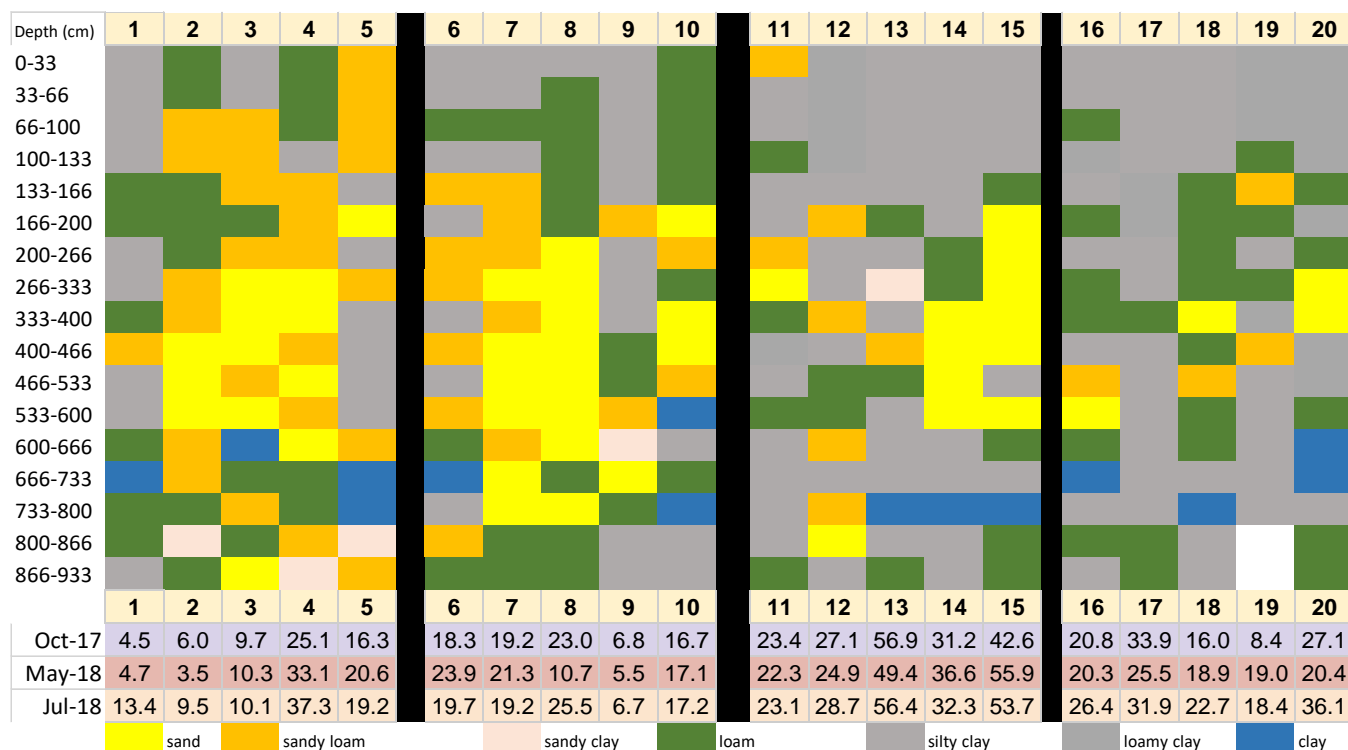
Figure 11: Top; Soil texture classification by depth at each monitoring well site (1-20). Bottom; Nitrate-N (mg/L) measured in the 20 monitoring wells at the Bowman Ranch over time (10/29/2017, 5/7/2018, 7/23/2018. 25 gallons of water was removed before a sample was collected. All samples were kept cold until analysis at the UC ANR Analytical Laboratory. The monitoring well network consists, roughly, of twenty wells arranged in 4 north-south transects, with five wells in each transect. Wells are numbered consecutively from north to south, then from east to west. Groundwater flow is from east to west. Well 1 is located in the NE corner of the orchard. Well 20 is located in the SW corner of the property. Black profile borders in the delineate each north-south transect.

Table 3: UC ANR Analytical Laboratory for analysis of all major anions and cations measured after 25 gallons of water were purged from the 20 monitoring wells at Bowman Ranch for May 7-8, 2018. Zn, Cu, Mn were not detectable.

Bow-MW#	Depth to Water (feet)	Removed (gallons)	Temp (celsius)	EC (mS/cm)	pH	NH4-N (mg/L)	Cl (meq/L)
1	22.27	25	18.20	1.04	7.70	<0.05	0.34
2	22.59	25	17.90	1.23	7.40	<0.05	1.65
3	22.84	25	18.40	1.27	6.60	<0.05	3.89
4	21.39	25	18.90	0.63	6.89	<0.05	1.02
5	21.92	25	18.40	0.72	7.09	<0.05	0.30
6	22.48	25	17.90	1.18	7.34	<0.05	1.45
7	22.57	25	18.30	0.84	7.83	<0.05	0.33
8	23.11	25	17.70	1.01	7.32	<0.05	0.43
9	21.79	25	18.10	0.31	7.73	<0.05	0.16
10	21.14	25	18.20	0.49	7.55	<0.05	0.55
11	20.74	25	18.30	1.14	7.09	<0.05	1.28
12	20.97	25	18.20	1.33	7.14	<0.05	1.04
13	21.28	25	18.20	2.05	7.40	<0.05	1.54
14	21.30	25	17.90	1.15	7.14	<0.05	1.18
15	21.19	25	17.50	1.12	7.37	<0.05	1.31
16	21.16	25	17.90	1.11	6.86	<0.05	0.86
17	21.27	25	18.30	1.18	6.85	<0.05	0.51
18	20.85	25	18.60	0.86	7.58	<0.05	1.08
19	20.85	25	18.80	1.06	7.47	<0.05	0.90
20	21.20	25	17.70	0.80	6.97	<0.05	0.27

Bow-MW#	HCO3 (meq/L)	K (Soluble) (mg/L)	Ca (Soluble) (meq/L)	Mg (Soluble) (meq/L)	Na (Soluble) (meq/L)	Fe (Soluble) (mg/L)	SO4-S (Sol S) (mg/L)
1	4.5	3.84	1.10	1.13	4.60	0.027	28.5
2	3.1	3.72	1.23	1.51	3.32	<0.010	19.7
3	6.4	5.24	4.08	4.21	5.85	<0.010	50.5
4	2.2	3.45	3.92	2.21	0.67	0.039	18.8
5	4.7	3.45	3.30	3.12	1.07	<0.010	11.7
6	7.8	8.87	3.00	3.94	7.61	<0.010	69.7
7	5.3	6.28	3.07	2.90	3.21	<0.010	33.5
8	2.6	2.64	1.87	1.42	1.85	<0.010	22.3
9	1.6	1.98	1.35	0.93	0.31	<0.010	4.4
10	2.5	2.27	2.73	2.10	0.46	<0.010	16.4
11	4.6	6.79	2.66	3.42	6.83	0.019	62.8
12	4.7	6.71	2.36	3.23	6.78	0.150	75.5
13	4.6	7.71	4.98	4.89	10.04	<0.010	181.6
14	5.4	8.02	4.32	4.27	6.34	<0.010	91.2
15	4.7	4.70	5.66	4.39	3.65	<0.010	62.4
16	5.3	4.27	2.12	3.76	3.47	<0.010	28.2
17	5.7	5.19	1.71	3.39	4.92	<0.010	27.7
18	3.3	4.81	3.12	3.04	1.47	0.046	32.6
19	6.6	6.94	2.70	2.74	7.52	<0.010	58.5
20	2.1	2.83	2.18	1.54	1.06	<0.010	15.8

Three sets of nitrate-N data were collected so far. While we observe some significant temporal variability, spatial variability between wells is overall larger than the variability over time, at individual wells. Some patterns emerge. Fifteen of the twenty monitoring wells consistently

exceed 10 mg N/L, the maximum contamination level for nitrate in drinking water. The lowest concentrations are observed in three wells in the northeast corner (MWs 1, 2, and 3). These wells represent groundwater that has been recharged mostly upgradient of the orchard, where a vineyard used to be located that was replaced with a new almond orchard only about three years ago. It is expected that the concentrations in these three MW may increase with time due to the higher nitrogen inputs in almonds compared to vineyards. The upgradient property is outside this project's management zone.

Two other wells have relatively low N concentrations, sometimes less than the drinking water limit (MW 9 and MW 19), both located in the southwestern portion of the orchard. While the wells are approximately along a flowpath, the third well monitoring well, located between these two (MW 14), has much higher concentrations. High concentration (above 25 mg NO_3-N/L) are found in MW 4,12-15, 16-17 and 20. Higher values could be due to many variables. For example, sites 4, 8 and 15 have higher sand and loam content in the profile compared other sites, allowing faster leaching in these profiles. Some of the highest concentrations are located at locations, where the orchard was removed last fall due to old age (MWs 13 and 14). Higher nitrate concentrations may be due to the low nitrogen consumption of the trees prior to their removal in 2017. The profiles that consist of more heavy soils as silty clay or loamy clay (MW 10,12,17) show concentrations that are less fluctuating. These hypotheses will be tested in coming months using robust statistical analysis on the entire data set collected (N management, root zone N, hydrogeology, climate, groundwater geochemistry).

There is some variability in time, which we will analyze after we have obtained a year's worth of twice quarterly samples. However, there is more variability between wells with the above pattern being the most prominent features across the set of 20. It seems there is some consistency in the overall spatial pattern of the nitrate distribution over time.

The western-most transect is most likely to be reflecting recharge exclusively from the orchard. The average nitrate concentration in the five monitoring wells is 23 mg N/L. Assuming an average annual recharge of 15 – 30 cm/yr, mostly during the winter rainy season, this concentration represents average N losses of about 35 – 70 kg N/ha/yr. This is consistent with past N fertilization practices and N harvest amounts. These losses are also consistent with those measured across the almond industry as part of the Irrigated Lands Regulatory Program.

From a management perspective, the challenge before us is to reduce N losses from the root zone as much as possible, ideally to the point where nitrate-N levels in the shallow groundwater are less than the drinking water limit of 10 mg N/L. If winter recharge is maintained in the 15 – 30 cm/yr range, this would require us to reduce N losses from the root zone (after any denitrification) at least two-fold. We anticipate that improved management practices begun this year will take several years to fully affect monitoring well data.

Future analysis will look at temporal trends and spatial variability in the context of measured hydrogeologic conditions, results from the vadose zone monitoring program, and from the water and nitrogen mass balance monitoring.

Objective 5: Results will be presented in the next report.

Research Effort Recent Publications:

Research efforts were presented at the Annual Environmental Stewardship Tour of the Almond Board of California, on May 11, 2018.

Two poster abstracts were submitted to the SSSA conference in San Diego (Jan 6-9, 2019):

Evaluating HFLC Nitrogen Management Strategies to Minimize Reactive Nitrogen Mobilization from California Almond Orchards. Ouaknin Hanna, Patrick K. Nichols, Christine Stockert, Thomas Harter, Patrick Brown, David R. Smart

Gaseous nitrogen losses in California almonds: fertigation management as a control. Patrick K. Nichols, Ouaknin Hanna, Christine Stockert, Thomas Harter, Patrick Brown, David R. Smart

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