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

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Objective

The goals of this project were:

1. **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).**
2. **To explore the impact of irrigation and best management fertigation practices (BMP) on nitrate (NO_3^-) leaching below the root zone of almond orchard with and without accounting for groundwater nitrate-nitrogen (NO_3^--N) as 1:1 equivalent to fertilizer-N.**

Methods

Working with growers we established three different N application practices (Advanced Grower Practice – *AGP*, P&F and high frequency low N concentration – *HFLC*) to almond orchards in two hydrogeologically vulnerable area (HVA) in the Central Valley. We have established fully randomized complete blocks designs for the two orchards. (Fig. 1 and 2).

N loads for the orchard were based on prediction models for almond (Patrick Brown's laboratory; https://www.sustainablealmondgrowing.org). In 2014 fertilizer was applied at the middle of a 24 – 48 h irrigation, while in 2015 it was applied 3 h before the irrigation ended.

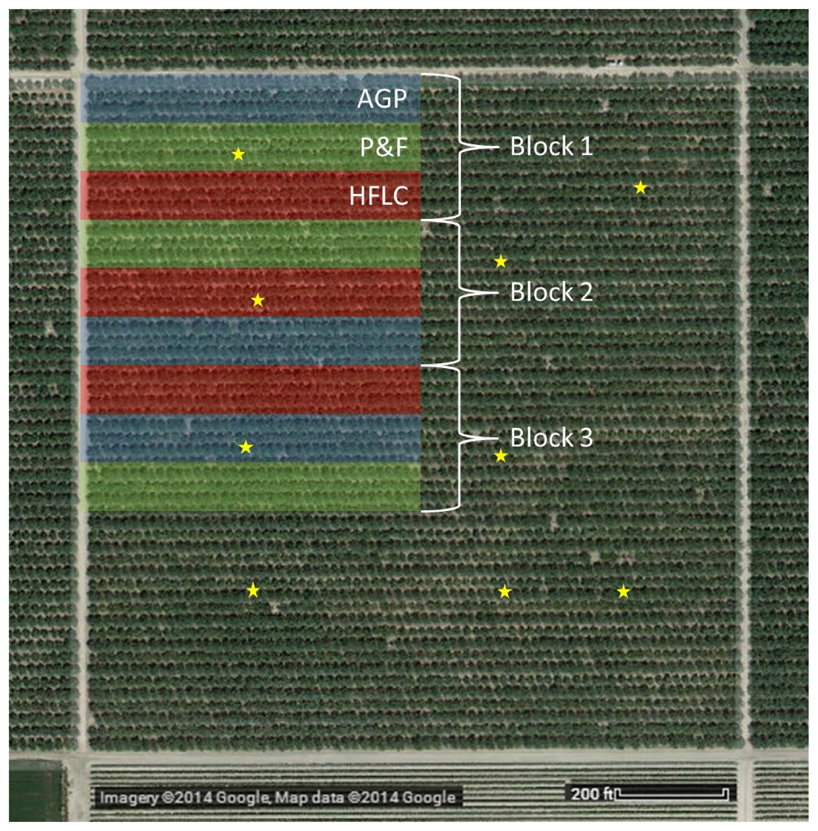

Figure 1. Basic experimental design. Four rows of trees in each treatment, three replications for each of AGP and HFLC to be contrasted with P&F. Each star represents an intensively monitored location.

Figure 2. Microfertigation apparatus used in the HFLC subplots.

Eight sites were selected to represent the different layering in the subsurface horizons for assessment of NO_3^- leaching below the root zone (Fig. 3).

Each one of the eight sites was instrumented with an accesses tube for neutron probe, five soil solution samplers, four tensiometers, and five 5TE probes (Decagon, Pullman, WA, USA). The installed sensors monitor processes in and below the root zone (Fig. 4 and 5).

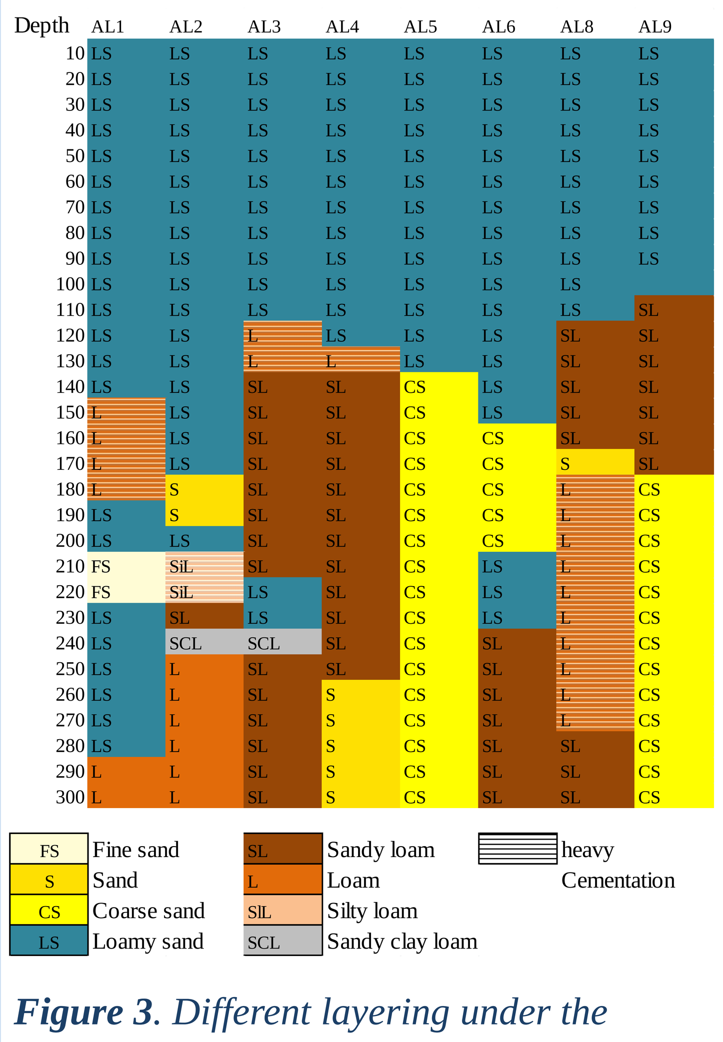

Figure 3. Different layering under the instrumented sites (AL1-9).

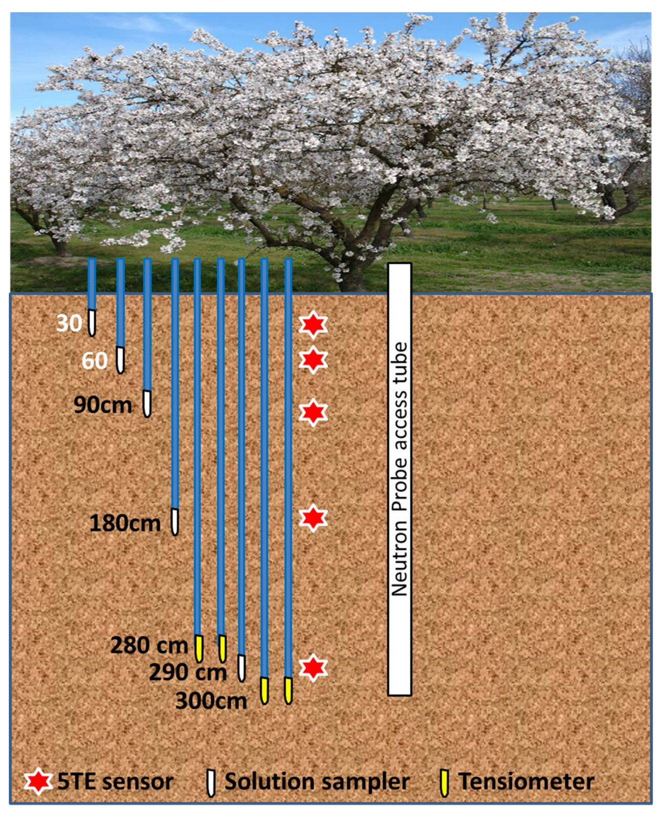

Figure 4. Schematic representation of the instrumentation setup (not to scale).

Results

In the 2014 and 2015, the almond orchards have been irrigated almost on a weekly basis (total irrigation height ~1.0 m (40 in.)). Fertilizer was applied on three occasions (Mar., Apr., Jun). During each fertigation event, the P&F subplots received ~70% of the planned load and the HFLC subplots received none (Table 1). The HFLC subplots were fertigated during each irrigation event with 5% of the total N-load planned for the season using microfertigators (total of 215.5 lb./acre). Summery of yields and nitrogen mass balance presented in Table 1.

	AGP		HFLC		P&F	
Year	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
Yield (lb/acre)	2699±49	2371±397	2869±461	2401±70	2695±124	2572±190
	Input (lb-N/acre)					
Fertilizer	215	210	215	159	186	159
Groundwater	73.8	21.4	73.8	21.4	73.8	21.4
Compost	40	40	40	40	40	40
	Output (lb-N/acre)					
N-in kernel*	119	87	130	112	112	127
N-in wood	25	25	25	25	25	25
Hull and shell	67	63	72	56	67	68
Loss	118	94	102	27	95	0
NUE*	0.64	0.65	0.69	0.88	0.68	1.00

Table 1. *Kernel yield and nitrogen mass balance for the 2014 and 2015 growing seasons. *Nitrogen Use Efficiency – ratio between tree N-uptake to N-application.*

Over a 600 porewater samples were collected from the soil profile below the root zone at depths of 1.8 and 2.9 m across the almond field site. NO_3^- was the dominant N-form in the vadose zone. The NO_3^- concentrations below the root zone ranged from <1 mg/L to over 2400 (Fig. 5) with huge spatial variability at the orchard scale. The mean concentration below the root zone was almost an order of magnitude, higher than the drinking water standard of 44 mg-NO_3^-/L.

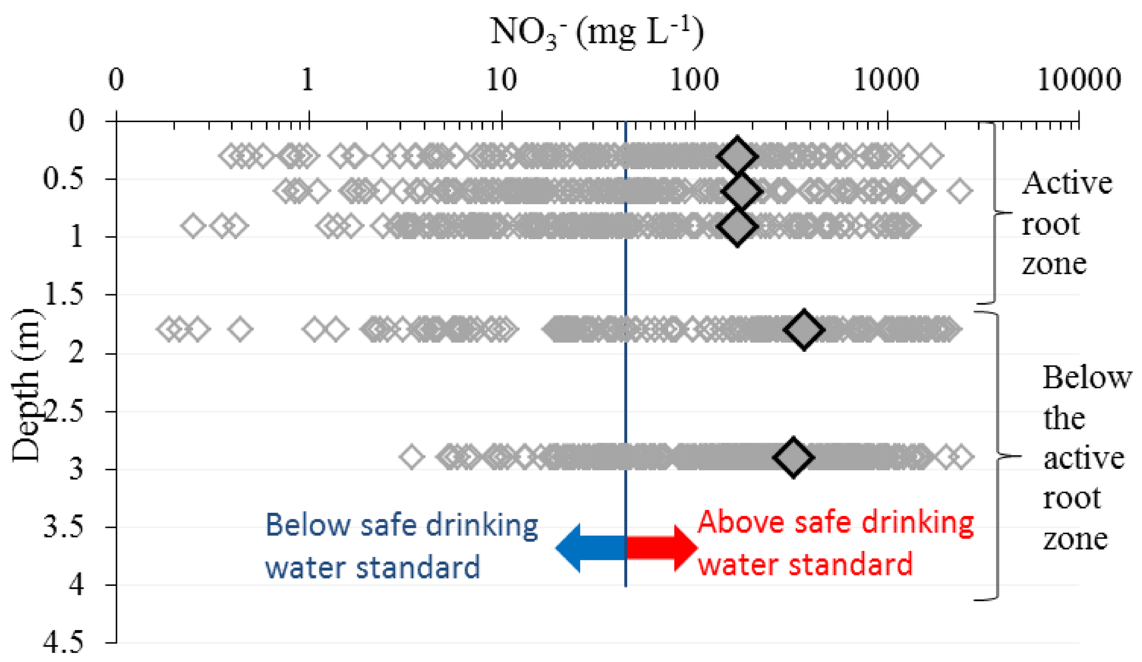

Figure 5. *Nitrate (NO_3^-) concentrations in porewater samples from eight vadose zone monitoring sites in the almond orchard, each sampled during the 2014 and 2015 growing seasons. Large symbols represent average concentrations.*

Fertilizer application in the middle of irrigation led to higher losses below the root zone compared to application at the end of irrigation (Fig. 6).

Pre-bloom (January) and post-harvest (October) flood irrigations led to sharp increase in soil water content, a corresponding increase in soil water matric potential (less negative) and increase in the water leaching flux below the root zone (Fig. 7).

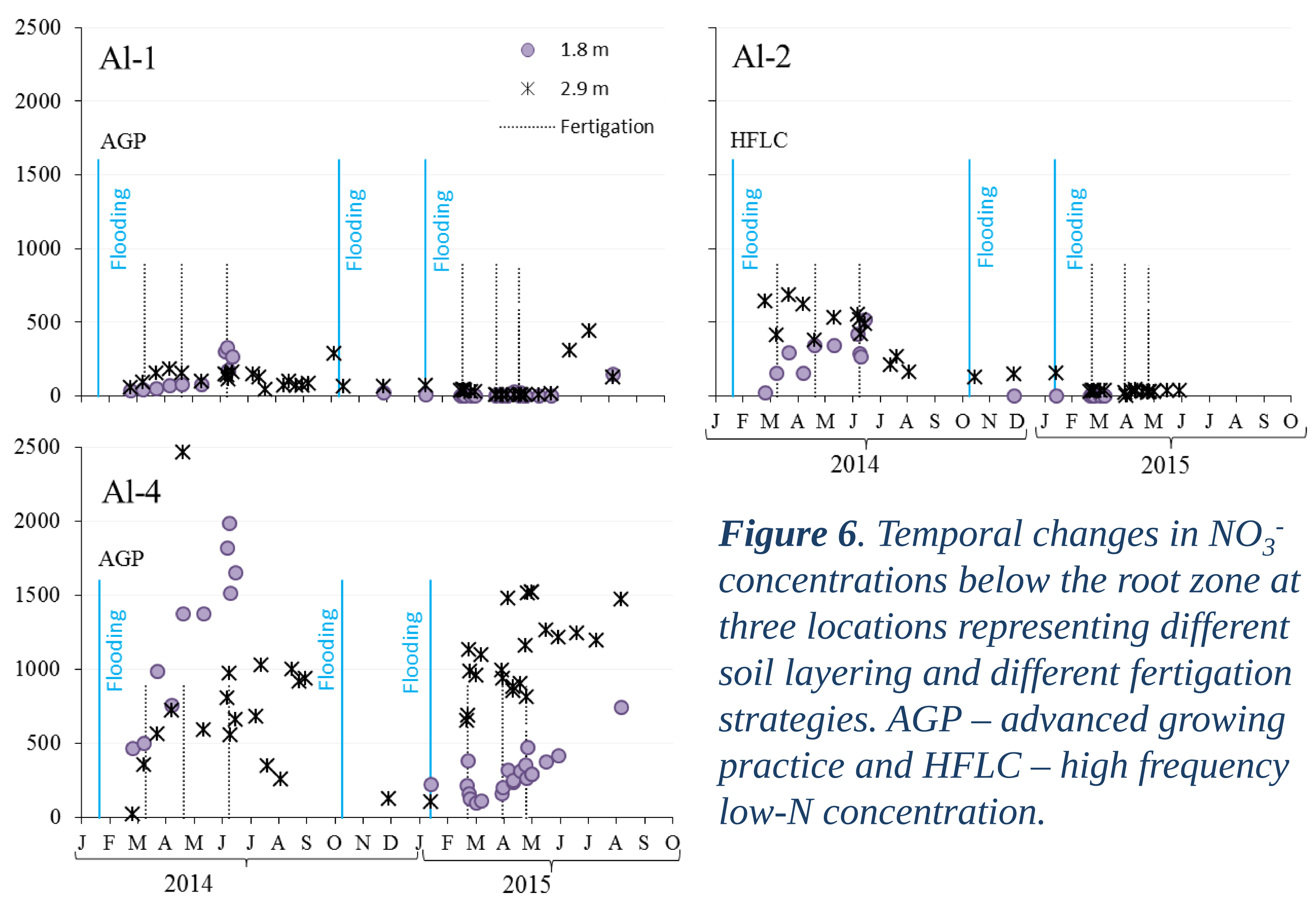

Figure 6. Temporal changes in NO_3^- concentrations below the root zone at three locations representing different soil layering and different fertigation strategies. AGP – advanced growing practice and HFLC – high frequency low-N concentration.

Early in the growing season (April) the deep soil (>2.5 m) under the well-managed micro-irrigated orchard dries, the matric potential increases (more negative), the leaching flux decreases and nutrients (such as NO_3^-) build up below the root zone (Fig. 6 and Fig. 7). Accordingly, extreme wetting events (e.g. heavy winter storms, flood irrigation) which lead to deep wetting events associated with buildup of high soil NO_3^- concentrations below the root zone pose a special threat to groundwater quality. Such deep wetting events are causing a sharp increase in soil water content, a corresponding increase in soil water matric potential (less negative) and increase in the water leaching flux below the root zone. Examples of such events were observed following pre-bloom (January) and post-harvest (October) flood irrigations (Fig. 7)

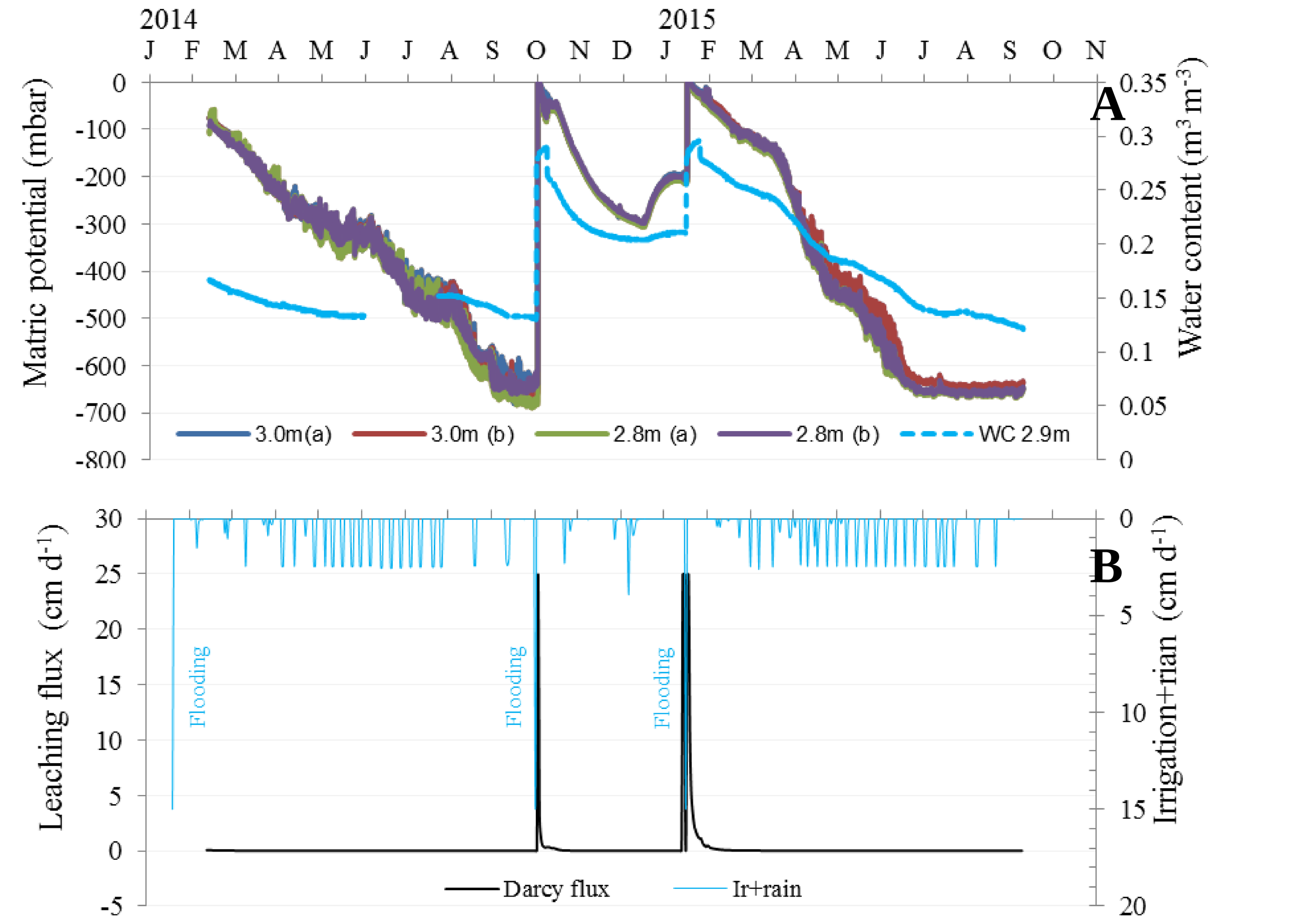

Figure 8. *Temporal changes in the matric potential at depths of 2.8 and 3.0 m and the volumetric water content (A) along with the daily leaching flux and precipitation (rain and irrigation, B), measured at one of the almond orchard sites. Flood irrigation is presented by the wetting events at the beginning of October and Mid-January*

Variables	HP	HPD	HPT	TAF	ID	Flood	CL	FAT	No. of sites	No. of samples
With HP		-0.28	-0.12	-0.06	0.12	-0.31	-0.59	0.25	14	324
No HP				0.02	0.19	-0.36	0.45	0.25	3	103
AGP	0.08	-0.10	-0.18	-0.04	0.10	-0.28	-0.19	0.23	9	249
HFLC		-0.57	0.58	-0.03	0.25	-0.41	-0.12	0.34	4	87
P&F				-0.01	0.29	-0.08		0.02	4	92
All data	-0.13	0.00	-0.16	-0.03	0.13	-0.33	-0.34	0.27	17	427

Table 2. *Correlation between NO_3^--N concentrations at 2.9 m and different variables using principal component analysis (PCA)*
HP – hard pan; HPD –hard pan depth; HPT –hardpan thickness; TAF – time after fertigation event; ID – irrigation duration; Flood – flood irrigation; CL – clayey soil at 290 cm; FAT- fertilizer application time (middle/end of irrigation).

Conclusions

- **Accounting for groundwater nitrate-nitrogen (NO_3^--N) as 1:1 equivalent to fertilizer-N (P&F) did not decrease the yield.**
- **Current fertigation BMPs lead to nitrate (NO_3^-) build up below the root zone with huge spatial variability.**
- **The bulk physical-hydrological properties of the soil could attribute up to 50% of the variability in the NO_3^- concentration.**
- **The statistical analysis along with the huge spatial variability suggests that it is not feasible to get an accurate estimate of NO_3^- leaching\accumulation below the active root zone of an orchard.**
- **Development of better fertigation and irrigation practices is the only viable way to protect groundwater from N-leaching from orchards.**

Acknowledgements

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