Optimizing the Use of Groundwater Nitrogen (NO_3^-): Efficacy of the Pump and Fertilize Approach for Almond

Project No: **13-PREC6-Smart**

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Objectives:

The overarching objectives being pursued under the proposed investigation contribute to a multidisciplinary investigation funded by the California Department of Food and Agriculture (CDFA) Fertilizer Research and Education Program (FREP) that will answer a number of questions relevant to the “pump and fertilize” (P&F) approach to groundwater nitrate (NO_3^-) management. The P&F approach will be contrasted with Advanced Grower Practice (AGP) that consists of 4 to 6 fertilizer N applications of 30 to 75 lbs. N per acre and targeted to tree N demand. Pump and fertilize consists of the hypothesis that a unit mass of NO_3^--N is equivalent to a unit mass of properly managed synthetic N fertilizer. P&F has been projected to diminish potentially leachable NO_3^- while sustaining economic production to improve nitrogen use efficiency (NUE) of nut crops (Harter et al. 2012). Further, there is a need for development of monitoring technologies that are practical and provide real time feedback to growers and can be correlated with information from of long-term groundwater monitoring wells, to reduce the possible reliance on wells as the feedback mechanism. The overall objectives being pursued under this agreement include:

1. Establish research and demonstration orchards for “Advanced Grower Practice” and “Pump and Fertilize” nitrogen (N) management in almond (and pistachio) within “Hydrogeologically Vulnerable Areas” (HVAs).

2. Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to describe best management practices and contrast those practices with ‘Pump and Fertilize’ N management treatments.

3. Characterize key biological and physical parameters relevant to P&F concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc.).

4. Establish proof of concept for use of stable isotopes of $^{15}N^{18}O_3^-$ in tracking N leaching.

5. Develop and ground-validate decision support models (including Hydrus) to assist growers with optimal management of groundwater nitrogen (mainly NO_3^-).

6. Demonstrate and proactively extend developed results, technologies relevant to on-site self-assessment and BMP’s to growers.

Interpretive Summary of Work for This Year:

The goals of this project are to test the pump and fertilize concept (P&F) as a realistic alternative to the use of synthetic fertilizers like calcium ammonium nitrate (CAN) and urea ammonium nitrate (UAN). Our primary objective during the first half of 2014 was to work with growers to establish three different N application practices (AGP, P&F and high frequency low N concentration (HFLC)) to almond orchards in two hydrogeologically vulnerable area (HVA: DWR, 2000) in the Central Valley (**Figure 1**).

We have established fully randomized complete blocks designs for the two orchards (**Figure 2**). Prior to the beginning of the irrigation season (February 2014) ~200 soil samples were collected from the three blocks in each site down to 3m below land surface (bls.). The soil samples were analyzed to determine the N concentration distribution in the vadose zone prior to the beginning of the different N-applications. At the beginning of the year, using a sampling grid, the soil profile under an almond orchard in Madera was characterized based on particle size distribution in 20 boreholes excavated to 3 m bls. Eight sites were selected to represent the different layering in subsurface horizons (**Figure 3**) which is critical to modeling and assessment of NO_3^- leaching. Each one of the eight sites was instrumented with five solution samplers, four tensiometers, and five 5TE probes (Decagon, Pullman, WA, USA). The installed sensors monitor processes in and below the root zone (**Figure 4**). The volumetric water content (θ_v) distribution in the sediment profile and the matric potential below the root zone have been continuously monitored and logged since February 2014.

In the current growing season, since mid-March 2014, the almond orchards have been irrigated almost on a weekly basis. Fertilizer was applied to the orchard on three occasions. During each fertigation event, the P&F subplots received ~70% of the planned load and the HFLC subplots received none. The HFLC subplots were fertigated during each irrigation event with 5% of the total N-load planned for the season using microfertigators (**Figure 5**). Irrigation water was sampled on a weekly basis from the sprinklers in each subplot. Porewater from the vadose zone was sampled every few weeks. More than 300 porewater samples have been collected so far. The samples were analyzed for ammonium N (NH_4^+-N) and nitrate N (NO_3^-–N) concentrations. Two composite leaf samples were taken (mid-April and mid-July) and mineral tissue content was analyzed.

Figure 1. ATB orchards (Madera, HVAI left panel) and Yamamoto orchards (Turlock, HVAII right panel where intensively monitored experiments for AGP, P&F and HFLC fertigation approaches are being tested for mass balance and intensively monitored for potential leachable.

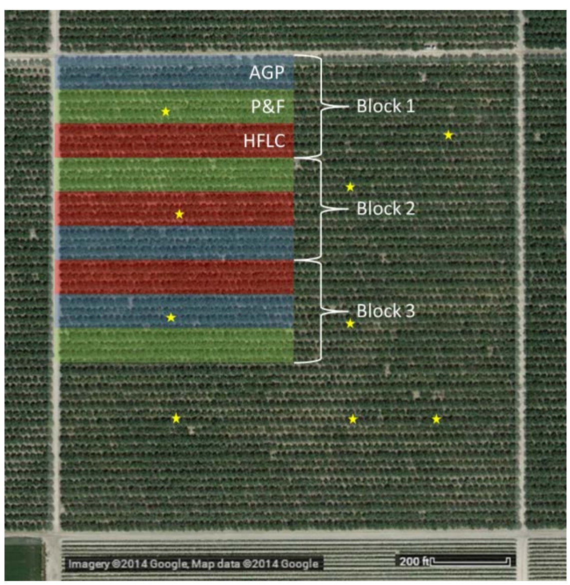

Figure 2. Basic experimental design for both almond orchards with 4 rows of trees in each treatment, three replications for each of AGP and HFLC to be contrasted with P&F. Each star represents an intensively monitored location.

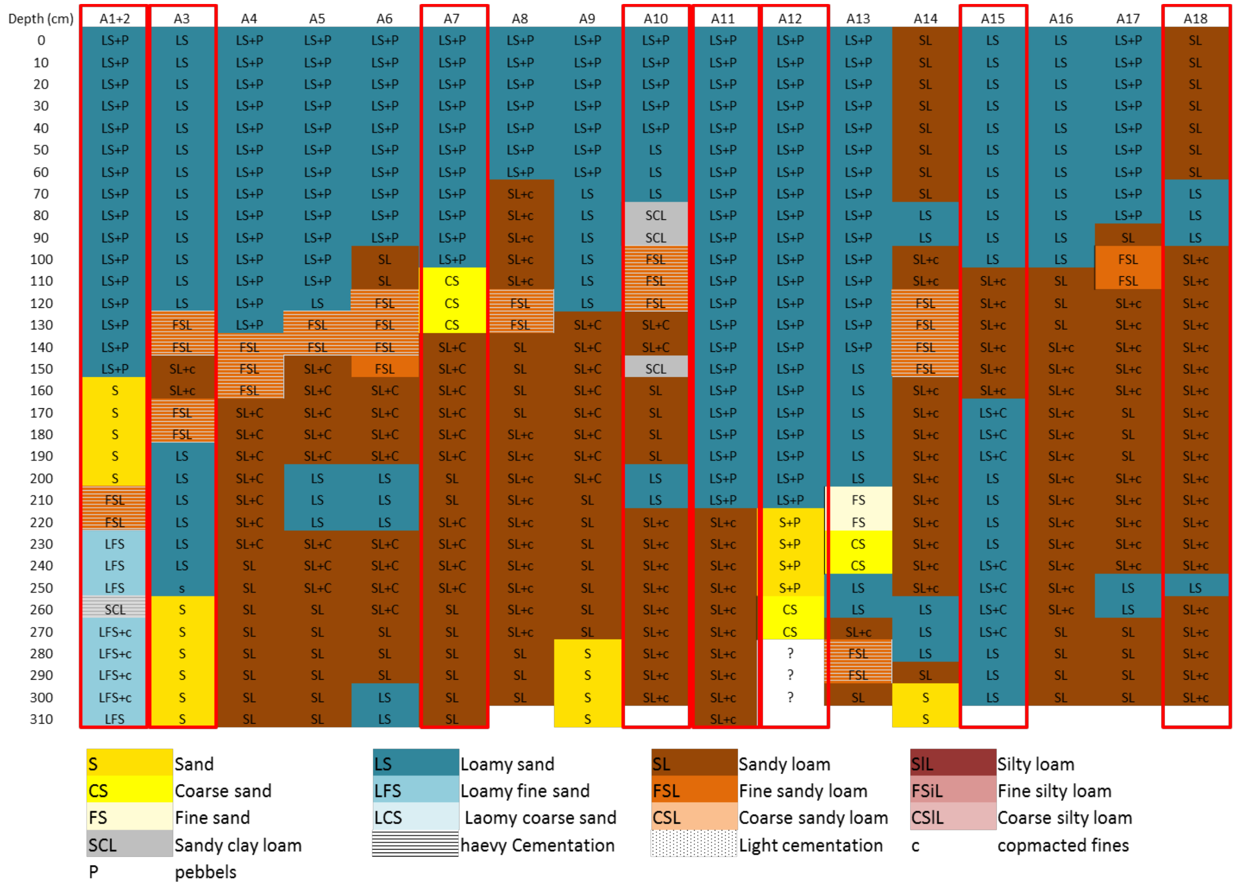

Figure 3. Lithological profile from eighteen locations in the monitored almond orchard. Highlighted in red are the locations instrumented with 5TE sensors (Decagon, Pullman, WA, USA), solution samplers and tensiometers.

Materials and methods:

<u>Soil sampling</u>

During February 2014 soil samples were collected from the AGP, HFLC and P&F subplots in orchards located in the Madera and Turlock HVAs. Three boreholes were excavated using a hand auger, 10m apart, in each subplot that constituted plots in the experimental design. Composite soil samples were analyzed for the depths of 0-30cm, 30-60cm, 60-90cm, 90-130cm, 130-180cm, 180-240cm and 240-300cm intervals after sieving through a 2mm mesh (sieve #10). Sieved soil samples from each depth were extracted for NH_4^+-N and NO_3^-N concentrations using 2M KCl solution. The extracted solutions were analyzed to determine the mineral-N concentration distribution in the vadose zone prior to the beginning of the different N-applications.

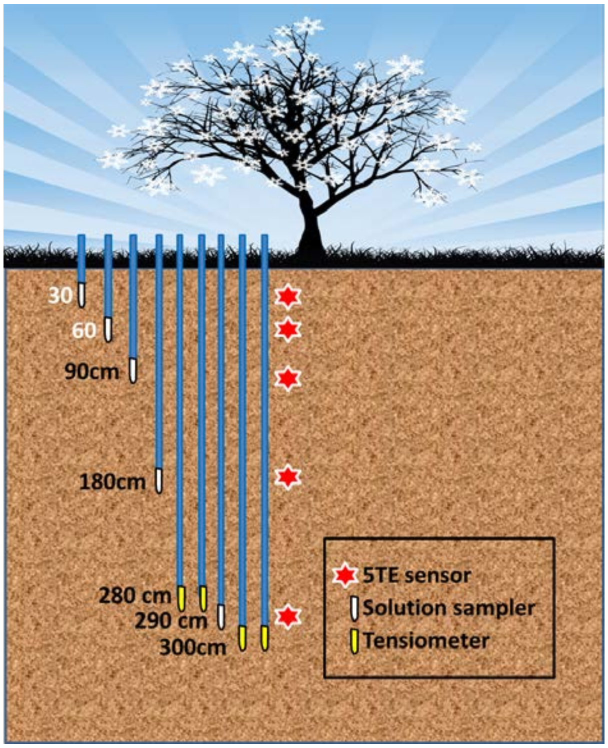

Figure 4. Schematic, not to scale, representation of the instrumentation setup.

Figure 5. Microfertiligation dosetrons used in the HFLC subplots.

<u>Soil survey and instrumentation</u>

At the beginning of 2014, using an orchard scale sampling grid, the soil profile under the almond orchard in Madera was characterized based on particle size distribution from 20 boreholes excavated to 3 m bls. Eight sites were selected to represent the different horizonation we encountered in the subsurface (**Figure 3**). In February eight sites in the almond orchard at Madera were instrumented. In each one of the eight sites five solution samplers, four tensiometers, and five 5TE probes (Decagon, Pullman, WA, USA) were installed (**Figure 4**). 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.

<u>Porewater and irrigation water sampling and analysis</u>

Porewater from the vadose zone was sampled every two weeks following suction application for 12–24 h. Overall, from February to July 2014, more than 300 porewater samples were collected from the depths of 30, 60, 90, 180 and 290 cm bls. Irrigation water has also been sampled from the micro-irrigation lines in each subplot every week as a composite sample for the 24 to 48 h of irrigation. The samples were analyzed for NH_4^+-N and NO_3^--N concentrations.

Fertigation

Based on the nitrogen prediction models for almond developed in Patrick Brown's laboratory a total of 280 lb of N were planned to be applied by the grower on the almond orchard during the 2014 growing season (https://www.sustainablealmondgrowing.org) (**Table 1**). For the P&F and HFLC practices the irrigation water was assumed to contribute an N load of 70 lb/acre, which was subtracted from the total N budget. The total N load for the HFLC subplots was divided into 20 applications of 10.5 lb.-N/acre. In the HFLC subplots fertilizer was applied via microfertigators during the irrigation.

Leaf sampling

According a mid-April sampling and yield estimations a prediction of N demand was obtained for in-season fertilizer adjustments. Based in the analysis result of April (**Table 2**) a value 2.17% of nitrogen should be expected for the July sampling (result for the sampling not obtained yet) and 39.75% of the trees in the orchard should be over the critical value. The result of the July sampling will allow for an adjustment for the post-harvest fertilization avoiding over-fertilization. Those samples are now being analyzed for total organic N.

Table 1. AGP N application planned for the 2014 growing season**.**

Fertigation event #	Percentage of total N (%)	N-amount lb./acre
1	20	56
2	30	84
3	30	84
4	20	56
Total	100	280

Table 2. April leaf sampling result used for mid-July prediction.

Nutrient	Units	**April**
N	(%)	3.10
P	(%)	0.21
K	(%)	2.01
S	ppm	2193
B	ppm	42.6
Ca	(%)	2.2
Mg	(%)	0.55
Zn	ppm	133.8
Mn	ppm	59.8
Fe	ppm	209.7
Cu	ppm	8.13

Results and Discussion:

Fertigation

Up to July 2014 three fertigation events have occurred in the orchard. The fertigations deviated from the planned loads where the first event was at 45 lb/acre (16%), the second event was at 102 lb/acre (36%) and the third event was at 68 lb/acre (24%). All together 215 and 186 lb-N/acre (as NO_3^-, NH_4^+ and urea (CH_4N_2O) in UAN32 solution) were applied to the AGP and P&F subplots, respectively. At the same time 43 lb-N/acre were applied to the orchard from groundwater. In all the fertigation events the fertilizer was applied to the field following 24h of irrigation. At this point in time it seems the total N application by the grower would be lower than the planned budget. But we anticipate a fourth post-harvest application of 68 lb/acre later in the season. It is yet to be determined by the grower. Complete discussion on the N application would be provided at the next report which would summarize the whole season.

Nitrate is the dominant nitrogen form in the groundwater used for irrigation. For an experimental orchard located near Madera the well water NO_3^--N was consistently 9 mg NO_3^-—N/liter. The average nitrogen concentration in the irrigation water during the fertigation events ranged from 100 to 220 mg N/liter (based on division of the N load applied by the volume of water used for irrigation). In the first two fertigation events the fertilizer was applied after 24 h of irrigation and was followed by an additional 20 h of irrigation. Such practice can potentially result in the transport of N, especially a mobile form like NO_3^-, below the root zone since 20 h would be sufficient water to saturate the root zone.

Water in the soil profile

Continuous monitoring of changes in the volumetric water content of the sediment profile showed variation in time down to 290 cm bls. Abrupt changes in the water content were observed mainly in the upper profile (<180cm bls) following rain and irrigation events (orange, blue and purple lines, **Figure 6a-h**). The water content profiles indicated rapid (~ 1 m/h) propagation through the loamy sand that composes the upper subsurface (blue color, **Figure 3**). In sites were hardpan or accumulation of fines did not occur in the subsurface, the wetting front could be observed through the profile down to 290cm bls (**Figure 6e**). In locations where hardpan did develop, the pan significantly slowed the wetting front, such that no direct correlation between the wetting event and the water content was observed. Example to such slowing down can be observed in **Figure 6a, b, f, g,** where sharp changes were observed down to 180cm but not below that depth. It is possible that there is continuous propagation of water through and below the hardpan, albeit its low hydraulic conductivity would greatly slow such movement. The electrical conductivity (EC) profiles show similar relations between the water propagation velocities with depth in relation to the location of the hardpan (**Figure 7**). The EC profiles indicate minimal to no salt accumulation in the subsurface, probably due to flushing with the irrigation water. Detailed estimates of the water flux below the root zone (i.e. >260cm) are currently being calculated. In the calculations the hydraulic characteristics of the profile are used in conjugation with the matric potential measured by the tensiometers below the root zone in the field. The subject should be available for our next report.

Nitrogen (N) in the subsurface

Sediment extractions from the orchard in Madera and one in Turlock indicated that NO_3^--N is the dominant N-form in the subsurface (**Figure 8**). The NO_3^--N concentrations were two orders of magnitude higher than the NH_4^+-N concentration (~20 vs ~0.5 mg/kg dry soil, respectively). In both locations the upper soil profile had lower concentrations than the deeper (>150 cm) profiles (**Figure 8a**). Such differences could be the outcome of flushing of the upper soil profile by seasonal rains. The high concentrations in the deep profile, below the root zone, suggest there is a risk for groundwater contamination by NO_3^- leaching. Nevertheless the exact magnitude cannot be determined without further hydrological work, as discussed above.

Porewater samples were collected repeatedly every few weeks since the end of February. The NO_3^--N concentrations prior to the beginning of the fertigation season varied across the orchard and ranged from 5 to 150 mg/liter (**Figure 9**). Similar variability was observed throughout the season. In some locations the concentrations remained low (**Figure 9a**), in some the concentrations fluctuated from high to low (**Figure 9d, c, f, h**), and in some they remained high (**Figure 9b**). So far, we could not determine the causes for the variability and the subject warrants further study. In all locations the concentrations below the root zone were much higher than the maximal allowed values for drinking water (10 mg NO_3^-N/l) (black squares, **Figure 9**). In some sites the concentrations were up to more than an order of magnitude higher. The porewater concentrations are in agreement with the sediment extractions, and highlight a potential for groundwater contamination by leachates.

Close inspection of the NO_3^--N concentrations below the root zone (290cm) prior to a fertigation event and 24 and 48h following it was conducted. In most sites we could not identify propagation of NO_3^--N below the root zone immediately after a fertigation event of 68 lb-N/acre (**Figure 10a, b, e, f, g, h**). In these sites the concentration was very high (>100 mg-NO_3^-N/l) prior and following the fertigation event. Two exceptions were observed, where the concentrations at 290cm substantially increased within 24 h from the fertilizer application (**Figure 10c, d**). Such sharp increases suggest fast and deep movement of water and contaminates, such as NO_3^--N, below the root zone, and potentially into the groundwater. It should be noted that at the last fertigation event, the fertilizer was applied at the last few hours of the irrigation, unlike in the first to applications. It is likely that due to the relatively fast movement of water in the soil profile the actual concentrations in the subsurface are higher than the range calculated for the fertigation event (100-220 mg-N/liter). An example of such extreme high concentrations was observed during the second fertigation event at sites c and f and during the last fertigation event at site h (**Figure 10**). We believe that additional emphasis should be given to the timing of the fertilizer application in regards to the irrigation duration following it.

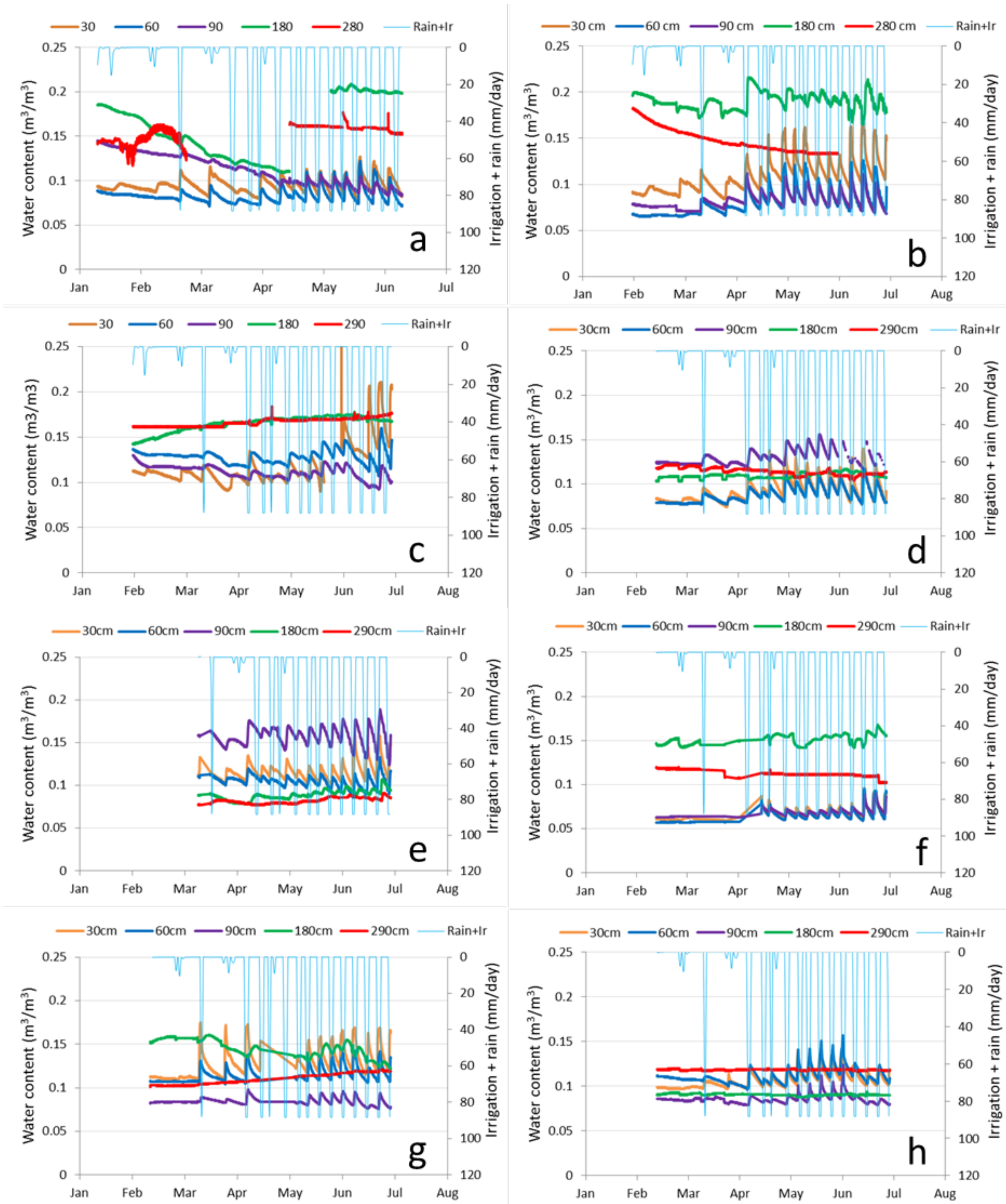

Figure 6. Temporal changes in the volumetric water content of the soil profile under the eight sites monitored in the almond orchard (a-h) and the rain and irrigation events.

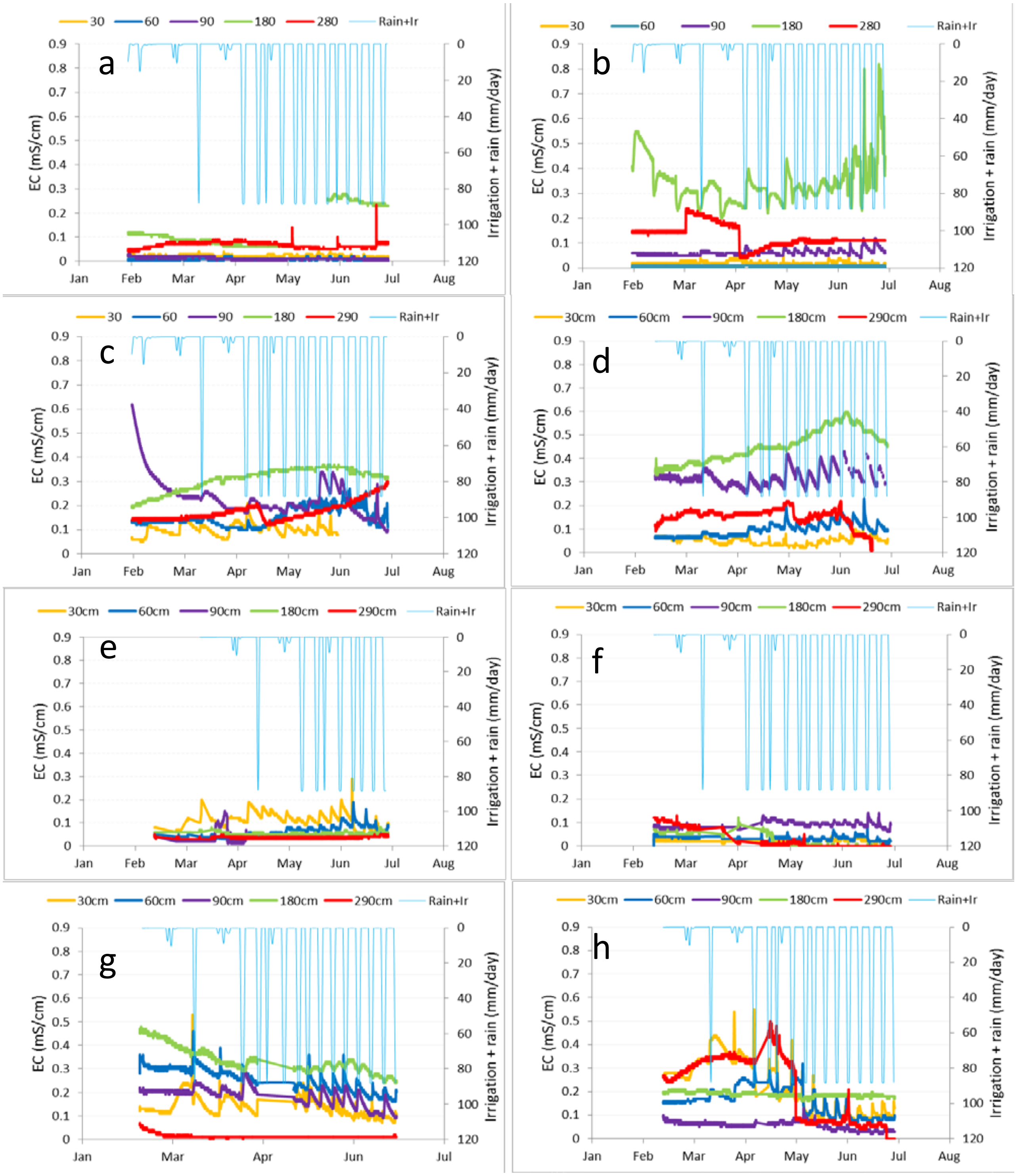

Figure 7. Temporal changes in the electrical conductivity (EC) of the soil profile under the eight sites monitored in the almond orchard (a-h) and the rain and irrigation events.

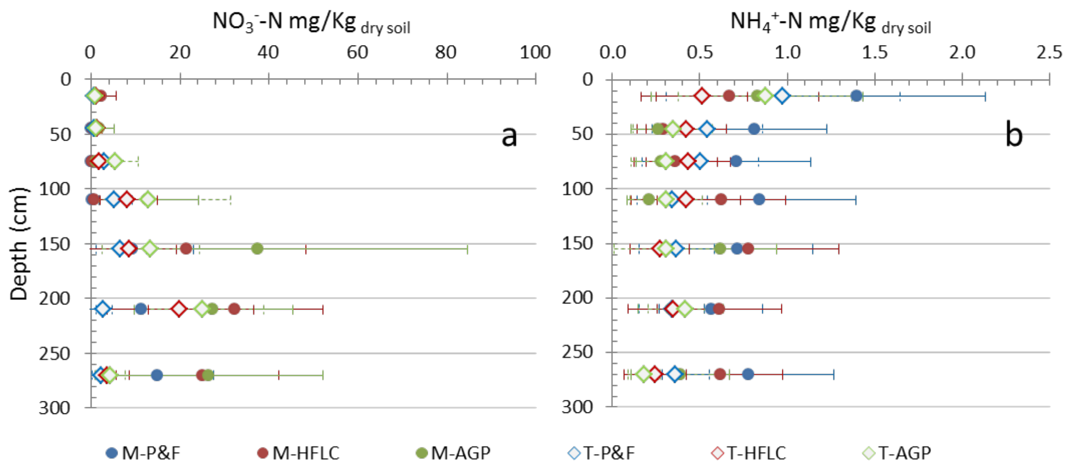

Figure 8. Nitrate (NO_3^--N) and NH_4^+-N concentrations in the subsurface under the almond orchards in Madera (M) and Turlock (T), at the end of the winter prior to the beginning of the fertigation season.

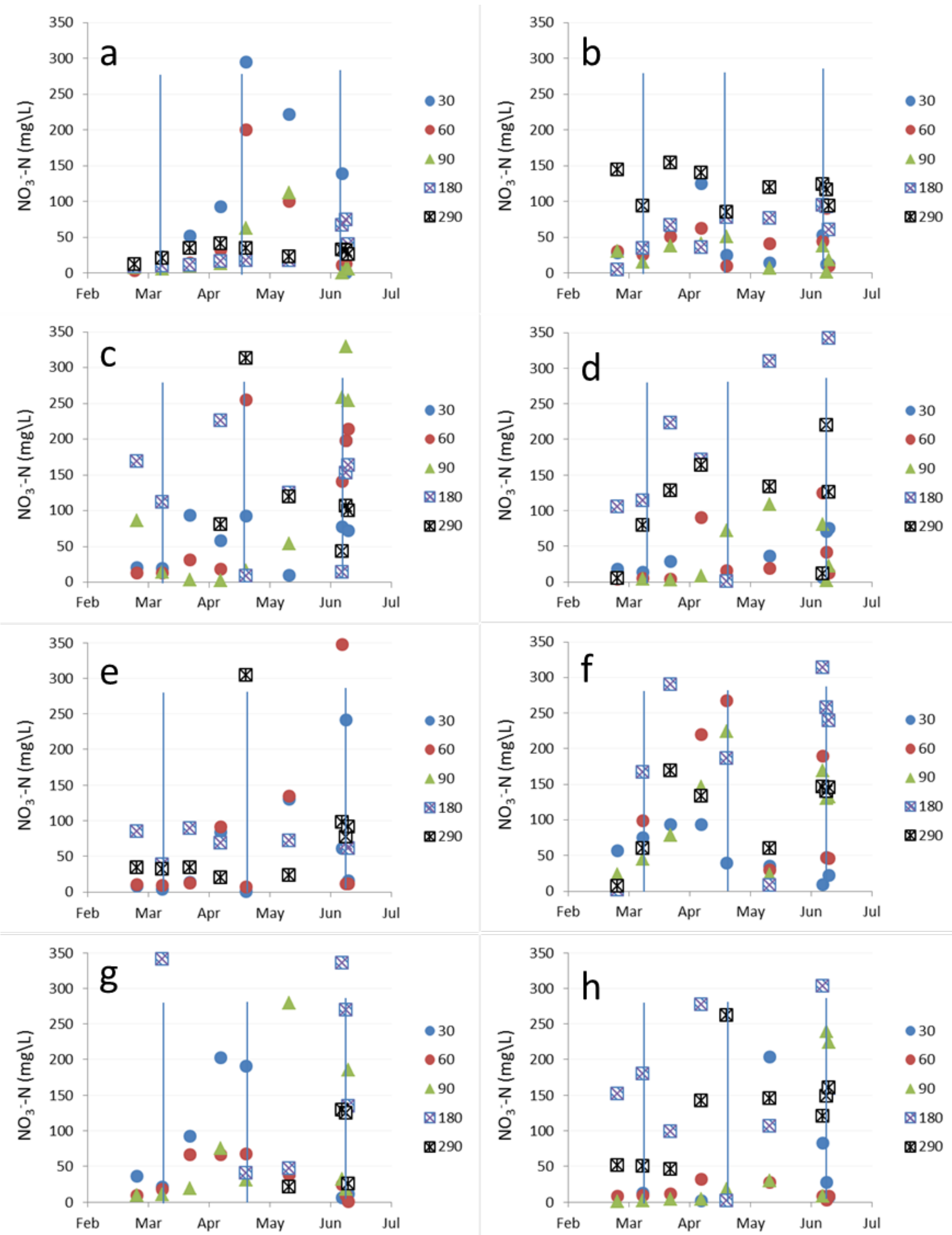

Figure 9. Changes with time in NO_3^--N concentrations at different depths in the subsurface below eight sites (a-h) in the almond orchard. Vertical blue lines represent fertigation events.

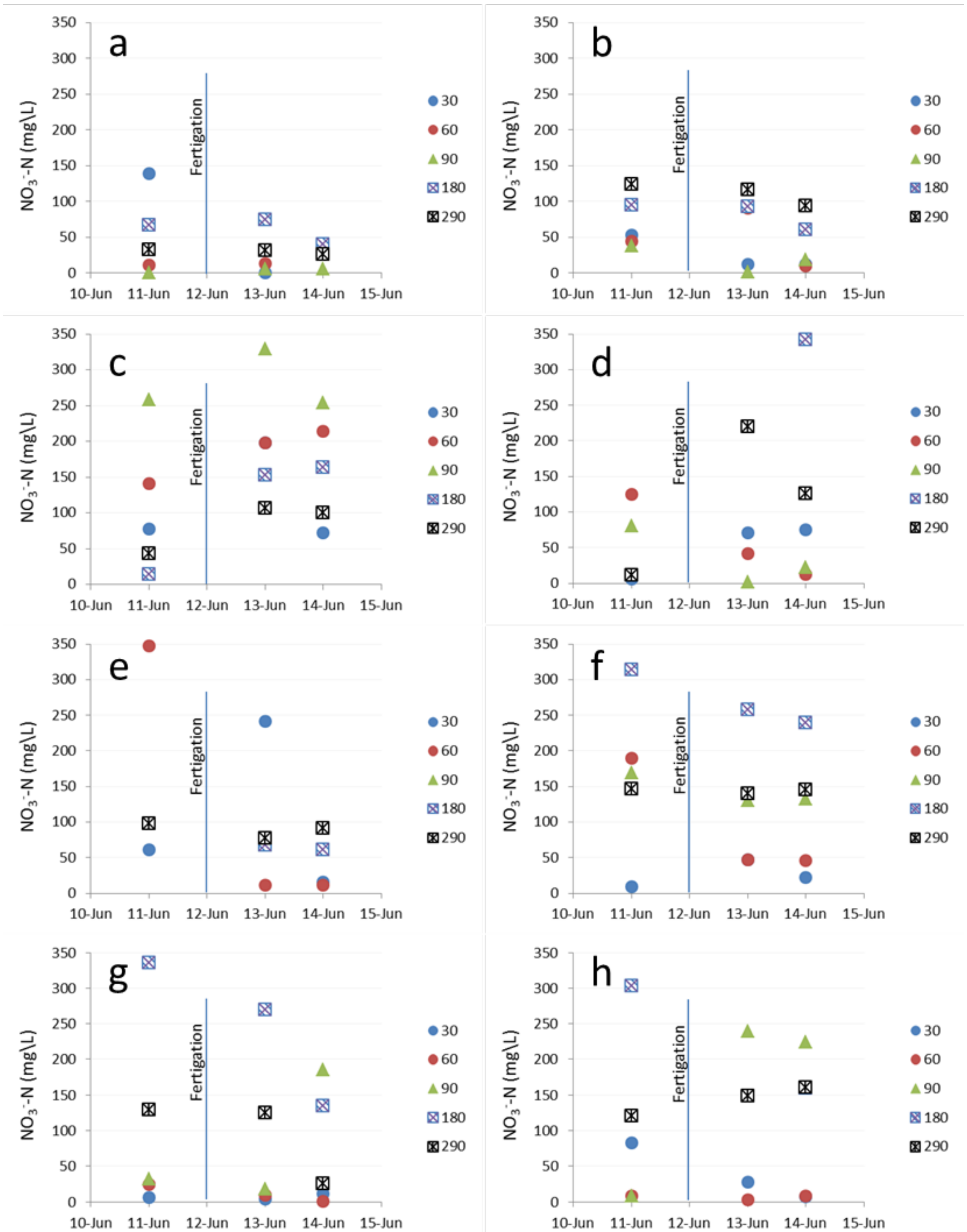

Figure 10. Changes in NO_3^--N concentrations at different depths in the subsurface below eight sites (a-h) in the almond orchard prior and following a fertigation event. Vertical blue lines represent fertigation events

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