Precision nutrient management in California orchards

Orchard variability and its implications for fertility management.

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Premises on which adoption of Site-Specific Management is Based.

Relevance to Tree Crops, Contrast to Field Crops.

- Significant within-field and between year variability exists.
  - Greater overall variability in trees than in field crops.
  - Greater, but more complex, dependency between years
- The causes of this variability can be identified, monitored and predicted and crop management practices can be adjusted accordingly.
  - Gross soil and topographical determinants can be addressed (deep tillage, leveling, drainage, amendments)
  - More management options in trees than in field crops (fertigation, foliar fertilization etc)
- The improvement in economic output or sustainability justifies the increased investment and ongoing management cost.
  - High value and long lived species provides greater time to recover investment in technology (fertigation systems etc).
  - Fertigation investment (>70%) allows 'management' of topography, soil characteristics, irrigation, nutrition and other yield determinants.

Constraints/Advantages to the Adoption of Precision in Management in Californian Orchards

- Irrigation
  - Engineered for uniformity of application
  - Irrigated to meet the demand of the most water demanding portion of the field.

- Fertilization
  - Generally uniform ‘whole field’ management . (esp. N, K)
  - Rates are based on crude and generic recomendations
  - Nutrient testing is inadequate and insensitive.
  - Fertilized to avoid deficiency in the most demanding portion of the field

As fields get larger and fertigation becomes more common, site specific management becomes harder.

Precision Nitrogen Management
-the 4 R's-

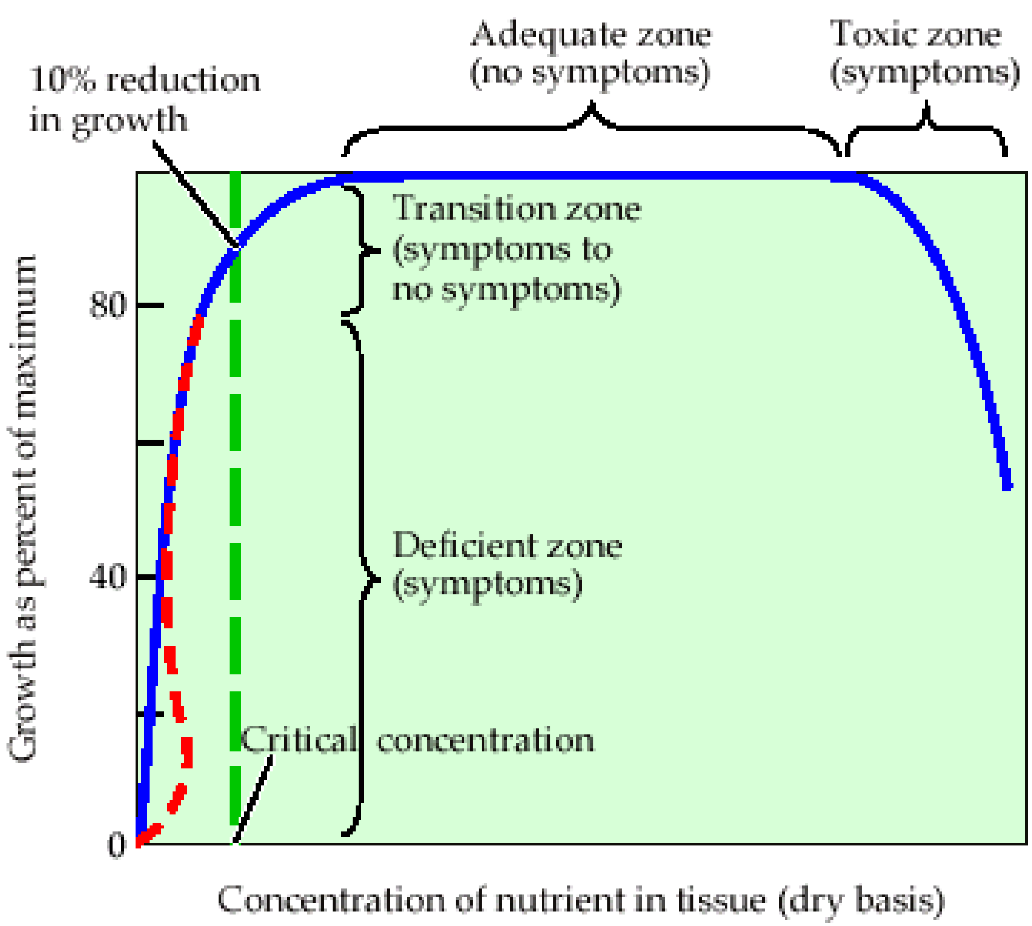
- Applying the Right Rate
  - Determine demand and variability.
  - Account for all inputs (water, soil, plant).
- At Right Time
  - Determine when uptake from the soil occur.
- In the Right Place
  - Ensure delivery to the active roots.
  - Managing variability across the orchard.
- Using the Right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

What do we know and how do we manage?

Leaf Sampling and Critical Value Analysis in Orchard crops

(based on Ulrich @ U Calif in 1950-70's)

Tab
leav
Nitro
Phos
Pota
Calc
Mag
Sodi
Chlo
Bor
Cop
Mar
Zinc

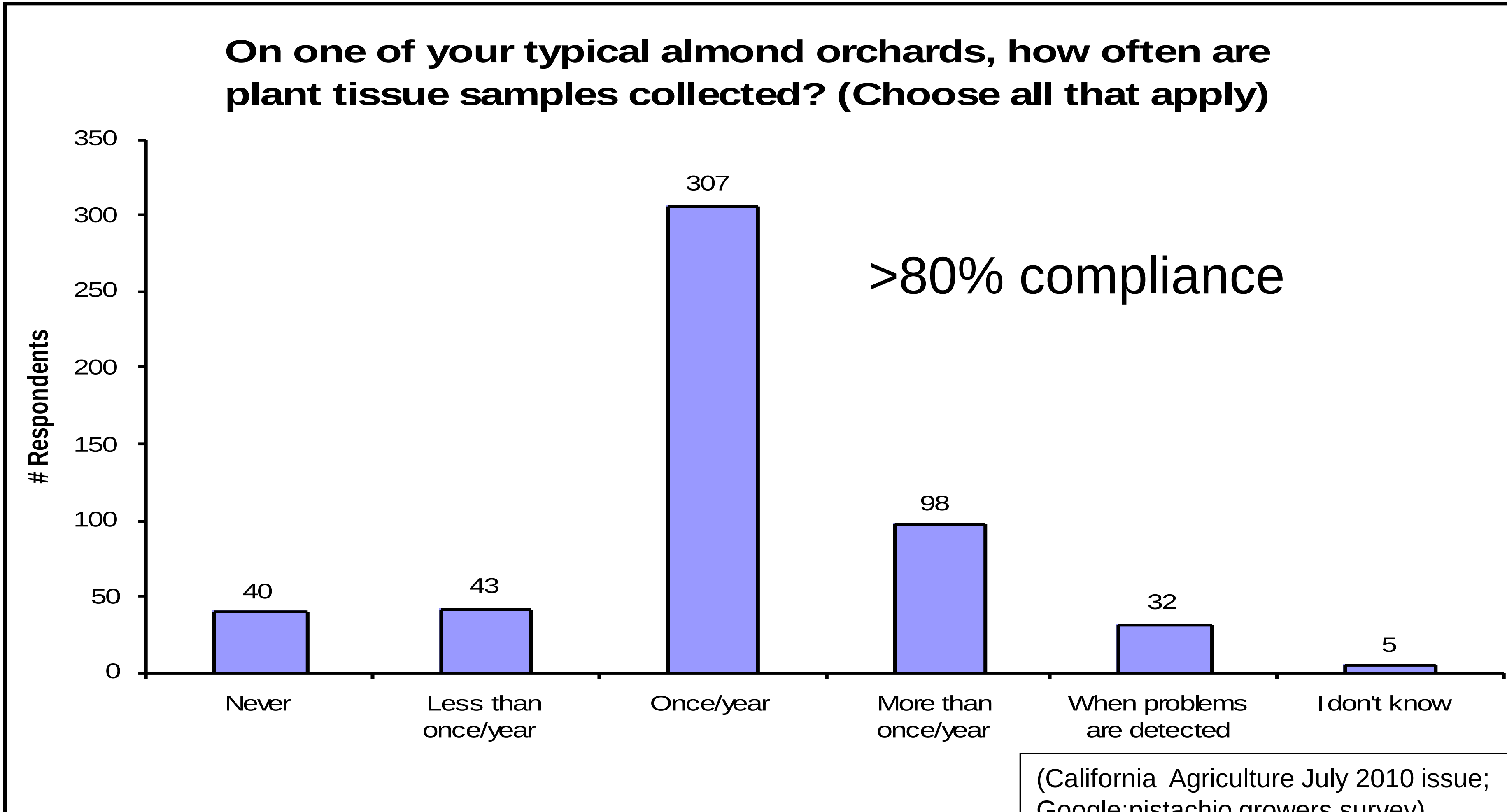


*Cri...
>300 ppm is excessive. Leaf sampling is not effective to determine excess boron.

- Sampling protocols are well defined
- ...r leaves
- ...adrant at 6'.
- ...alysis with standard Critical ... in Almond Production Manual
- ...s (N, K, B)
- ...ptoms (P, S, Mg, Ca, Mn, Zn, Fe,
- (Ni, Cl, Mo)
- ...sults (NO R'S!)
- ...sults do not tell the grower how
- ...enerally based on experience ... fertilizer needs
- ...ovides no information on 'cause' of deficiency or inefficiency.

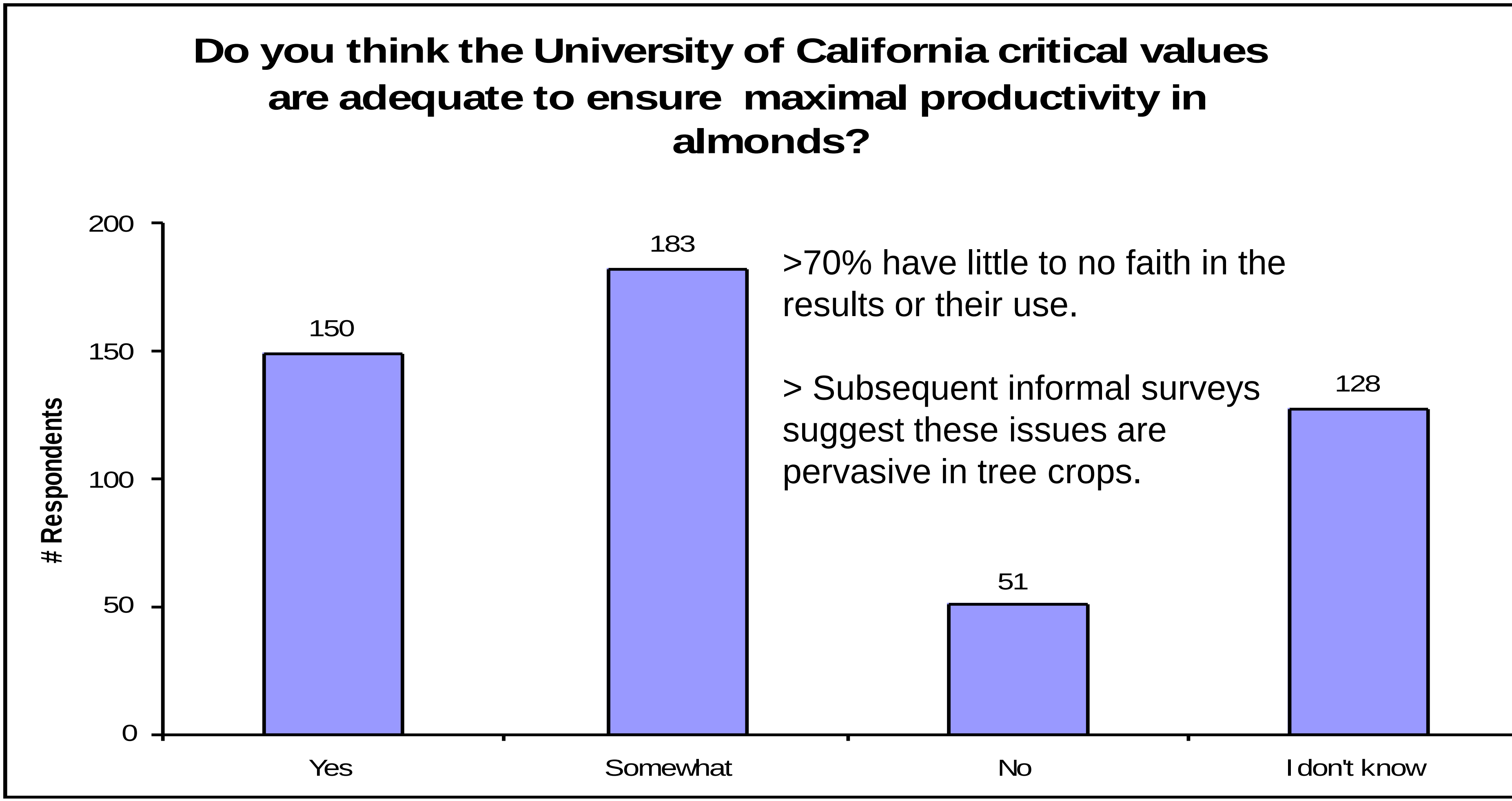
Almond and Pistachio Grower Survey

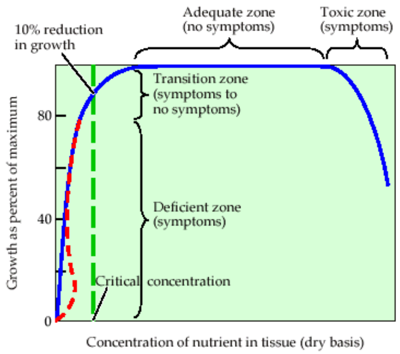
Are tissue samples collected and if so how often?



(California Agriculture July 2010 issue; Google:pistachio growers survey)

Are tissue samples being used to guide fertilizer management?





Apparently tissue sampling is not trusted- Why?

Is the use of Plant Samples and the Critical Value or Critical Range appropriate for Trees/Vines?

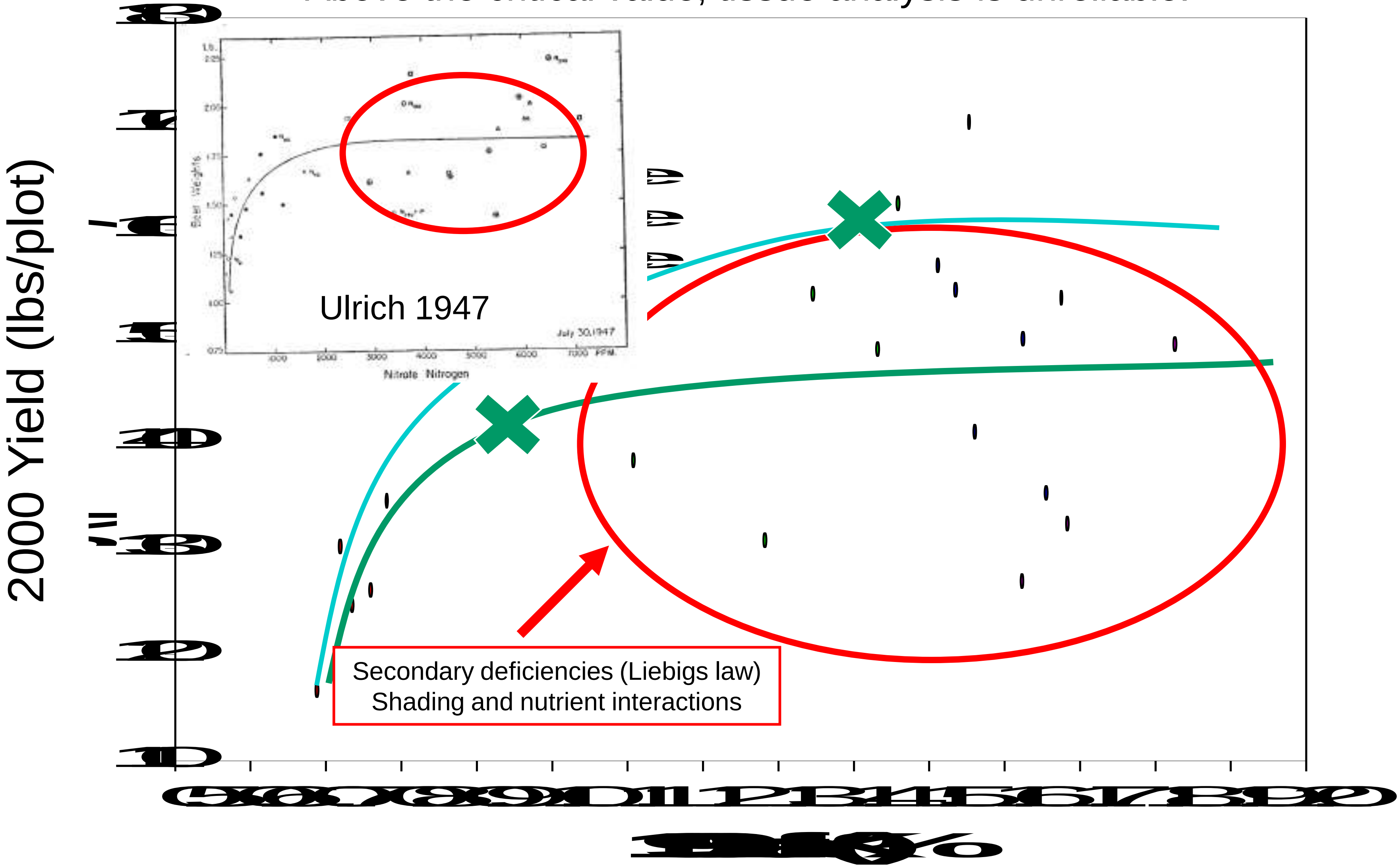
Development of the Critical Value concept

- von Liebig (1840), Pfeiffer et al (1919), Macy (1939),Ulrich (1952).
  - analytical techniques have developed, principles/practices remain unchanged or have been diminished with time.
- originally defined as a means to identify when a crop is '..*just deficient..rather than just sufficient.. to define if, but not how much, fertilizer should be added*..'(Liebig, 1852)
  - thus, soil depletion to sub-optimal levels is a pre-requisite to fertilization
  - however, in high value crops allowing crops to become 'just deficient' is untenable.
- Limited consideration of unique characteristics of tree/vine crops.
  - Goal is to prevent deficiencies ***not*** correct deficiencies
  - Long life and high investment cost requires the practice of sustainable, balanced nutrient management.

Variability in Plant Tissue Response to Nutrient Supply

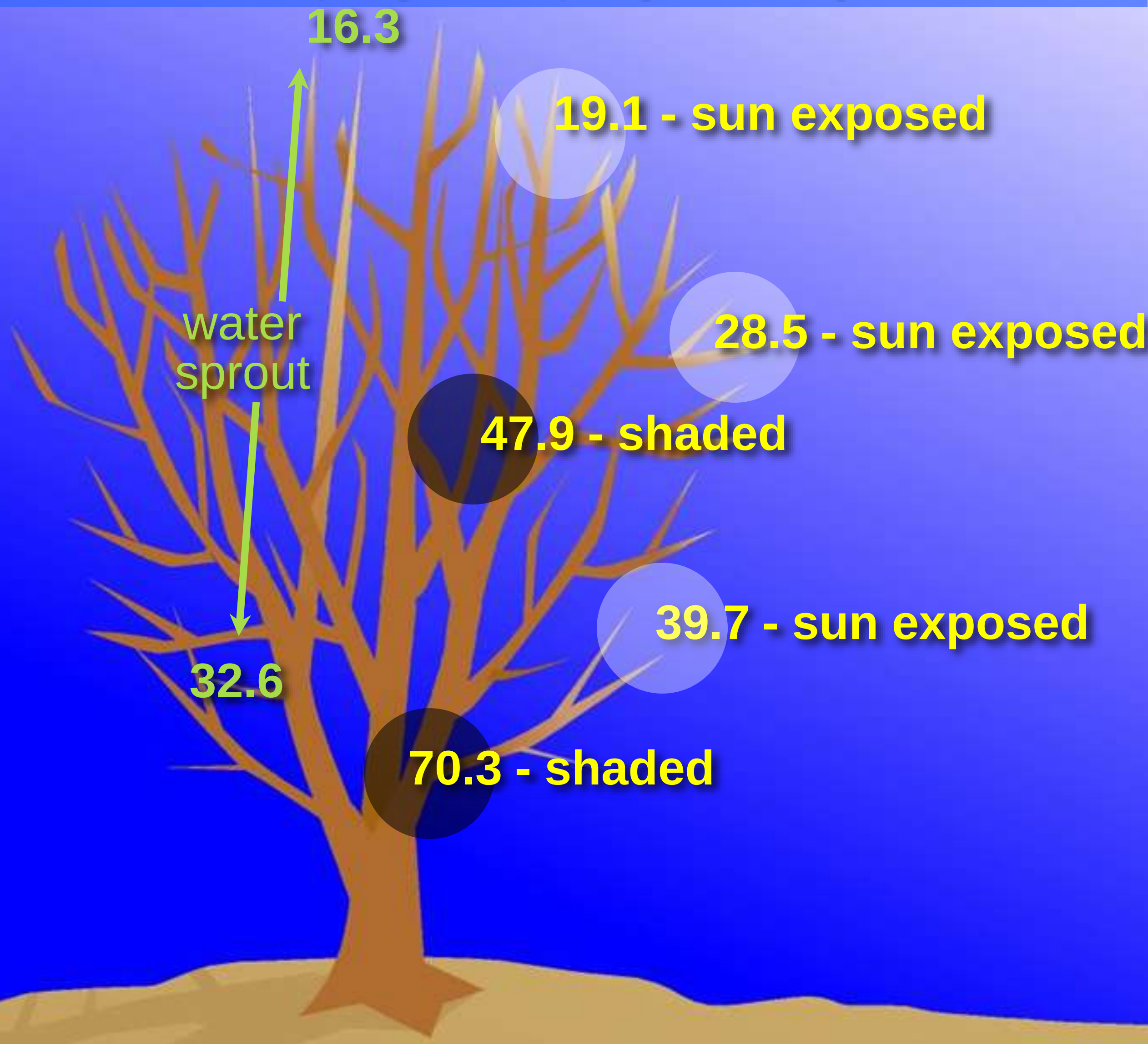
Effect of K on Yield in Almond

Above the critical value, tissue analysis is unreliable.



The relationship between leaf sampling and critical values with yield is complex. In trees the relationship is multi-year and ‘loose’.

Problem with leaf sampling: Sampling challenges.



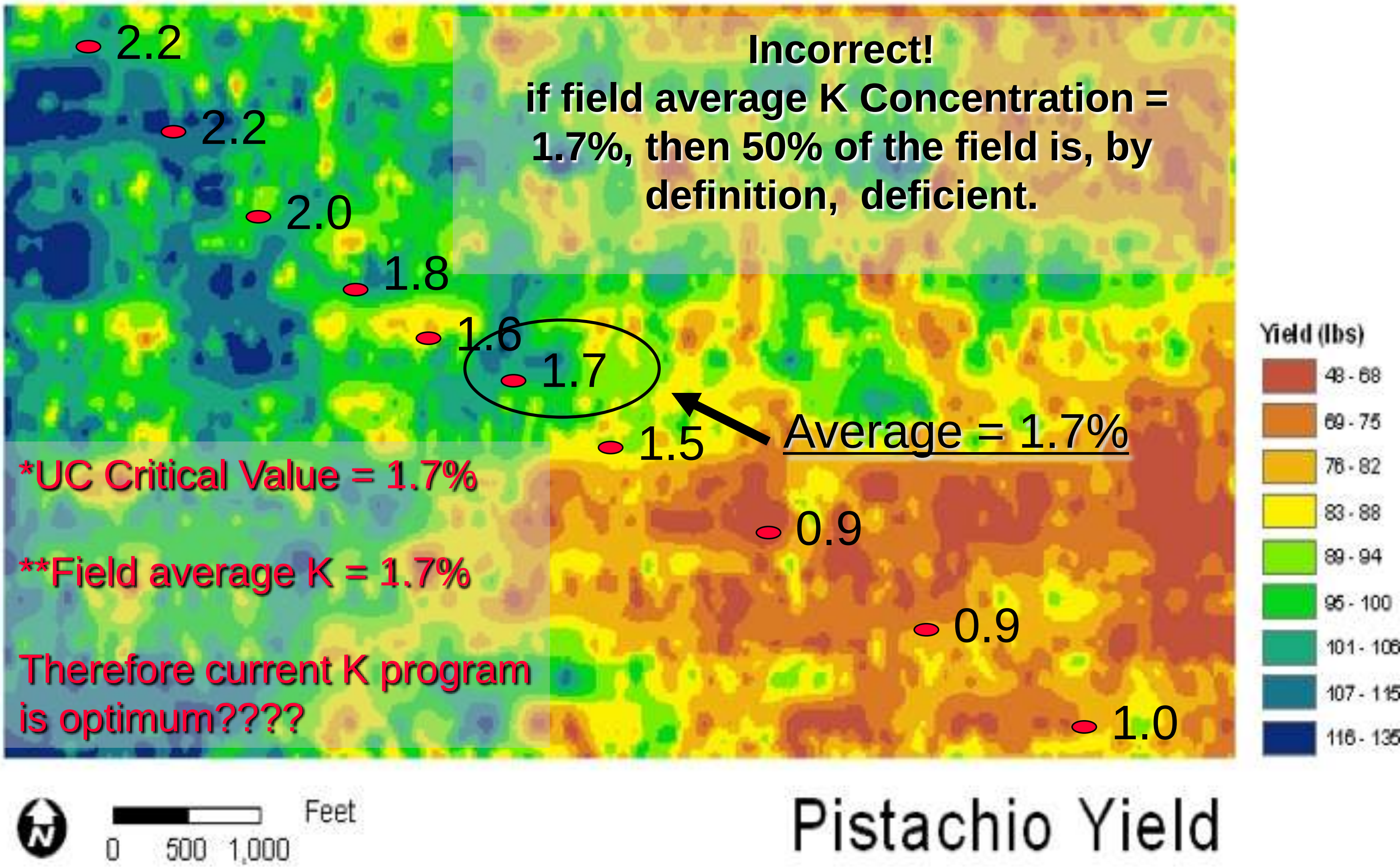
Shoot Zn Distribution Through A Dormant Peach Tree (ppm)

Standard Sample: Fully Exposed non-fruiting leaves in late summer

Courtesy Scott Johnson

Strong Yield Interactions
High Yield depresses Leaf Nutrients
Leaves near fruit are not collected – Valid?

Variability and Incorrect Interpretations

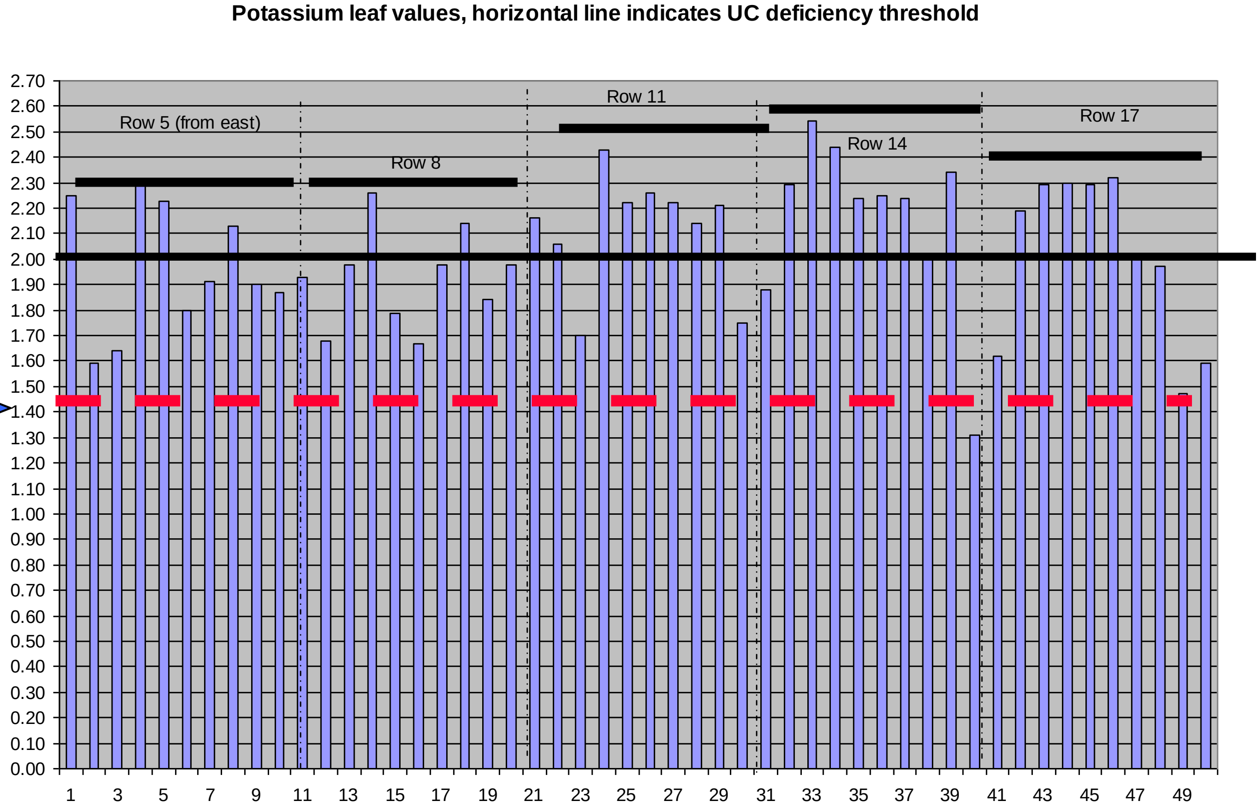


Growers worldwide invariably target higher tissue levels than supported by data. Why?

Leaf samples collected from an excellent grower and critic of UC critical values.

Grower target CV = 2.0% K (95% of trees are above 1.4%K)

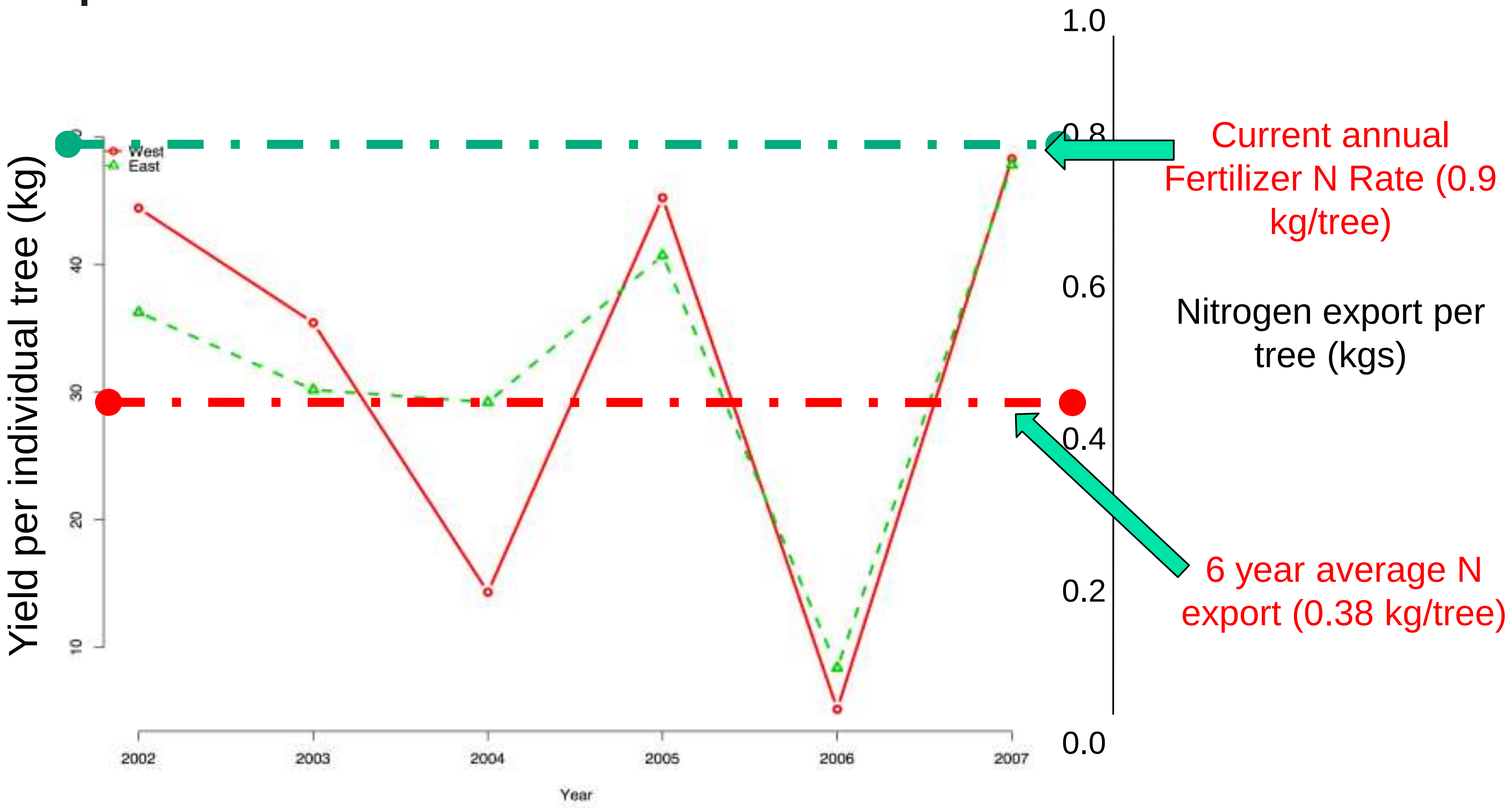
University of California recommended CV = 1.4% K)



Courtesy Franz Neiderholzer

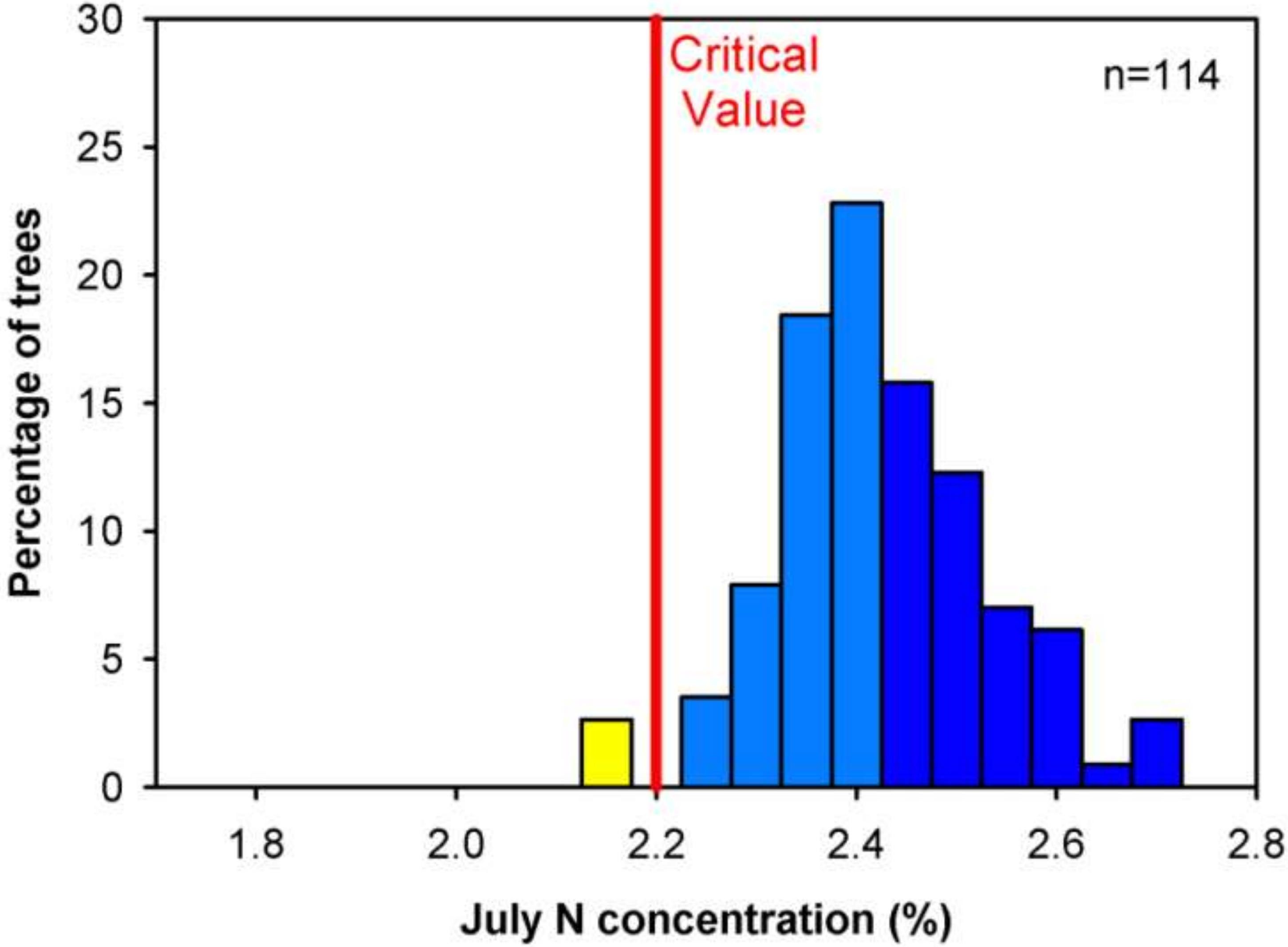
Variation in Yield over Time

Pistachio 4820 trees individually harvested.

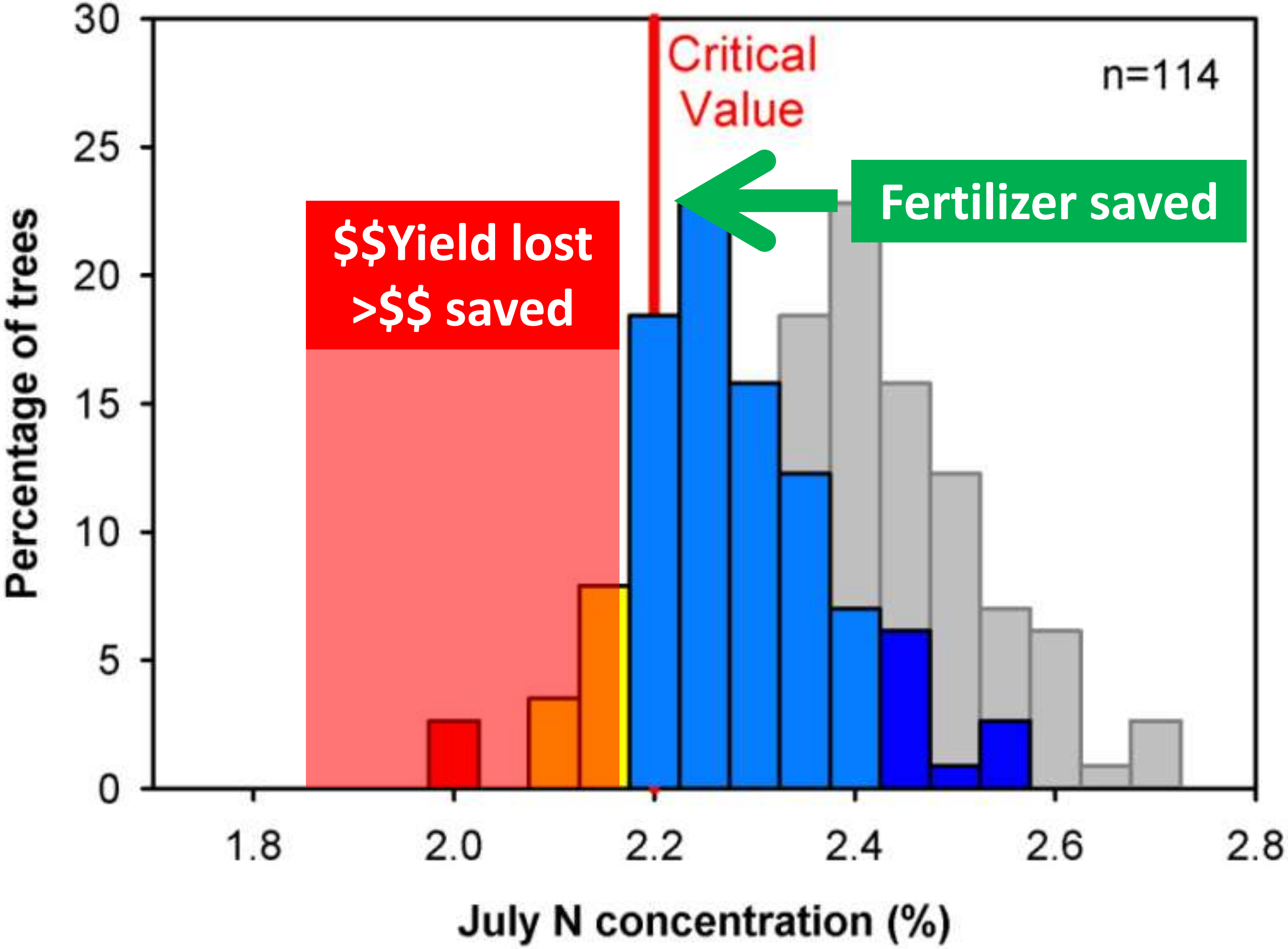


How Widespread is this 'Problem'?

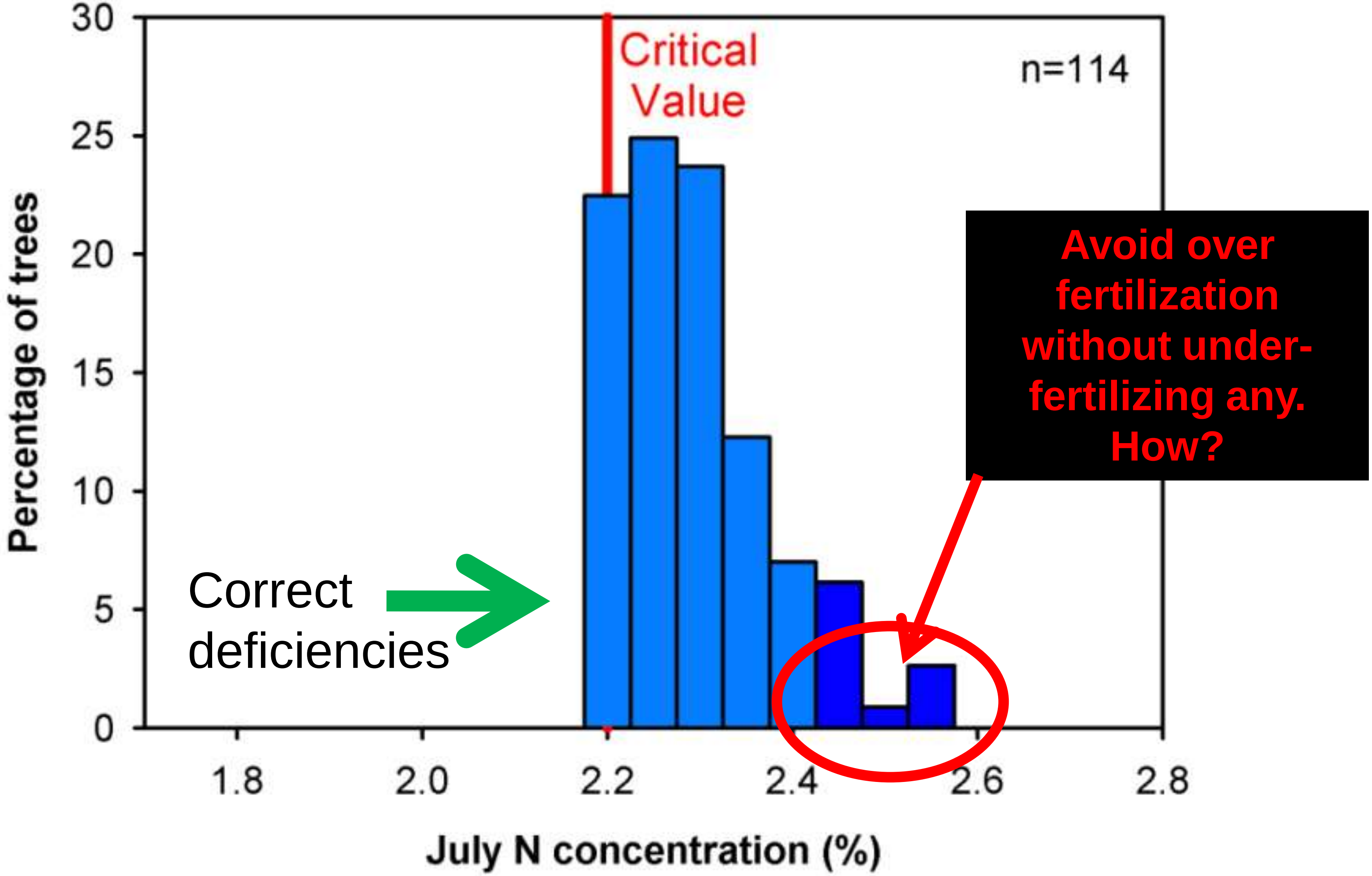
Survey of leaf N distributions in Californian Orchards



Improved sampling techniques, remote or handheld testing , re-education, regulation will all fail if the rationale for grower behavior is ignored.

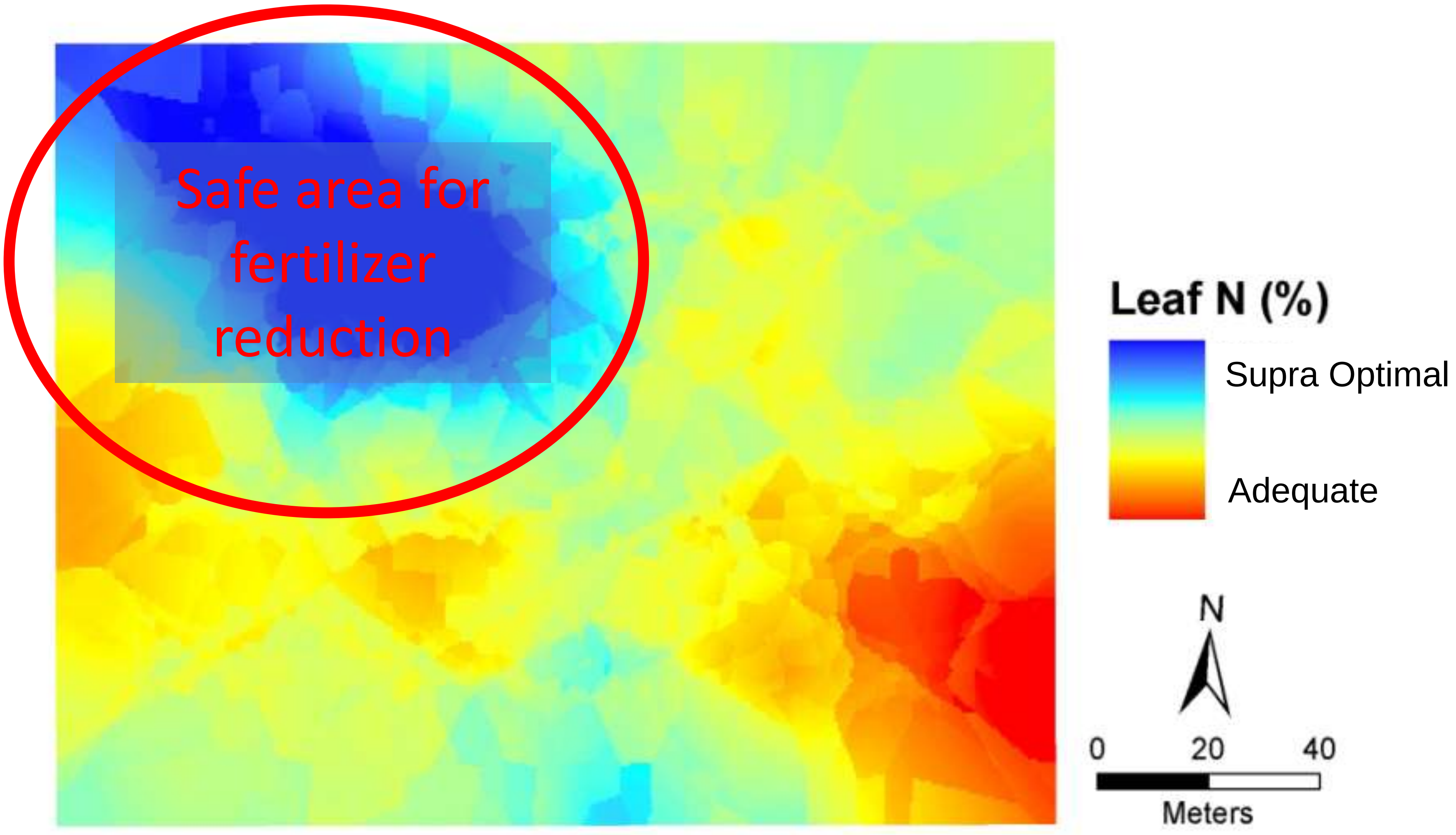


Managing Nutrition of High Value Crops



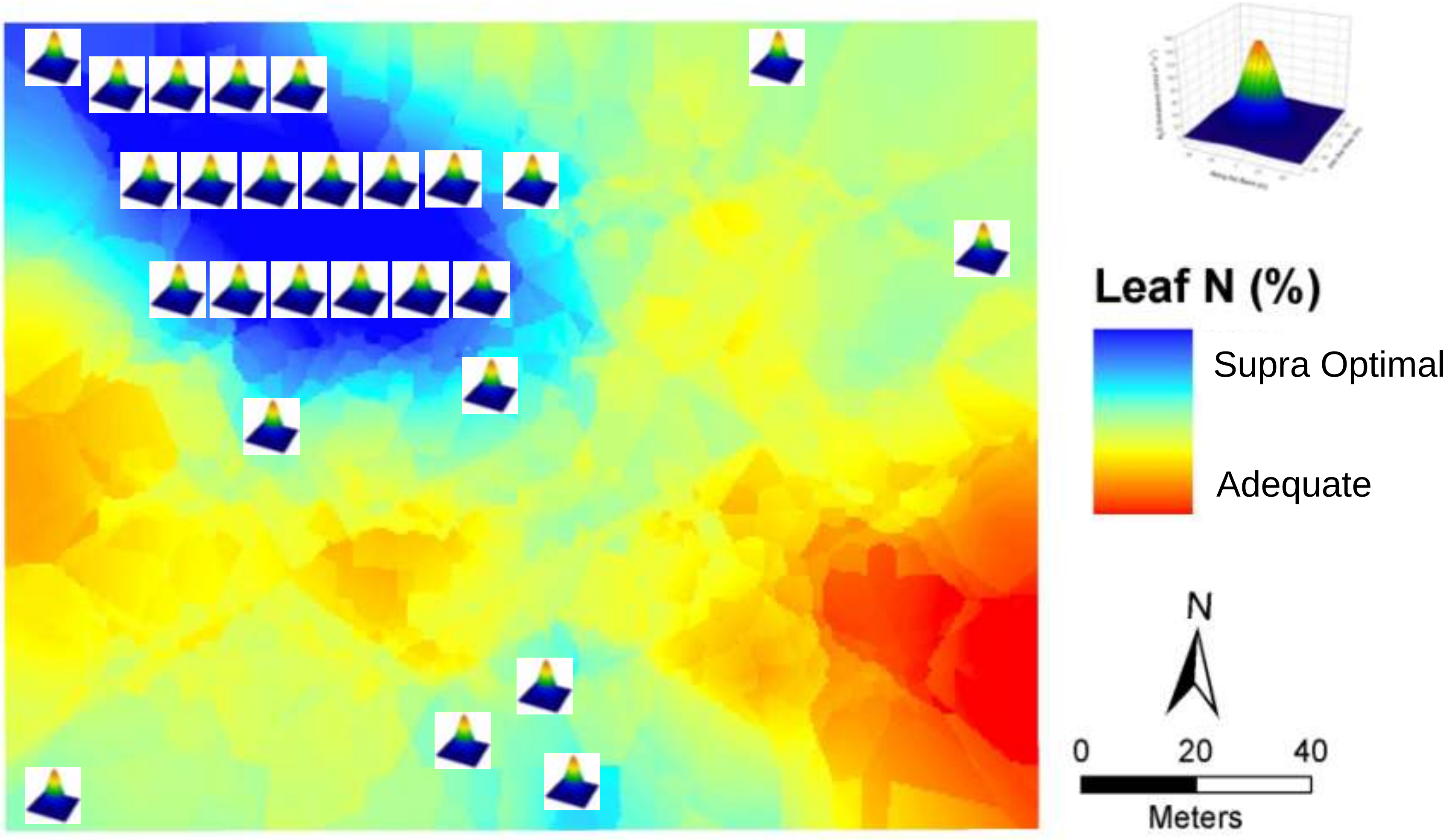
Spatial distribution of leaf N

Identification –Management - Economics



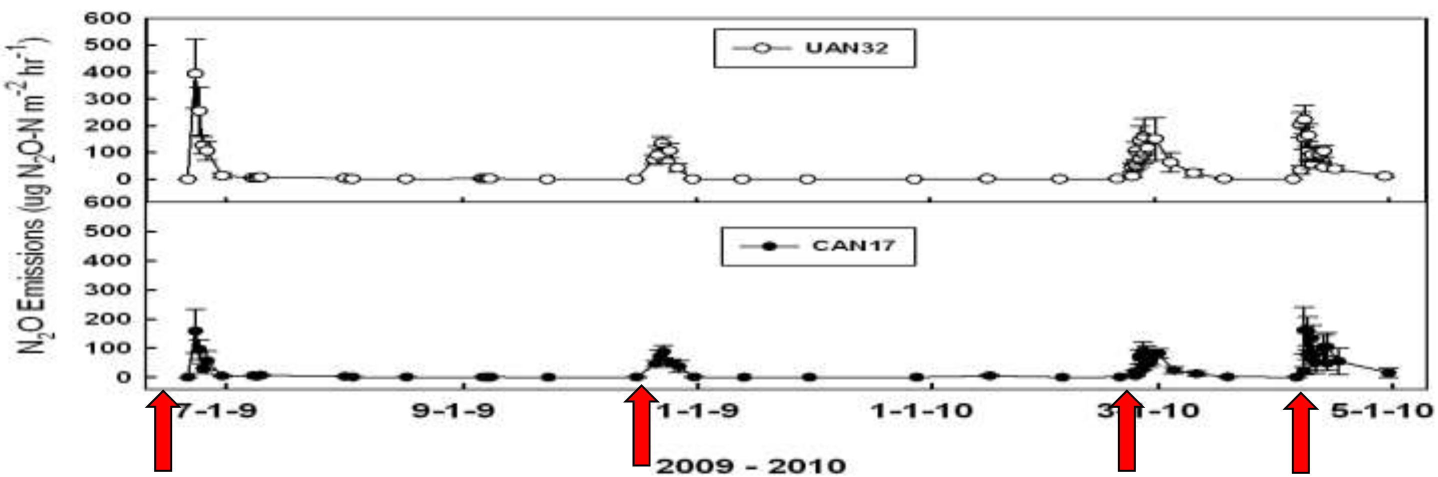
Spatial distribution of N

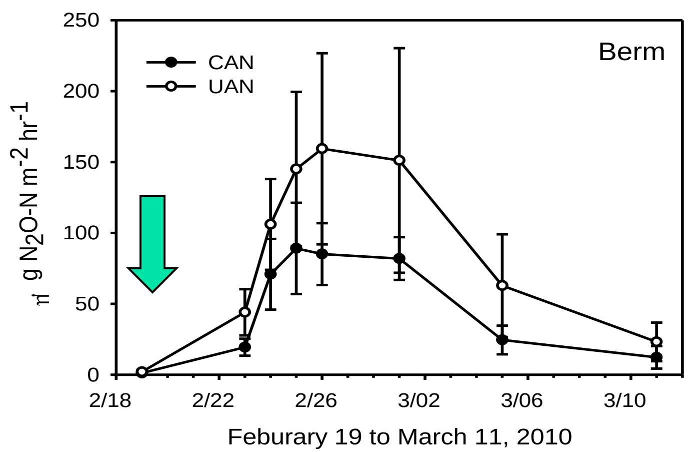
Sites of Excess Fertilization have the highest potential for Nitrous Oxide release

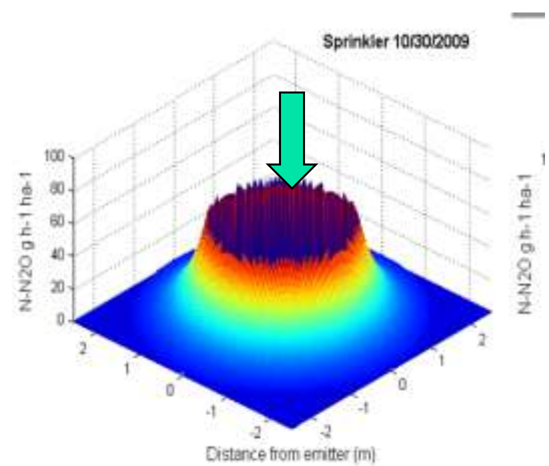


D. Smart et al

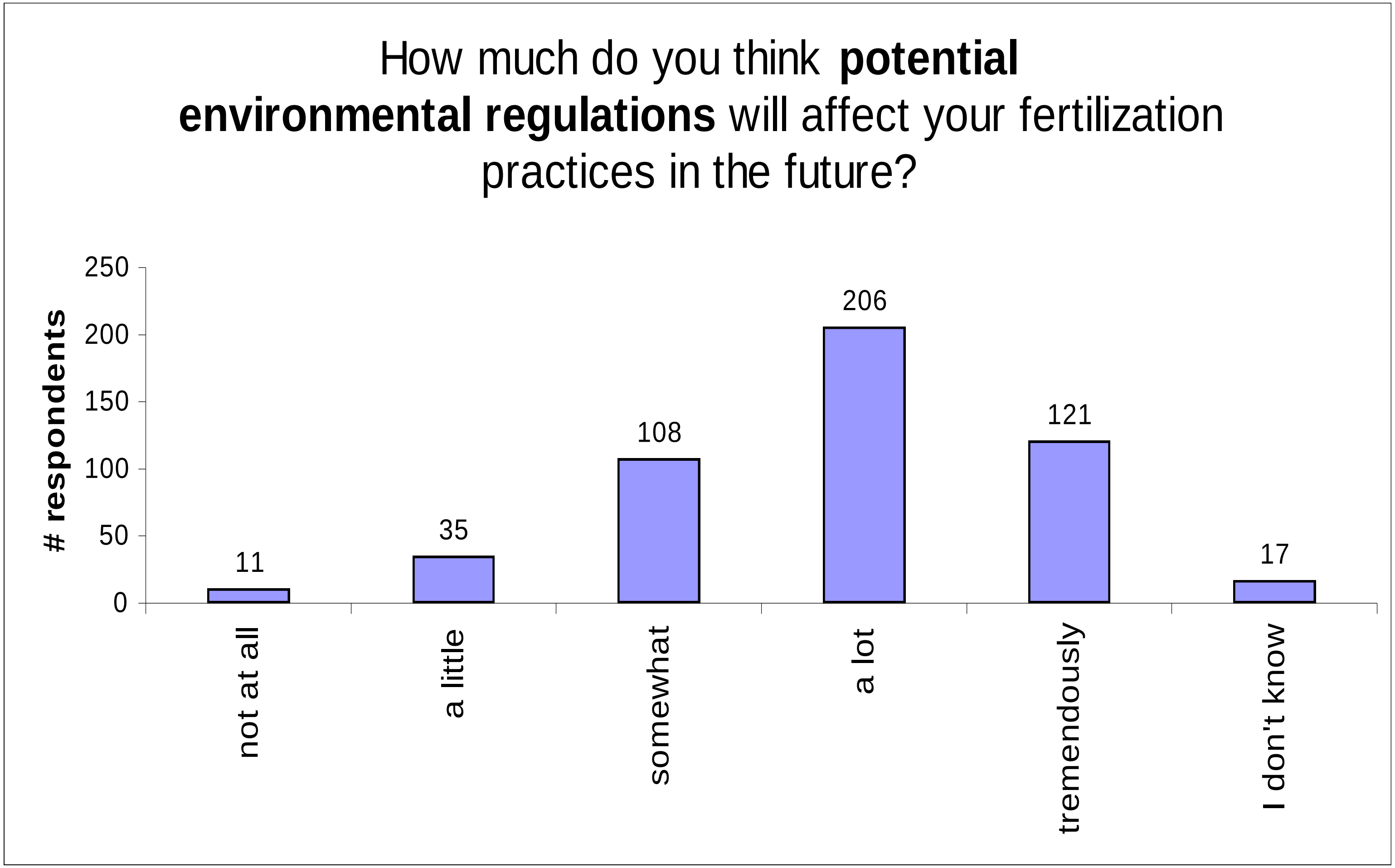
Spatial and Temporal Variability in Nitrous Oxide Release





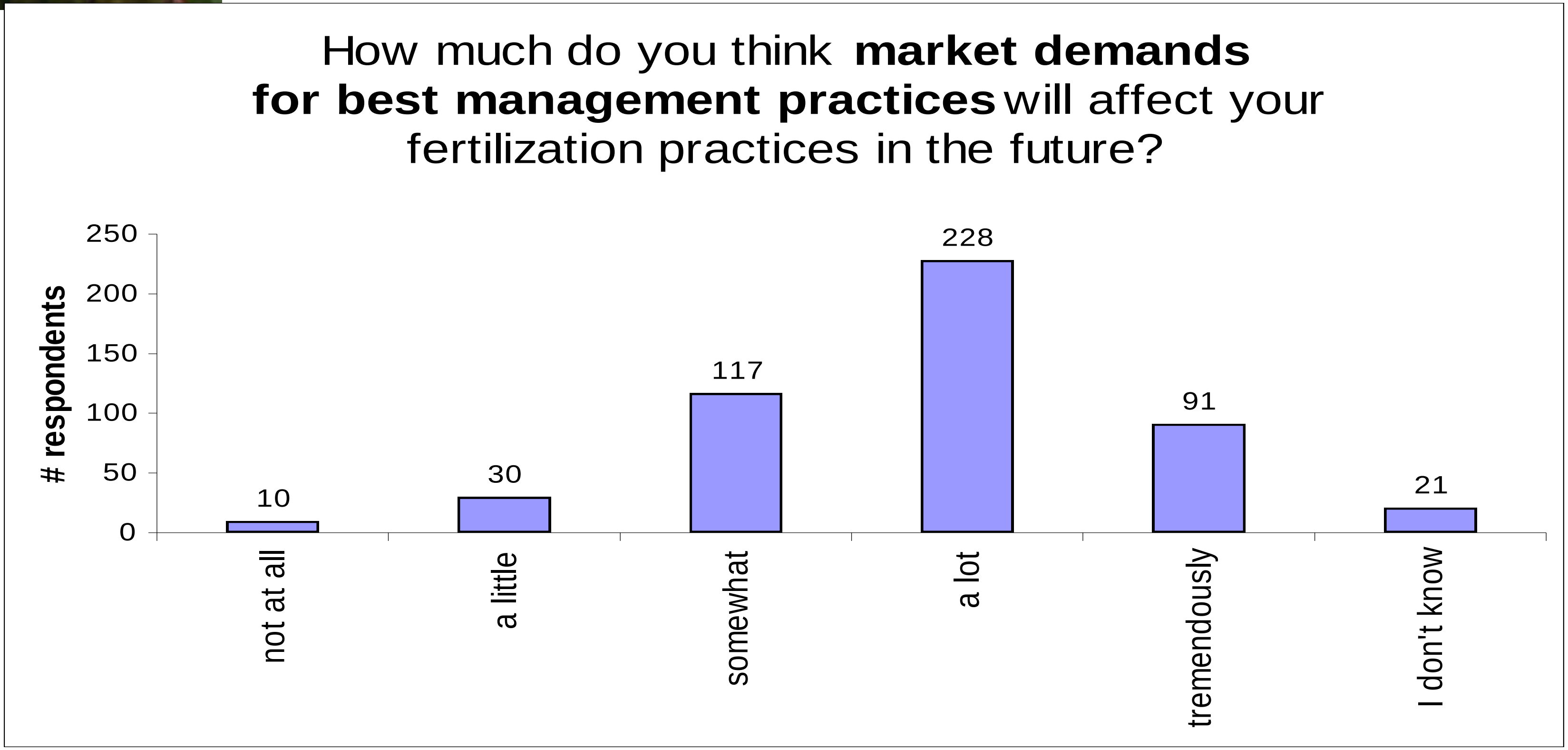


There is a growing consensus that nutrient management in tree crops is inadequate and that sustainability matters.



Market Demands for Best Management Programs

(Germany and the EU are the most imprortant export market for US nuts)



- CDFA-Fertilizer Research and Education Program, Almond Board, Pistachio Commission all rank improved nutrient management as their highest research priority.
- Cal-ARB has added N emissions from Agriculture as a target for reductions

Summary: Tissue Testing for Horticultural Crops

- As currently practiced an inadequate technology for well managed high value crops.
  - Difficult to practice and hard to interpret (except in deficiency range –rare)
  - Does not inform management practice
  - Not suitable for detection of supra optimal fertilization (insensitive, uptake and NUE decrease with application in excess of needs and induces interactions)
- Grower dissatisfaction with approach is understandable
  - ‘Over’ fertilization is a logical response to uncertainty and lack of viable tools.
  - Improved tools or lower cost (remote sensing, hand held meters, increased sampling and testing, better standards) will help but are not enough.

Alternatives?

Supplemental Approaches to Nutrient Management in Horticulture

Nutrient Budgeting

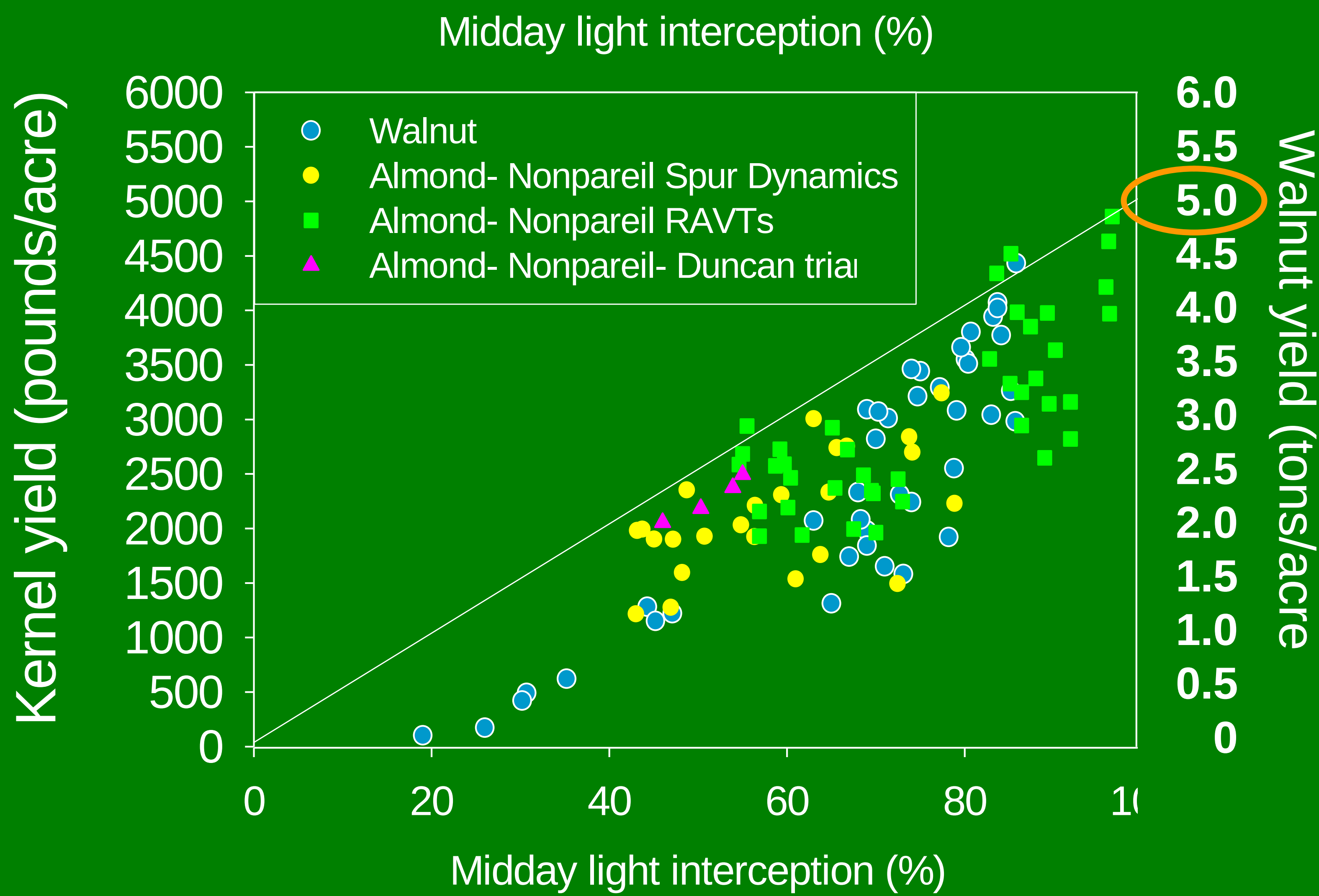
Replacing nutrients removed from the orchard or vineyard

Essential Components and Challenges:

- Determine or estimate demand (Yield monitoring or simulation)
  - Nitrogen content in harvested crop (yield x nutrient concentration) (GIS/Remote sensing etc)
  - Losses (pruning, leaching, runoff, volatilization)
- Measure and control inputs (GIS Mapping, Remote Sensing etc.)
  - soil, fertilizer, irrigation
- Manage efficiencies and interactions (Variable rate fertilization)
  - Synchronize time and location of nutrient applications
  - Monitoring crop response

How?

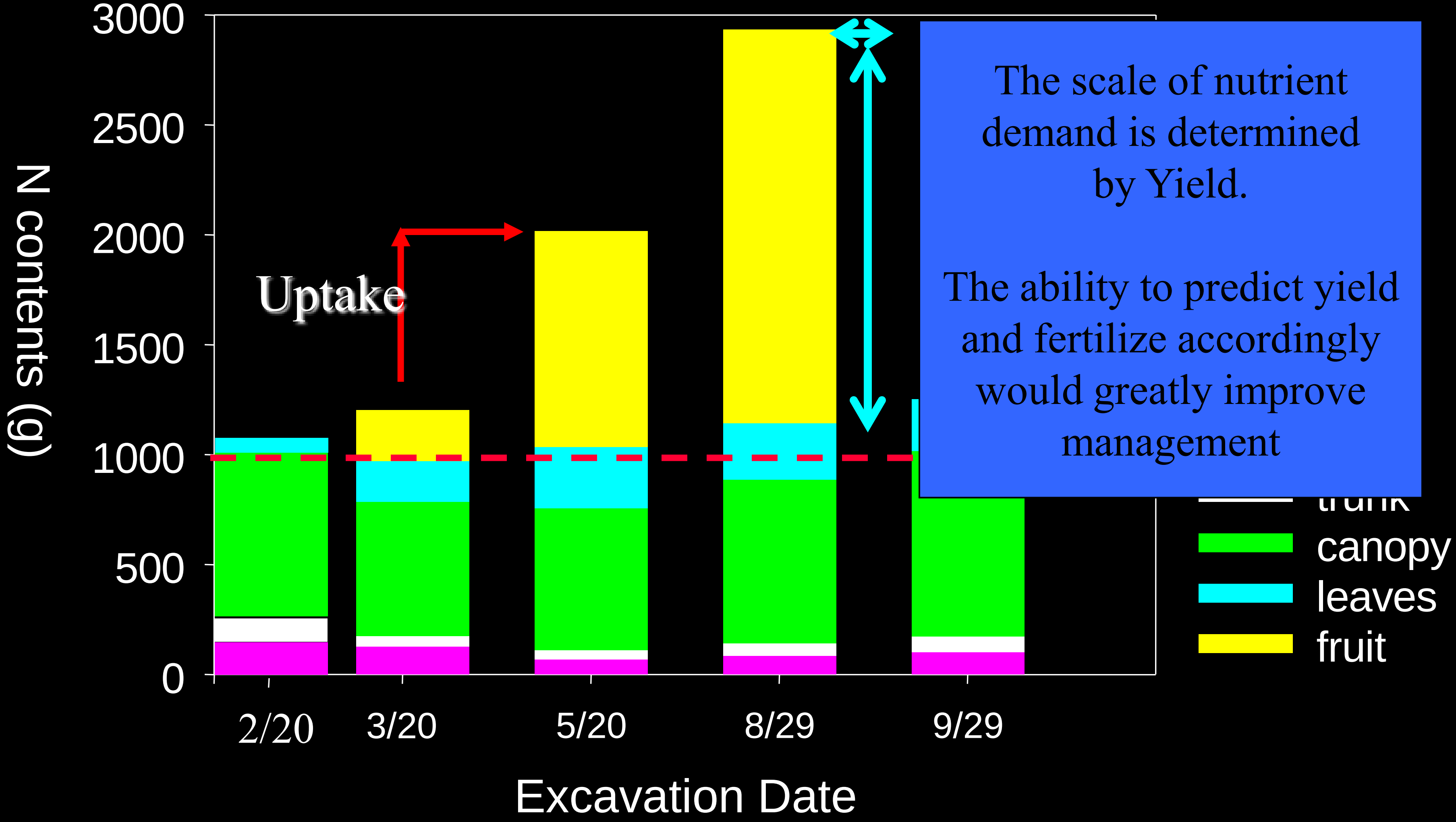
Demand: Predicting Yield Potential in Almond and Walnut



Bruce Lampinen, UCD

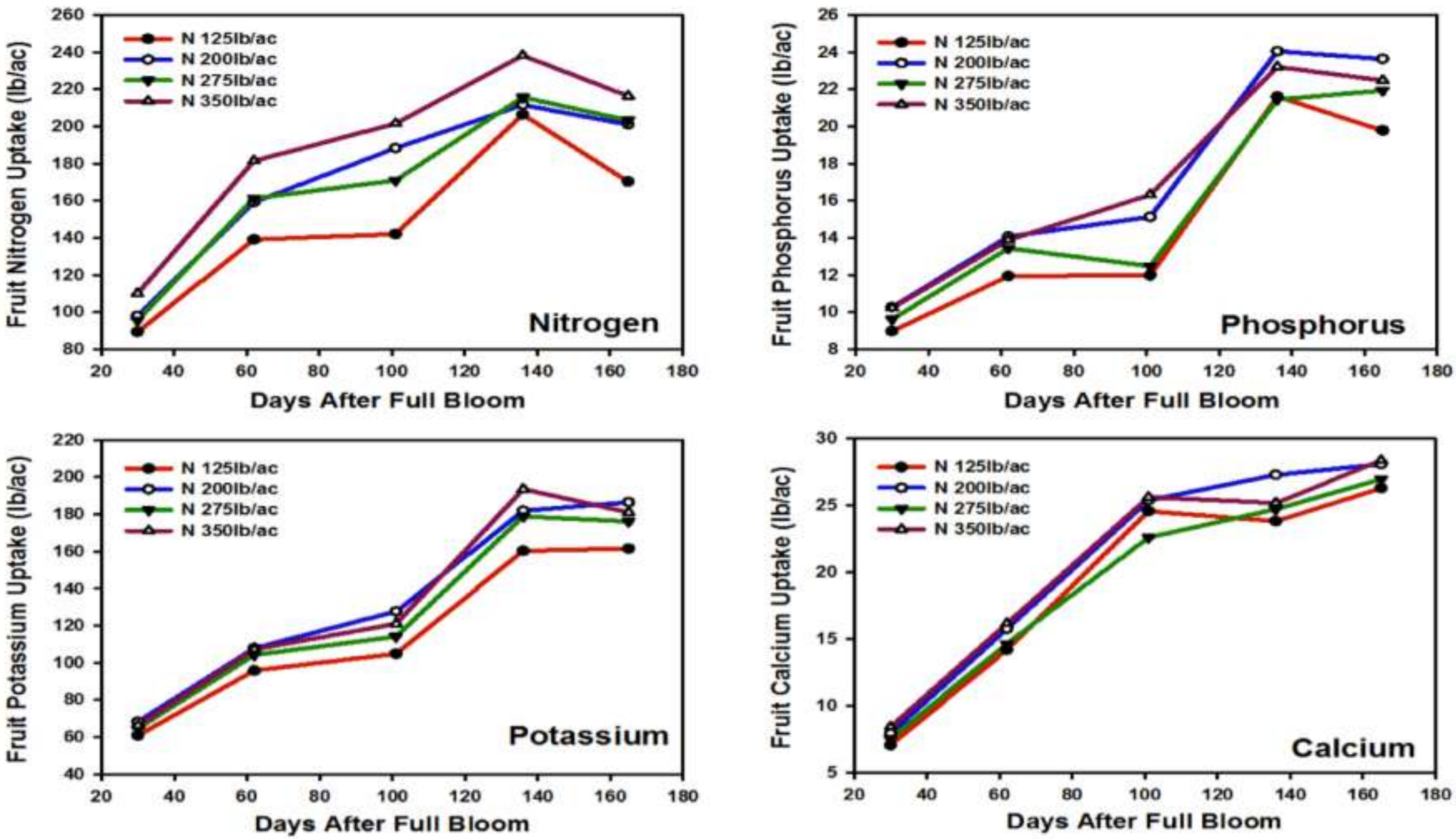
Nutrient Demand: Whole tree Harvesting:
5 mature trees x 5 times in a year

Whole Tree N Contents by Organ in Almond.



Nutrient Demand and Seasonal Dynamics in Almond

Export from Orchard in Crop (3,500 lb.ac^{-1})



Replace or Estimate?

Nutrient Removal in Kernels, Shell and Hulls

(does not include prunings and other losses. 8yo, Nonpareil test orchard)

Nutrient	Nutrient Removal (lbs / 3560 kernel lb)	Nutrient Removal (lbs / 1000 kernel lb)
N	204	58
P	24	7
K	180	51

Critical Baseline Information: How Efficient can Almond be??

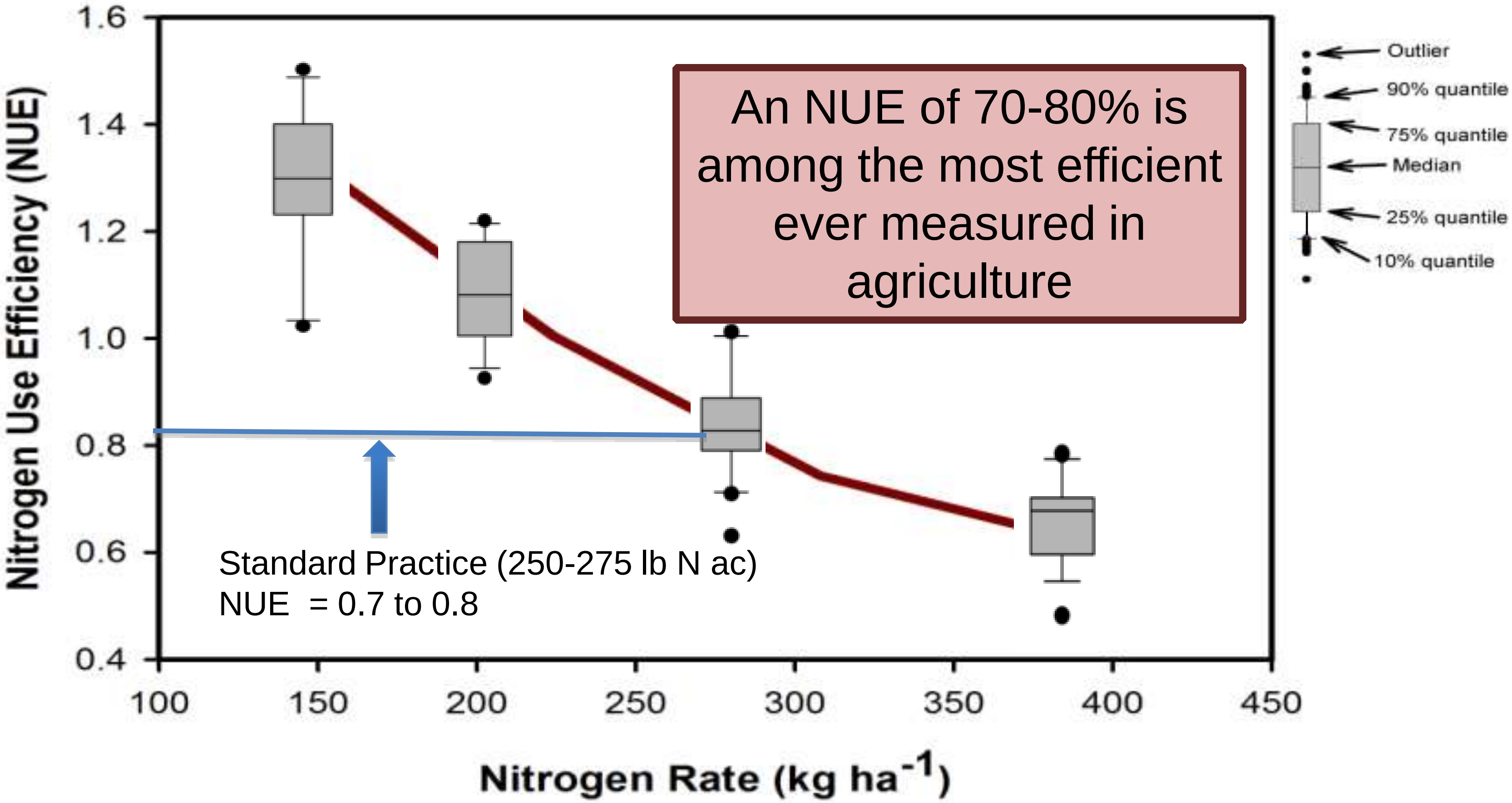
Almond

NITROGEN USE EFFICIENCY

(N removed in harvested fruit / N applied 118 trees measured in 2008)

Fertigated: 5 times in-season times with tree demand

Low rainfall, neutral soils.



Nutrient Use Efficiency Declines with N Rate.

Table 27.4 Influence of nitrogen (N) application on yield of Nonpareil almond and amount of N removed.

N in fertilizer (lb N/acre)	Kernel N (% dry weight)	Yield (kernel lb/acre)	N removed (lb/acre)	
			Crop*	Prunings
0	3.0	2,290	89	3.3
56	3.2	3,158	133	3.9
112	3.6	3,651	170	[illegible]
225	3.8	3,830	194	[illegible]
450	3.9	3,679	198	[illegible]

Source: K. Uriu and W. C. Micke, unpublished data.

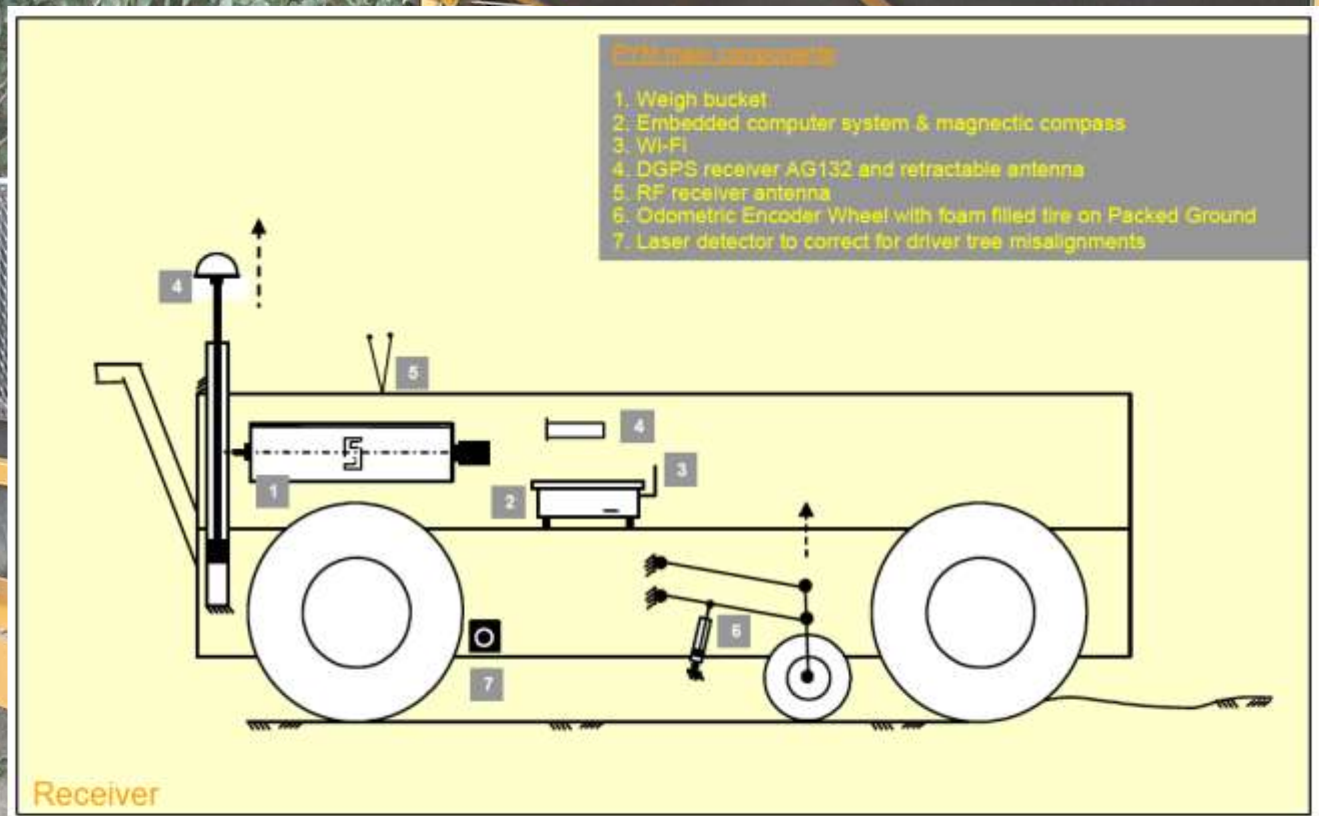
>80 % NUE(PNB)

<45% NUE(PNB)

Matching supply (fertilizer) with demand (yield) is the best way to enhance efficiency.

How does yield vary across a field and between years?

Pistachio Yield Monitor: UC Davis and Paramount Farming Company



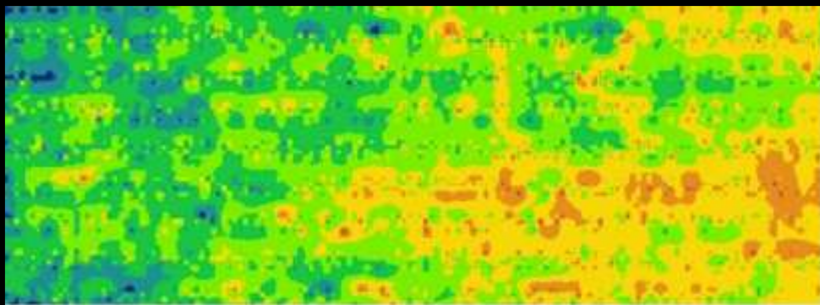
Uriel Rosa (UCD - BioAgEng)

Results: Yield Maps

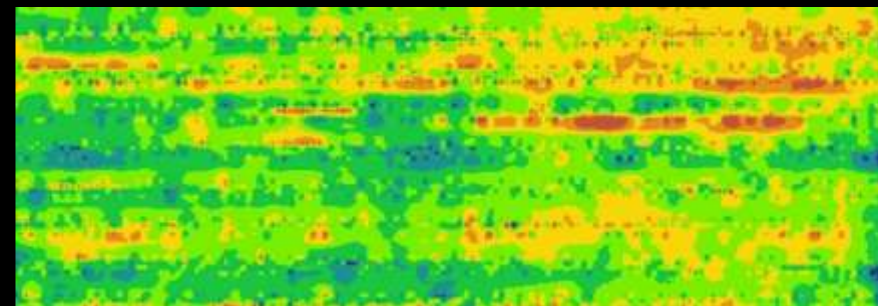
(4,280 to > 10,000 trees harvested each year)

> -2 std. dev
-2 - 1 std. devs
< -1 std. devs
Mean
< +1 std. dev
+1 - +2 std. dev
> +2 std. dev

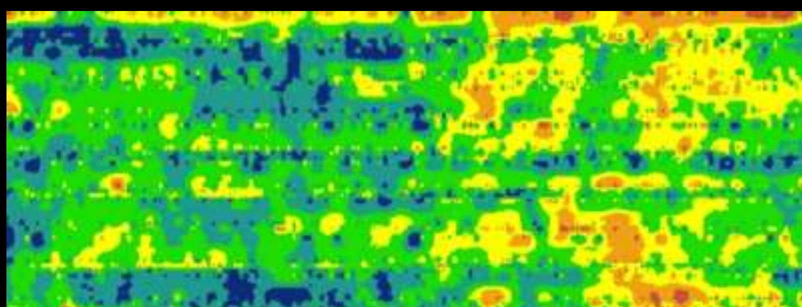
2002 89lbs



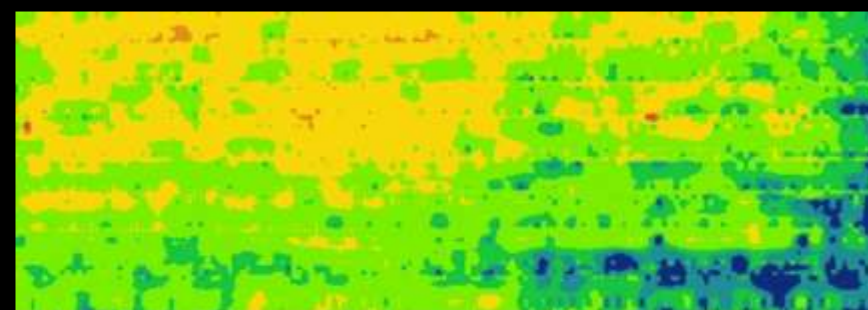
2005 95lbs



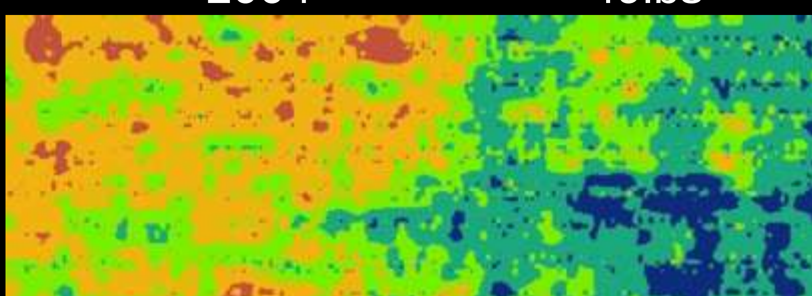
2003 73lbs



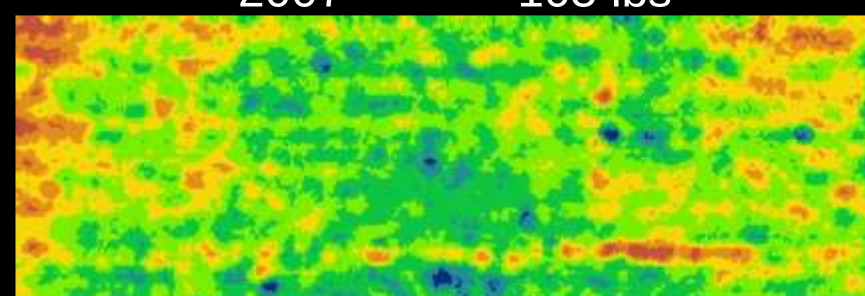
2006 15lbs



2004 49lbs

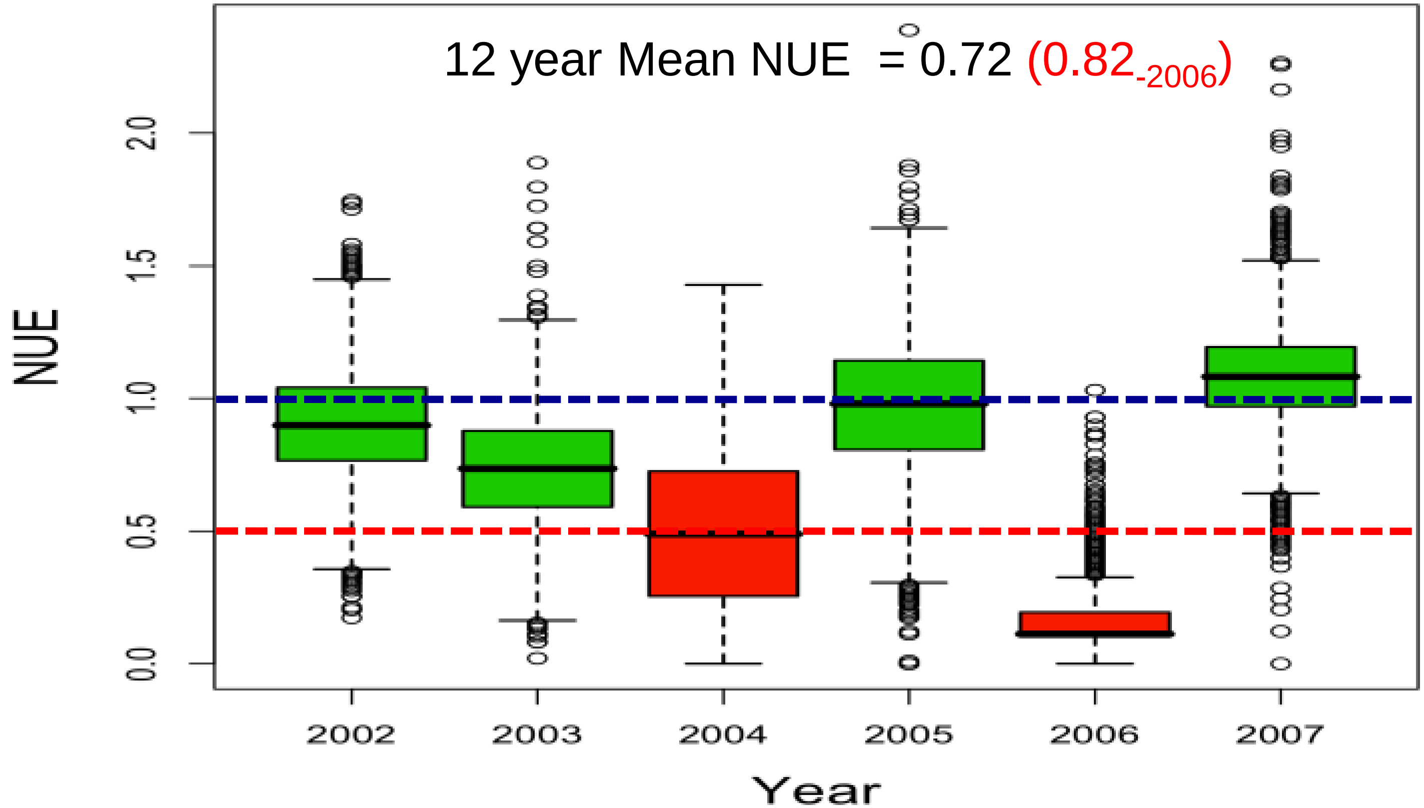


2007 105 lbs



Nutrient Use Efficiency and Variability in Pistachio.

4850-9650 individual Tree NUE estimations
(N removed in harvested fruit / applied)

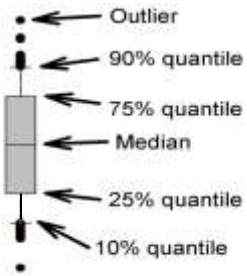


60,000 lb total 6yr N application (40 ac).

41,000 lb exported in yield.

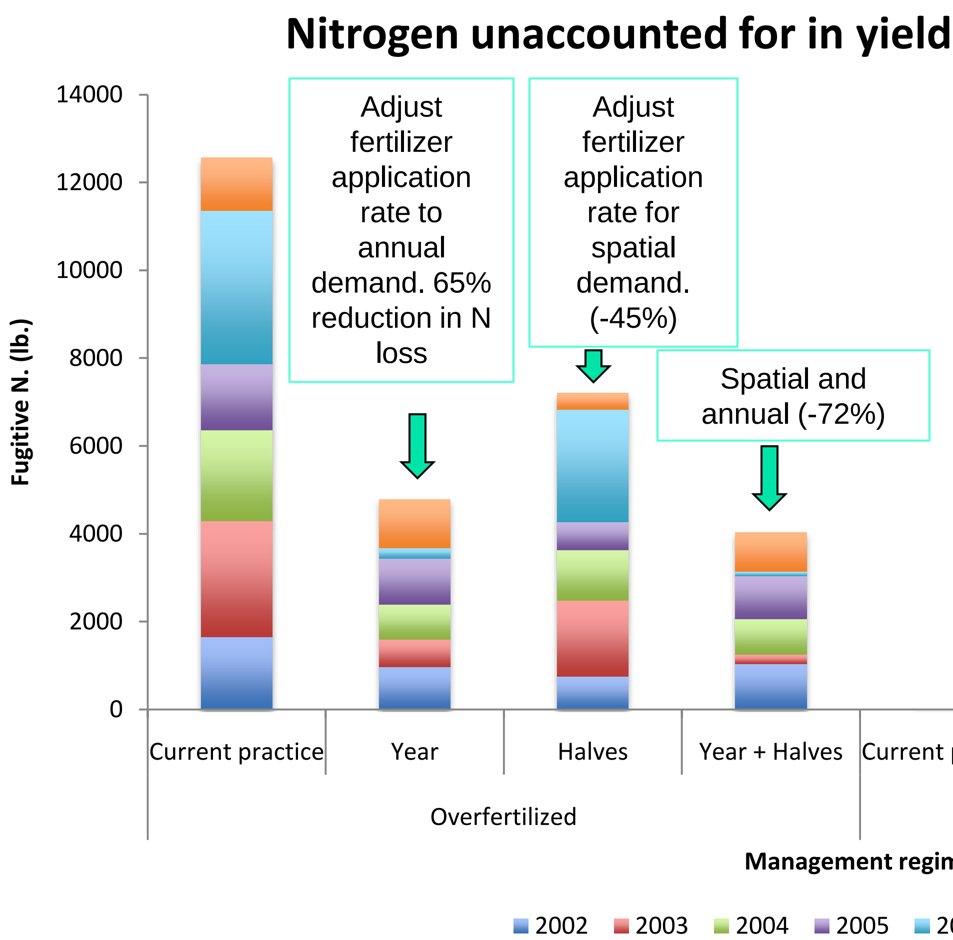
$7{,}000_{est}$ lb pruning, leaf loss and growth

12,000 lb 'lost'
50 lb ha^{-1} yr^{-1}



24 yo Pistachio, 5 inch rainfall zone, no deep percolation.
Silt loam, pH 6.7-7.0, OM 0.6%, 2 ppm NO_3N (100cm). Fertigated with five in-seasons split apps.
10 yr ave yield = 4,000 lb ac= 180 lb N ac in exported fruit
Mean N application 250.

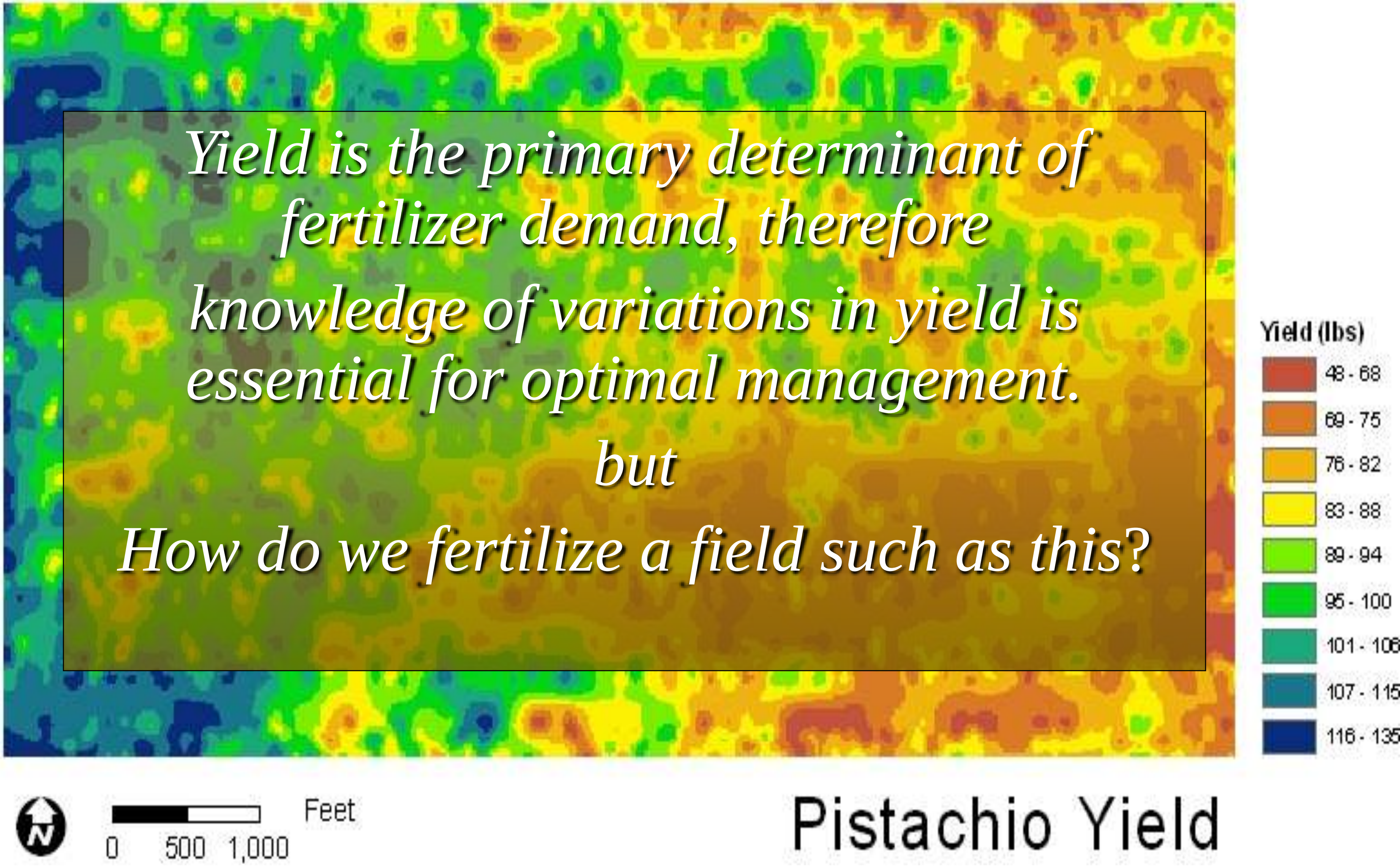
Influence of Precision Management on Fertilizer Losses – first steps.



To maximize NUE, fertilization should be adjusted for:

1. Expected/actual yield
   1. Yield Monitoring
   2. Yield Prediction
2. Variability across and between fields
   1. Remote sensing, sampling and GIS mapping etc

Yield is not uniform in any field.
Yield of 16040 trees Pistachio trees (40 ha)



Yield is the primary determinant of fertilizer demand, therefore

knowledge of variations in yield is essential for optimal management.

but

How do we fertilize a field such as this?

Individually controlled microsprinkler system.

Robert Coates, Mchael Delwiche, Patrick Brown

Individual microsprinkler with controller. Current version integrates wires into pipe, and valve and actuator into sprinkler head.

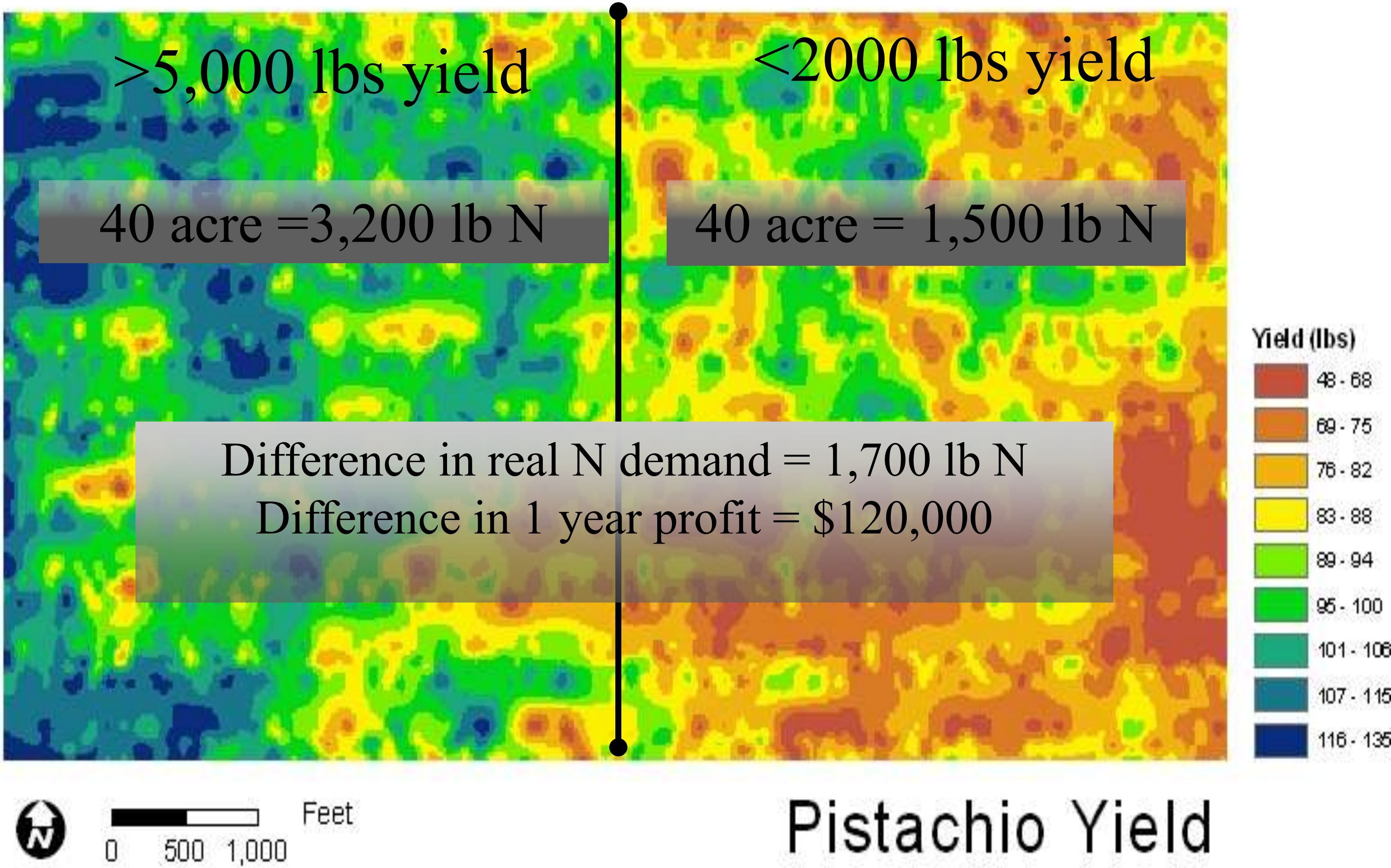
Nitrogen Demand by 20 acre block

Whole Field Average N demand = 150 lbs N

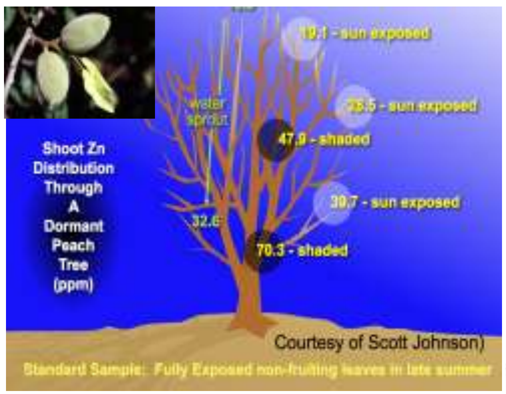
Managing for Spatial Variability

Introduces greater complexity in management

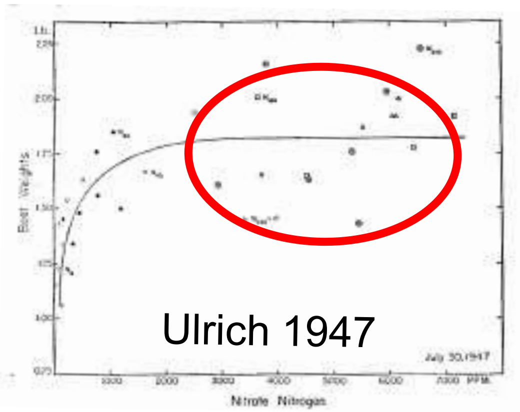
Is it worth it?



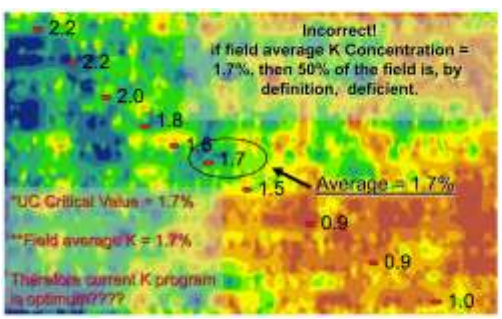
Current Practices: Leaf Sampling And Critical Values are Inadequate Tools for Almond.



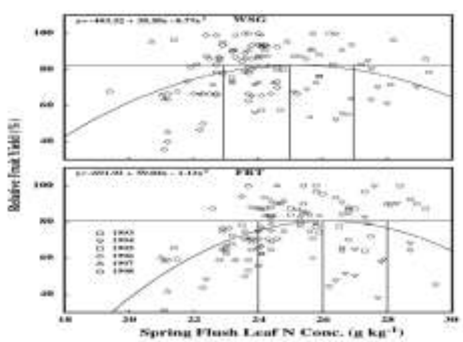
Sampling and physiological significance



Poor Sensitivity at typical concentrations



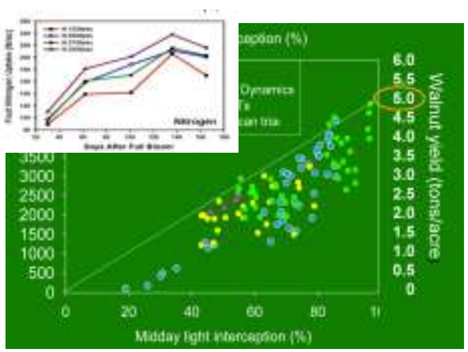
Spatial Variability Interpretation Errors



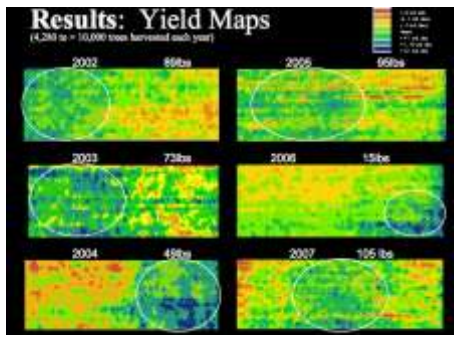
Poor Standards

- Variability within a tree and orchard is substantial. Rigorous standardization increases reproducibility but not relevance.
- Leaf sampling is not adequately sensitive at supra optimal nutrient concentrations.
- Sampling protocols and interpretation have been misused.
- As a consequence orchard level critical values are difficult to interpret.

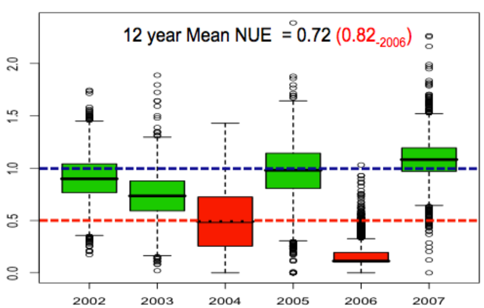
Alternate Practices: Nutrient Budgeting and Spatial and Temporal Fertilization



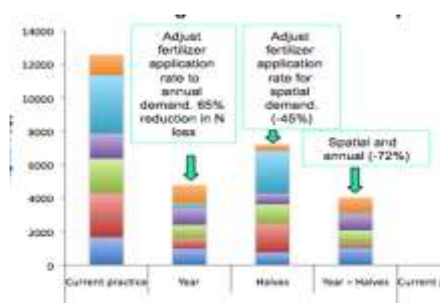
Modeled and measured yield prediction is viable



Biological basis for variable production remains poorly understood..



Temporal and spatial variability is significant. Overall NUE can be very high.



Site specific management is promising and viable.

- Acceptable yield prediction, and hence nutrient demand, can be achieved with existing technologies and could be improved significantly.
- Variability within an orchard and over time is substantial, but poorly documented and understood.
- Under good management, high NUE's are observed in Californian Almond and Pistachio orchards.
- Managing nutrients by managing for spatial and temporal variability is critical to efficiency.

Site Specific Management - Optimizing Fertilization by applying the 4 R's. – What is Needed?

APPLYING THE RIGHT RATE (estimate demand)

- Determine total demand (Inputs - Outputs)
  - Inputs (fertilizers, N in irrigation (0 - 80 lb N Acre yr))
  - YIELD MONITORING OR PREDICTION
  - MAPPING
  - NUTRIENT MONITORING – REMOTE/HANDHELD/QUICK
  - VARIABLE RATE/PLACEMENT TECHNOLOGY

AT THE RIGHT TIME (fertilize according to nut growth rate)

- Timing of demand is reasonably well defined by biology
  - FERTIGATION
  - VARIABLE RATE/PLACE TECHNOLOGY

IN THE RIGHT PLACE (fertilize active roots and 'hungry' trees)

  - FERTIGATION/FOLIARS/VRT, SYNCHRONIZE

Site Specific Management of Nutrients in Tree Crops. WHAT NEXT?

Given the high value and long life of perennial systems, and the inadequacy of current practices, now is an ideal opportunity to re-invent our approach to nutrient management .

This will require: Research, Technology, Engineering, Tools

- Yield Measurement and Prediction – Integrated mathematical, biological, engineering and ecological approaches.
- Determination of Spatial Variability - Statistical and geo-statistical tools, sampling and sensing technologies, improved experimental designs.
- New Management Tools – Rapid yield and nutrient measurement techniques. New approaches to precision application -sub sector fertigation to single tree fertigation; VR devices and materials (surface/liquid).

Almond Board-USDA-CDFA funded projects are ongoing.

Adoption will require development of sound information, packaged with an approachable technology that simplifies management.

Estimate N and Water Demand

Validate ETa models (SEBAL, NCAR-WRF), estimate orchard water needs (Ustin, Sammis)

Remote Sensing of yield, phenology, crop development (Slaughter, Upadhyaya, Whiting)

Develop fertilizer response curve (Brown, Sanden, Lampinen)

Modeling of crop nutrient and water demand
Climate/phenology based yield modeling (Whiting, Ustin)
N and water modeling in pecan and almond (Sammis, Wang)

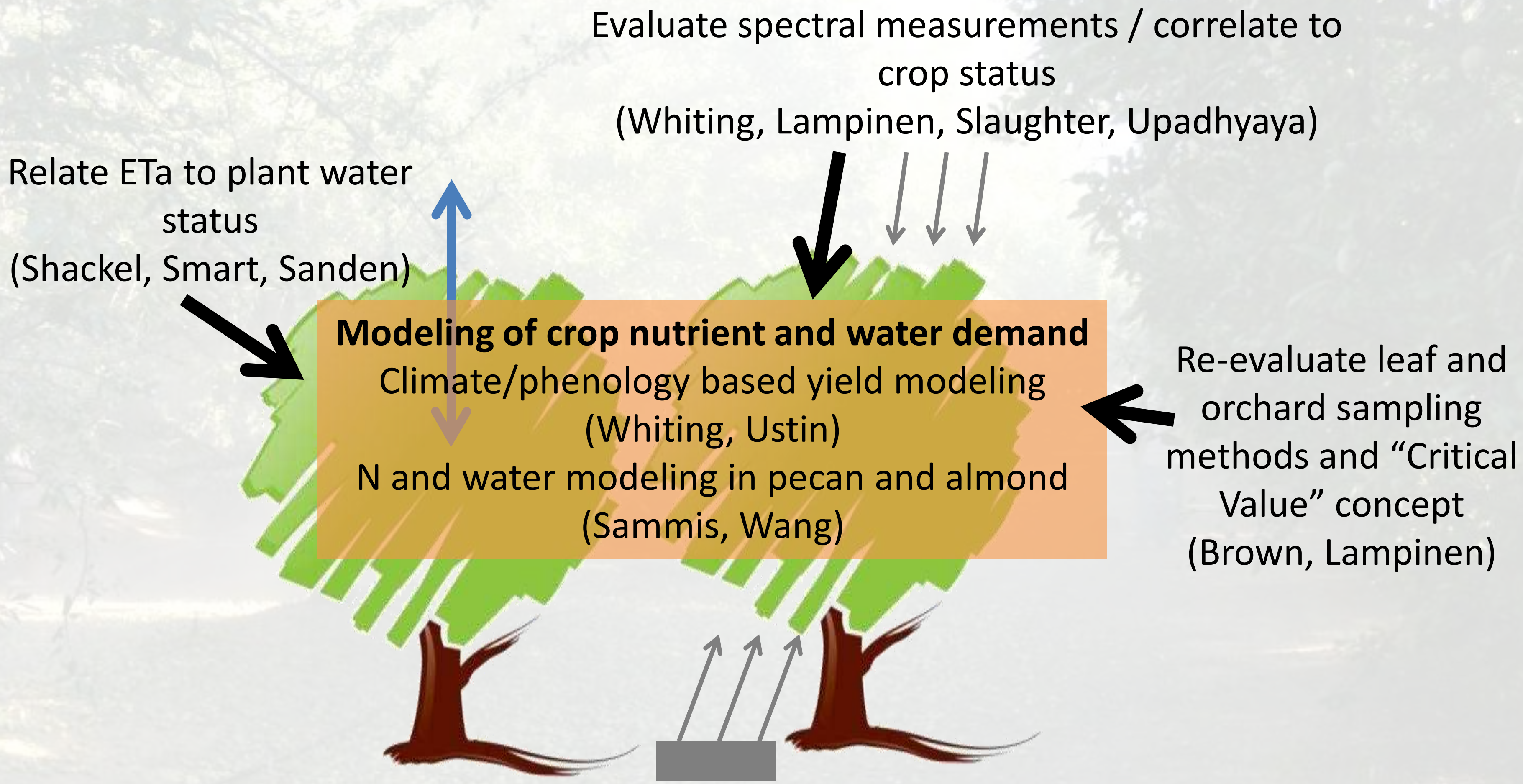
Develop phenology and yield based nutrient demand model (Brown, Sanden, Lampinen)

Physiological/soil environmental controls on N and water uptake (Hopmans, Shukla, Lombardini)

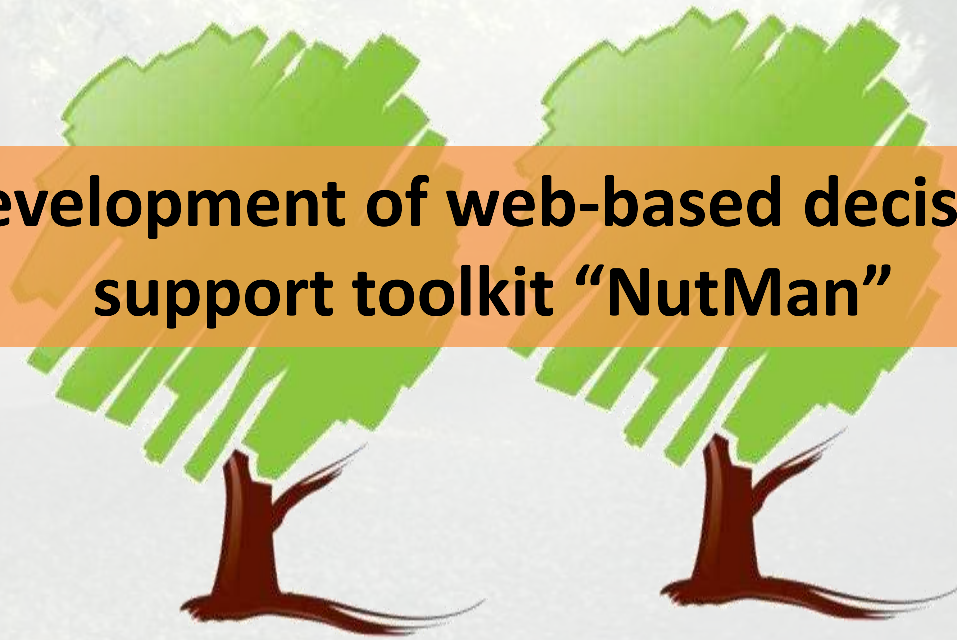
Gaseous, sub-soil N losses (Smart, Brown)

Interactive effects of irrigation and nutrient status on plant water use and plant response (Shackel, Brown, Sanden)

Determine N and Water Status



Integration / validation



Development of web-based decision support toolkit "NutMan"

Nutrient Demand and Seasonality

Nutrient	Nutrient Removal (lbs / 3560 kernel lb)	Nutrient Removal (lbs / 1000 kernel lb)
N	204	58
P	24	7
K	180	51

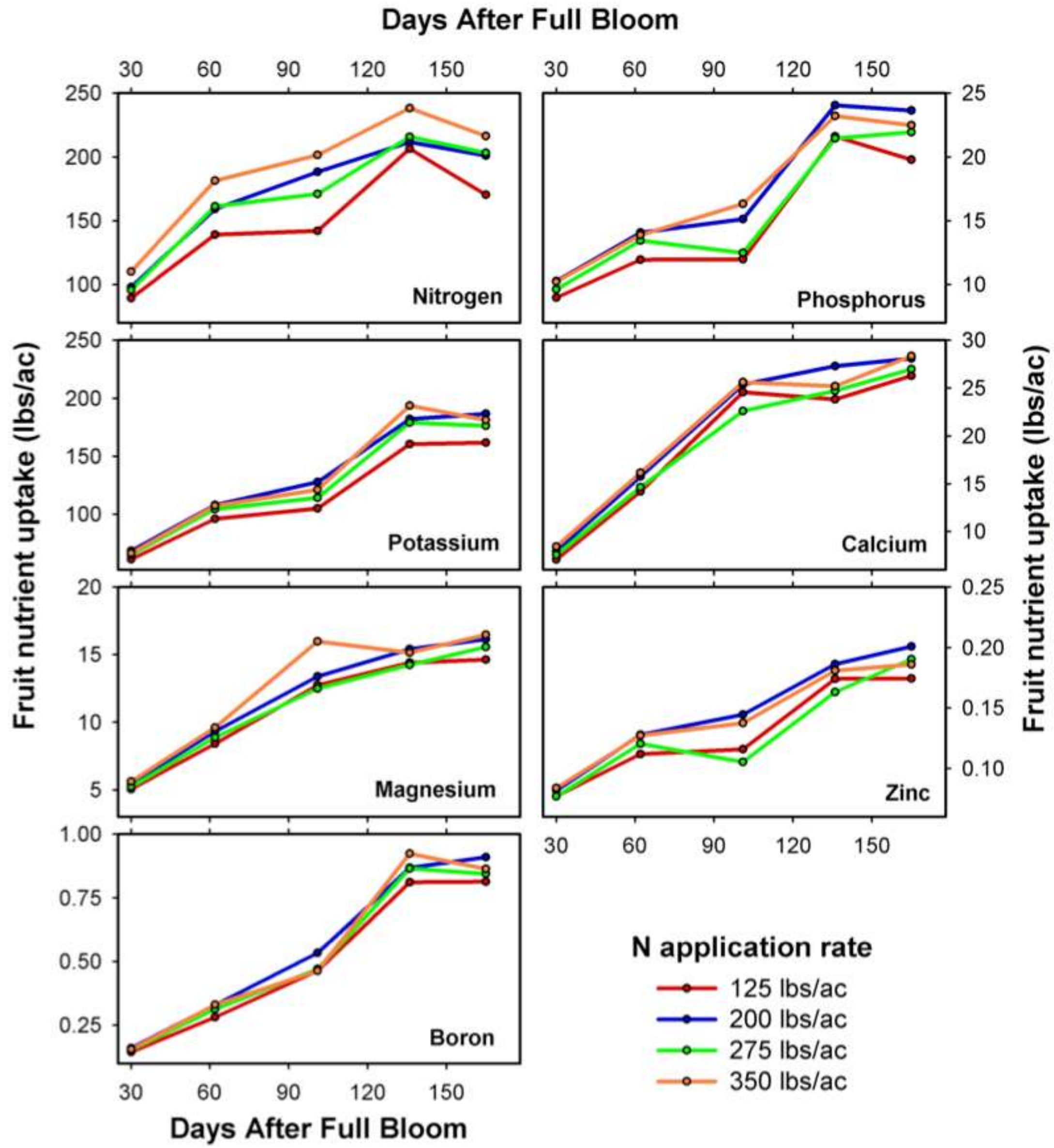
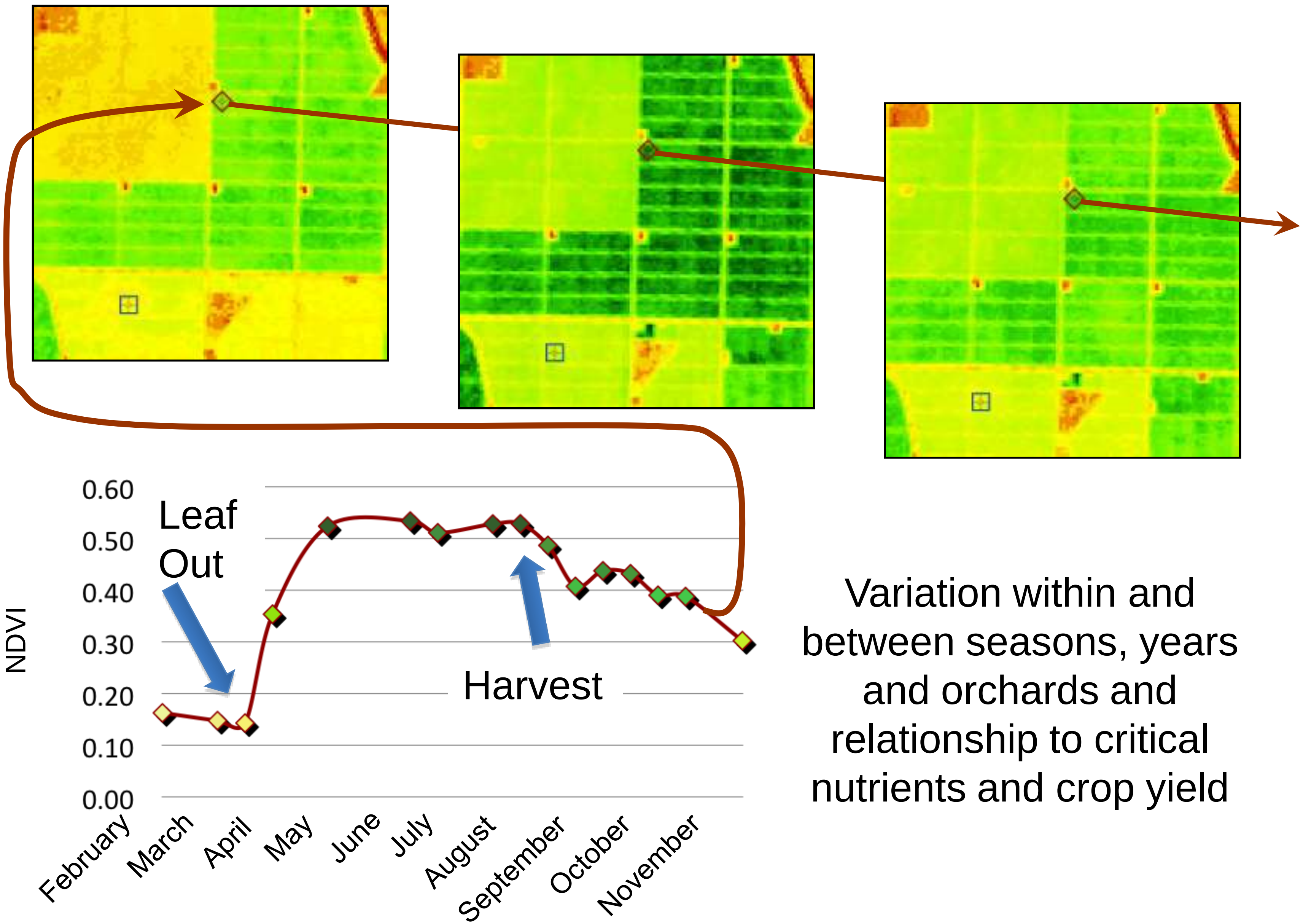


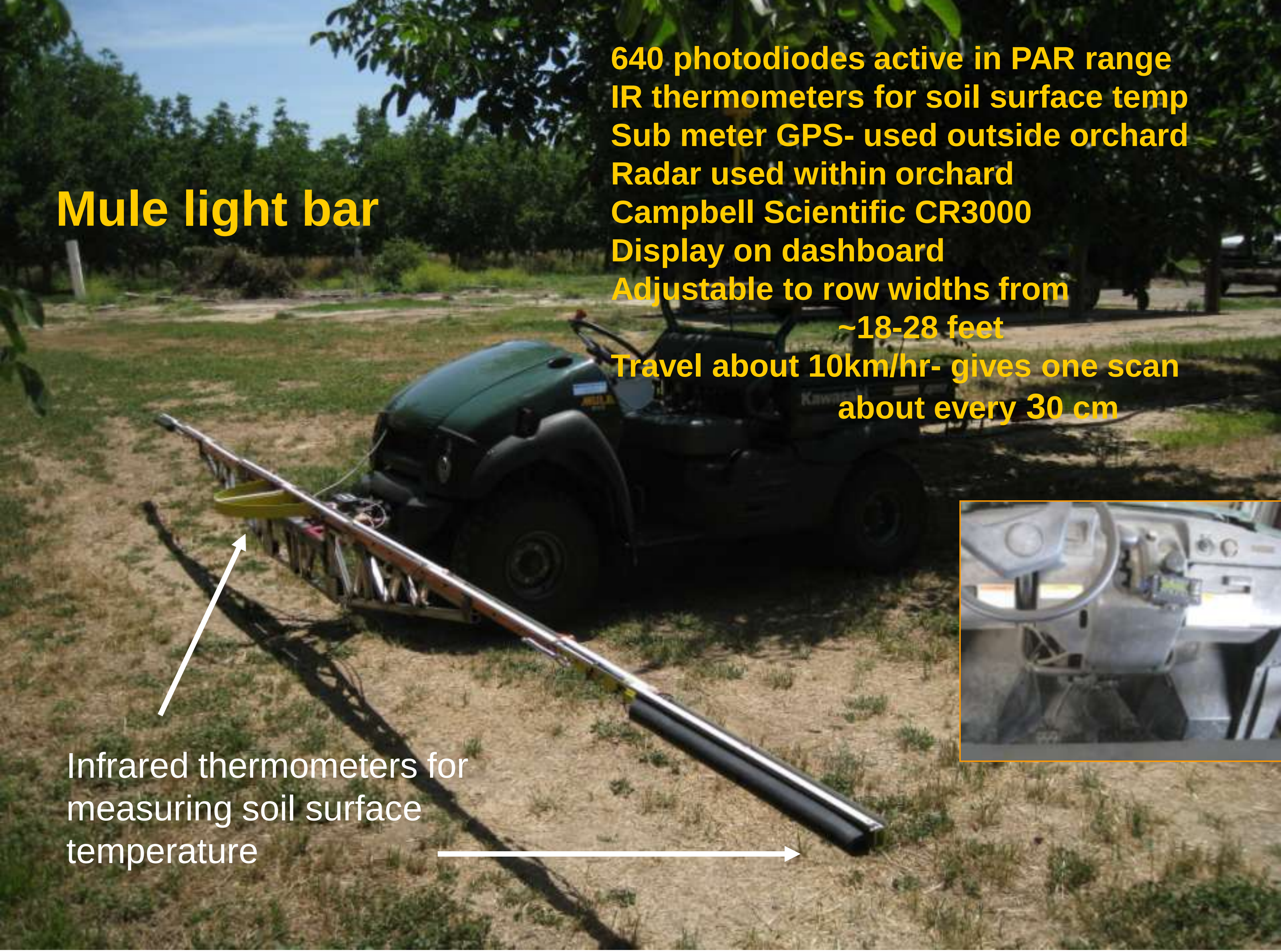
Figure 4. Nutrient uptake dynamics throughout the season

Data from the Belridge fertigation trial during the 2008 season
n=36 per date for 275 lbs/ac; n=30 per date for all other treatments

YIELD PREDICTION: Vegetation Index Tracking Orchard Phenology Through Biweekly Free Satellite Imagery

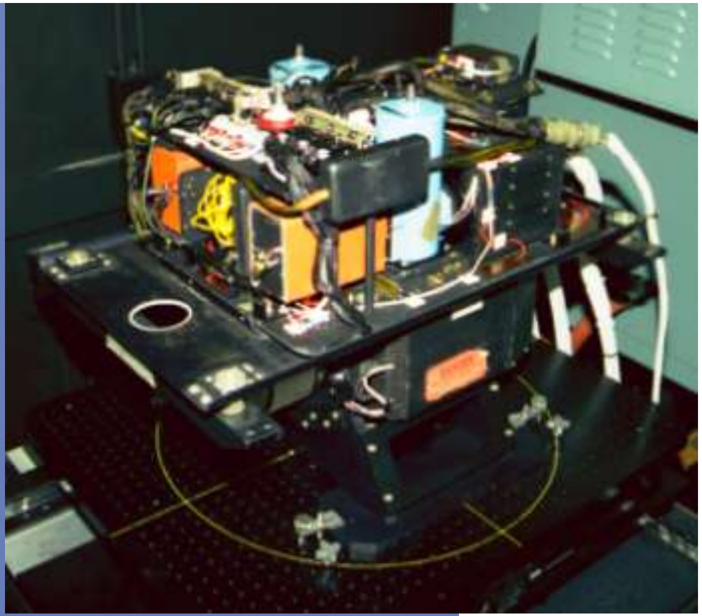


Variation within and between seasons, years and orchards and relationship to critical nutrients and crop yield


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
Infrared thermometers for
measuring soil surface
temperature

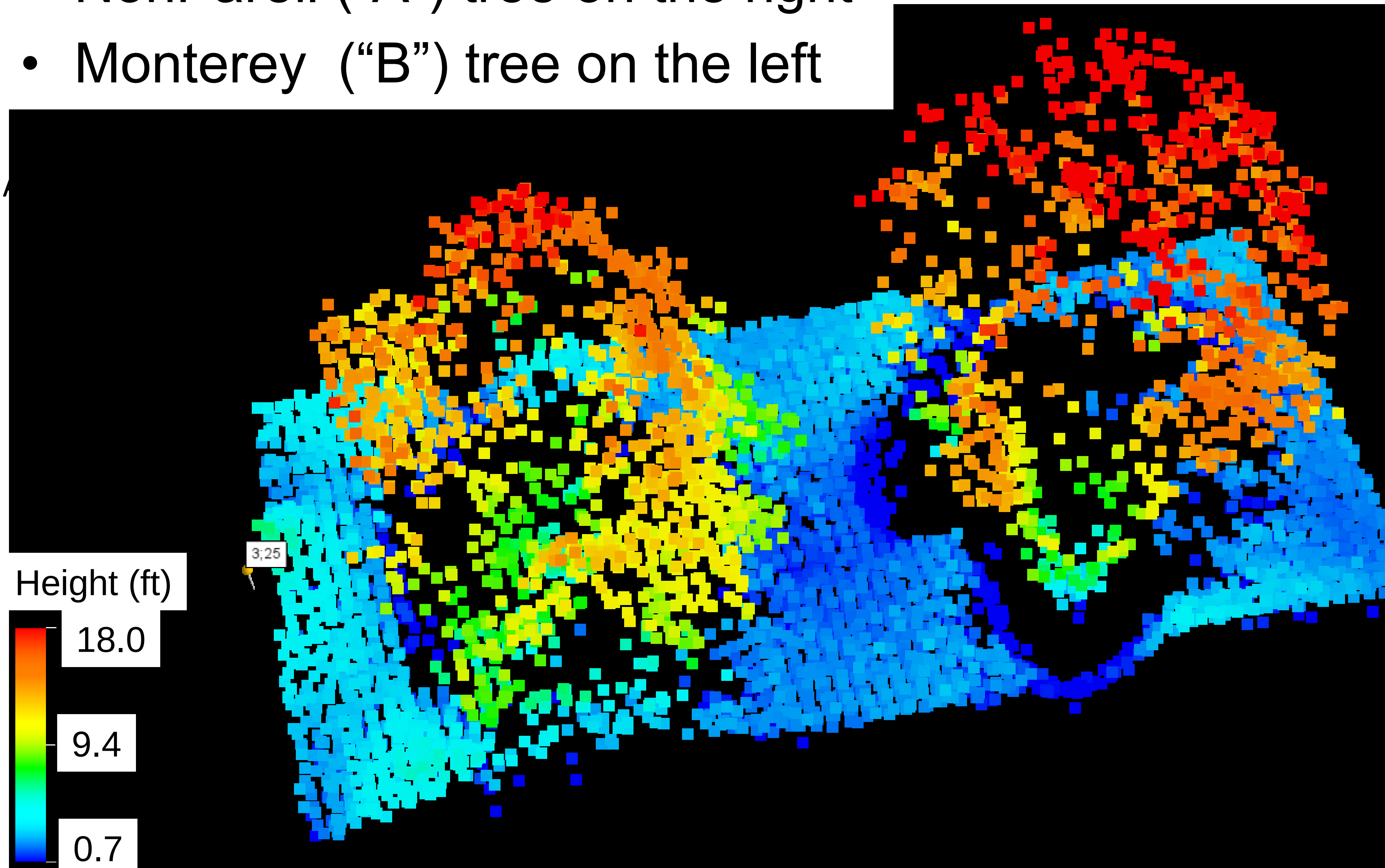
NASA DC-8 Orchard overflight 22 & 24 July 2009, ~10,000 ft. alt., MASTER sensor

MASTER airborne simulator instrument for MODIS and ASTER satellite sensors



Single Trees from Scan AO3

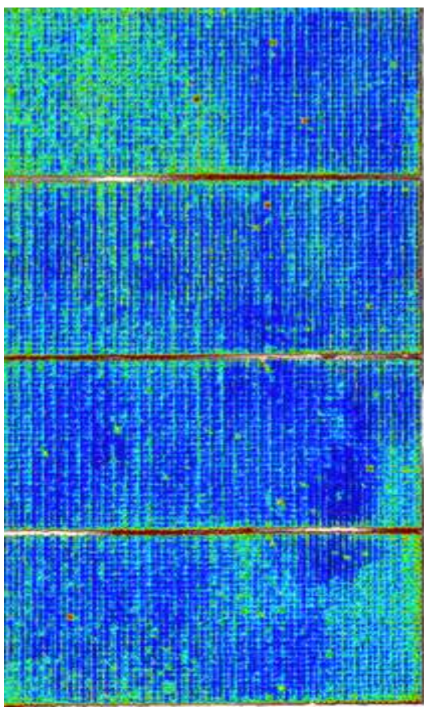
- NonPareil (“A”) tree on the right
- Monterey (“B”) tree on the left

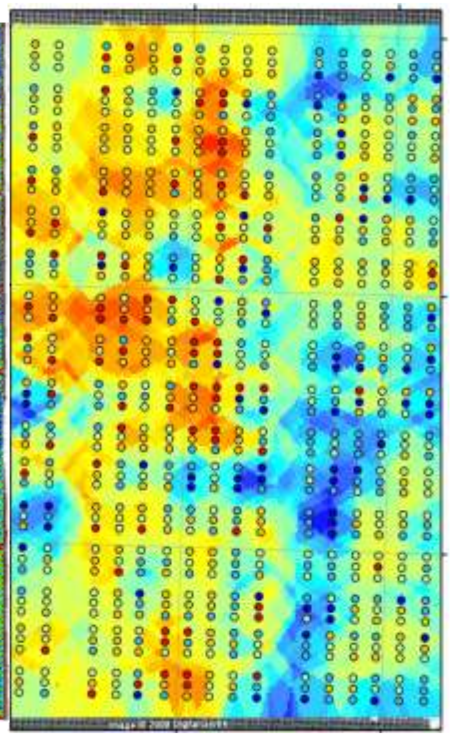


ONGOING RESEARCH

•Yield Prediction and Monitoring , Rapid-Sensitive Nutrient and Water Analysis, Remote Sensing,

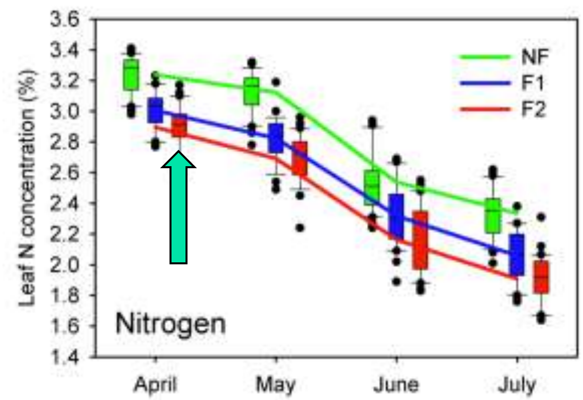
Ground and Aerial Imagery: In season nutrient status and yield prediction.





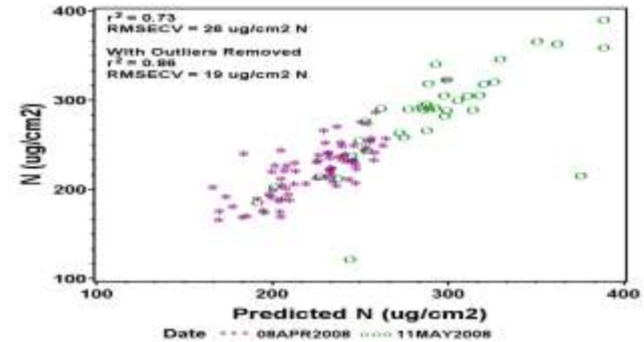
Aerial Image April 29 2009 Yield 2008

Early Season Sampling



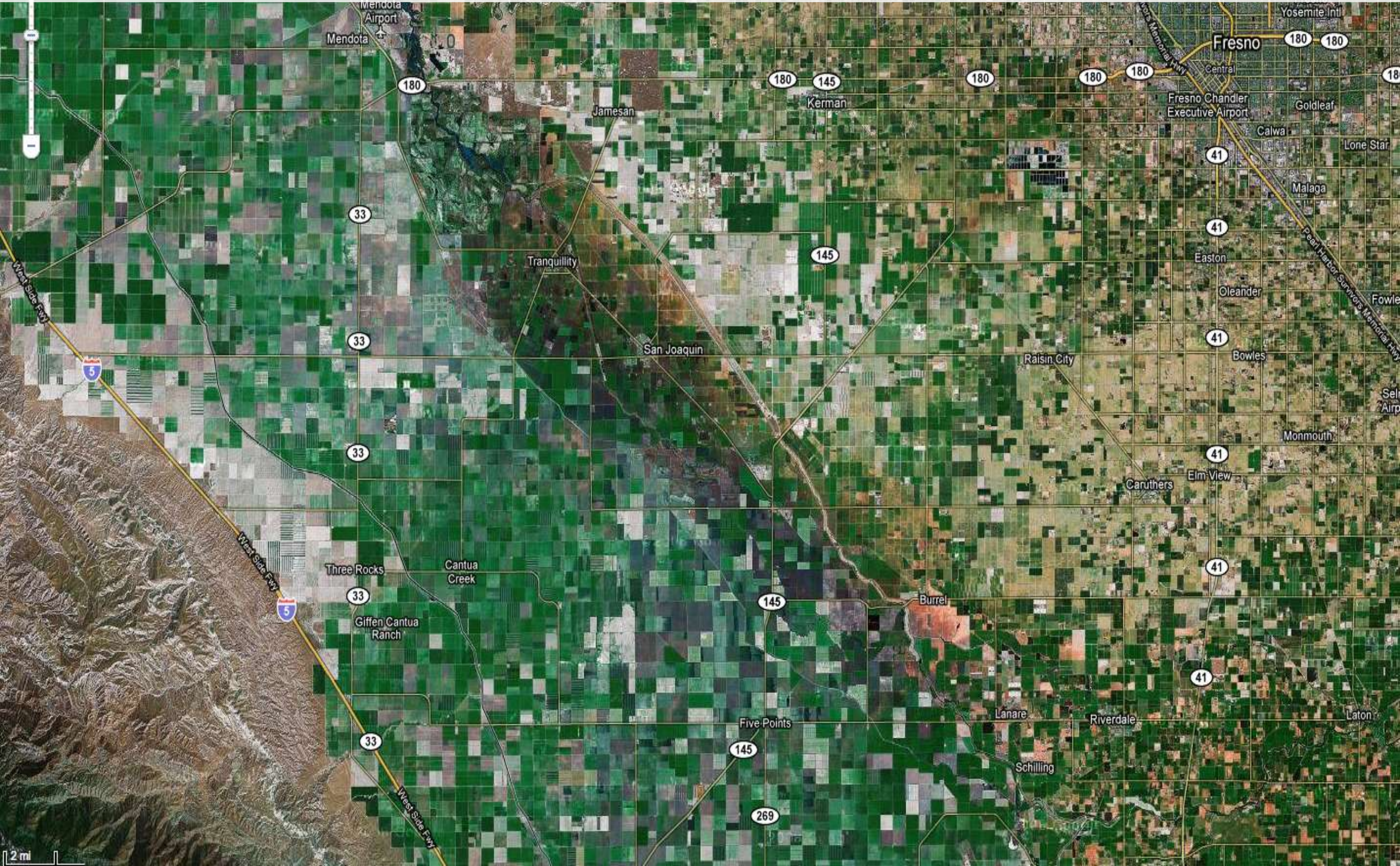
Handheld Monitors

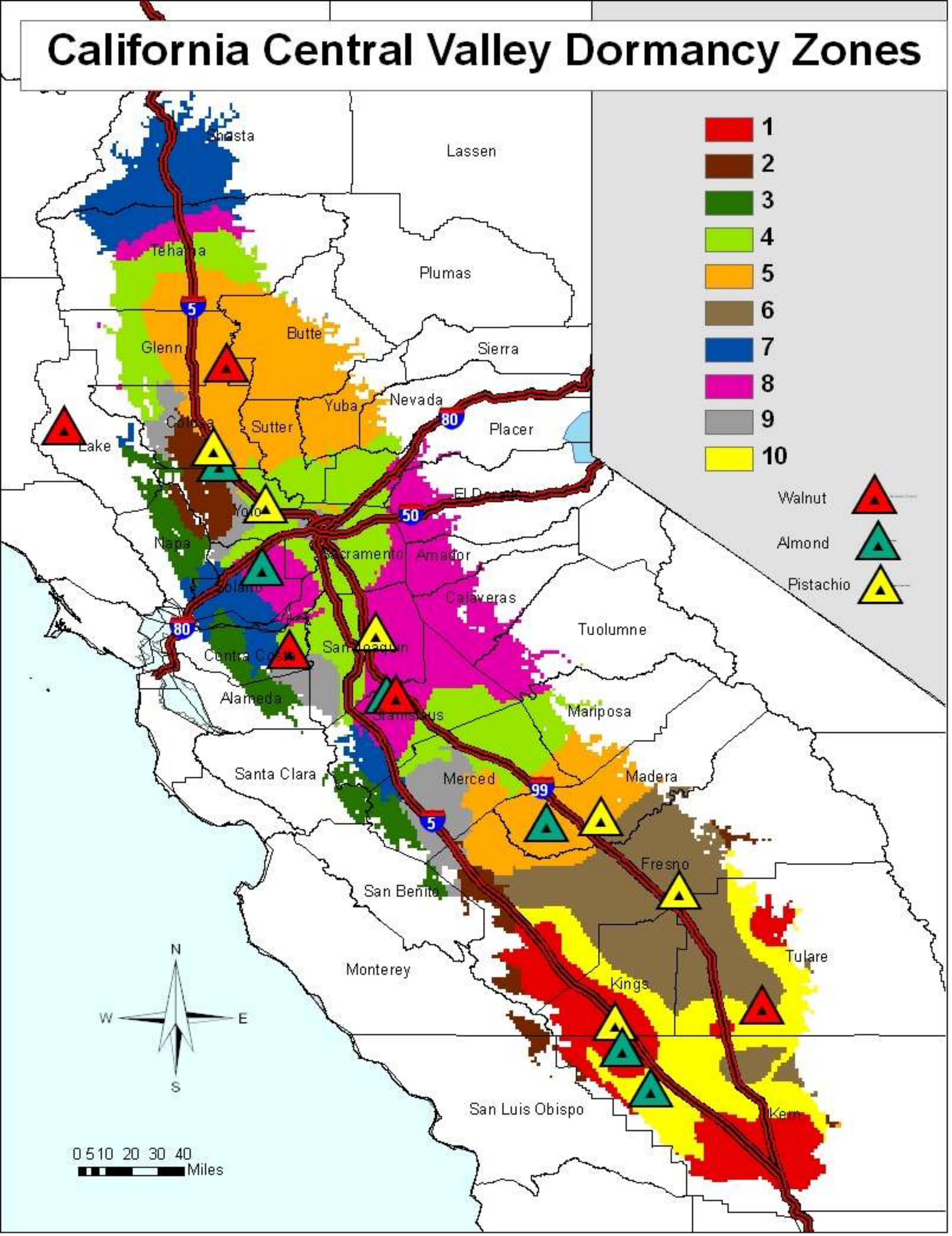
Rapid nutrient measurements



Large Scale Spatial Variability

2 Million Ha, 70% Fertigated, 10,000 growers, 5 Deg Latitude.





6 Almond Orchard Sites

All Sites: (>100 trees)

- 5 in-season full nutrient analysis
- 5 in-season Stem WP
- 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/FJ)

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

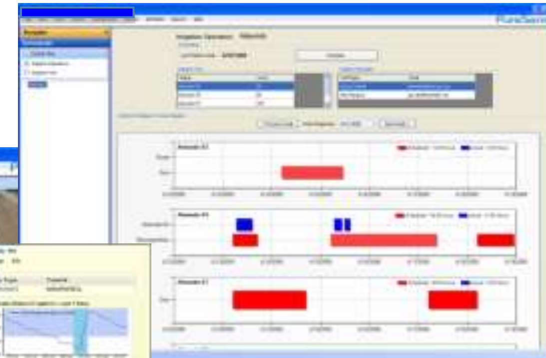
- 5 in-season full nutrient analysis, 5 in-season Stem WP, Soil water and irrigation volume, Yield (768 individual trees)
- NUE
- Canopy level imagery
- Aerial and satellite imagery

NutMan: Decision Support Using Predicted Yields, Real-time Field Data, Automated Analyses, and Information Delivered to Growers

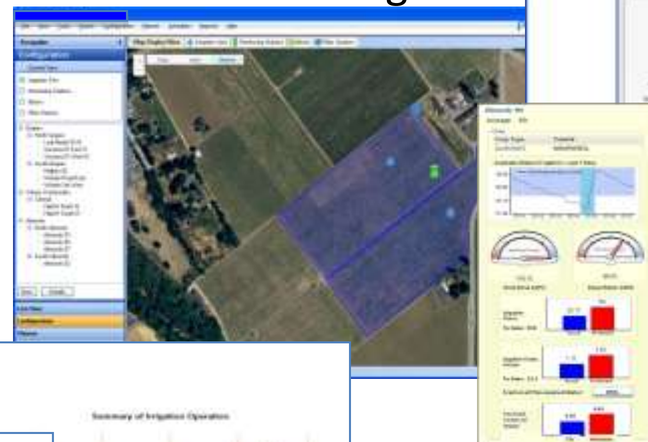
Automated Monitoring

Real-time Field Monitoring Stations Deliver Data Wirelessly So Growers Know Field Conditions On Demand

Models and Prediction

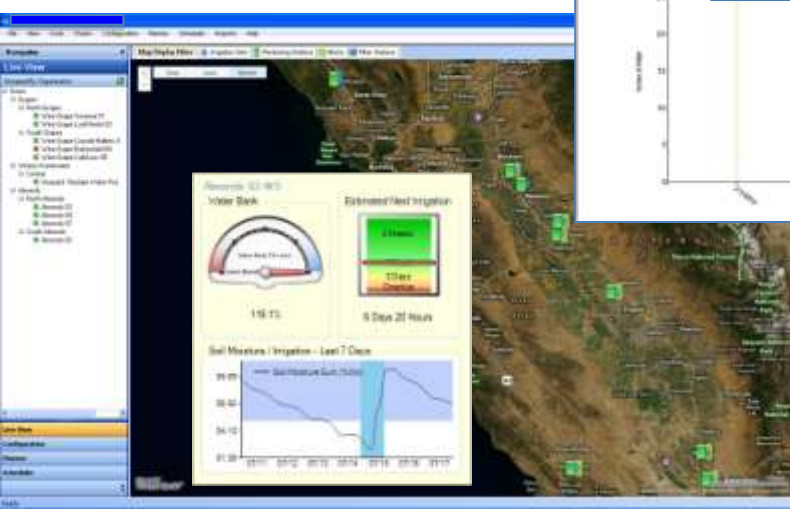


Remote Sensing



Growers can Use their Office or Field Computers, Even Their Phones, to Access their Information

Remote Sensing

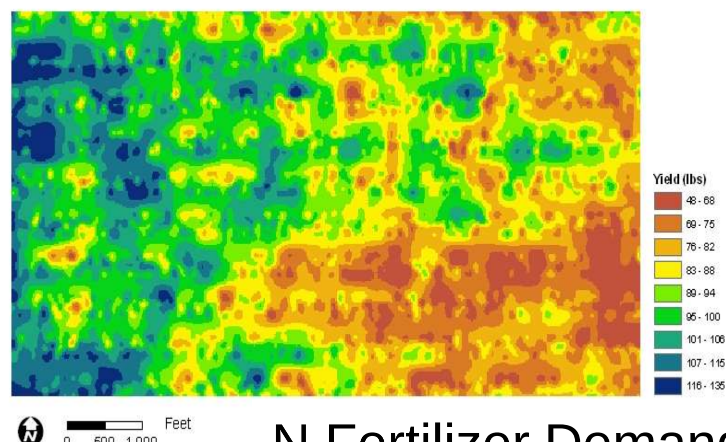


Provide Block Specific Decision Support in Easy to Use Format.

Nitrogen Demand by 5 acre Plot

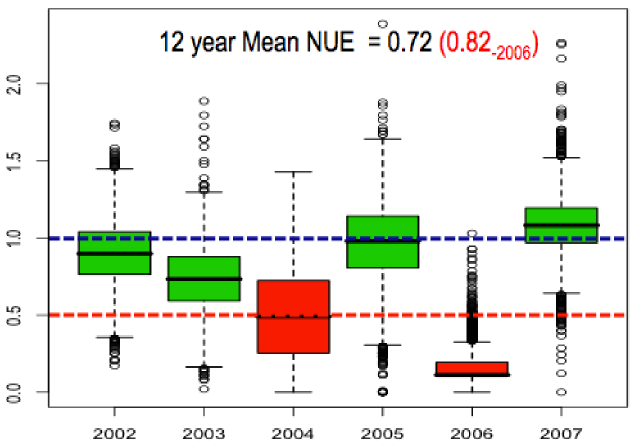
340 lbs	175 lbs	125 lbs	50 lbs
250 lbs	225 lbs	100 lbs	100 lbs
225 lbs	175 lbs	75 lbs	50 lbs
280 lbs	200 lbs	50 lbs	50 lbs

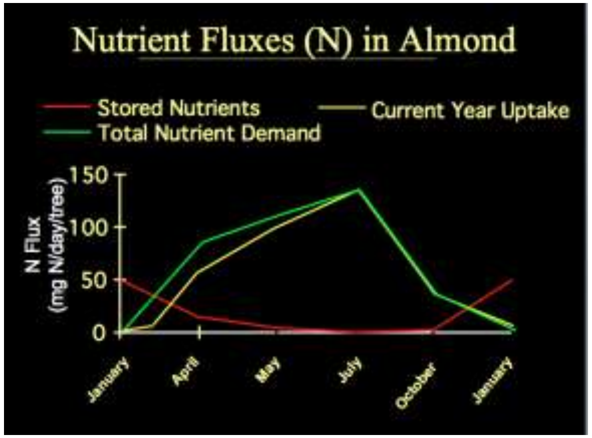
Yield (lbs)
- 136.636
- 137.099
- 143.397
- 148.51
- 149.55
- 149.668
- 154.514
- 158.025
- 166.666
- 171.823
- 173.783
- 175.463
- 176.924
- 179.882
- 183.041
- 186.476

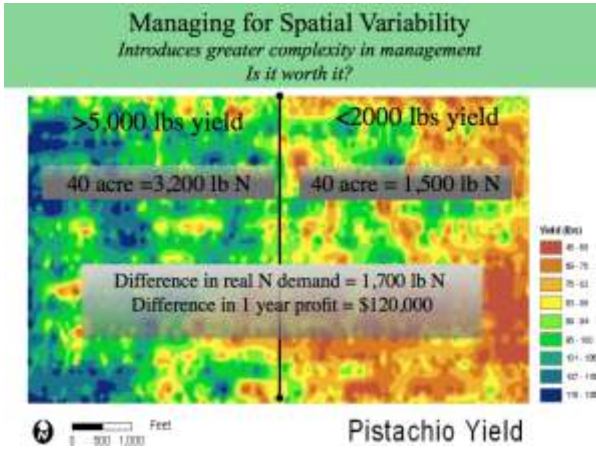


N Fertilizer Demand

Precision Nutrient Management Can Be Implemented In 2010 For Free







<u>Right Rate</u>

adjust N application to realistic yield expectation

Goal: Input = Demand

<u>Right Time</u>

Time N to match uptake

Goal: Fertilize during periods of growth

<u>Right Place</u>

Recognize and manage your field/block variability. Keep nutrients in root zone.

Goal: Precision

Acknowledgements

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Thank You

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