Optimizing Fertigation Protocols for Nitrogen in Tree Crops (Almond)

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Perennial Horticulture in California

- Perennial fruit and nut crops are a $20 billion (farm gate) industry. (Grape, almond, citrus, walnut, strawberry..)
- Approx 7 million irrigated acres
- Irrigated, fertigated, high input , high crop value ($3,000 - $30,000 acre)

- High Value/Low fertilizer cost
- High degree of variability
- Poor use of current technology → Low degree of precision in fertilizer management
- Great potential for control of rate, timing, placement.

Current practice

“One size fits all”

(>70% industry uses 250 lb N, 150 lb K and 48 inches water)

•Management recommendations for tree crops are not adequately site or time specific to optimize efficiency.

Why is management unsophisticated?:

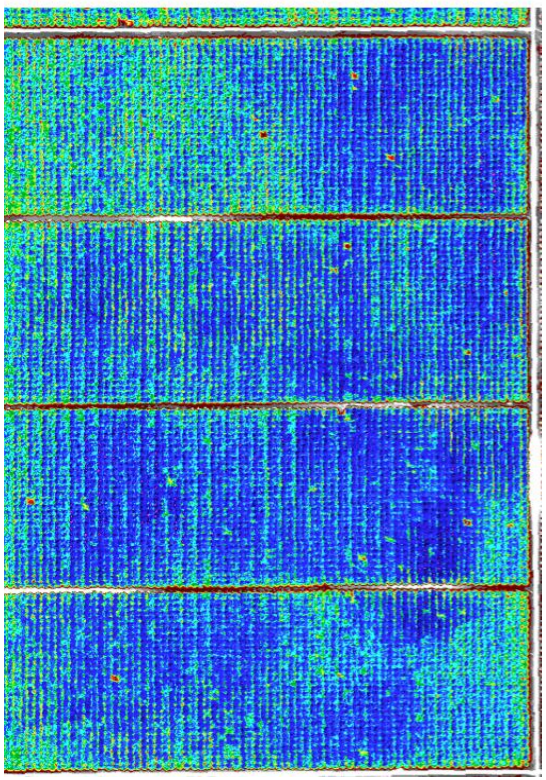
- Poor ability to estimate true demand
- Poor ability to monitor tree nutrient status
- Variability
- Lack of user friendly tools
- Lack of cost incentive

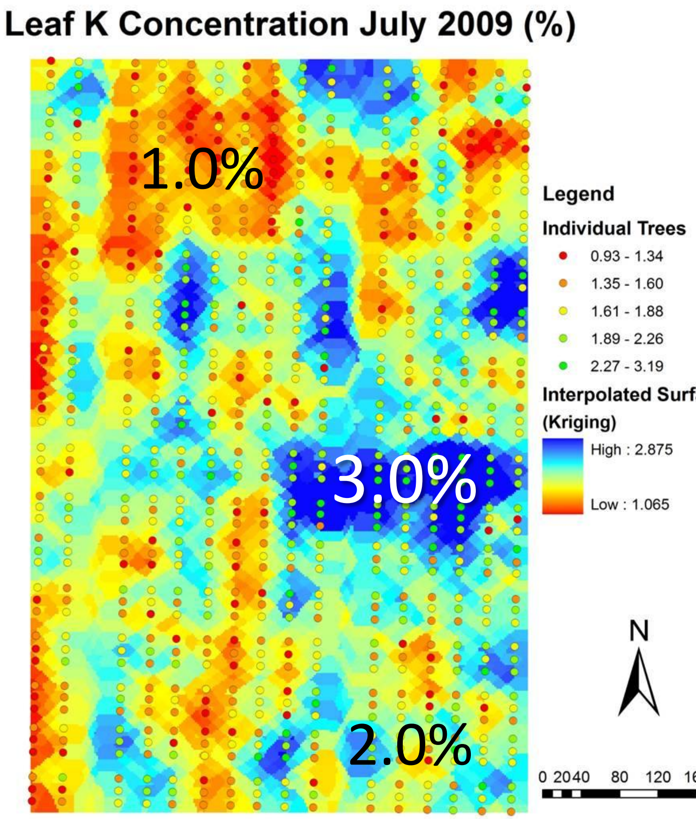
Why does it need to change?

- The market (EU, the Walmart’s) and the public (through policy) are demanding ‘sustainability’ and BMP’s.
- Financial and environmental sustainability

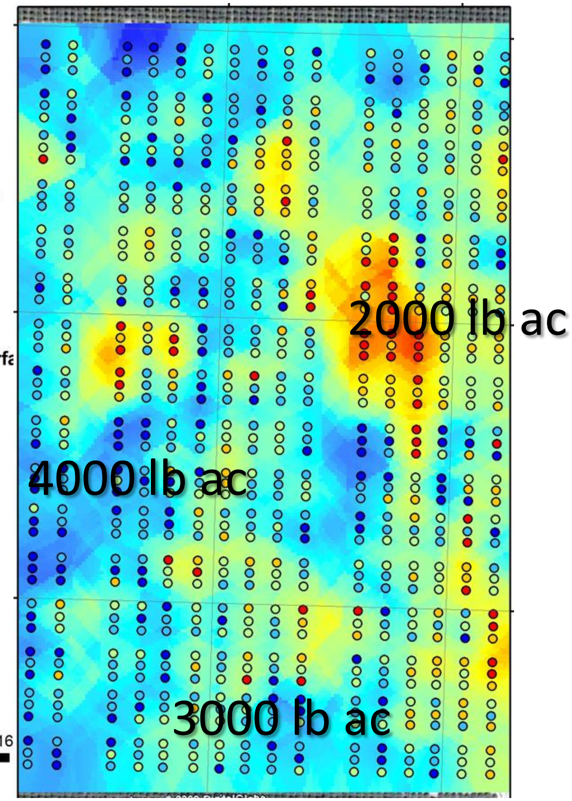
Within Field Variability complicates experimentation, understanding and management

NDVI (Leaf Area)





Yield



3700 lb three year average yield (top 5% yield level)

Can N be managed sustainably?

Motivations and Constraints

- Improve efficiency of N use

  Constraints: Inadequate understanding. Field variability and risk aversion, Low relative cost of fertilizer.

- Reduce nitrogen losses to the environment and decrease contamination of water and generation of GHG's.

  Constraints: Inadequate understanding of the processes, inability to quantify the effects, inability to link actions to outcomes.

- Policy development and legislative action, public perception. (AB35)

  Contraints: Poor information, no enforcement mechanism.

- Market demands for sustainability
  - Markets increasingly demand environmental accountability and many large wholesalers have sustainability initiatives (Walmart, Nestles etc)

Constraints: Powerful enforcement mechanism but no scientific basis for decisions.

Advanced sensing and management technologies to optimize resource management in specialty crops (Nitrogen and Water)

Multi-stakeholder Integrated Project 2009-2012
(≈$6 million)

Almond Board, USDA-SCRI, Calif Dep Agric, Yara, Mosaic, TKI, Compass, Pistachio Research Committee, Haifa, SQM, FFF.

Patrick Brown, Ken Shackel, Ted Sammis, Bruce Lampinen, Leonardo Lombardini, John Mexal, Blake Sanden, Manoj Shukla, David Slaughter, David Smart, Rolston St. Hilaire, Shrini Upadhyaya, Jan Hopmans, Susan Ustin, Michael Whiting

Project structure

Integrated Activity #1 – Demand estimation

a. Plant and orchard/vineyard scale investigations of N and water demand and fluxes
b. Modeling of crop nutrient and water demand.

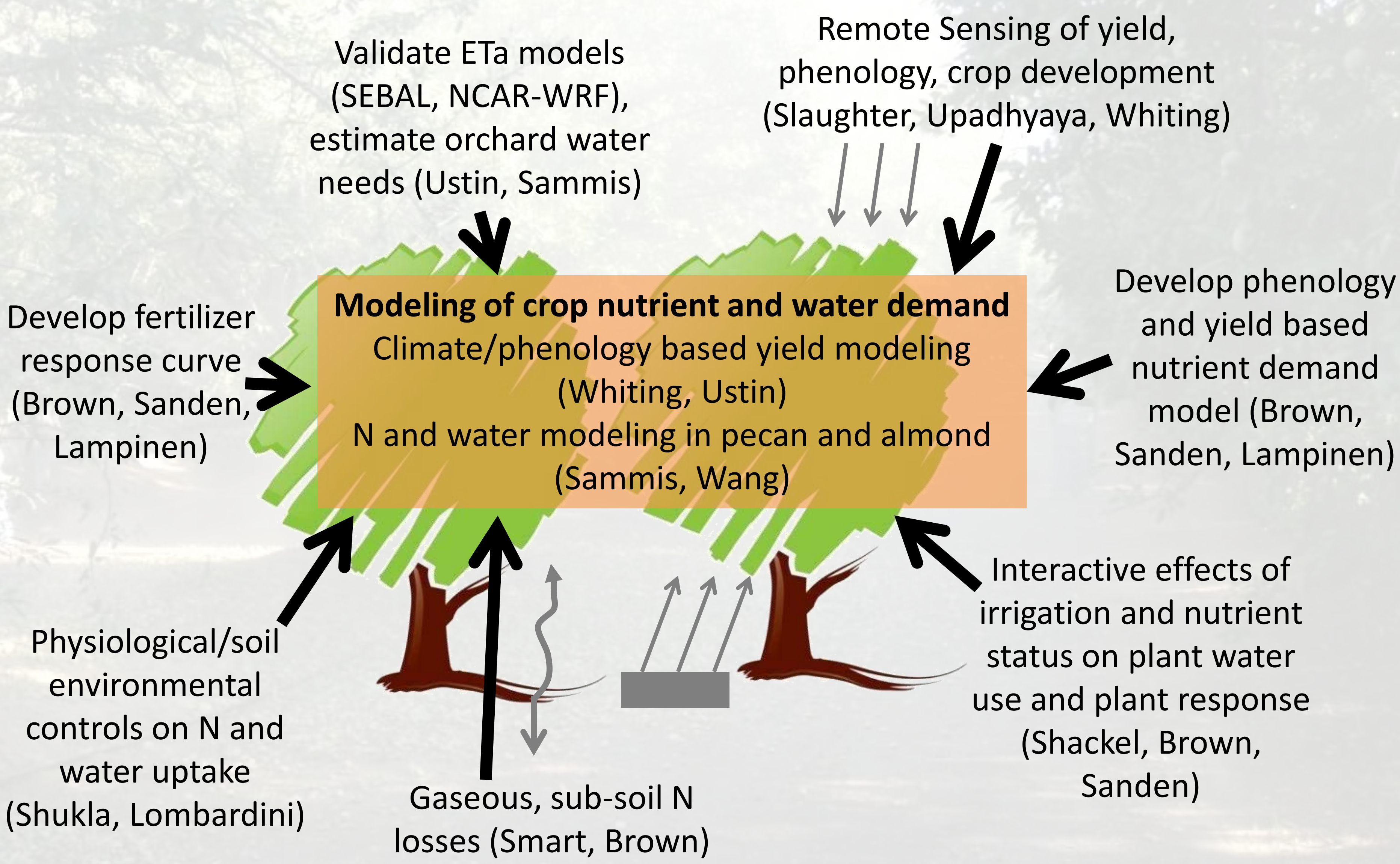
Integrated Activity #2 – Status determination

a. Plant and orchard/vineyard based determination of water and nutrient status
b. Remote and local sensing of water and nutrient status

Integrated Activity #3 – Integration / validation

a. Beta development of web based decision support toolkit 'NutMan' under control and deficit conditions
b. Iteratively test, refine and validate models and tools

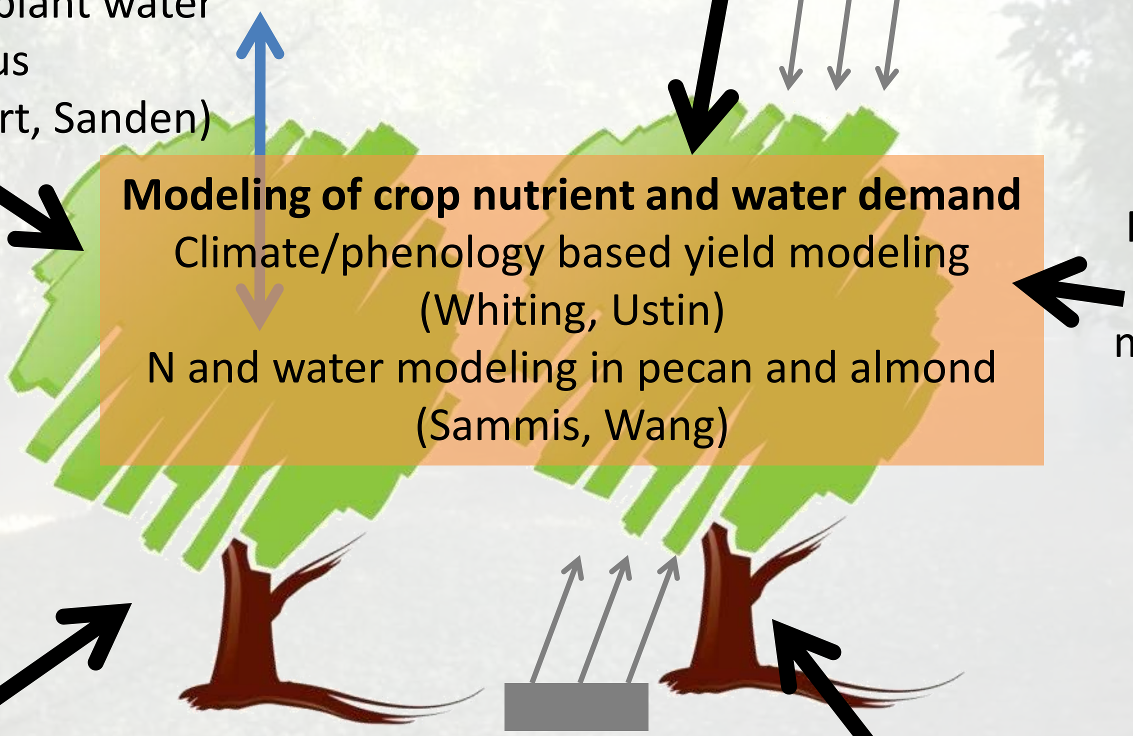
Activity #1 – Demand estimation



Activity #2 – Status determination

Evaluate spectral measurements / correlate to crop status
(Whiting, Lampinen, Slaughter, Upadhyaya)

Relate ETa to plant water status
(Shackel, Smart, Sanden)



Re-evaluate leaf and orchard sampling methods and “Critical Value” concept
(Brown, Lampinen)

Model solute transport
(Hopmans, Brown, Kandelous, Olivos)

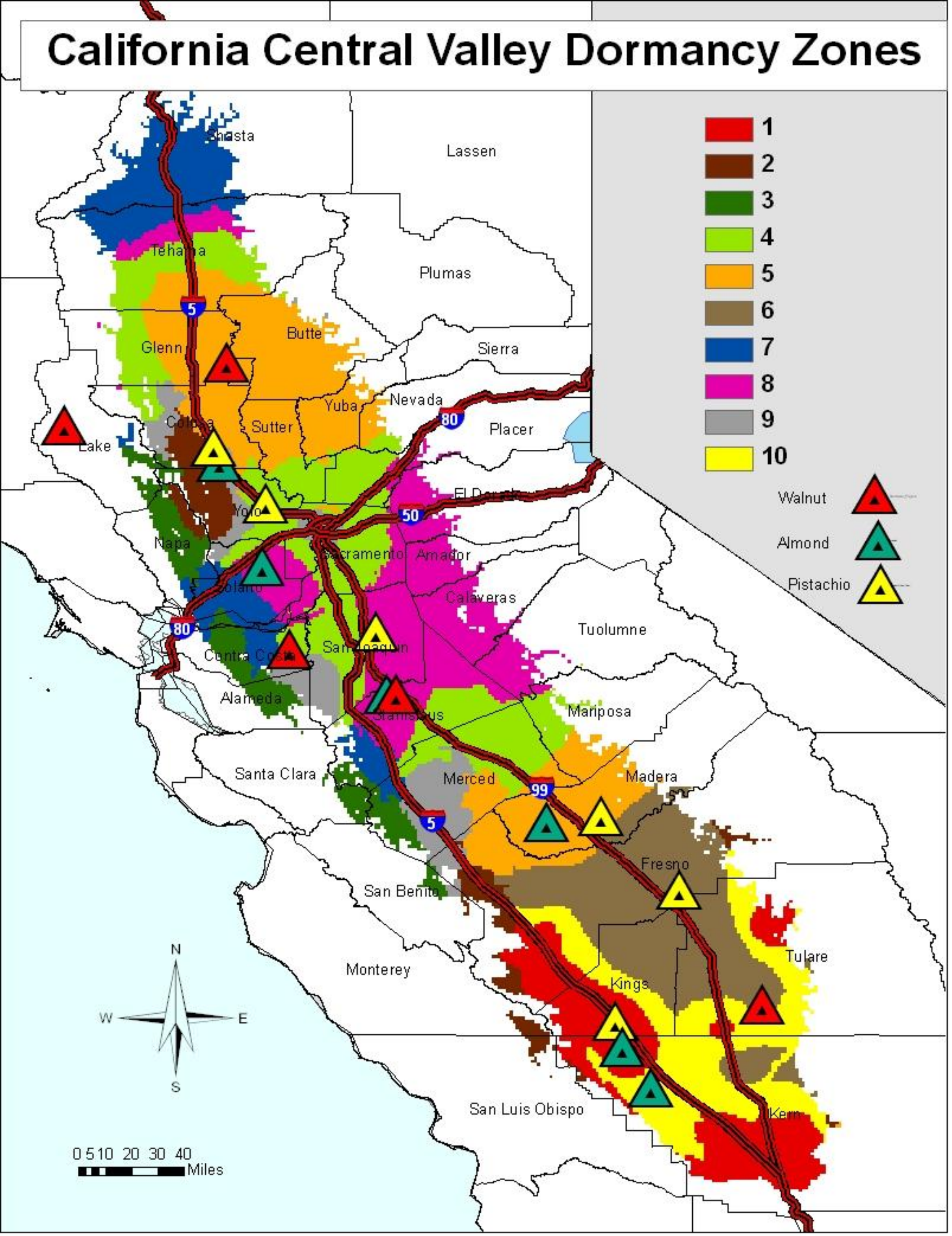
Determine root dynamics
(Brown, Hopmans, Olivos, Kandelous)

Activity #3 – Integration / validation

Development of basic data on resource demand and response and establishment of easy to use BMP's

Beta development of web-based decision support toolkit "NutMan"

Iterative validation and improvement of models and tools



<u>6 Almond, 6 Walnut and 5 Pistachio Orchard Sites</u>

All Sites: (>100 trees)

- •5 in-season full nutrient analysis
- •5 in-season Spectral Analysis
- •5 in-season Plant Water Status
- •Soil water and irrigation volume
- •Yield (100 + individual trees)
- •Nitrogen Use Efficiency (NUE)
- •Aerial and satellite imagery

Two Sites:

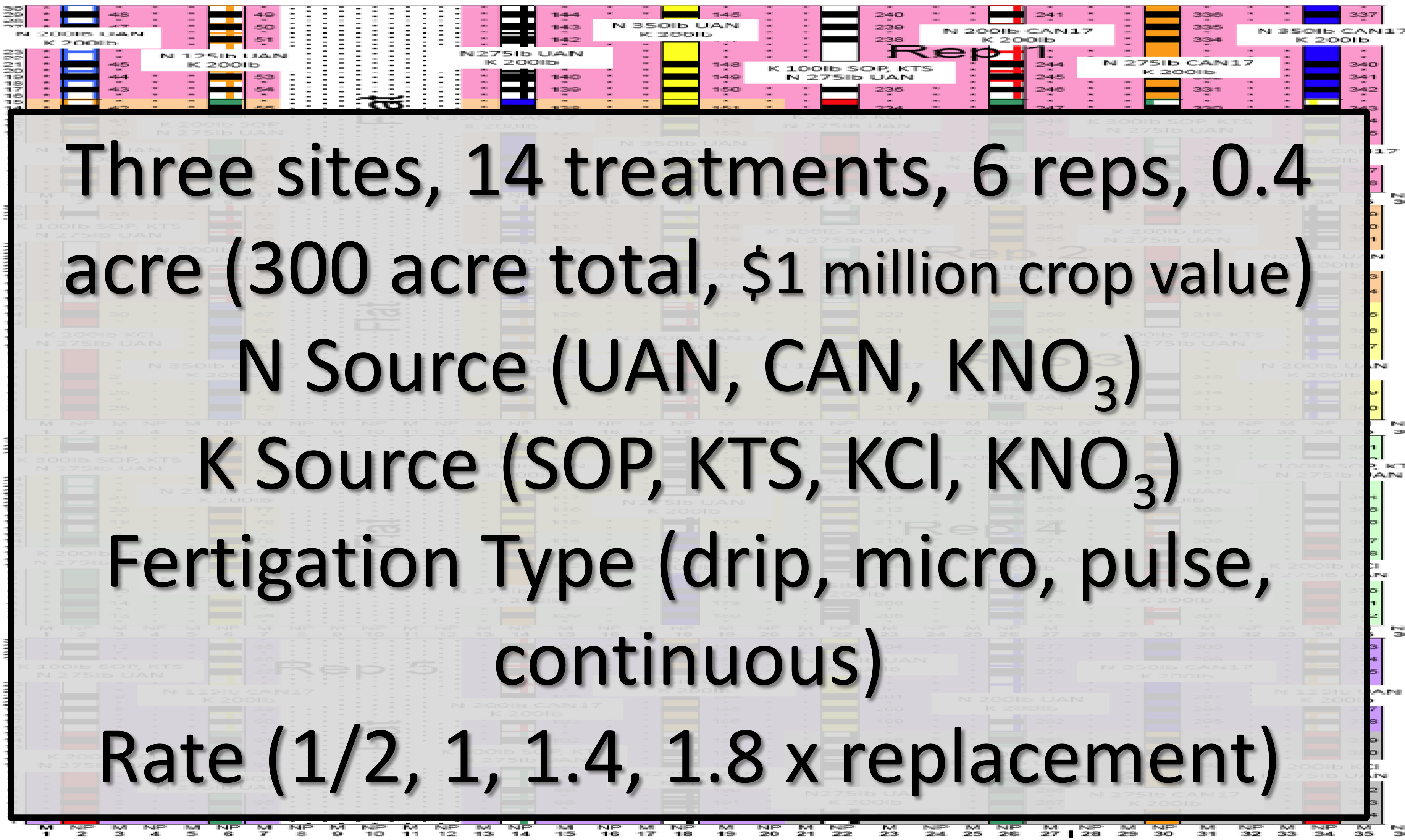
- •Gaseous nitrogen loss
- •NUE

One Site: 50 x 2 acre, (drip/Fan Jet)

- •Factorial 4N x 4K x source x Irrigation Trial

- •5 in-season full nutrient analysis, 5 in-season Stem WP, Soil water and irrigation volume, Yield (768 individual trees)
- •NUE
- •Canopy level imagery
- •Aerial and satellite imagery

Experimental Layout (almond)



Three sites, 14 treatments, 6 reps, 0.4 acre (300 acre total, $1 million crop value)

N Source (UAN, CAN, KNO_3)

K Source (SOP, KTS, KCl, KNO_3)

Fertigation Type (drip, micro, pulse, continuous)

Rate (1/2, 1, 1.4, 1.8 x replacement)

Fig: Layout of the experimental plot at Bakersfield (Fan Jet block only). Different background colors indicate different experimental units. Black rectangles mark trees that are intensively sampled in this experiment.

Leaf Analysis and Crop Demand

SEASONAL CURVES FOR EARLY SAMPLING

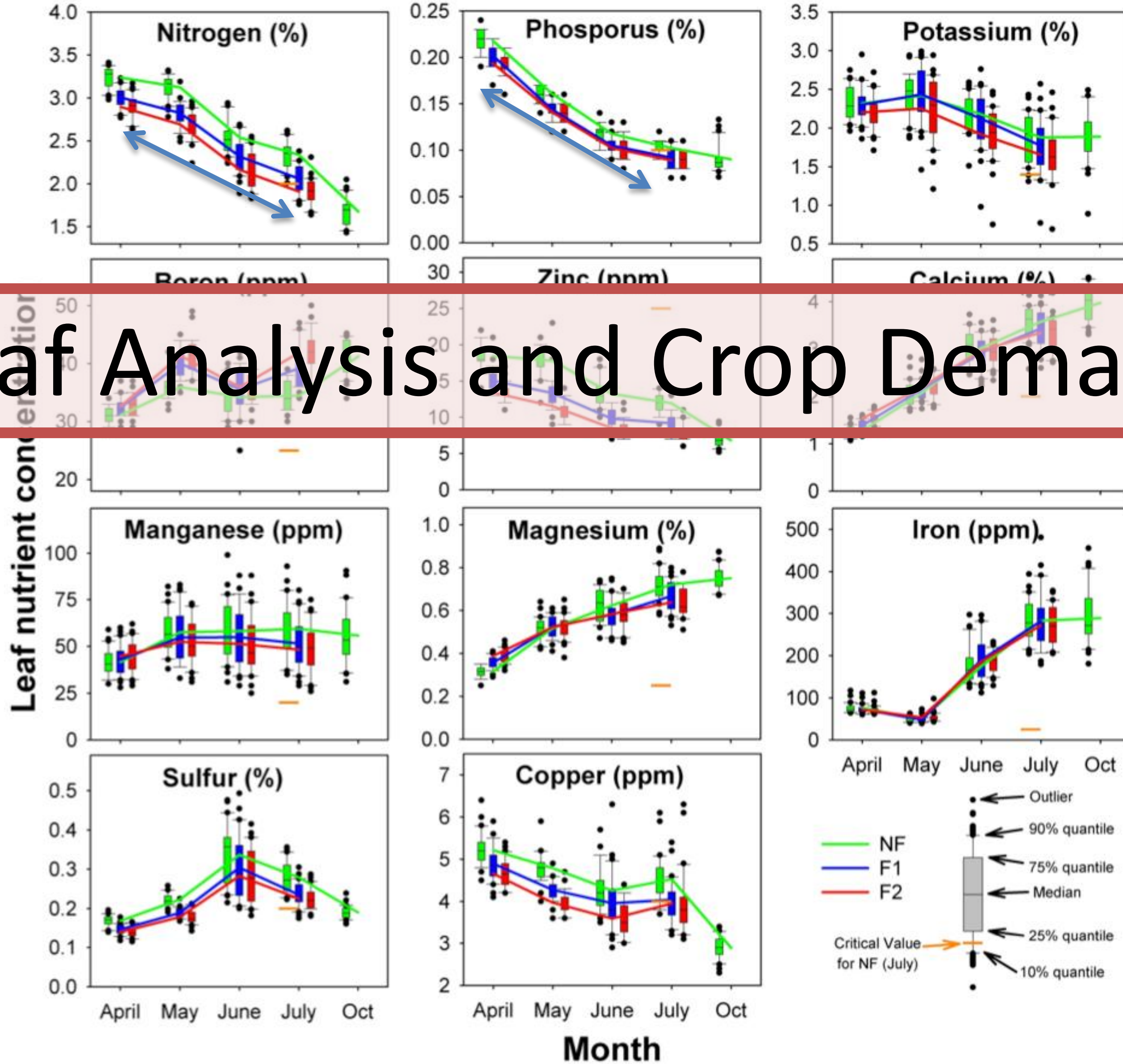


Figure 2. Nutrient dynamics during the season

Data for Arbuckle during the 2008 season

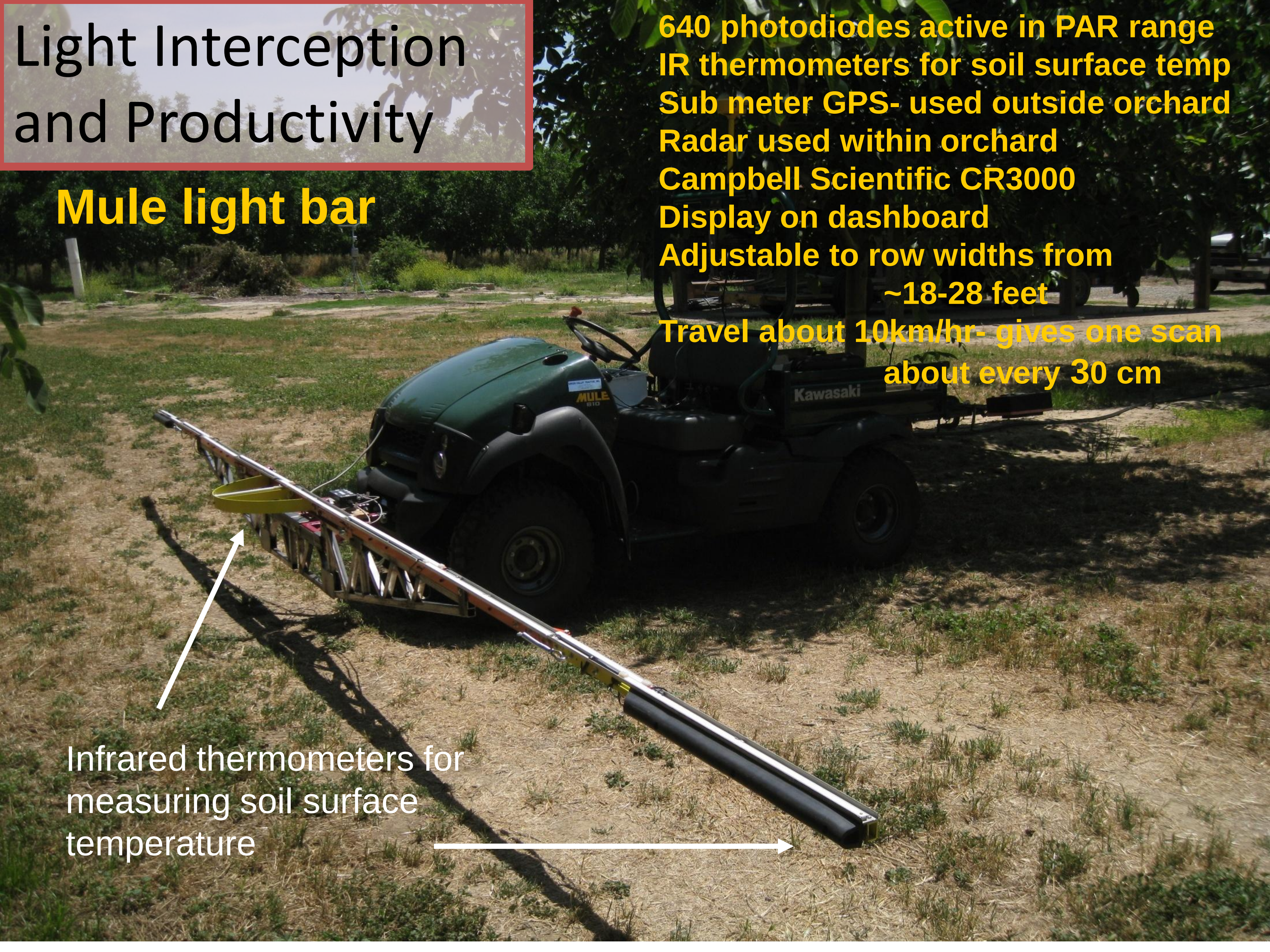
n=30 for each sample type and date (total of 390 samples)

Sebastian Saa and Patrick Brown

Light Interception and Productivity

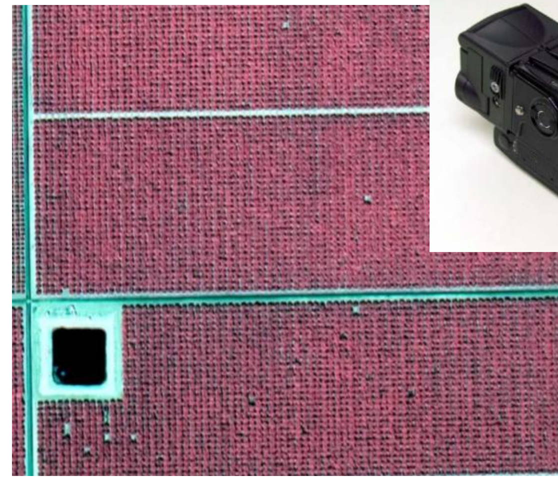
Mule light bar

640 photodiodes active in PAR range
IR thermometers for soil surface temp
Sub meter GPS- used outside orchard
Radar used within orchard
Campbell Scientific CR3000
Display on dashboard
Adjustable to row widths from ~18-28 feet
Travel about 10km/hr- gives one scan about every 30 cm



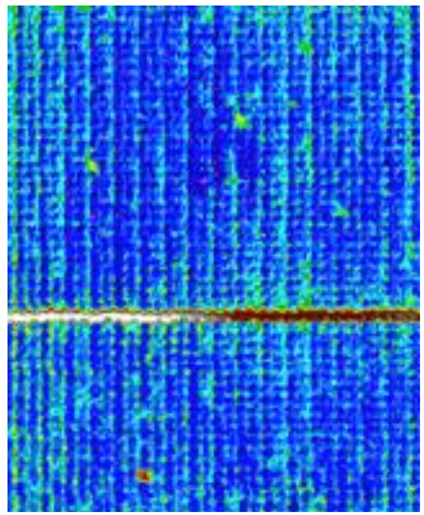
SMALL FORMAT AIRBORNE CAMERAS USED

NASA Digital Cirrus Camera System
1 m pixel, bands: B, G, R, or G, R, NIR Photographs provided at no charge to main systems users, such as MASTER

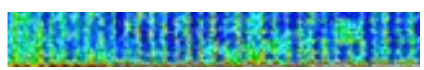


Color Infrared composite (G,R,NIR)

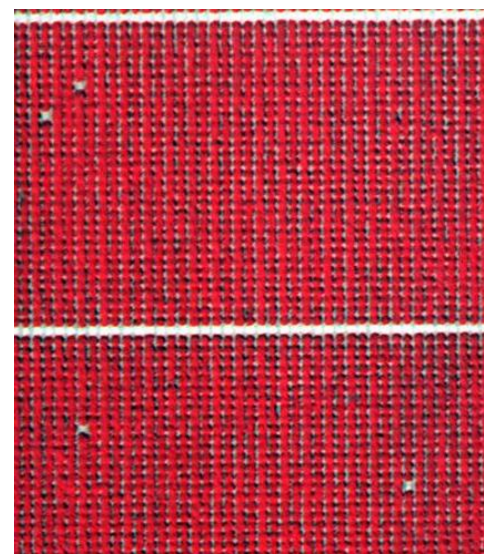
Smart Image (Beltsville, MD)
10 and 20 cm pixel,
bands: blue, green, NIR,
GNDVI product
$3.75 per acre (500 acre minimum)



Green NDVI product



GeoG2 (Mountain View, CA)
1 m pixel, bands: green, red, NIR
(creates NDVI, GNDVI and other indexes)
$1200 per 3 orchards

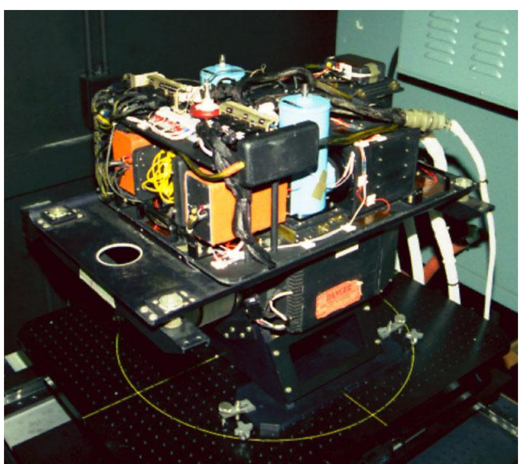


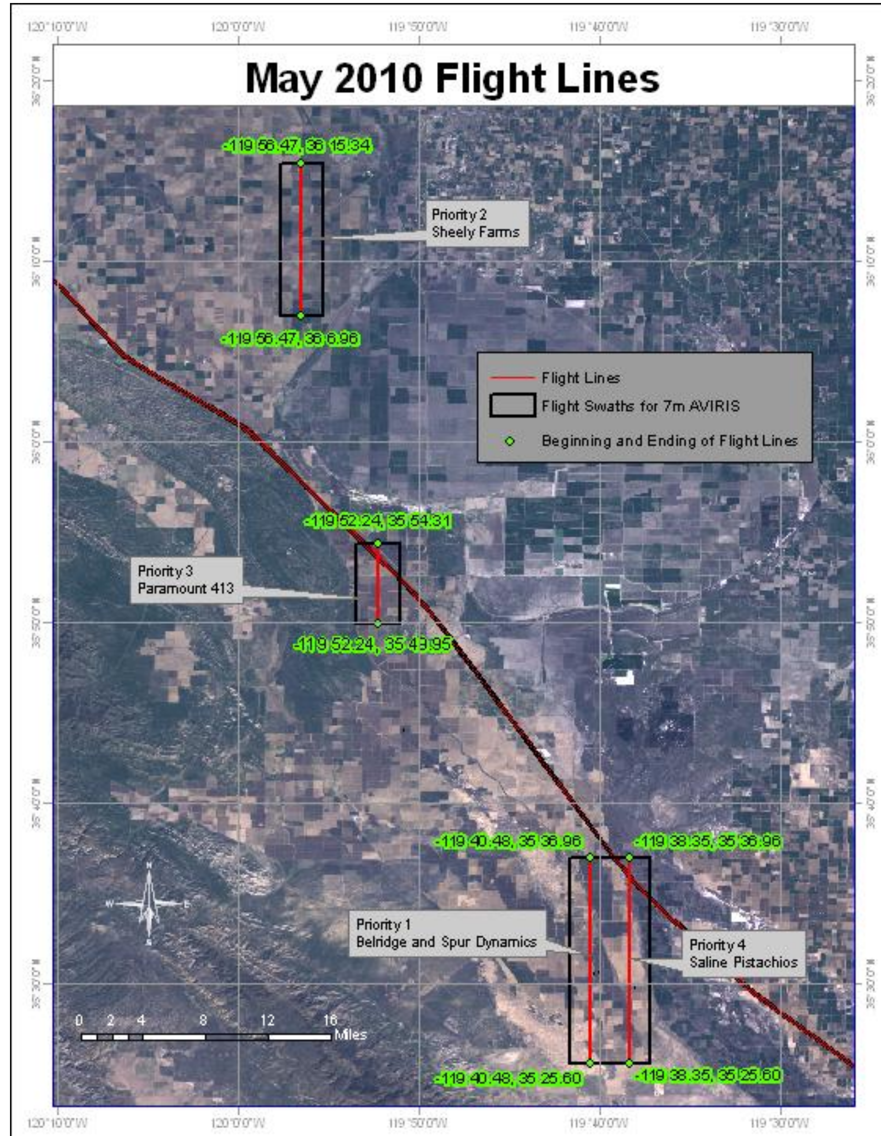
Color Infrared composite

Ustin, Whiting, Zarate.

(2009-10) 50 visible, near & shortwave infrared and thermal bands.

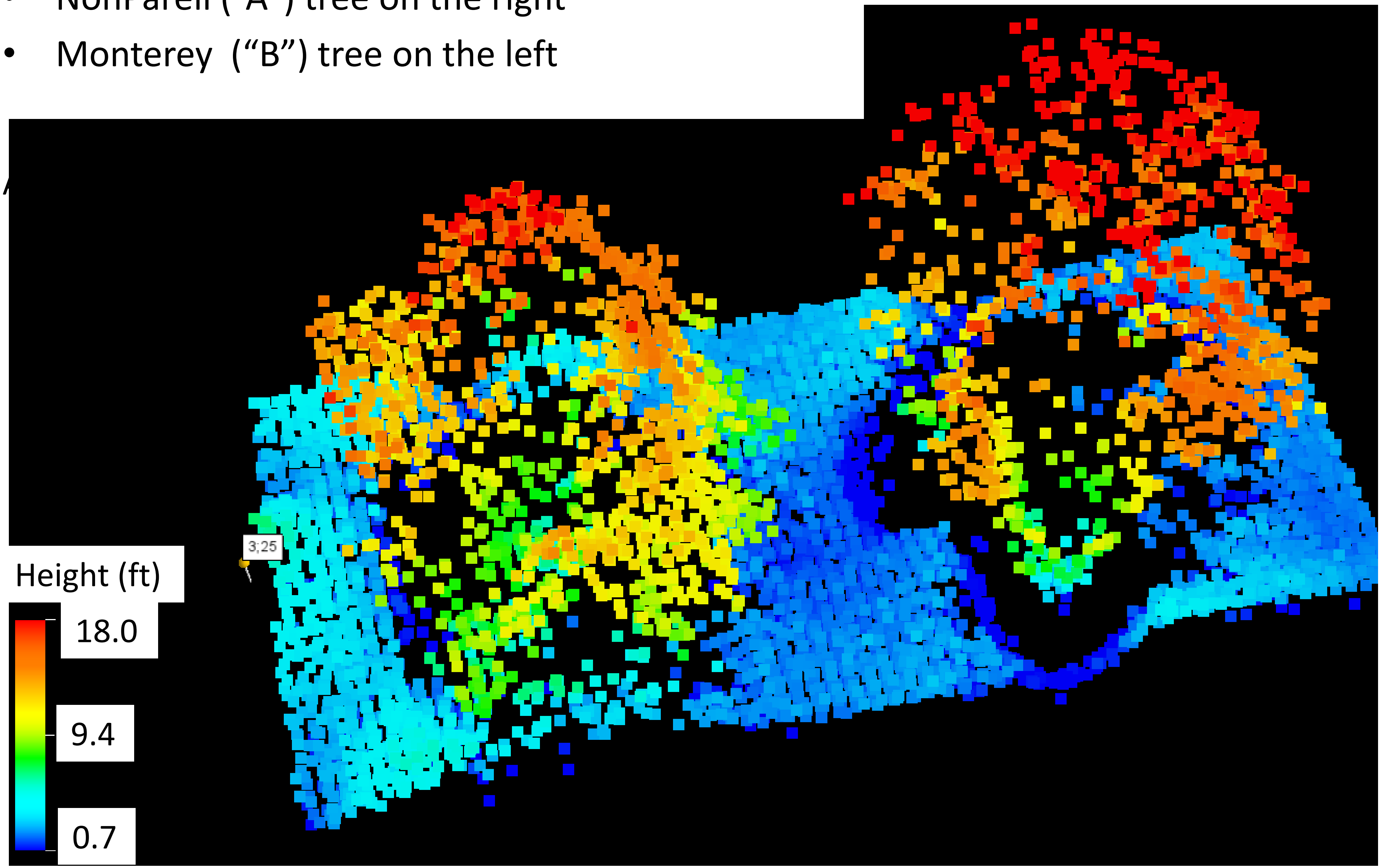
•Results contrasted with ground based LAI, hand held spectral readings, nutrient status, Stem Water Potential, NIR, and Yield





Northrup Grumman (Lidar Hyperspectral submeter from 10,000 meters)

- NonPareil (“A”) tree on the right
- Monterey (“B”) tree on the left



Nutrient Demand: Whole tree Harvesting:
5 mature trees x 5 times in a year

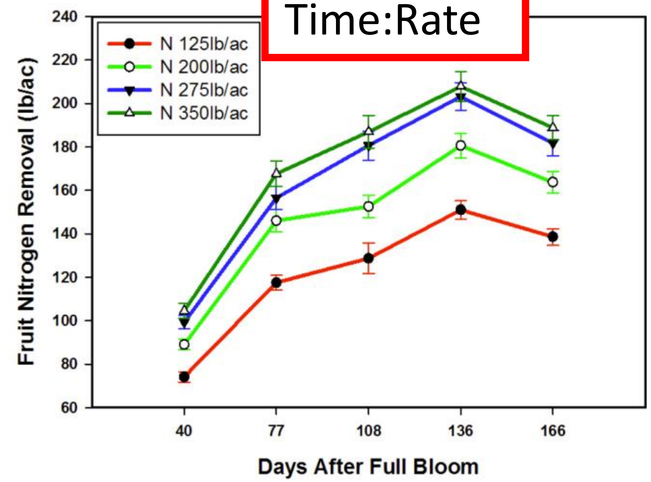
OPTIMIZING NUE: 4 R's

Rate:Source

Kernel Yield 2010 (lb/ac)

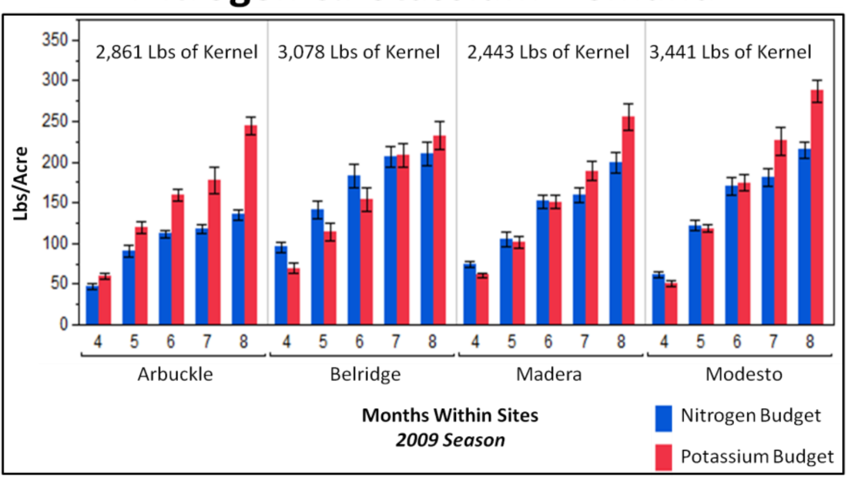
Treatment	N UAN 32				N CAN 17				K Rate			K Source		
	A	B	C	D	E	F	G	H	I	C	J	C	K	L
	125	200	275	350	125	200	275	350	100	200	300	200	200	200
Drip Irrigation	2,859	3,426	3,909	4,332	2,624	3,191	3,967	3,995	3,860	3,922	3,734	3,922	3,459	3,703
	C	BC	AB	A	C	BC	AB	A				A	B	AB
Fan Jet Irrigation	2,872	3,581	3,810	3,776	3,030	3,410	3,993	3,898	3,873	3,810	3,751	3,810	3,605	3,359
	B	A	A	A	B	AB	A	A						

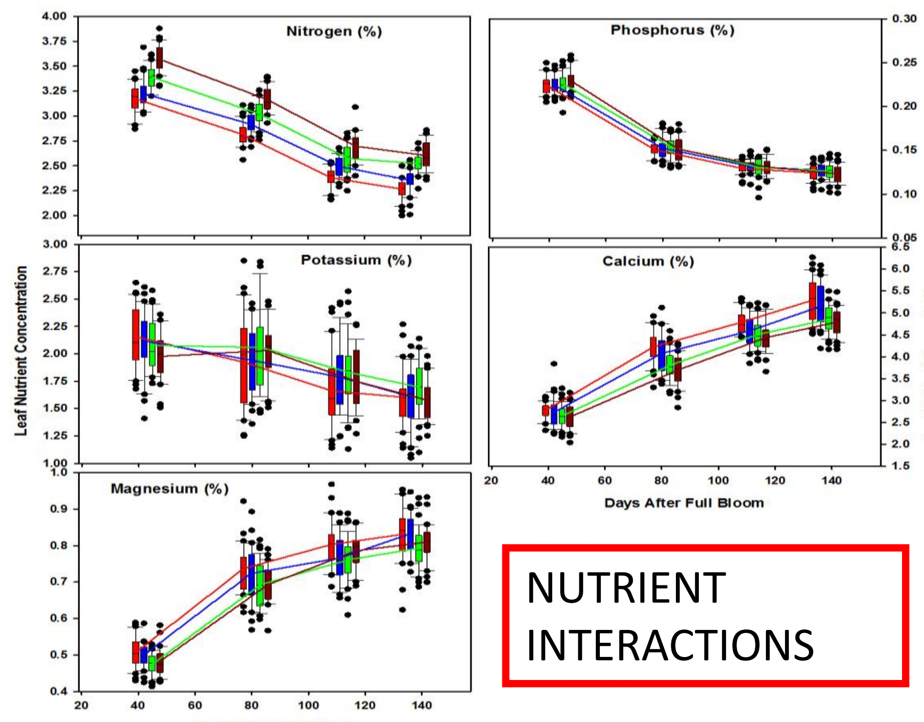
Time:Rate



Rate-Location

Nitrogen &Potassium Demand

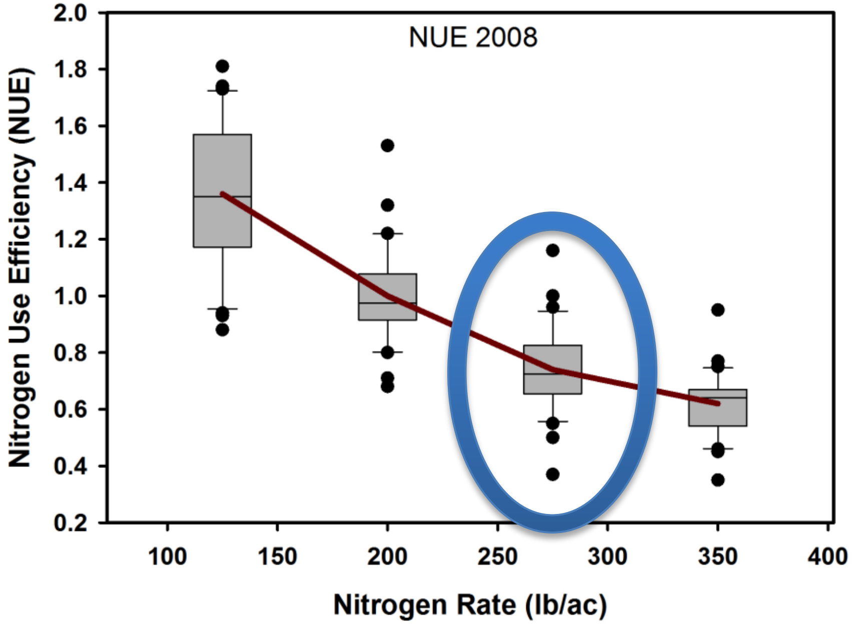




NUTRIENT INTERACTIONS

NUE in Almond

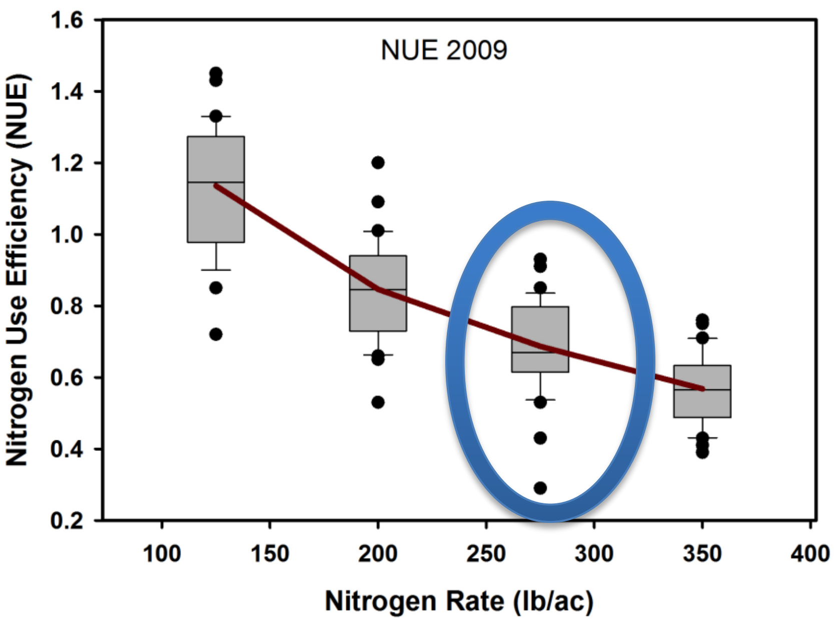
(N removed in crop/N applied)

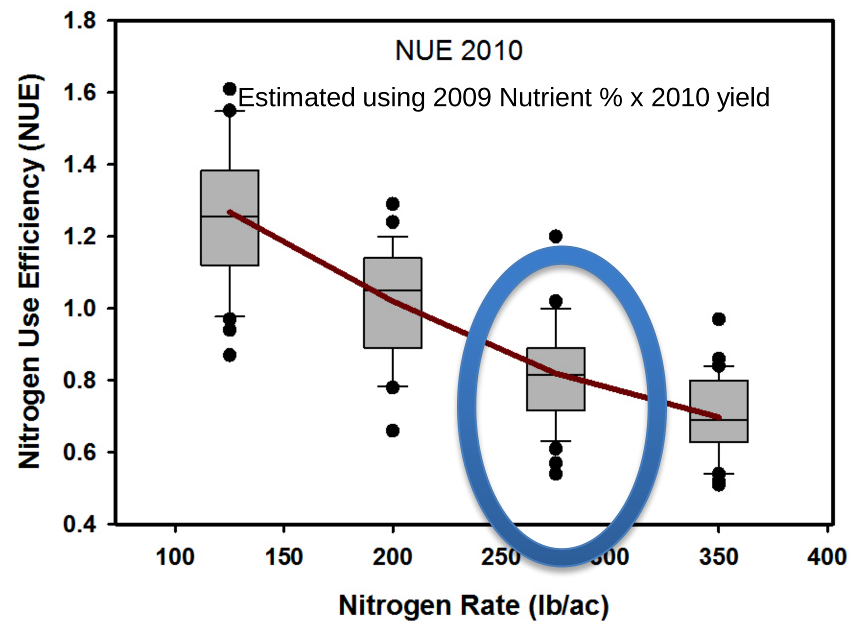


NUE at 275 lbs application:

2008 = 75%
2009 = 68%
2010* = 80%

N Removal = 50-60 lbs N /1000 lb kernel





Almond

NITROGEN USE EFFICIENCY

An NUE of 65-75% is among the highest ever measured in agriculture – is that good enough?

70% efficiency = 50 lbs N/acre/yr (x 500,000+ acres)

= 25,000,000 lbs N/yr (current best case scenario)

- However small changes make a big impact.
  - A 25 lb reduction in N application or 15% increase in efficiency HALVES this N loss

THESE RESULTS ARE UNDER THE BEST AVAILABLE PRACTICE – MOST OF THE INDUSTRY IS NOT AT THIS LEVEL OF NUE

Challenges:

Define yield potential

Improve Monitoring

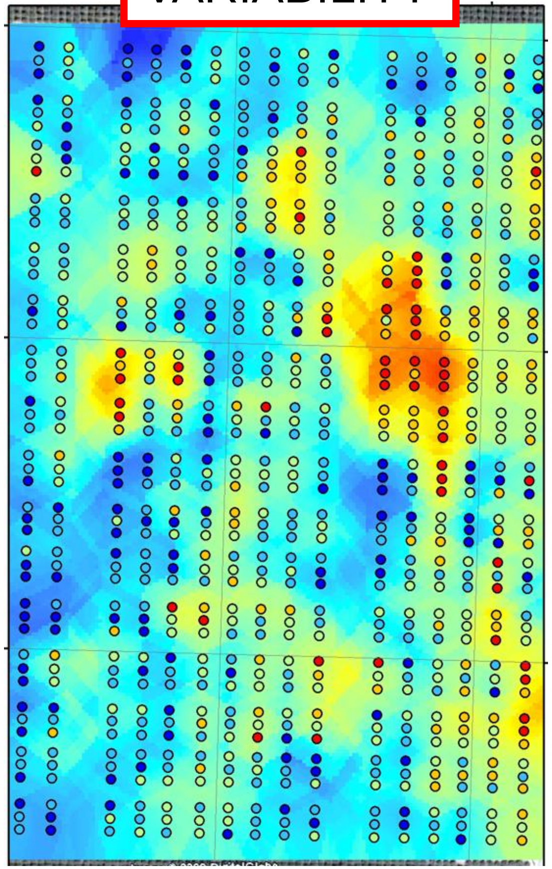
Define loss fate and movement of solutes and gases.

Define root growth, root uptake.

Optimize application (Right place, Right time)

Optimize and Integrate with Water management.

VARIABILITY



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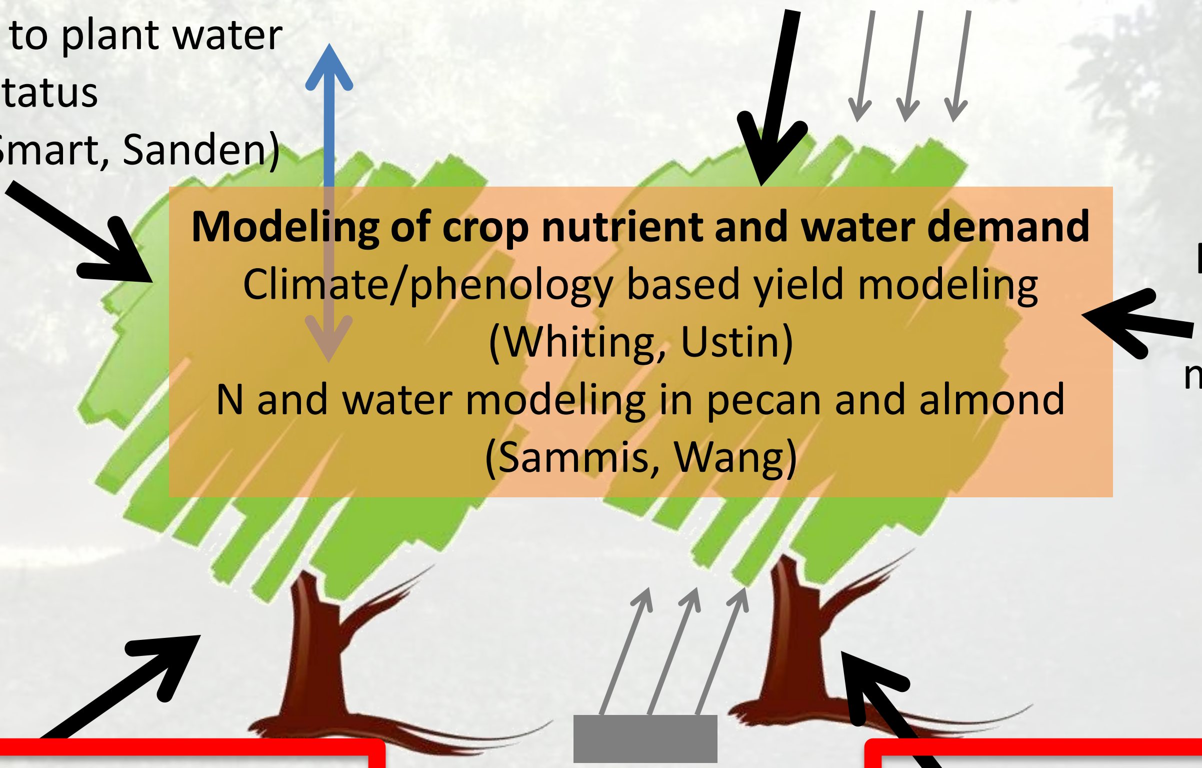


Re-evaluate leaf and orchard sampling methods and "Critical Value" concept
(Brown, Lampinen)

Model solute transport
(Hopmans, Brown, Kandelous, Olivos)

Determine root dynamics
(Brown, Hopmans, Olivos, Kandelous)

Managing Placement and Timing in Fertigated Crops:

- Where in the soil profile should growers put their fertilizers?
- How does nutrient concentration influence nutrient uptake ?
- How often should growers fertigate their orchards?
- How plant demand influences nutrient uptake?

Specific Objectives

- Determination of almond root growth and distribution .
- Determination of nutrient uptake dynamics (K_m, V_{max}, $C_{min/max}$) and the relationship to soil nutrient concentration, tree demand and time.
- Characterize water and solute (Nitrogen) movement within the soil profile.

Project Description

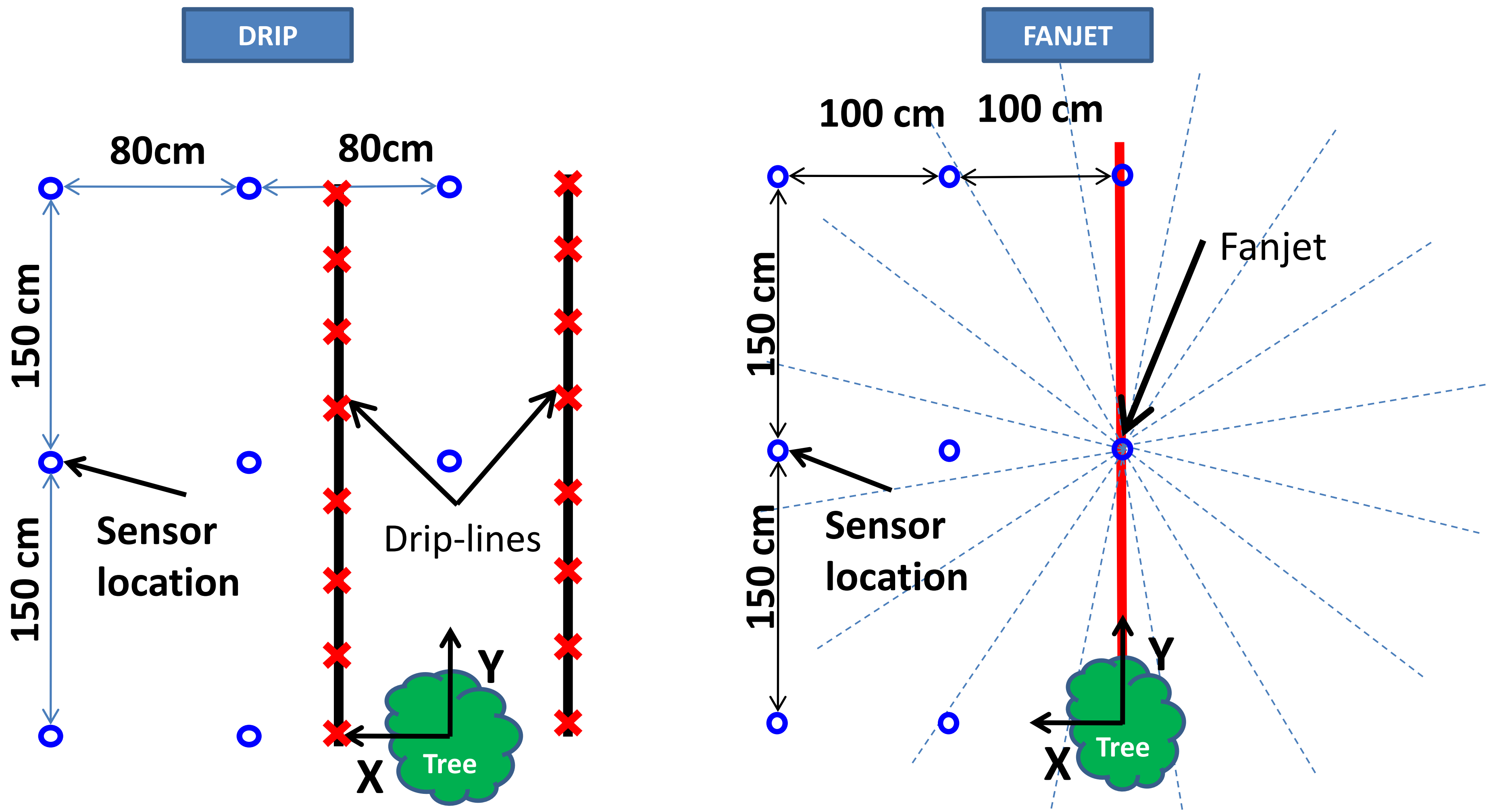
- Paramount Belridge Almond Orchard Project
- For Water and solute transport:
  - Two trees (Drip and Fanjet systems) heavily instrumented with 32 decagon 5Te (conductivity), 4 MPS (matric potential:
- Six trees lightly instrumented (4 Decagon 5Te) to determine variability and cross reference validation
- 48 trees with neutron probe installations (4 per tree in 4 trees).
- 24 soil solution sampling sites.

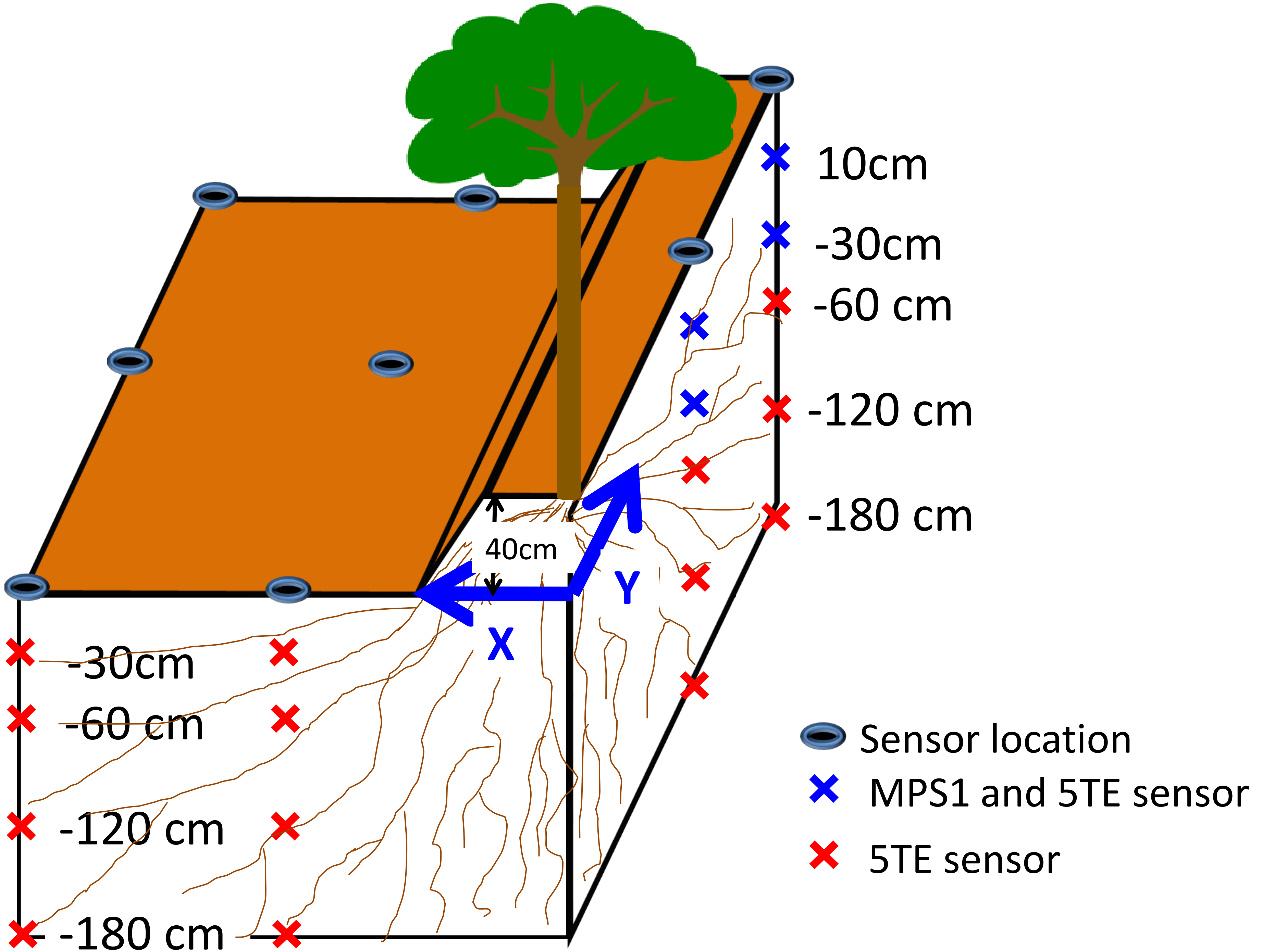
Sensor installation

32 sensor at the 30 and 60 cm depths were installed manually, the other 32 sensors at the 120 and 180 cm depths were installed by a newly designed installation device.

Sensor Installation

(X,Y) notation represents Cartesian coordinate system, with both X and Y, representing distances (cm) for the tree trunk. For example (0 150) denotes the location of a sensor which is 150 cm away from the tree along the Y direction. Figure 2 shows the sensor installation for both Drip and Fanjet irrigation system.

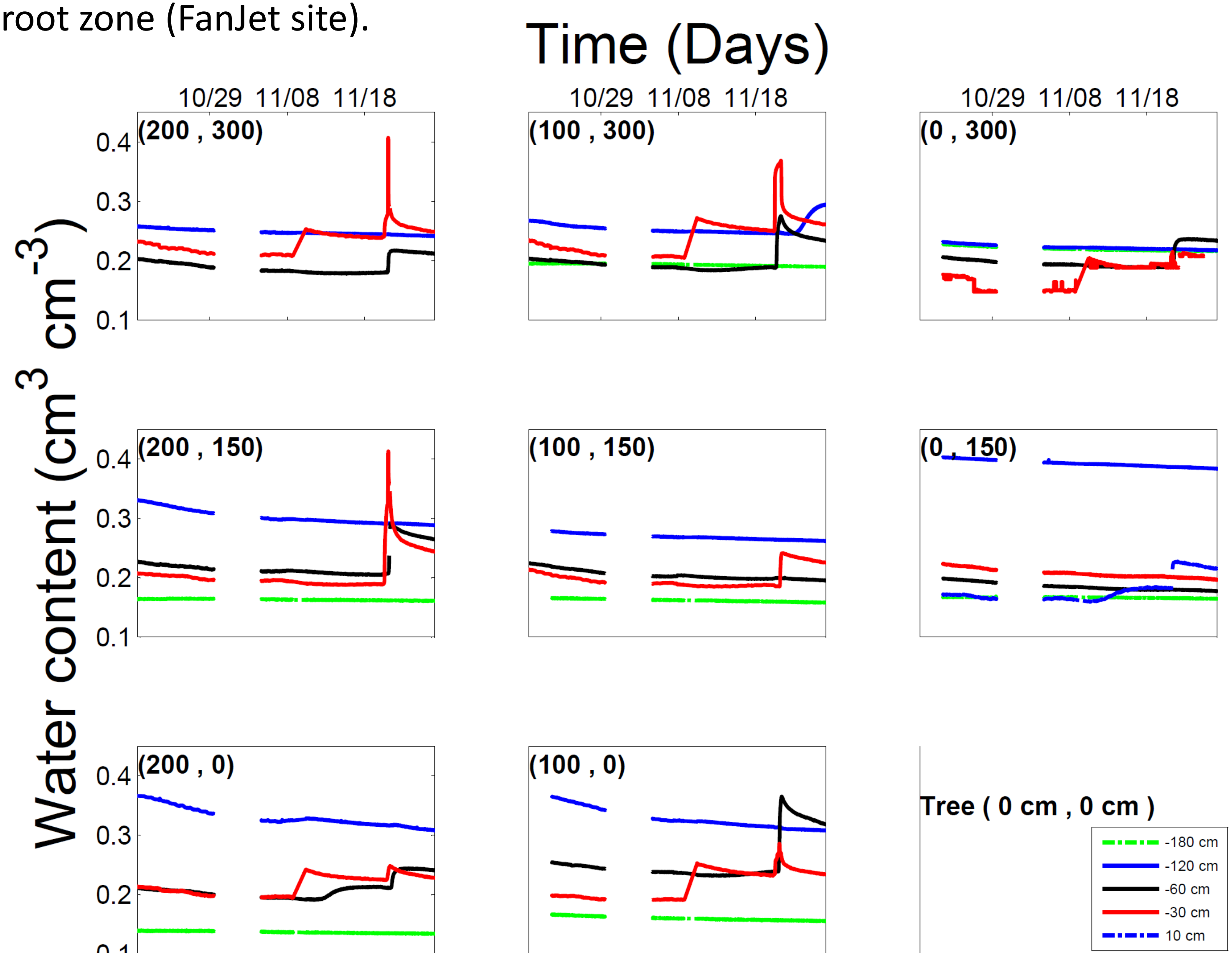




10cm
-30cm
-60 cm
-120 cm
-180 cm
40cm
Y
X
-30cm
-60 cm
-120 cm
-180 cm
Sensor location
MPS1 and 5TE sensor
5TE sensor

Spatial and temporal soil moisture distribution

Figure below shows the temporal and spatial variation of soil water content in the almond root zone (FanJet site).



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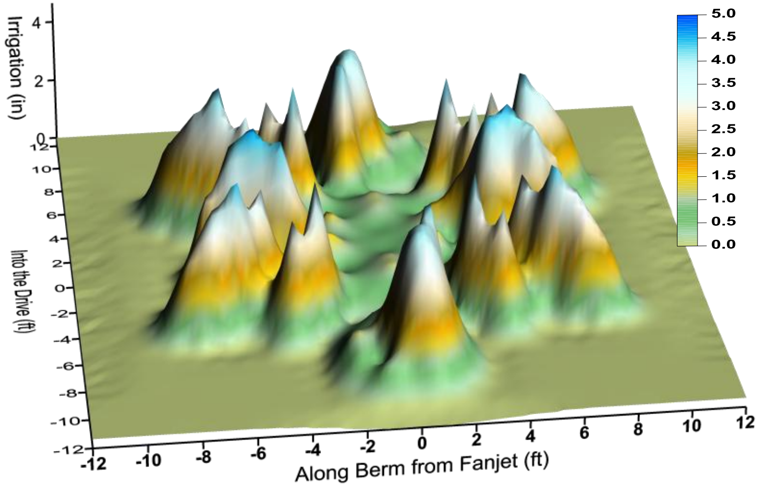
Irrigation evaluation, application patterns



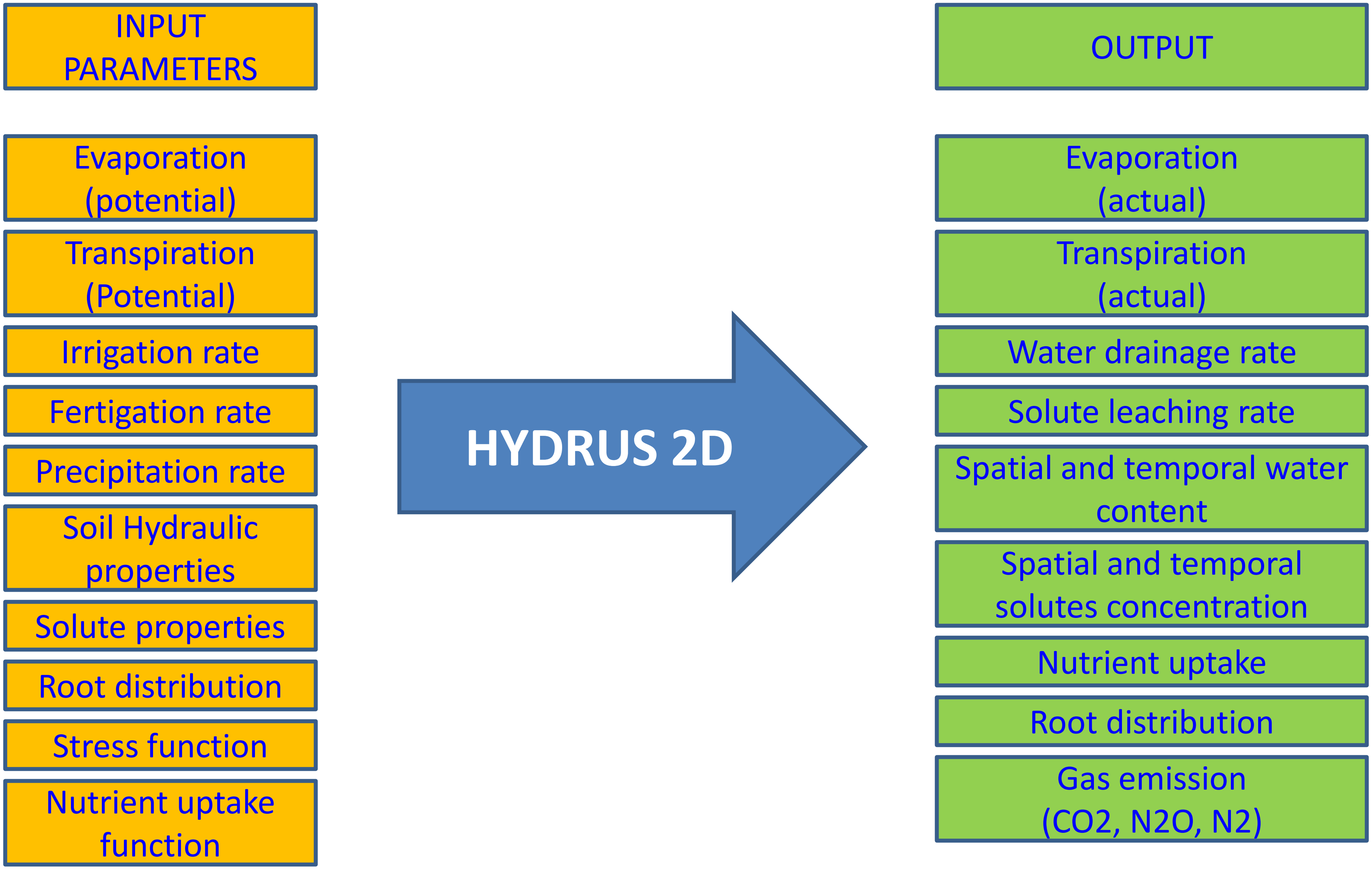
Data transfer

All sensors were connected to a data logger and radio, by which data were wirelessly transmitted to PureSense web site.

Determination of almond root phenology and characterization of root distribution

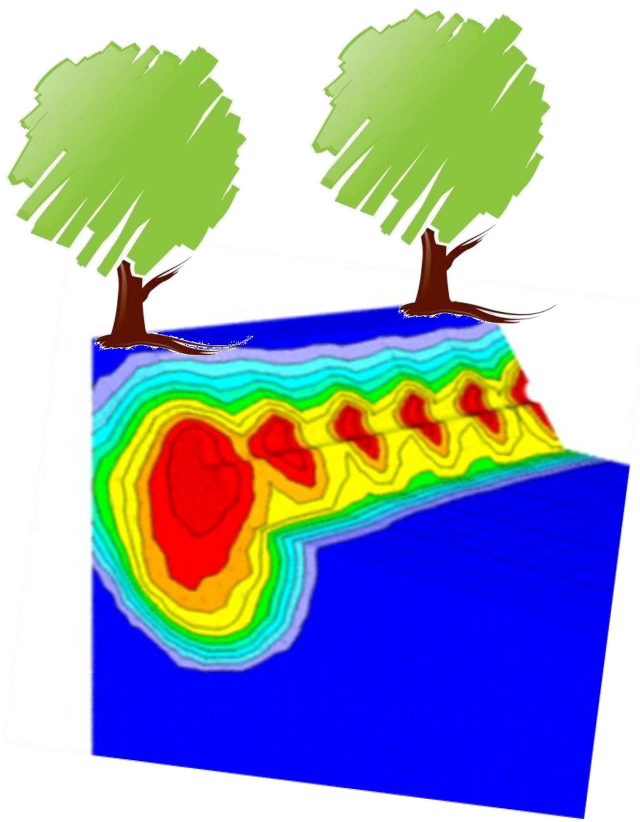
- Main Objective: Determine the spatiotemporal distribution of root in the field and in greenhouse conditions.
- Methodology:
  - Minirhizotron observation: Determination of root phenology and active root lifespan.
  - Soil Core sampling: Determination of spatiotemporal root distribution.
  - In growth core sampling: Isolation of roots to determine root nutrient uptake physiological parameters.
  - Greenhouse Setting to determine root nutrient uptake physiological parameters in controlled conditions in young trees.

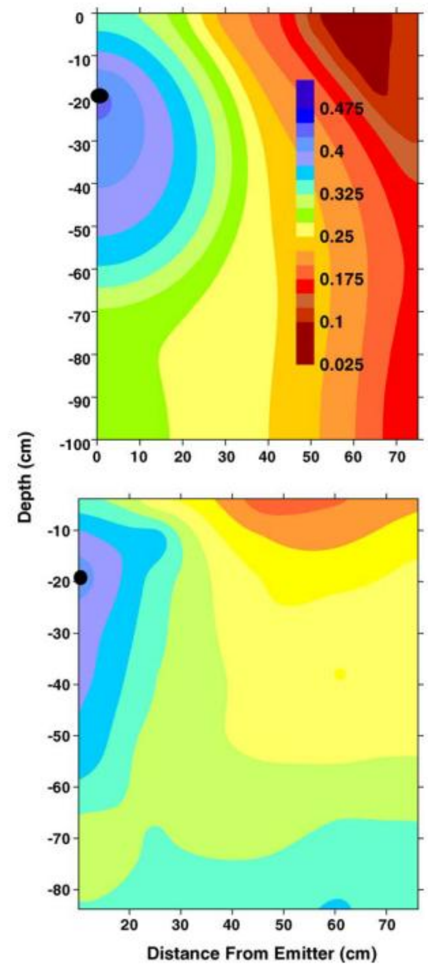
Modeling Water/Solute Transport and Uptake: The Role of Hydrus



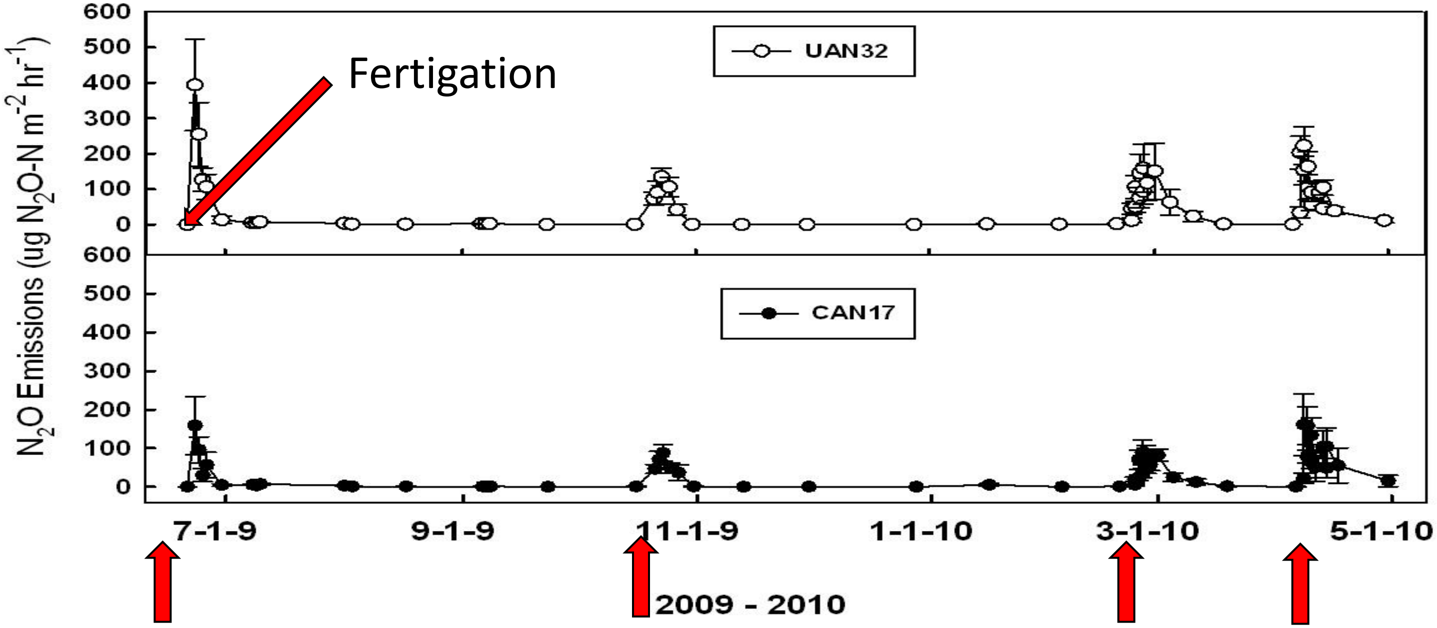
Hydrus Output and Simulation Results

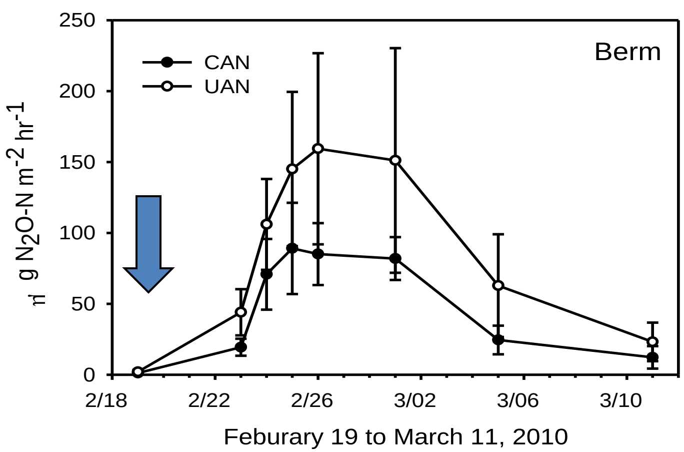
Water and Nitrate Distribution after fertigation event

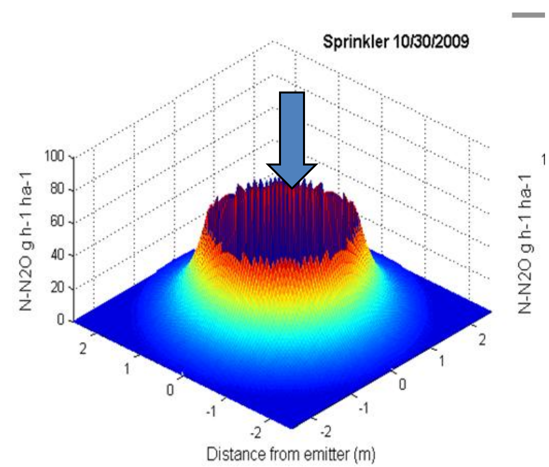




Spatial and Temporal Variability in Nitrous Oxide Release (<0.5 % emission)

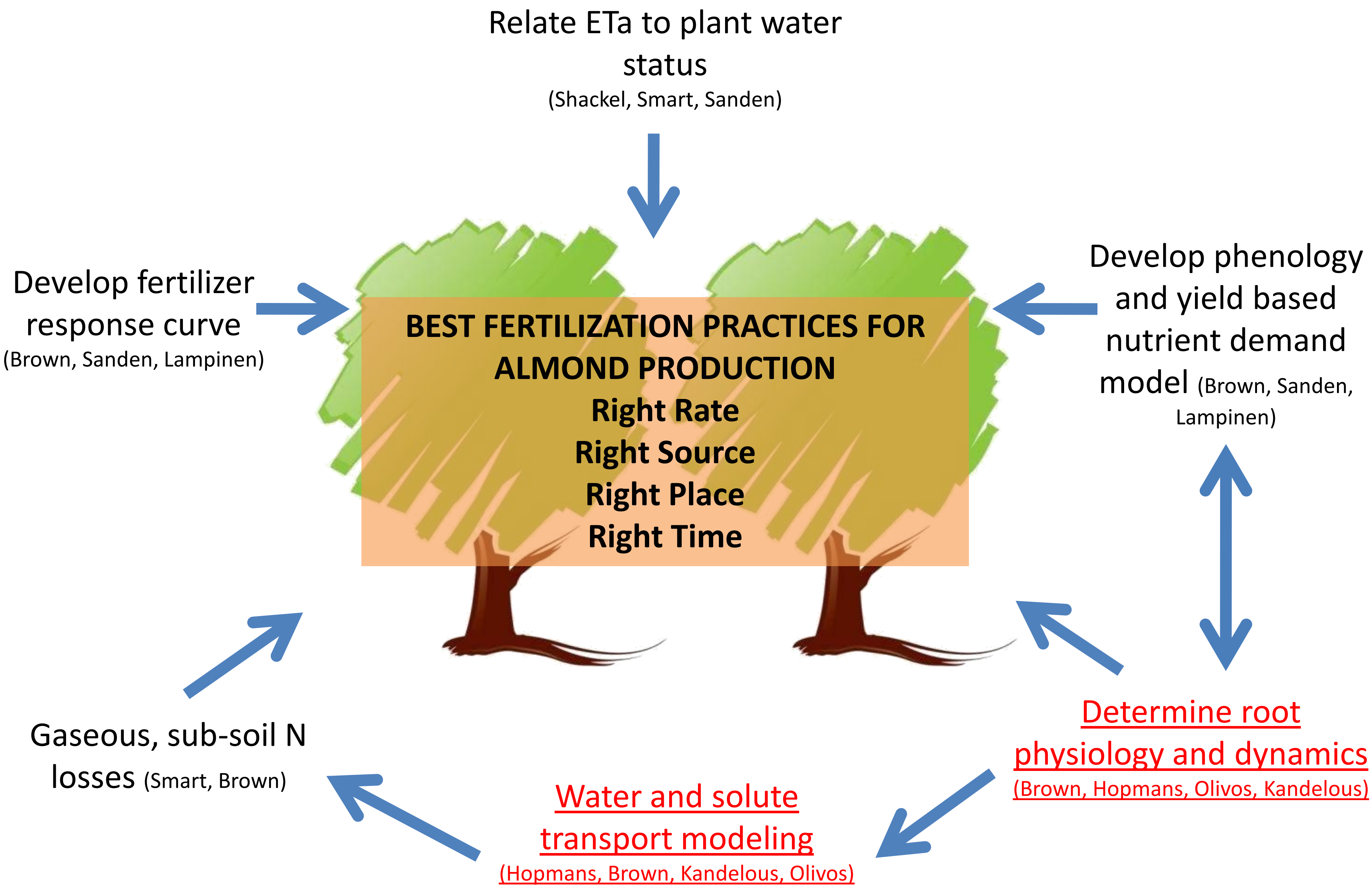






(Smart: UCD)

Project Synergisms



Acknowledgements

Financial support:

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Paramount Farming and numerous growers.

SCRI Co-PI's

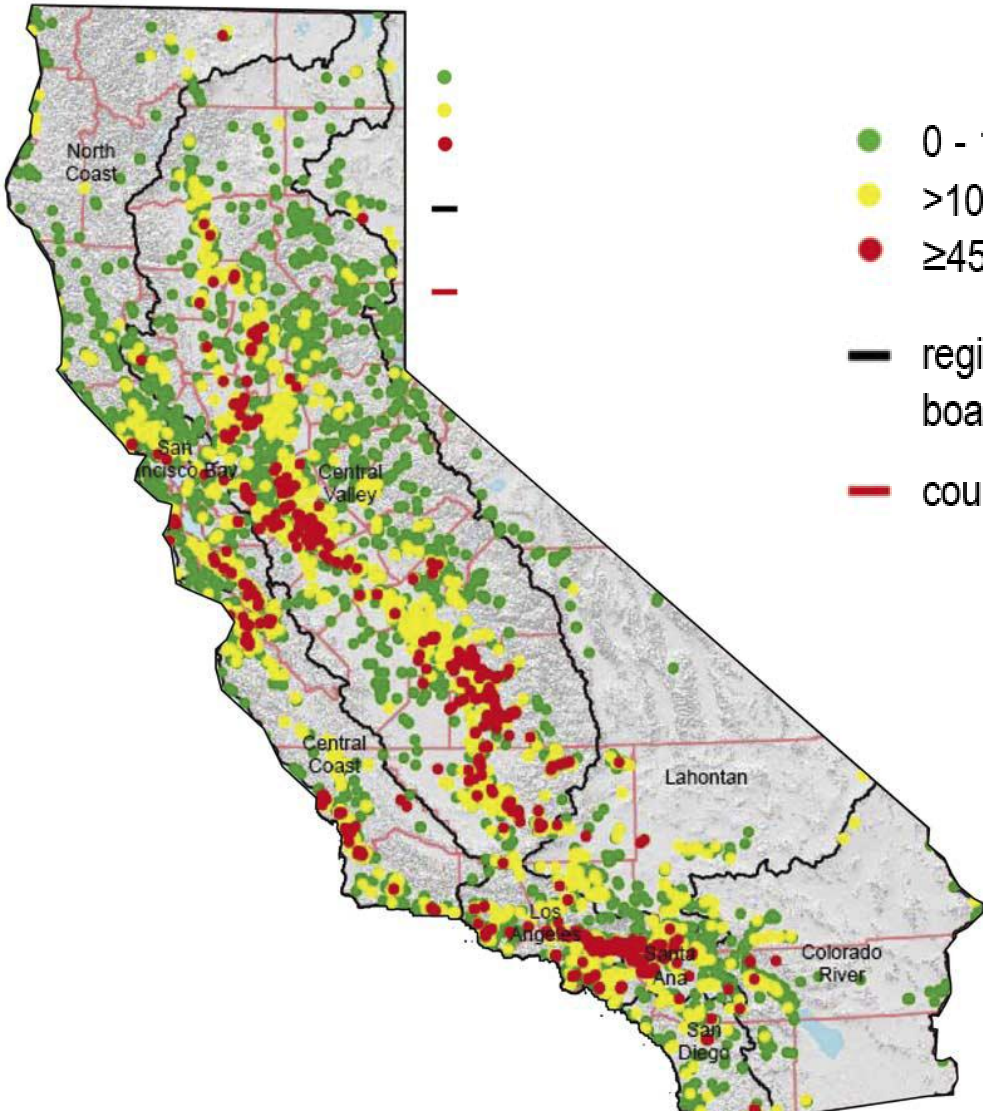
Ken Shackel, Ted Sammis, Bruce Lampinen, Leonardo Lombardini, John Mexal, Blake Sanden, Manoj Shukla, David Slaughter, David Smart, Rolston St. Hilaire, Shrini Upadhyaya, Jan Hopmans, Susan Ustin, Michael Whiting

Students, Faculty, Staff:

Eike Luedeling, Sebastian Saa, Jeremy Nunes, Ismail Siddiqui, Saiful Muhammad, Todd Rosenstock, Maria Paz Santibanez, Andres Olivos, Blake Sanden, Mike Whiting, Roger Duncan, Bruce Lampinen, Roger Duncan, Brent Holtz, John Edstrom and others…

Thanks

 (Thomas Harter)

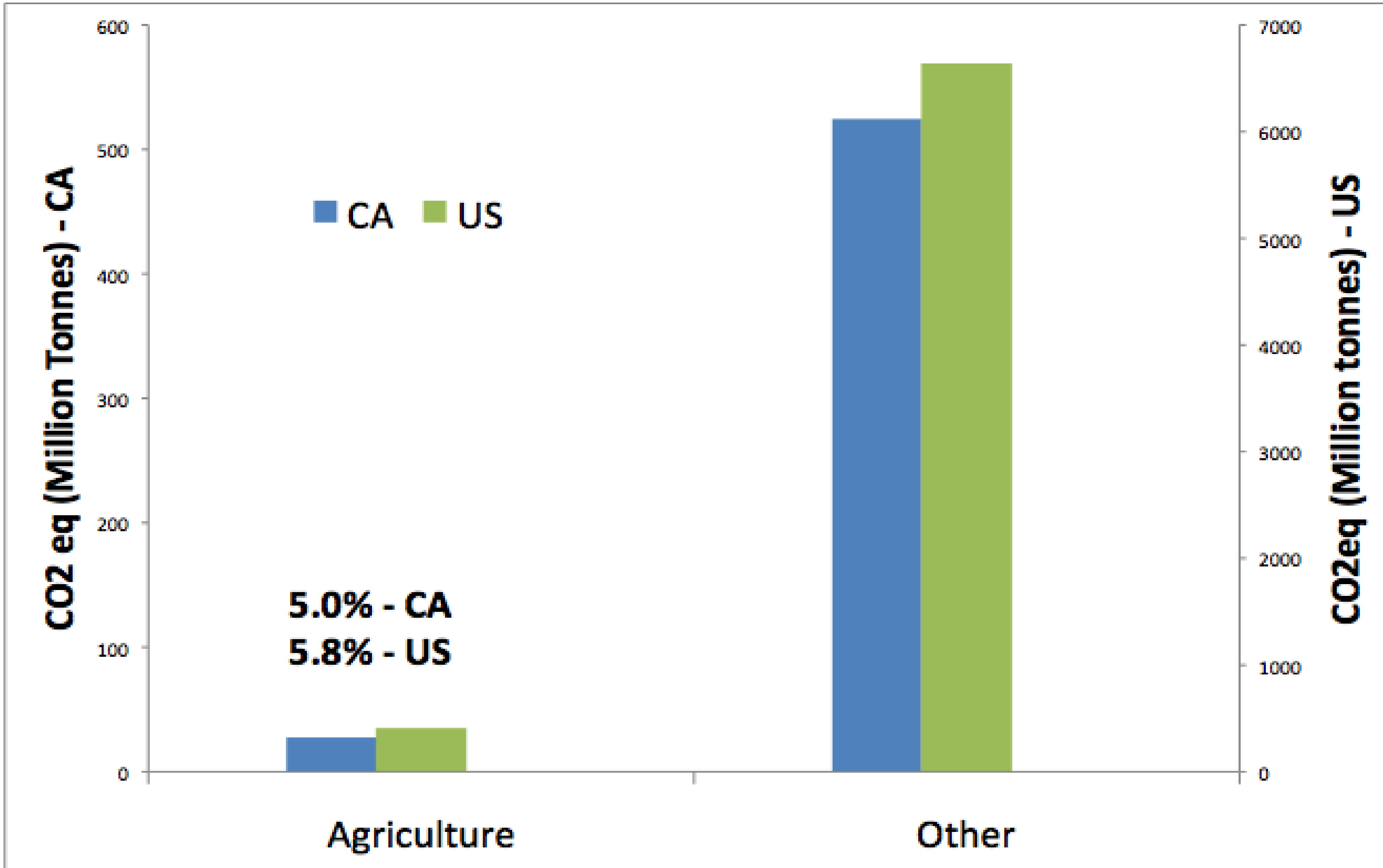


Large percentage of municipal wells in Californian exceed health standards for nitrate.

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.

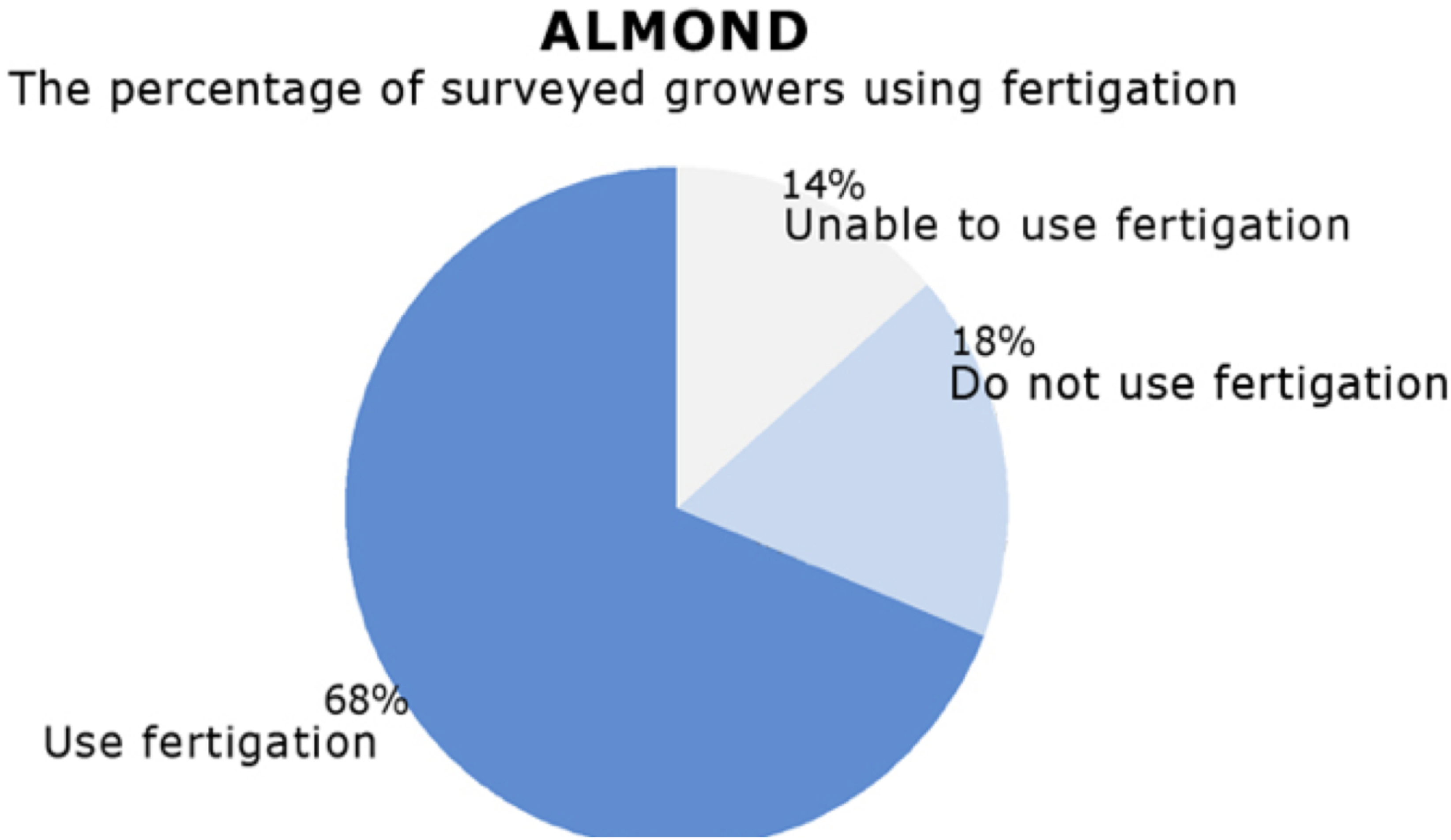
Contribution of Agriculture to GHG

Agriculture is a small but important source of greenhouse gases



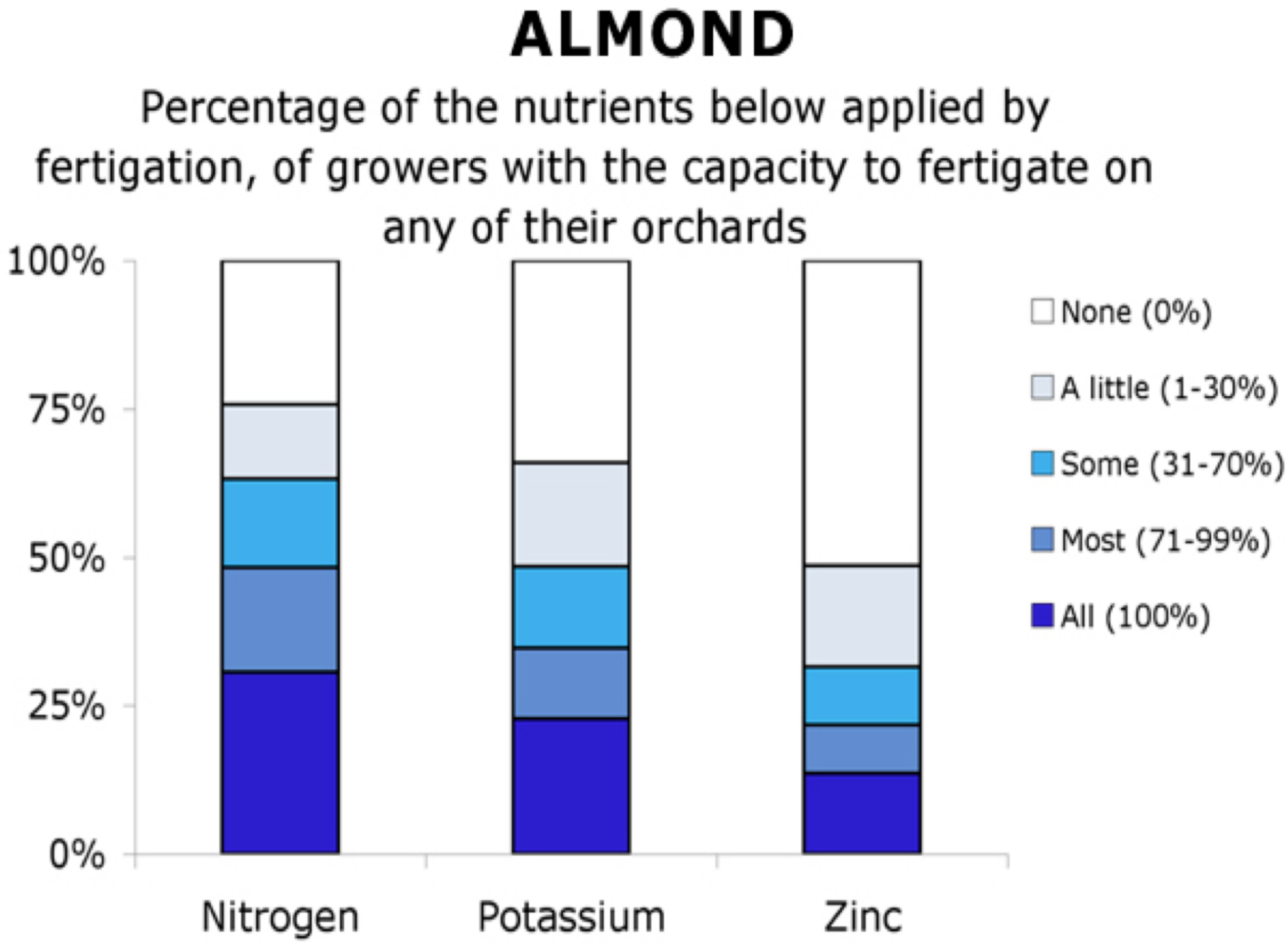
Growing Intensification:

70% utilize fertigation an additional 14% could and the remainder are transitioning



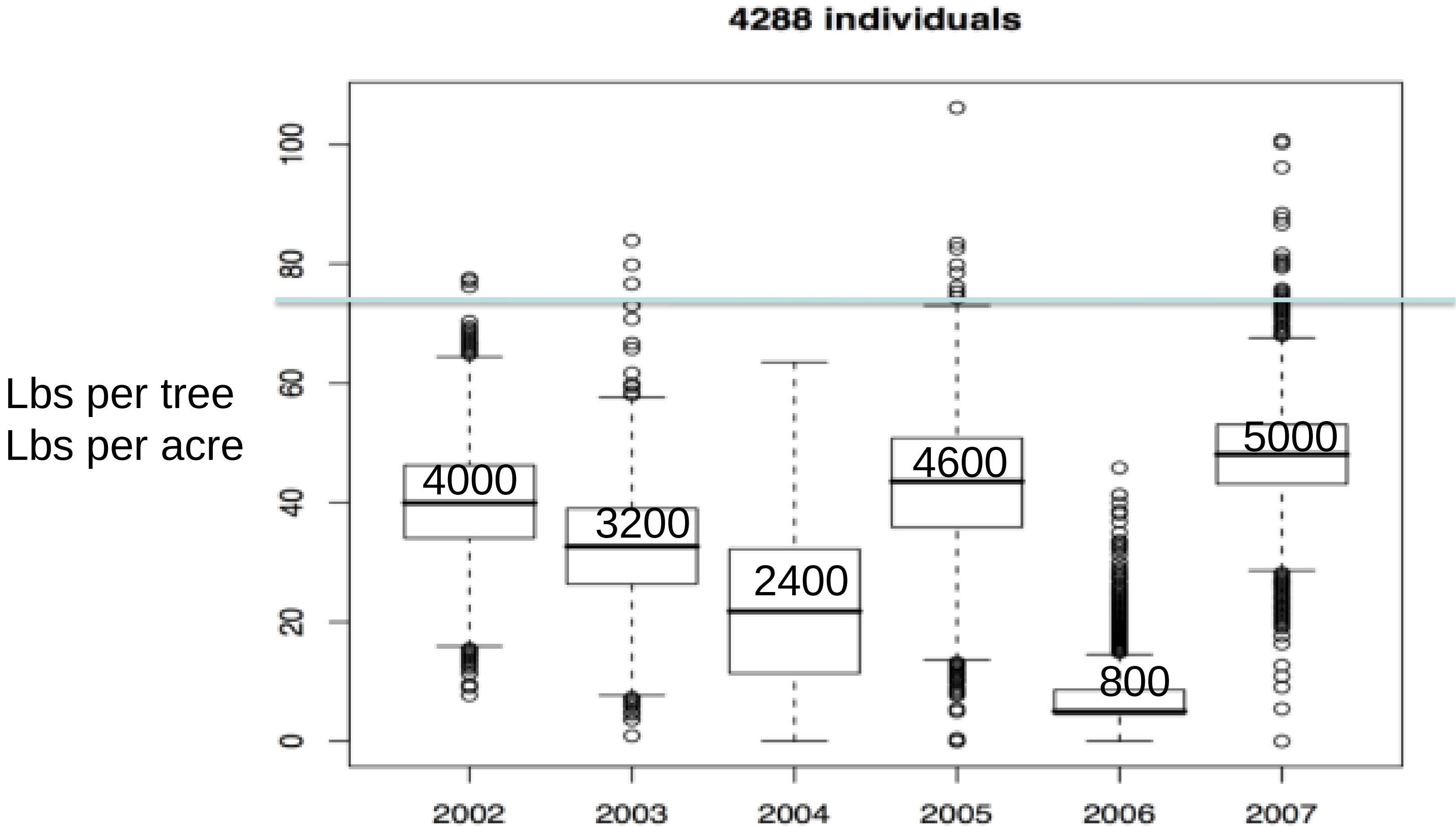
Growing Intensification:

70% utilize fertigation and 55% provided all/most N and K



UAN32:60%, CAN17:25%: K Sources: SOP (band) 60%, KTS (fertig) 25%, KCl

Between Year Variability: Pistachio



Precision Nitrogen Management
-the 4 R's-

- Applying the Right Rate
  - Determine demand and variability.
  - Account for all inputs (water, soil, plant).
- At Right Time
  - Determine when uptake from the soil occur.
- In the Right Place
  - Ensure delivery to the active roots.
  - Managing variability across the orchard.
- Using the Right Source and Balance
  - Balanced fertility