Measuring Water and Nitrate Fluxes Below the Root Zone of Crops: Possibilities and Limitations

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• Evaluation of Winter Cover Crops to Reduce Nitrate Leaching and Increase Yields in Drip-irrigated Tomato Rotations: a combination of multi-sensory measurements and modeling, funded by **California Department of Food and Agriculture**.

Why focus on measurements of nitrate leaching?

It is widely assumed that agriculture is the main source of nitrate loading to groundwater. However, there is little data on nitrate leaching below the root zone.

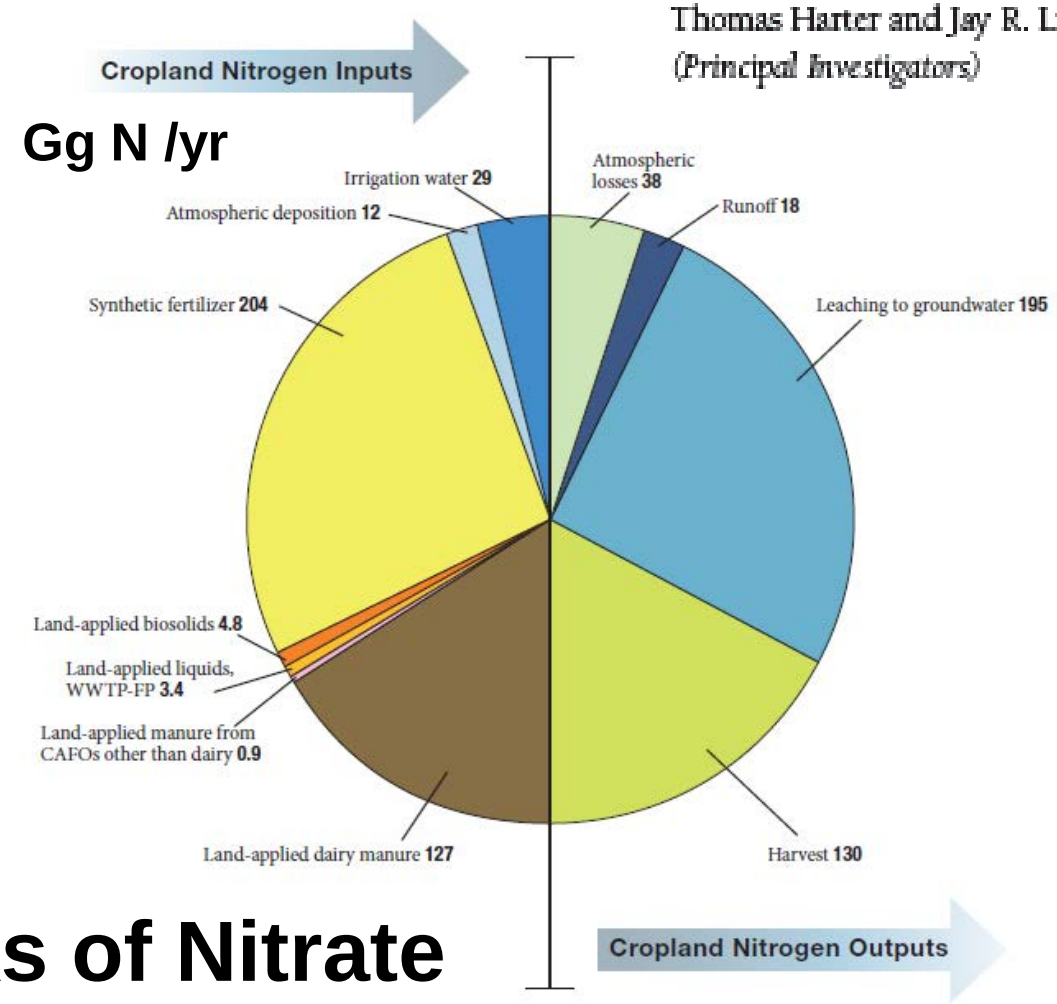
Reason: It is challenging!

Addressing Nitrate in California's Drinking Water

Summary of Key Findings

1. Nitrate problems will likely worsen for several decades. For more than half a century, nitrate from fertilizer and animal waste have infiltrated into Tulare Lake Basin and Salinas Valley aquifers. Most nitrate in drinking water wells today was applied to the surface decades ago.
2. Agricultural fertilizers and animal wastes applied to cropland are by far the largest regional sources of nitrate in groundwater. Other sources can be locally relevant.

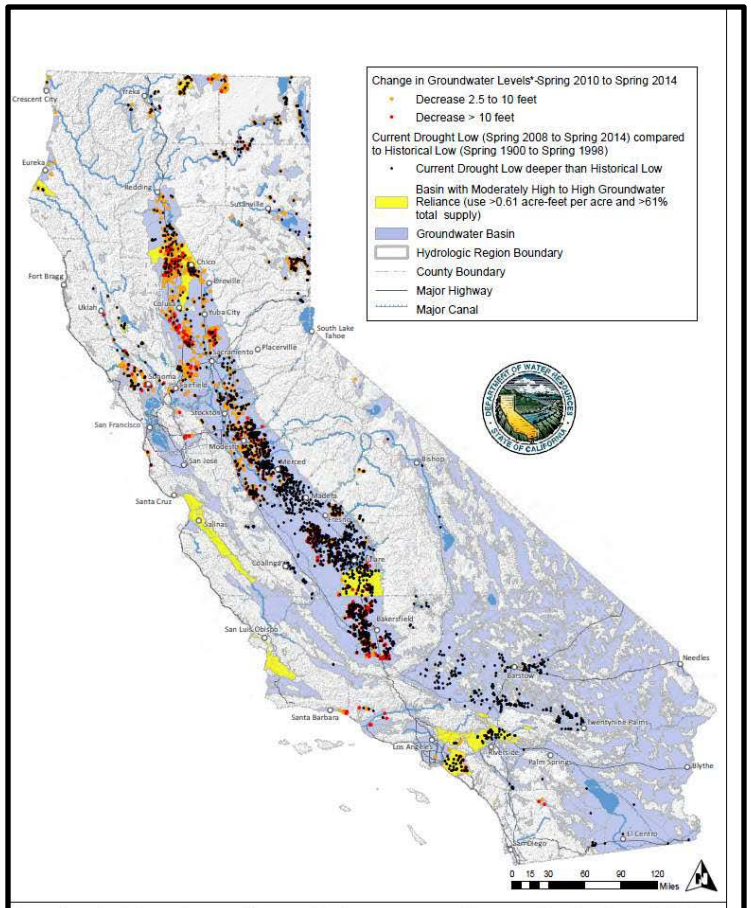
Thomas Harter and Jay R. Lund
(Principal Investigators)

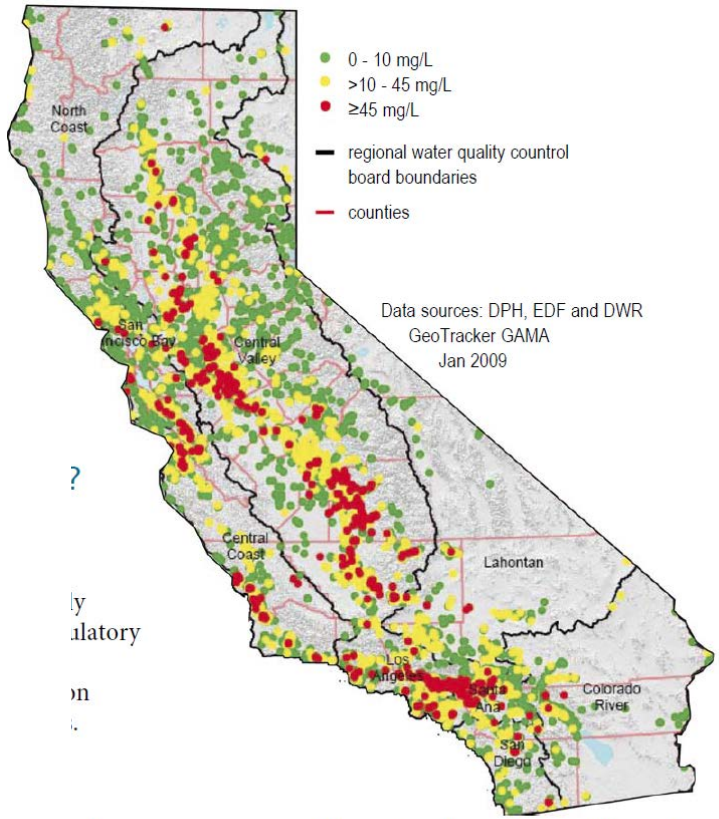


Sources and Sinks of Nitrate

California groundwater depletion and nitrate concentration

Groundwater pumping has increased, groundwater level deeper than historical low





Nitrate concentrations in public supply wells, monitoring wells, and domestic wells measured in 2007. Red wells exceed the drinking-water limit (44 mg/l nitrate = 10 mg/l nitrate-N). From Ekdahl and others, 2009.

California Croplands change dynamically

In response to economic benefits, water availability etc.

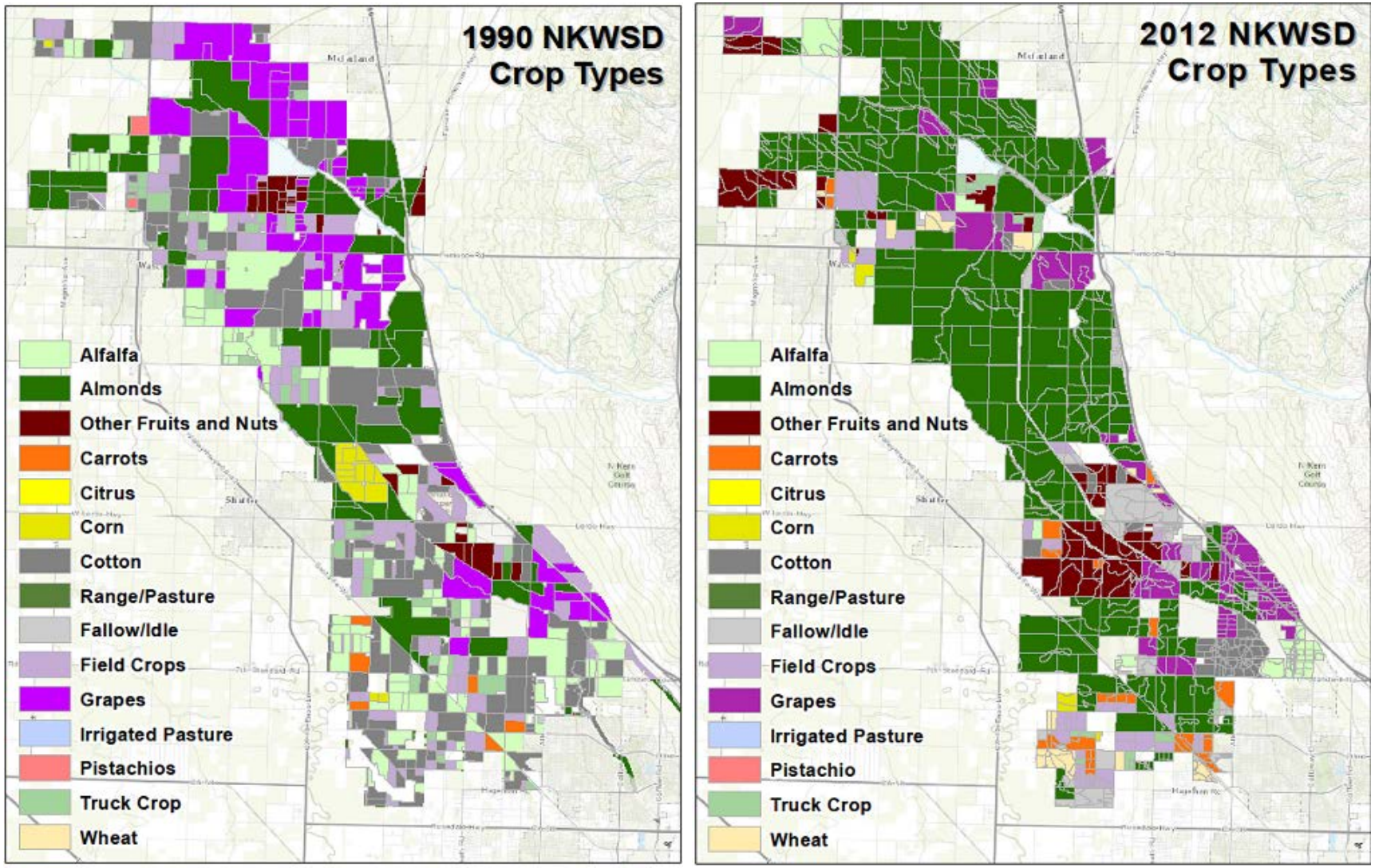
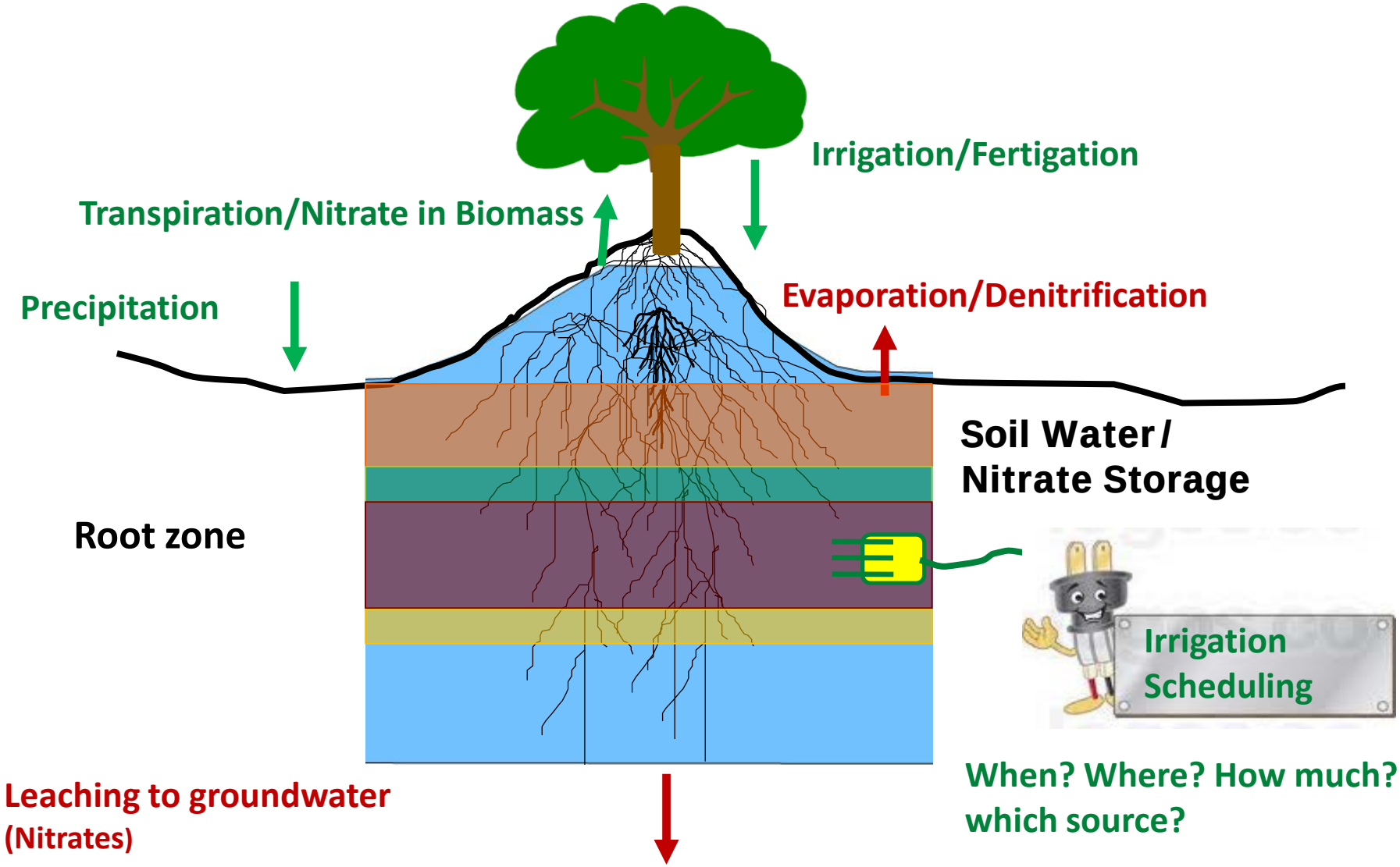


Figure 1. Crop type maps of North Kern Water Storage District, 1990 and 2012. Provided by Dr. Joel Kimmelshue

The need for NEW best management practices

Maximizing yield → High yield while simultaneously minimizing environmental impacts (e.g. Agricultural Expert Panel Recommendations to SWRCB, 2014)



FUTURE IRRIGATED AGRICULTURE MUST BECOME BOTH MORE PRODUCTIVE AND SUSTAINABLE

Requires better understanding of how plants take up water and nutrients, so we can do more with less;

Need to improve water use efficiencies, and nitrate use efficiencies

Requires Innovative multi-disciplinary Research, and engineering technologies

Challenges for management of water and nitrate in the root zone

Water and Nitrate Leaching can not easily be predicted

- High Soil Variability – textures, soil layers, soil structure
- Water redistribution as affected by irrigation water application method
- Volume of applied water across field is uncertain
- Mechanisms of root water and nitrate uptake unknown
- Root architecture and growth
- Kinetics of Nitrogen nitrification and de-nitrification rates

Instead, deep soil real-time monitoring

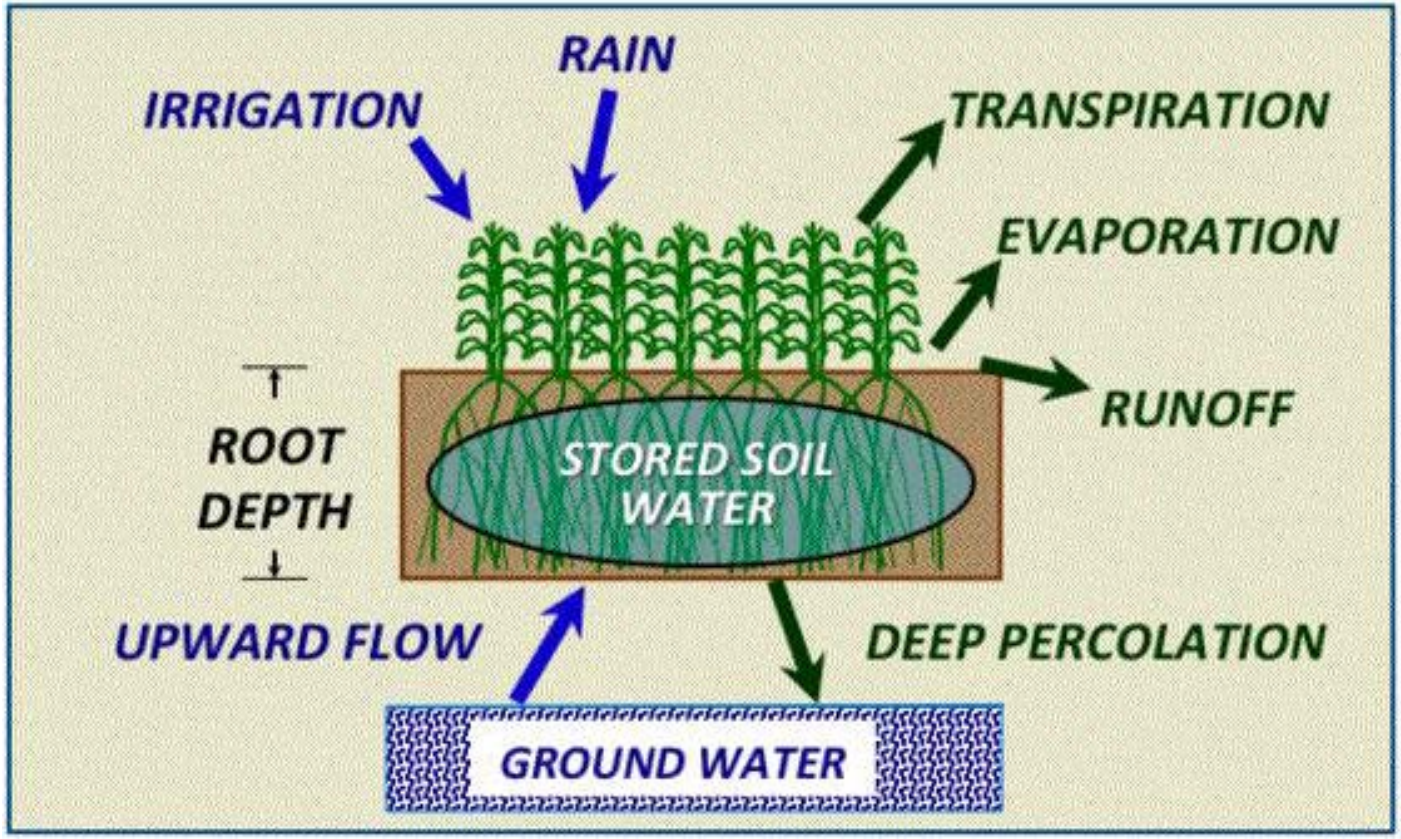
Mass balance approach

Soil storage monitoring:

Neutron probe

Soil moisture sensors

Etc.



$$Leaching = |Irrigation| + |Precipitation| - |Evapotranspiration| - Change\ in\ Storage$$

Soil nitrate monitoring using solution sampler

Darcy Flow approach

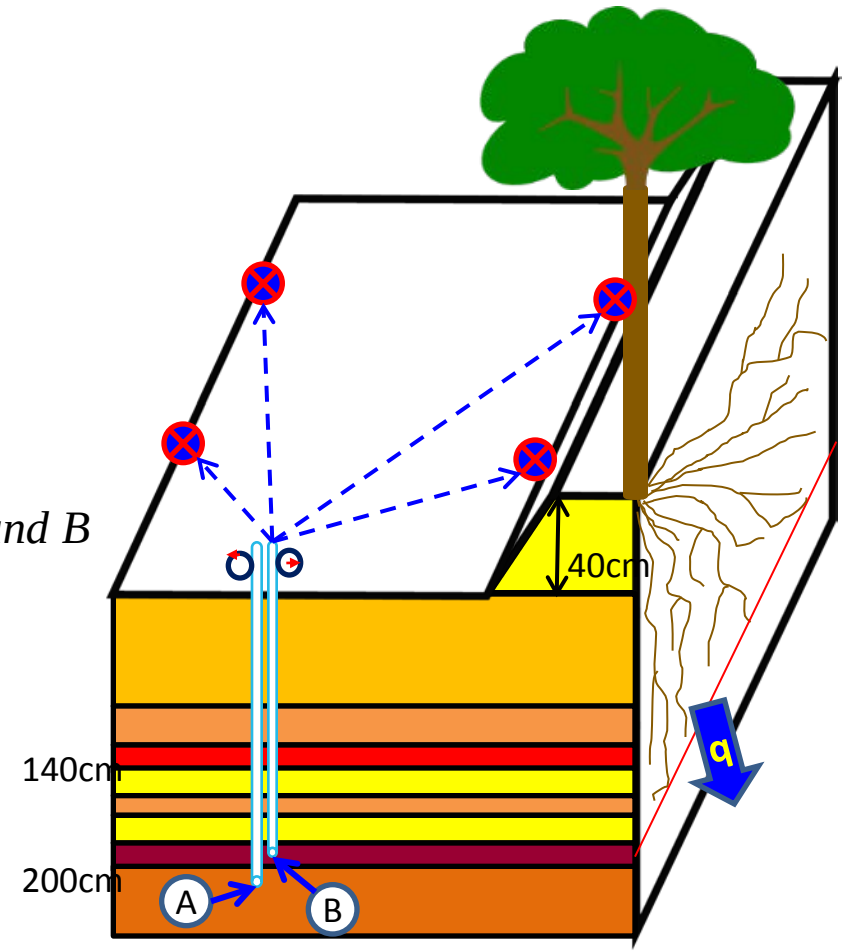
Tensiometers below root zone

$$q_{A-B} = -K(\theta)\frac{H_B - H_A}{\Delta Z_{A-B}};\ \ q = leaching\,(L/T)$$

$K(\theta) = average\ unsaturated\ hydraulic\ cunductivity$ $between\ A\ and\ B$

$\theta = volumetric\ water\ content;\ H_B = total\ head\ at\ B$

$H_A = total\ head\ at\ A;\ \Delta Z_{A-B} = distance\ between\ A\ and\ B$

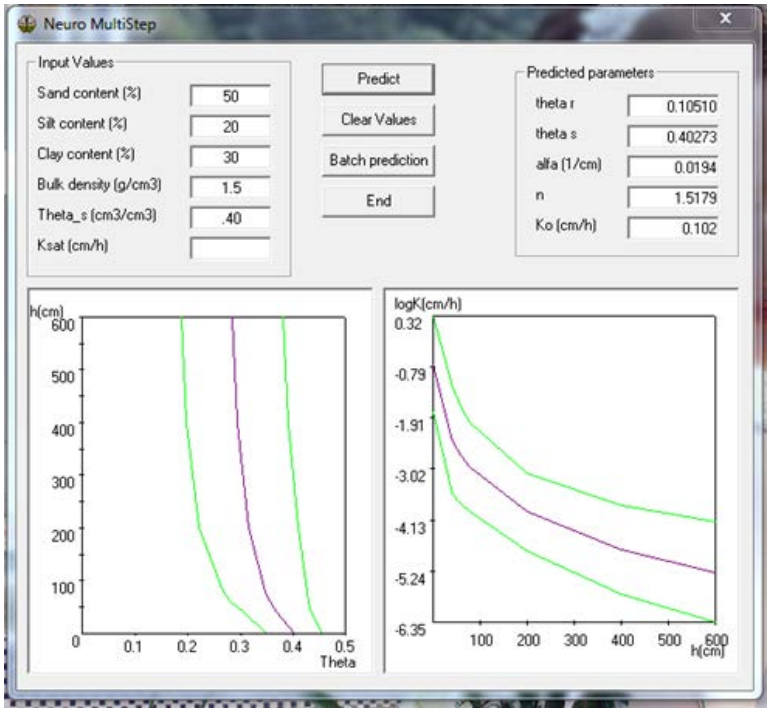


Soil nitrate monitoring using solution sampler

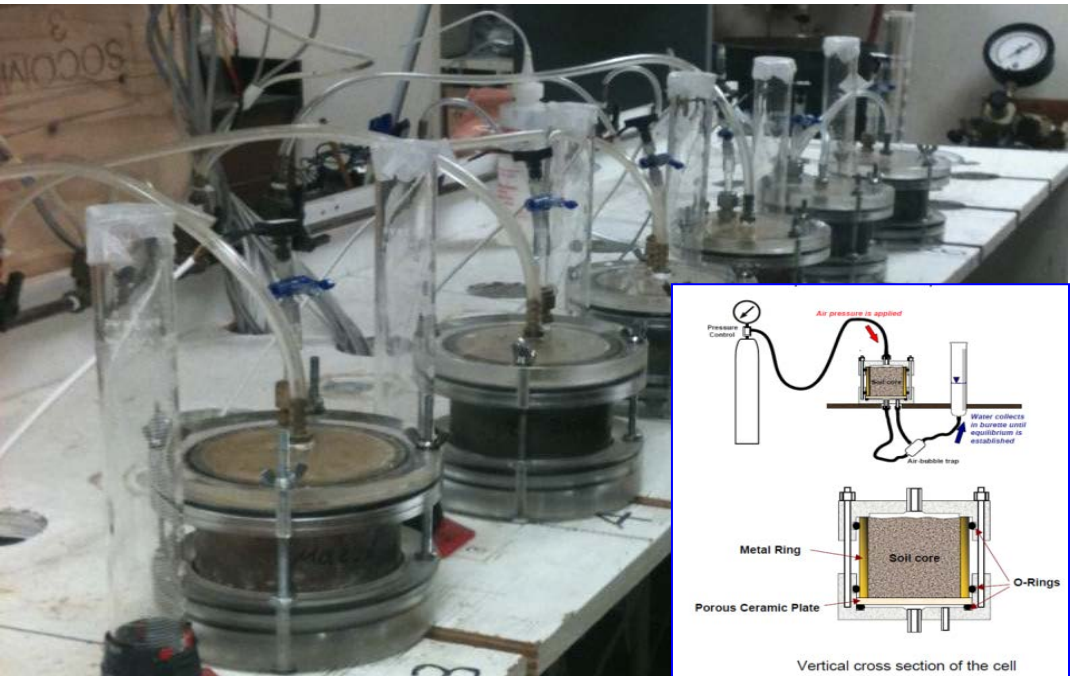
Darcy Flow approach

Soil hydraulic properties

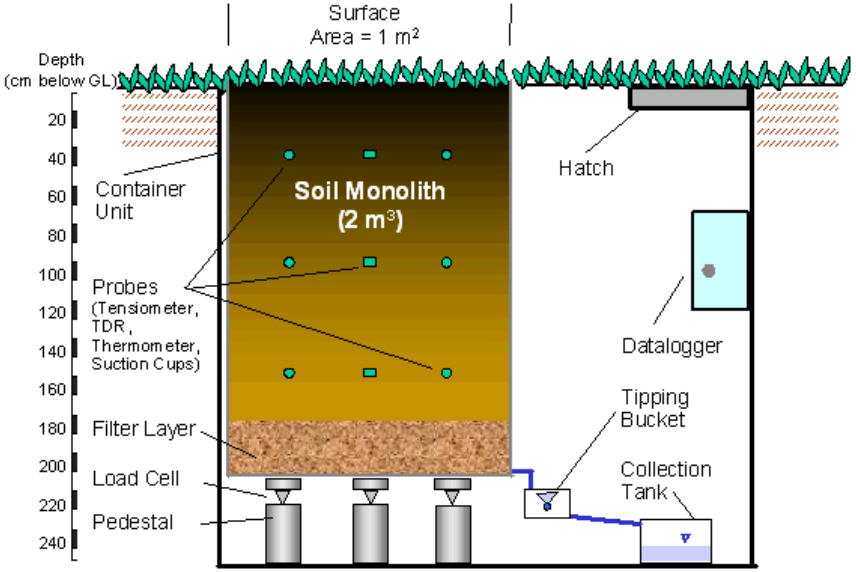
Modelling based on measured parameters
e.g. soil moisture monitoring



Laboratory methods
e.g. multi-step outflow experiments

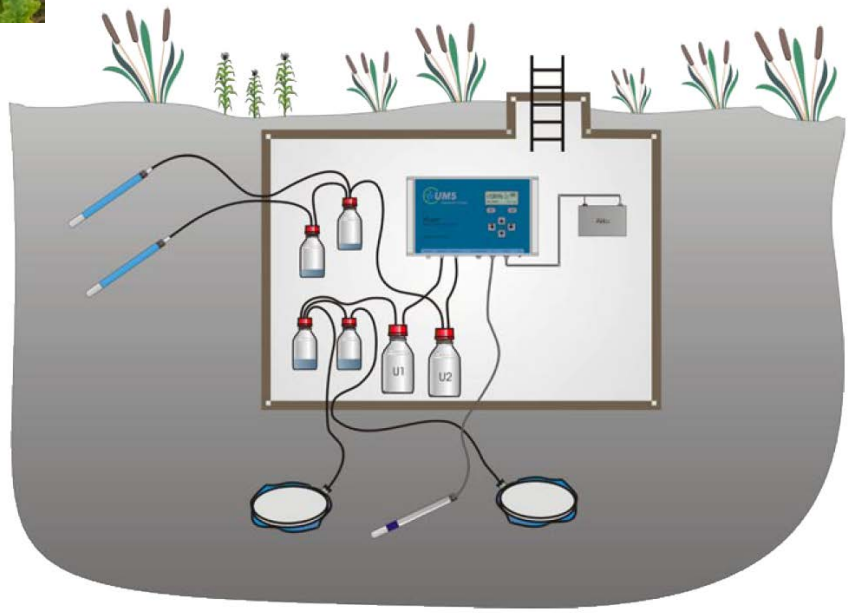


Lysimeter approach
(Various types and designs)



Weighable lysimeter

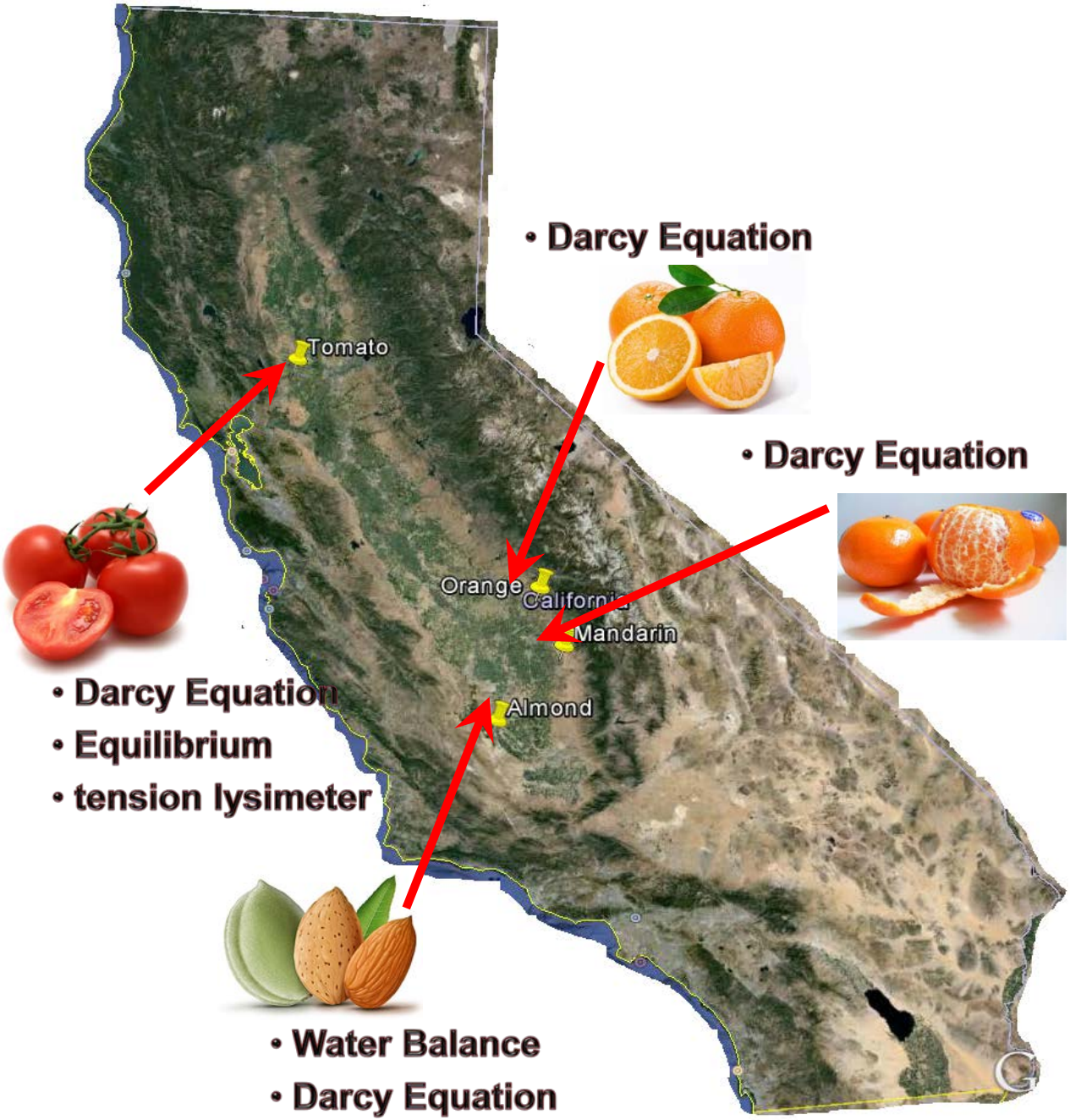
G3 passive capillary (Decagon)



Equilibrium tension lysimeter (UMS)

Equilibrium tension lysimeter installation

Study sites and crops



Russell Ranch Sustainable Agriculture Facility

<u>Two soil types:</u>

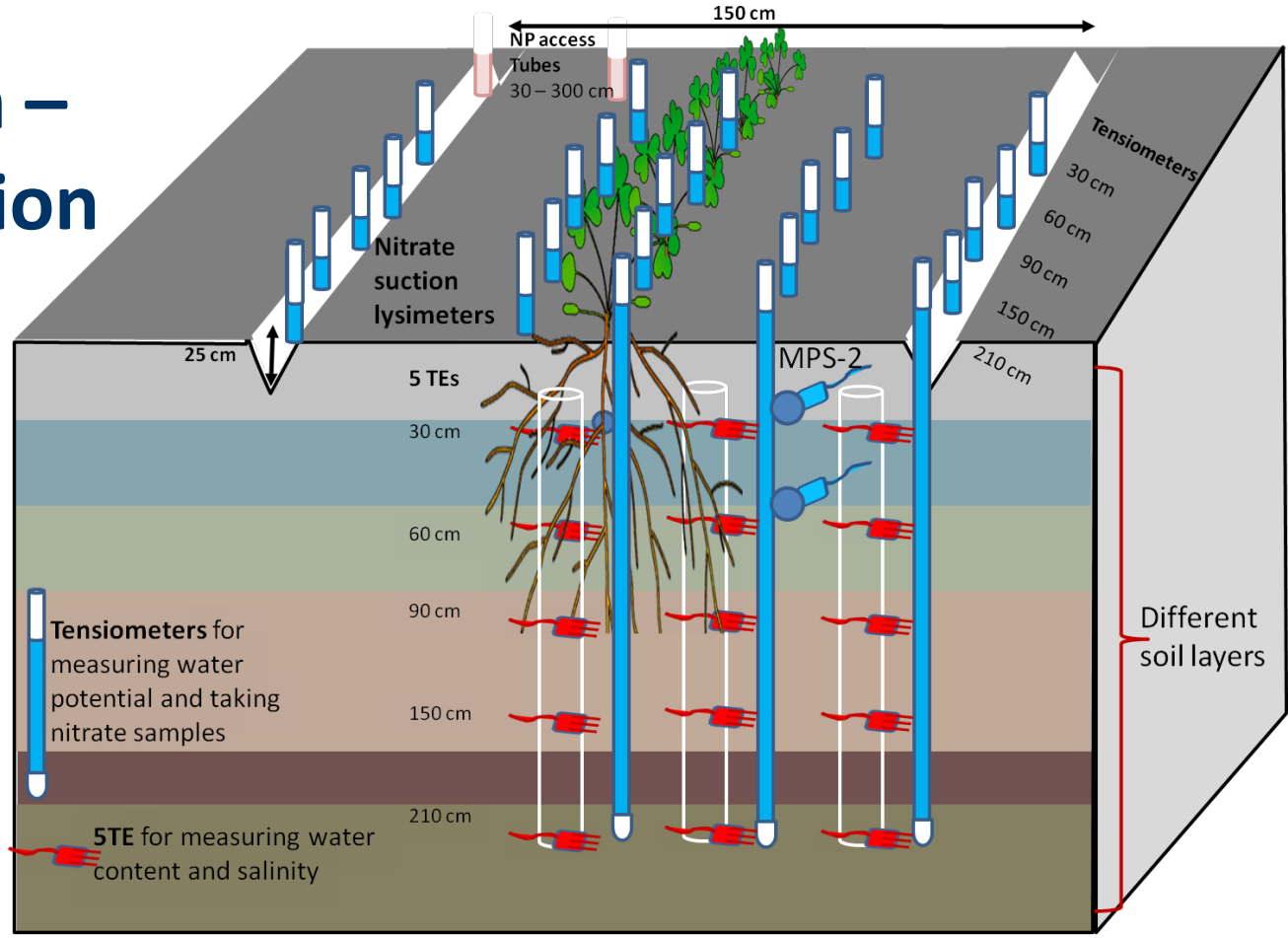
Rincon silty clay loam

Yolo silt loam

<u>Summer</u>		*<u>Winter</u>*
Tomato/ Corn	→	Fallow Bell Bean Triticale

- 3 replicates of each treatment

Russell Ranch – Instrumentation



Instruments list and functions:

1. **Tensiometers**: measures soil matric potential, range: -850 to 0 mbar, individually-calibrated pressure transducers
2. **Decagon 5TE sensors**: measures soil water content, electrical conductivity, temperature
3. **Decagon MPS-2 sensors**: measures soil matric potentials, range -4000 to 0 mbar
4. **Neutron Probe**: measures soil water content, large representative soil volume
5. **Suction lysimeters** : is used to collect soil solution for nitrate analysis
6. **Equilibrium-Tension Lysimeters**: measures drainage below the root zone and collect soil solution samples for nitrate analysis

Multiple sensors at various depths and locations for each treatment plot

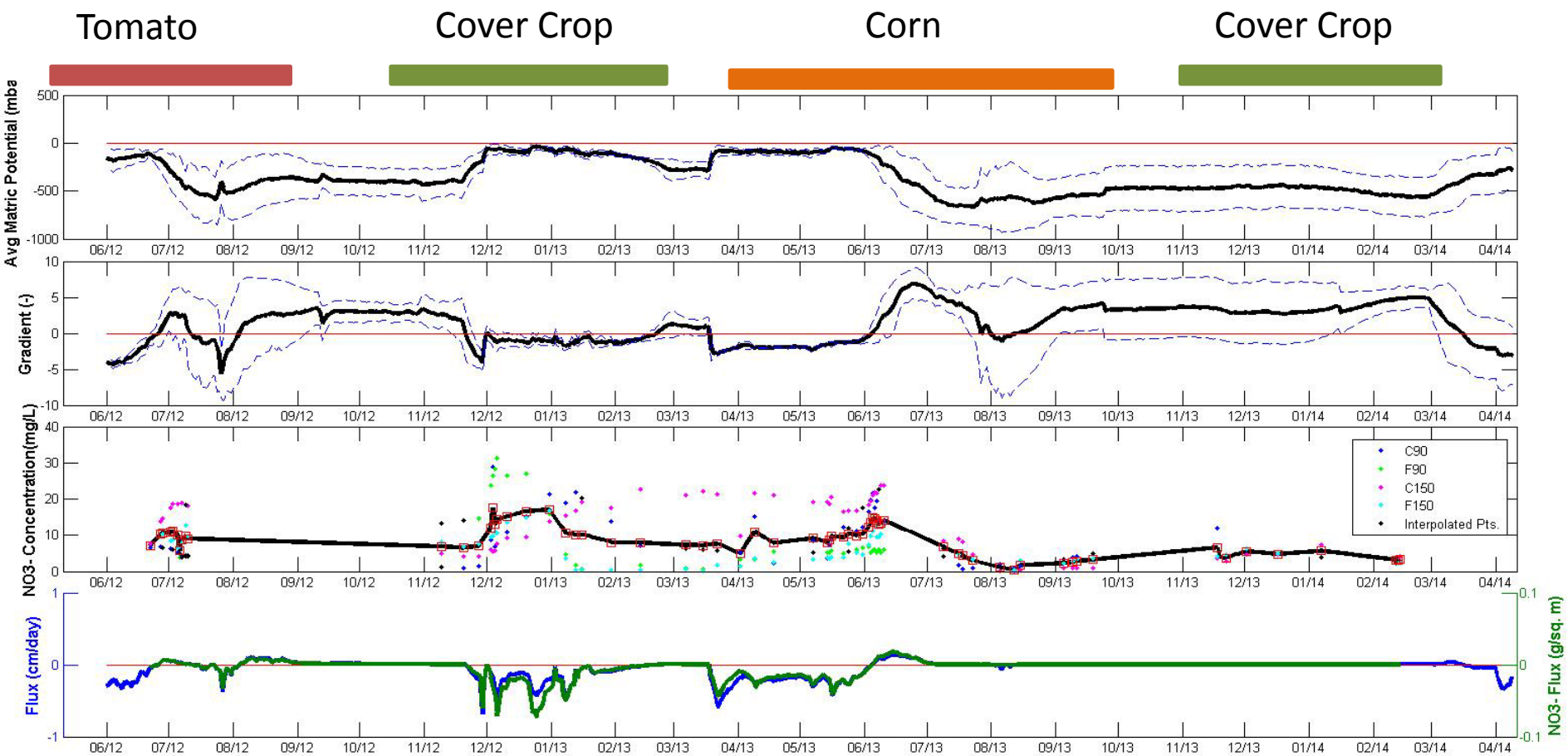
Seasonal water leaching at Russell Ranch

(Comparison of 3 approaches [cm])

	Start Date	End Date	Crop	Mass Bal.	Eq. Tens. Lysimeters	Darcy (Tensiometers)
Bell Bean	**BB**					
	11/4/2011	4/20/2012	Bellbean	-10.69		
	4/21/2012	5/1/2012	Bare	-2.56		
	5/2/2012	8/30/2012	Tomato	17.93		4.45
	8/31/2012	10/19/2012	Bare	-1.57		0.00
	10/19/2012	2/23/2013	Bellbean	14.58	3.18	14.26
	2/23/2013	3/28/2013	Bare	-1.62	0.00	4.11
	3/29/2013	10/2/2013	Corn	21.25	22.25	14.34
	10/2/2013	10/28/2013	Bare	3.60	0.00	0.00
	10/29/2013	3/17/2014	Bellbean	-14.64	0.30	0.02
	11/4/2011	**3/17/2014**	**Total**	57.36	25.74	37.18
W. Fallow	**WF**			0.00	0.00	0.00
	11/4/2011	5/1/2012	Bare	-2.51	0.00	0.00
	5/2/2012	8/30/2012	Tomato	6.39	0.00	2.27
	8/31/2012	3/28/2013	Bare	8.10	1.82	8.74
	3/29/2013	10/2/2013	Corn	8.56	17.34	7.60
	10/2/2013	3/17/2014	Bare	-7.25	1.85	3.39
	11/4/2011	**3/17/2014**	**Total**	23.06	21.01	22.00
Triticale	**TR**			0.00	0.00	0.00
	11/4/2011	4/20/2012	Triticale	-6.83	0.00	0.00
	4/21/2012	5/1/2012	Bare	-2.46	0.00	0.00
	5/2/2012	8/30/2012	Tomato	12.68	0.00	4.69
	8/31/2012	10/19/2012	Bare	0.63	0.00	0.05
	10/19/2012	2/23/2013	Triticale	15.90	0.68	15.56
	2/23/2013	3/28/2013	Bare	0.13	0.74	2.18
	3/29/2013	10/2/2013	Corn	8.98	8.94	12.06
	10/2/2013	10/28/2013	Bare	-5.27	0.00	0.00
	10/29/2013	3/17/2014	Triticale	3.59	0.00	5.83
	11/4/2011	**3/17/2014**	**Total**	41.92	10.37	40.36

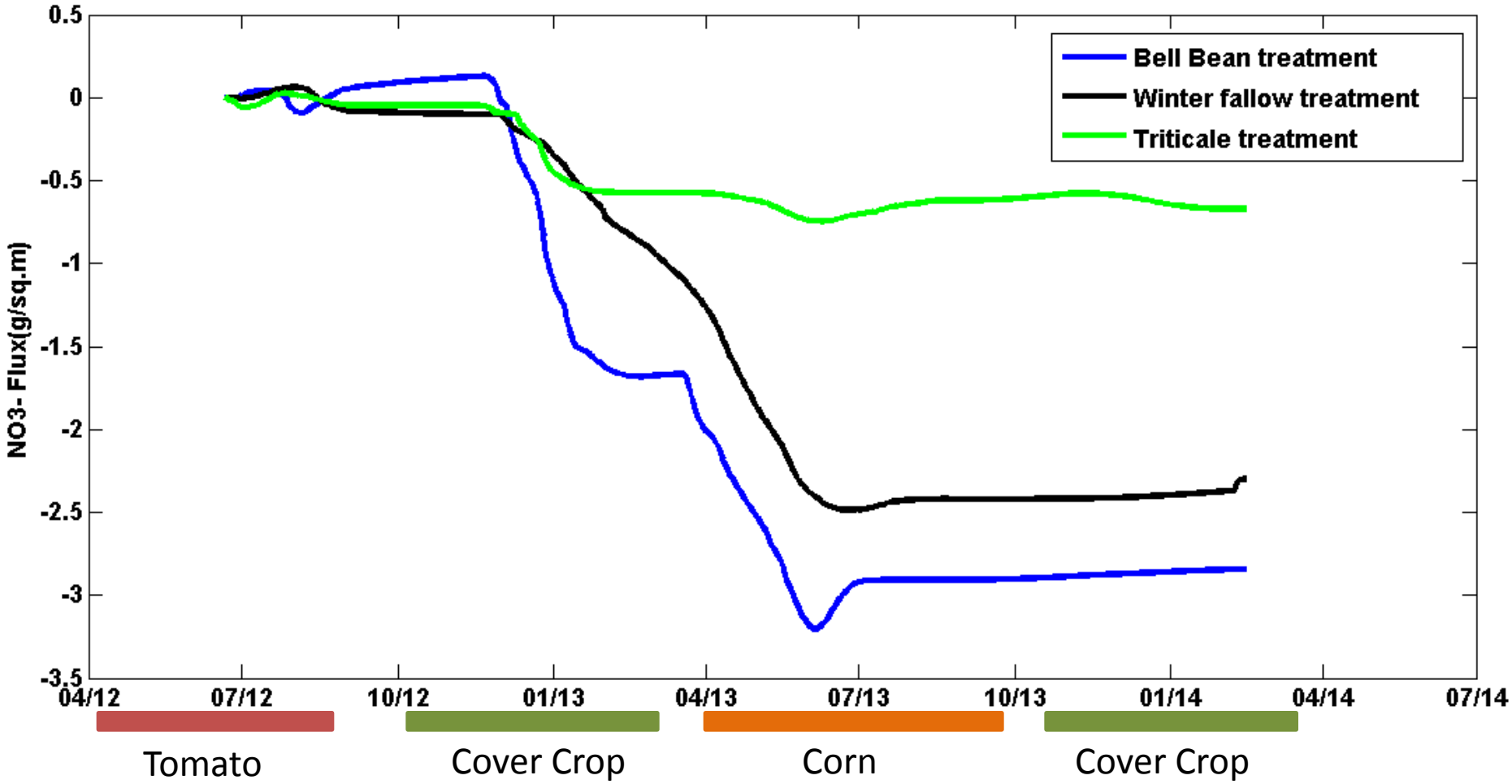
Daily leaching rates of water and nitrate in Bell Bean treatment

1st graph: Average water potential in soil profile (0 is soil saturation, the more negative the dryer the soil)
2nd graph: Soil water gradients (driving force for water movement) across a soil layer at 90-150 cm deep
3rd graph: Soil nitrate concentrations measured in soil solution in the 90-150 cm soil layer
4th graph: Daily vertical downward /upward fluxes of water (blue line on left Y axes) and nitrate (green line on the right axes). Negative fluxes are downward and positive fluxes are upward. Most of the leaching of water and nitrate seem to happen in the fall and early corn season.

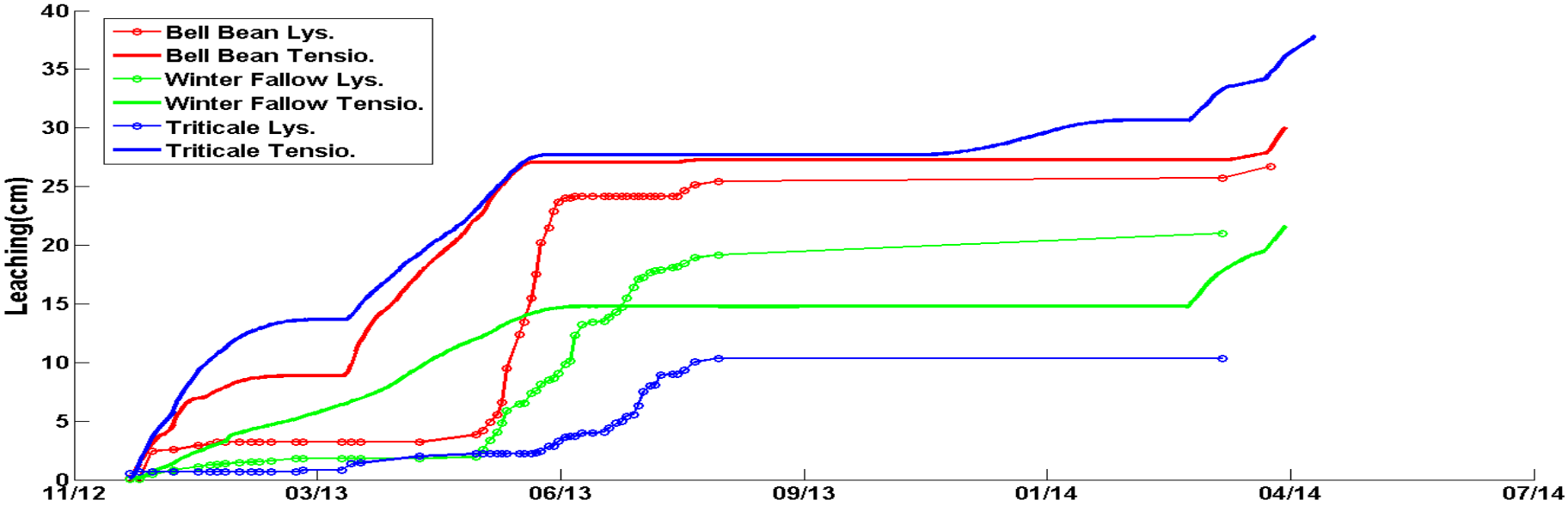


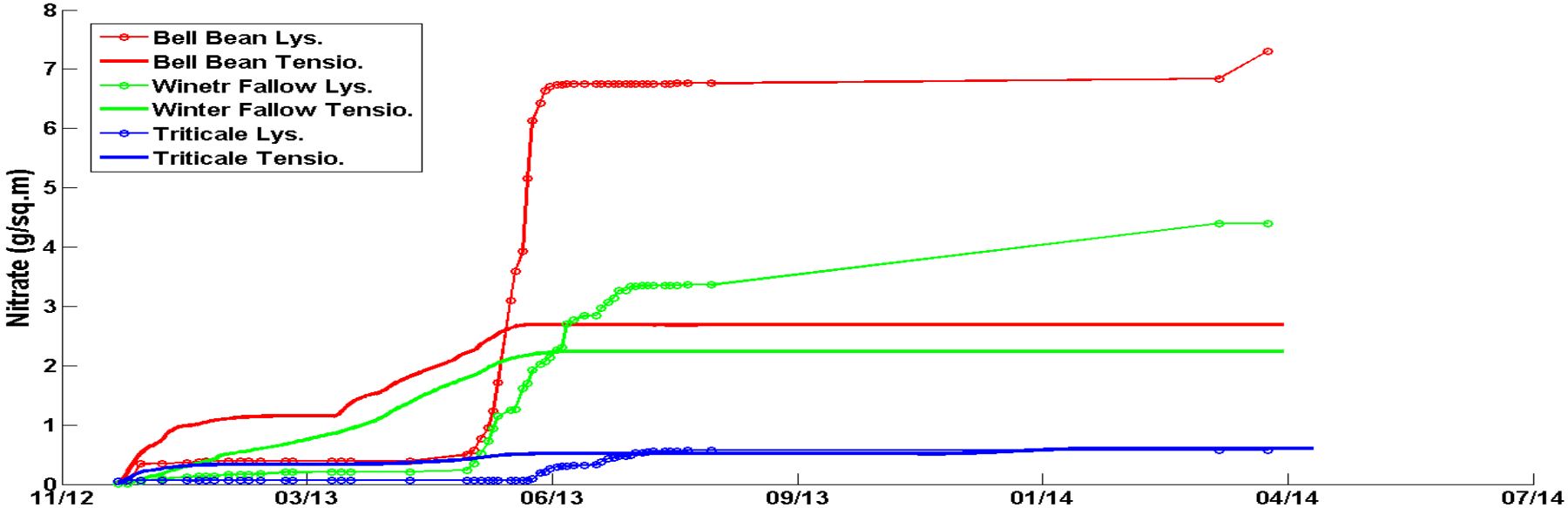
Cumulative nitrate leaching in all three treatments

Vertical downward leaching of nitrate (negative values) throughout the crop rotations. Triticale showed to be the most efficient in reducing the nitrate leaching below the root zone (150 cm deep). Note the difference in nitrate leaching rate during different seasons in different treatments. While nitrate continuously leached below the root zone of winter fallow in fall through corn season, it slowed down in the two cover crop treatments.



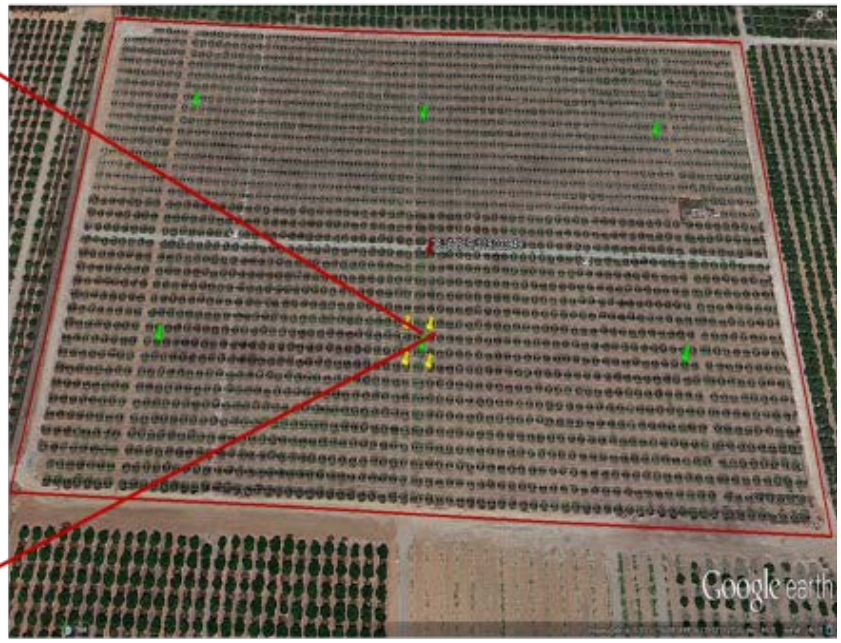
Comparisons: Cumulative water and nitrate leaching from tensiometers versus Eq.-Tens. lysimeter methods





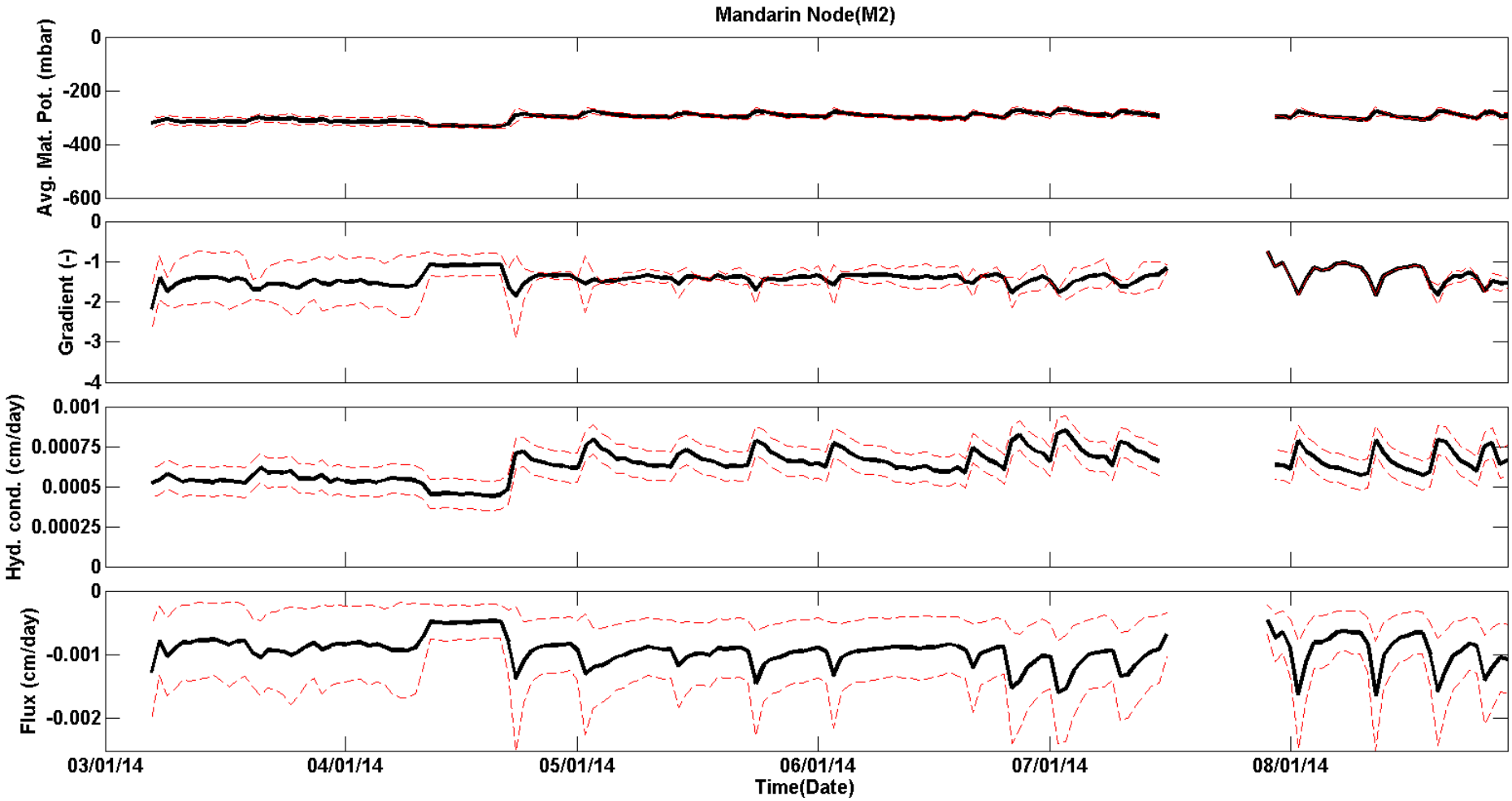
Citrus sites: Orange Cove and Strathmore, CA

- Collecting water and nitrate movement data in the root zone and below the root zone to capture seasonal variations in leaching and following irrigation and fertigation events
- Where the tree roots are taking up water? Excavating and imaging root distribution in depth and lateral distances from the trunk and irrigation sprinklers

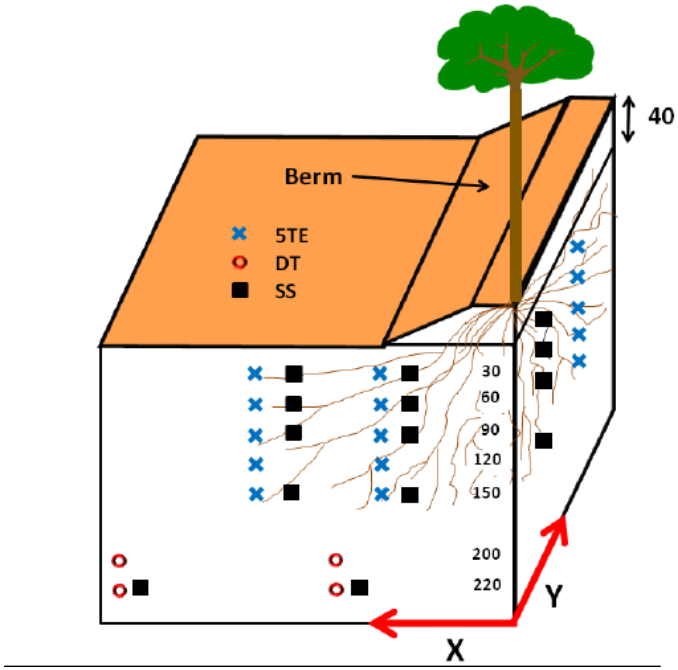


Wireless Sensor Networks

•Results - Mandarin



Almond-Paramount Farms (Lost Hills):
Fanjet versus Surface Drip



Uncertainty in leaching estimation in Almond

from single tree to field scale

	P (cm)	ET (cm)	IW (cm)	ΔS (cm)	L (cm)
Field	57.7 (±1.2)	580 (±3)	522.4 (±19)	1.3 (±5)	-1.3 (±19.7)
Drip block			529.7 (±19.8)	0.1 (±5)	7.1 (±19.5)
Fanjet block			515.1 (±14.8)	2.5 (±4.7)	-9.7 (±16)
Drip tree			555.8 (±3.2)	1.8 (±1.6)	32 (±4.9)
Fanjet tree			497.2 (±2.9)	9.1 (±1.6)	-34.4 (±4.7)

Table 3. Comparison of L and uncertainty range from water balance and Darcy equation approaches.

		Water balance	Darcy-Multistep K(h)	Darcy-Neuro Multistep K(h)
Leaching (cm)	Drip	15.05 (±2.61)	11.6 (±13.6)	3.7 (±3.2)
	Fanjet	-2.1 (±2.41)	6.2 (±15.85)	0.07 (±0.08)

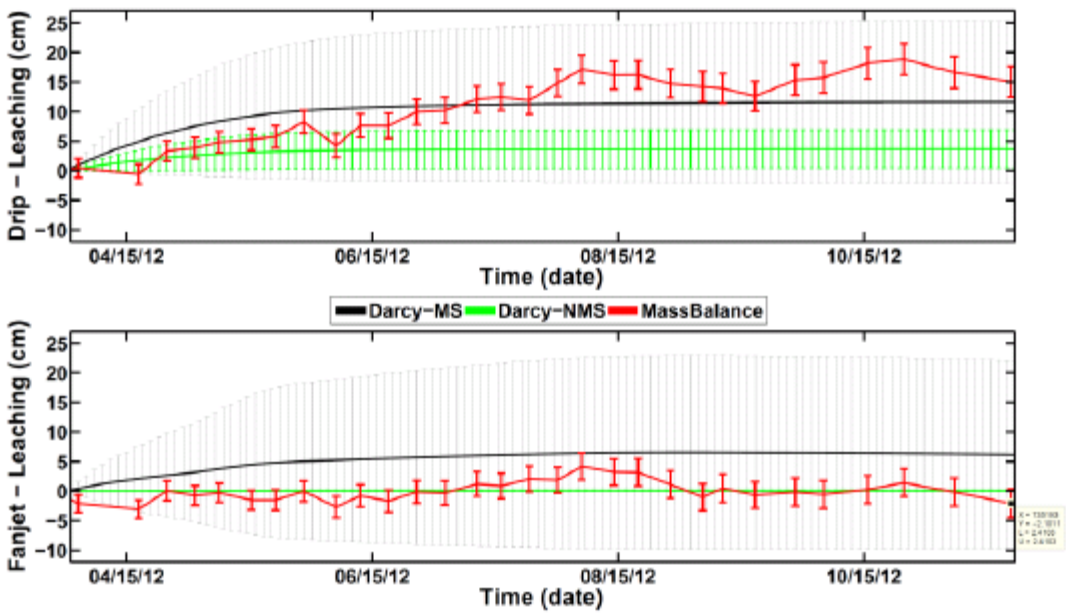
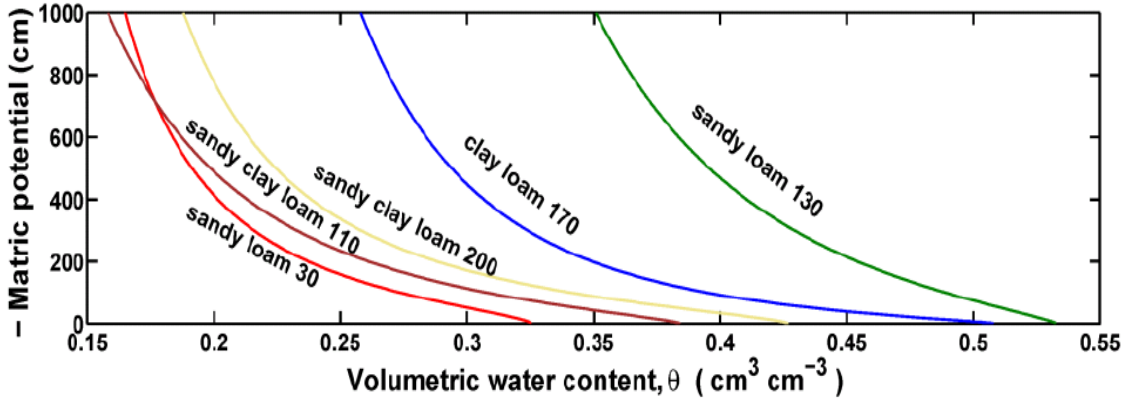
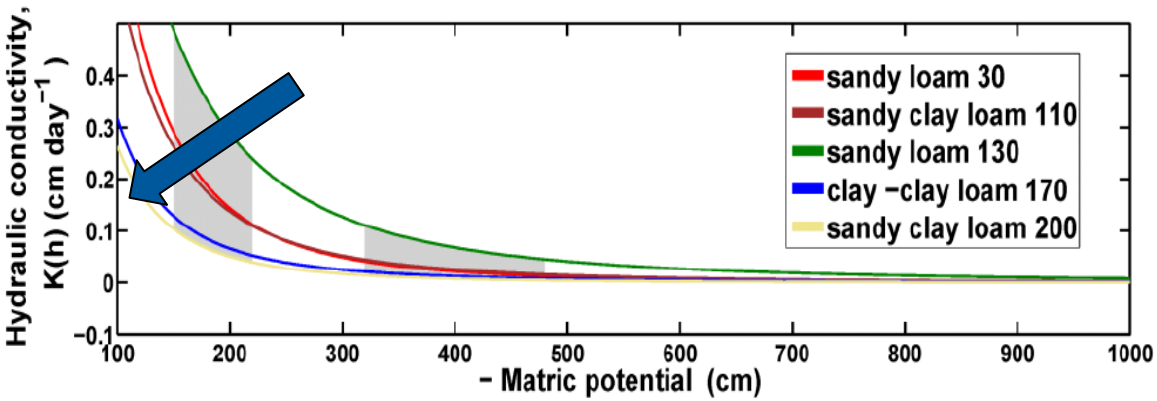


Figure 17. Comparison of leaching and the associated uncertainty range obtained from three different approaches of a) water balance (Red line), b) Darcy equation with measured soil hydraulic properties with combination of costant head and tempe cell (black line), and c) Darcy equation with predicated soil hydraulic properties using NeuroMultistep model (green line).

Enormous depth variation in soil texture/layering, soil water retention, with corresponding unsaturated hydraulic conductivity functions

Fan Jet	Clay (%)	Silt (%)	Sand (%)	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Drip
Sandy clay loam	21	18	61	10	73	12	15	Sandy loam
				20				
				30				
	27	26	47	40	75	13	12	
				50				
				60				
	21	26	53	70	72	15	13	
				80				
				90				
Loam	28	27	45	100				
				110	37	32	31	Clay loam
				120				
Clay	54	27	19	130	43	38	19	loam
				140				
Sandy loam	19	25	56	150				
				160	48	27	25	Sandy clay loam
loam	23	32	45	170				
Sandy loam	14	12	74	180				
				190	21	37	42	Clay
Silt clay	44	47	6	200				
				210				
Clay loam	29	37	34	220	37	29	34	Clay loam
				230				
				240				
				250	62	19	19	Sandy loam
				260				
				270				





Summary
Water and Nitrate Leaching / Monitoring

- Only relevant if deep surface is wet
- Deploy wireless sensor network at the field scale
- Develop deep tensiometers for accurate gradient measurements
- Use inverse modeling and in situ soil moisture gradient data to estimate unsaturated hydraulic conductivity in the wet range
- Still need in situ soil nitrate sensor