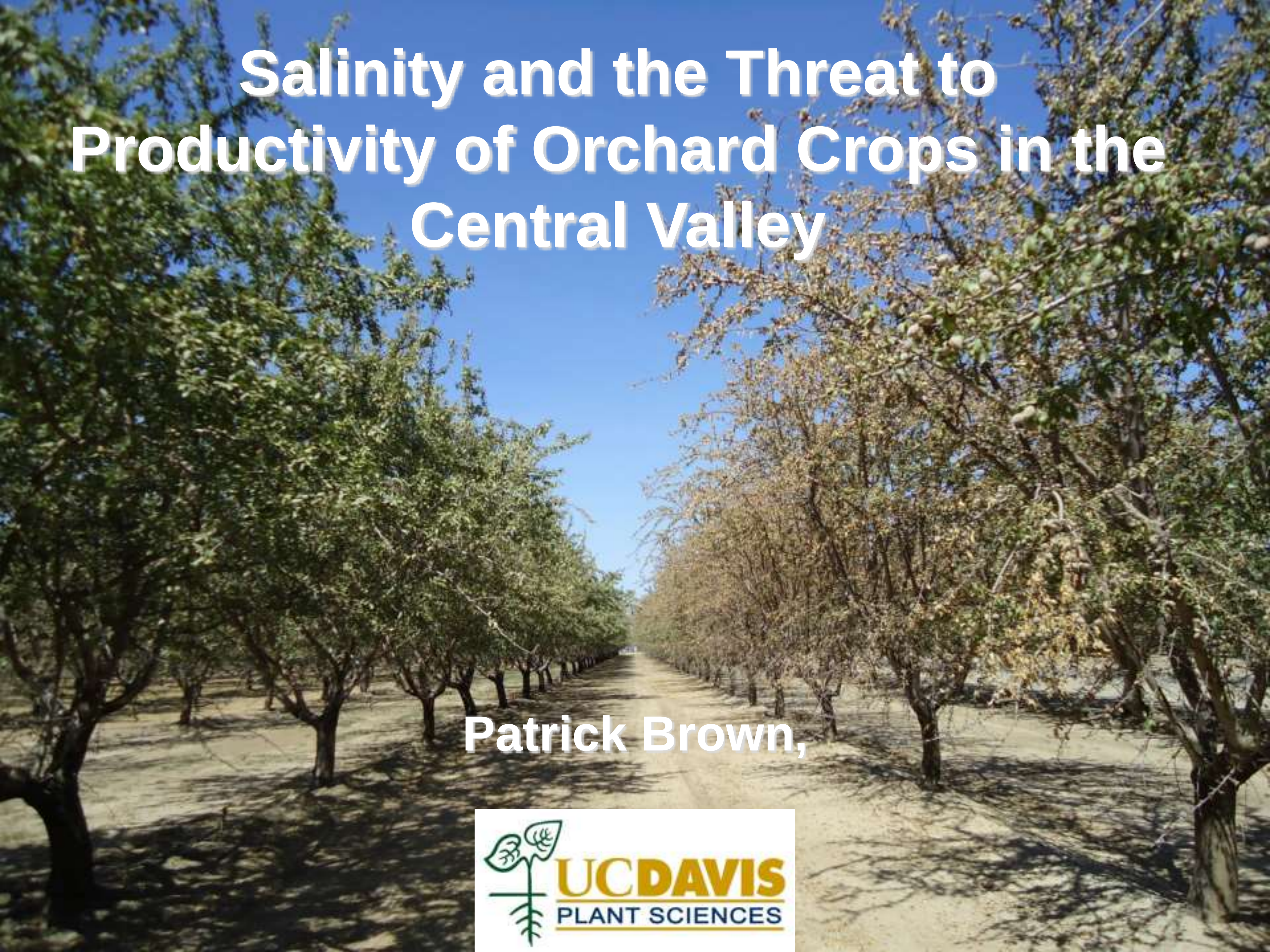
Salinity and the Threat to Productivity of Orchard Crops in the Central Valley



Patrick Brown,

UC DAVIS PLANT SCIENCES

PRODUCERS

Salt Is Slowly Crippling California's Almond Industry

July 24, 2015 · 4:33 PM ET

EZRA DAVID ROMERO

FROM

Almond orchards across California are dealing with trees showing signs of stress from the drought, such as smaller nuts and salt-burned leaves.

Salinity Stress in Plants

- 10-20% of the ~250 million ha of irrigated land in the world is currently degraded due to secondary salinization (Schoups et al. 2005; Munns and Tester 2008; Marschner 2012).
- ~4 million acres of irrigated cropland in California, corresponding to more than half of the total, are affected by salt stress to varying degrees (Letey 2000; Schoups et al. 2005).
- Estimated* >30% of orchard acreage in Central Valley is now using irrigation water that exceeds recommended salinity levels**.
- Drought worsens the situation by:
  - Reducing leaching,
  - Decreasing the availability and quality of surface water for irrigation, and increased dependence on lower-quality groundwater.

Salt – Transbasin Transport Per Year

SURFACE WATER salt transfer

311,000 Tons

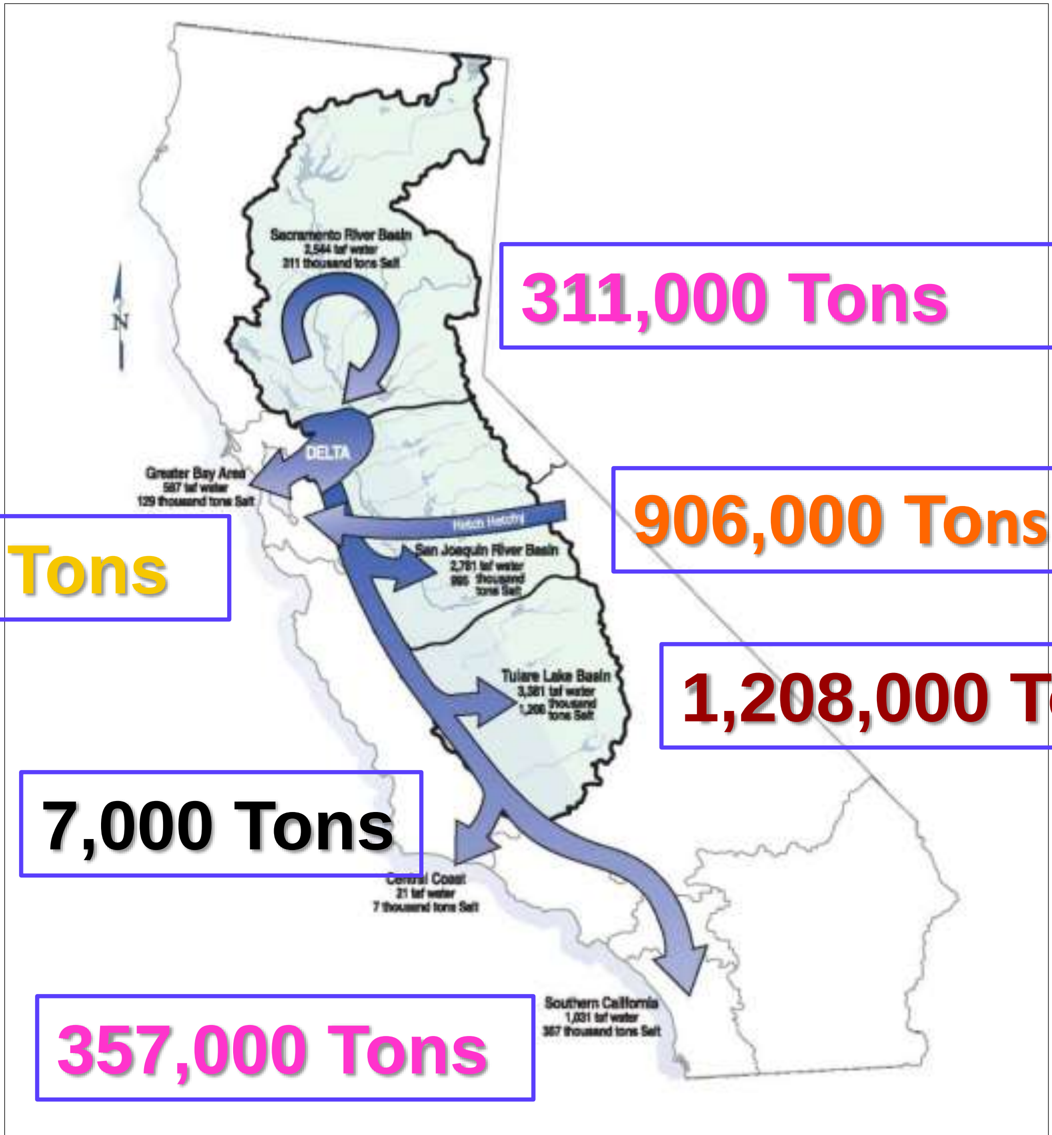
906,000 Tons

129,000 Tons

1,208,000 Tons

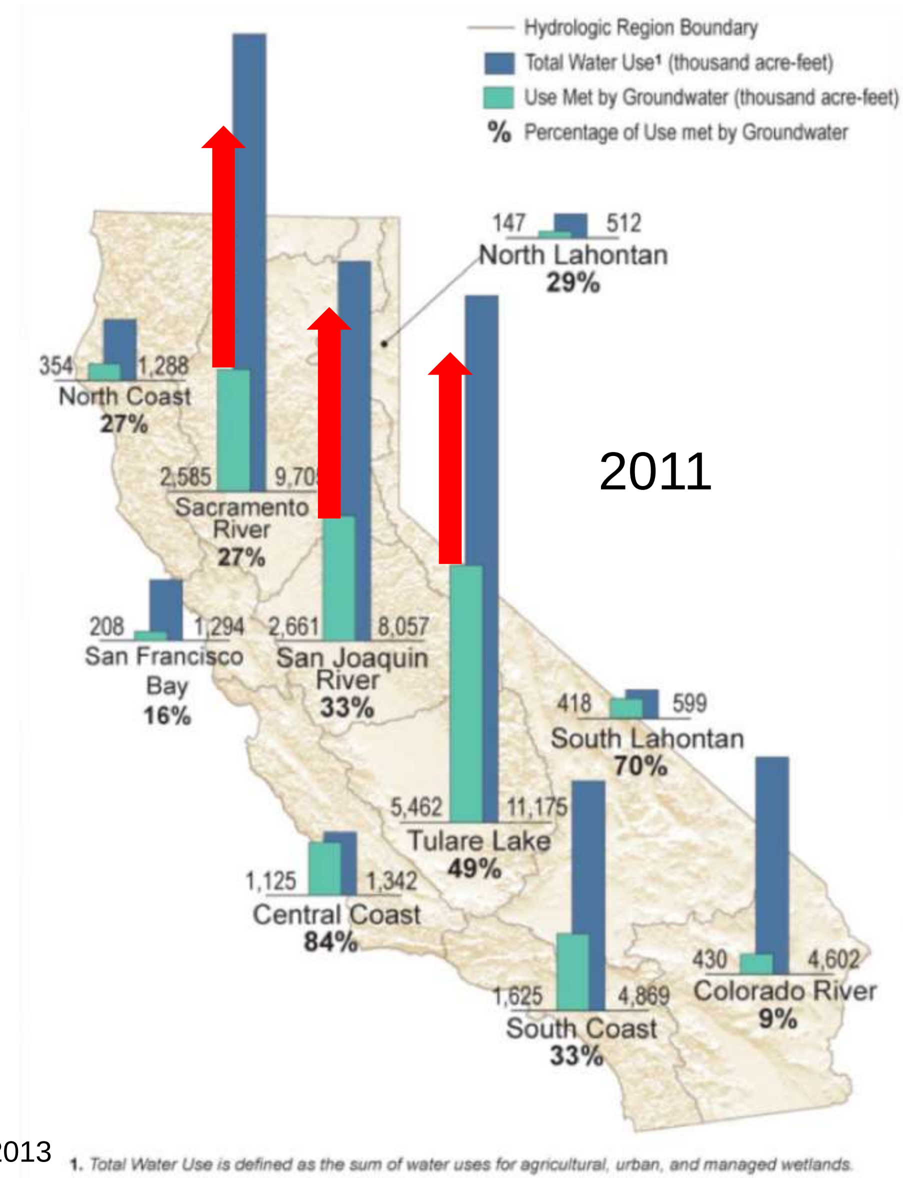
7,000 Tons

357,000 Tons



From DWR, Calif. Water Plan Update 2009

Total Water Use and Groundwater Contribution

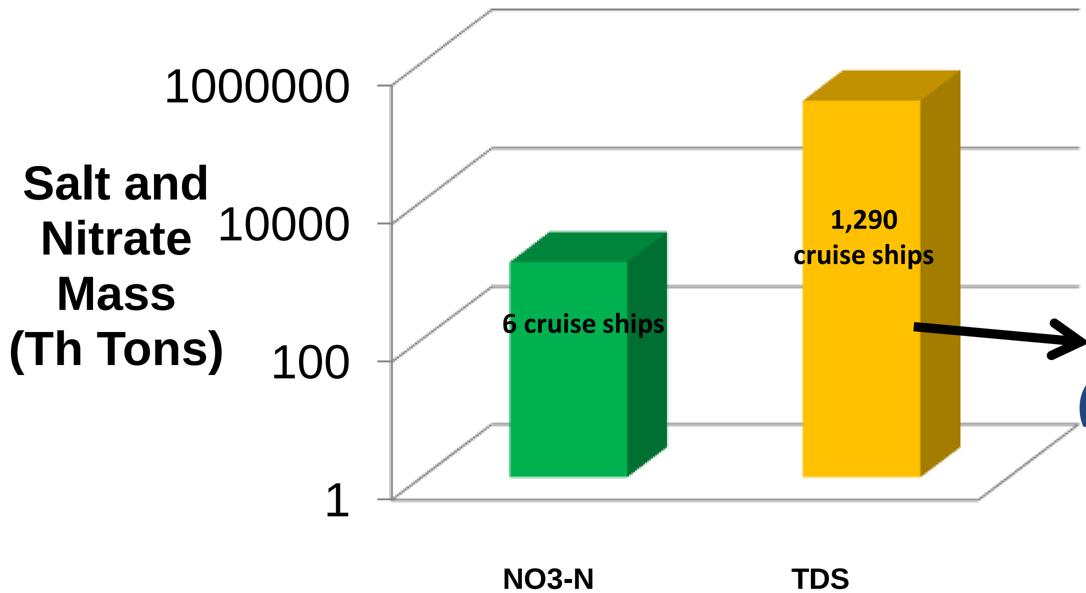


2011-2016 Increment in Ground Water Use as Proportion of Total

CV-Salts presentation to Central Valley Water Board 2013
Courtesy Vicki Kretsinger

How Many Cruise Ships….

Entire CV 20-Year Net Mass to Deeper Part of Aquifer System



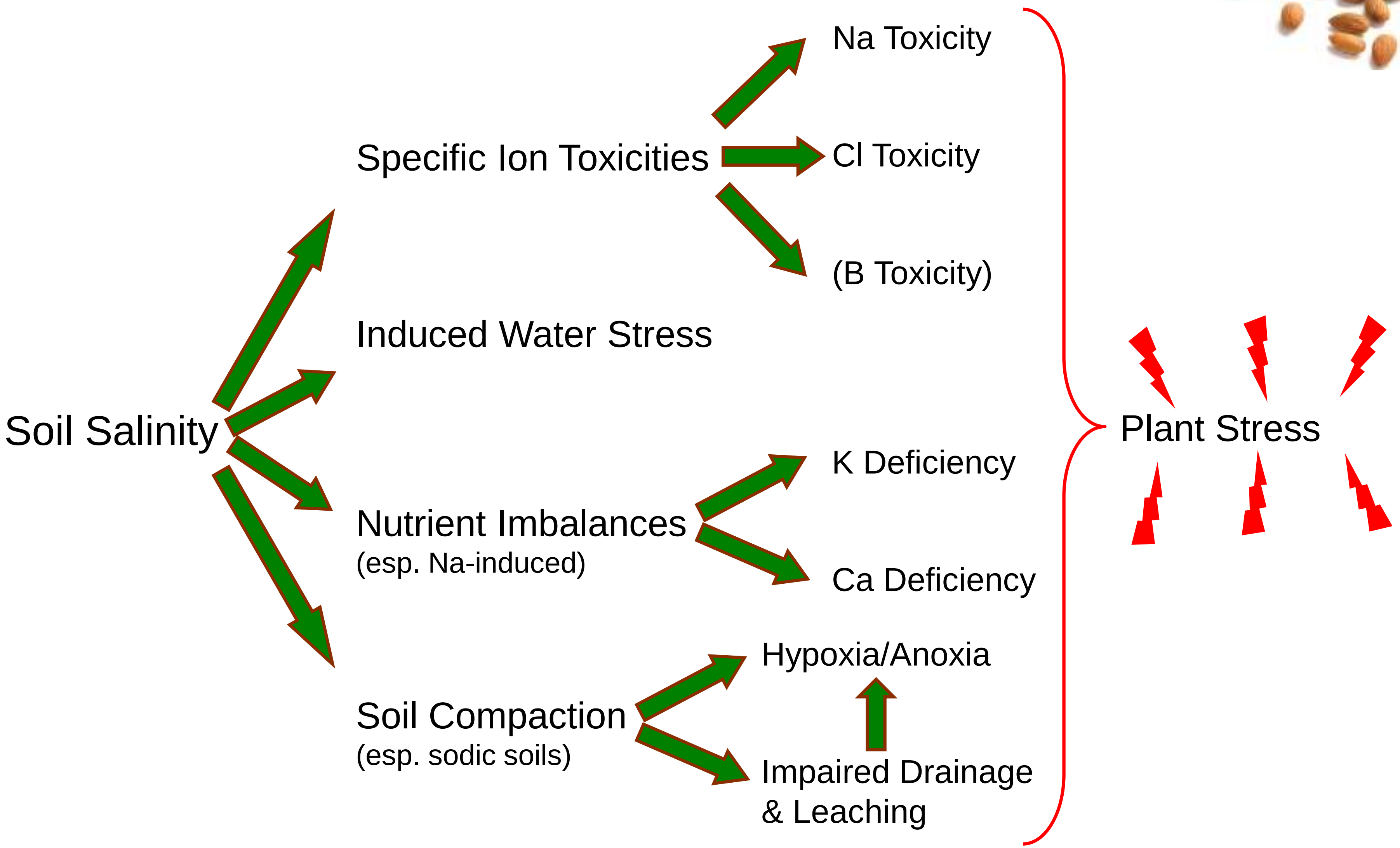
- 1,335 ThT NO_3
- 283,823 ThT TDS
- NO_3 is ~.5% of TDS

The equivalent of 289 miles long of cruise ships (~ Sacramento to Bakersfield)

Includes:
1 - applied water (SW/GW)
2 - nutrients + amendments
3 - ambient shallow mass

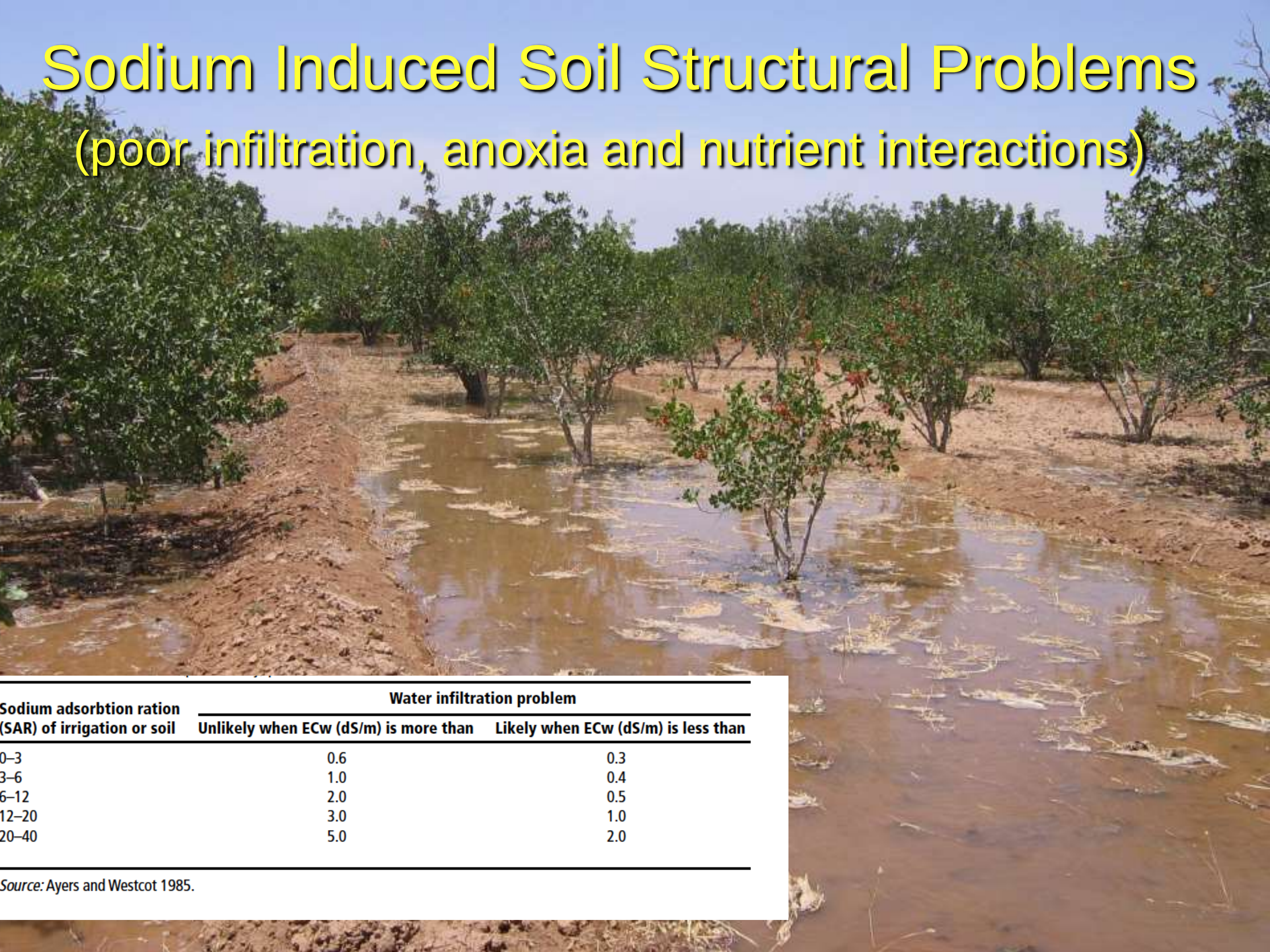
Courtesy Vicki Kretsinger

How does salinity harm plants in general and trees in particular?



Sodium Induced Soil Structural Problems

(poor infiltration, anoxia and nutrient interactions)



Sodium adsorbtion ration (SAR) of irrigation or soil	Water infiltration problem	
	Unlikely when ECw (dS/m) is more than	Likely when ECw (dS/m) is less than
0–3	0.6	0.3
3–6	1.0	0.4
6–12	2.0	0.5
12–20	3.0	1.0
20–40	5.0	2.0

Source: Ayers and Westcot 1985.

Salinity Thresholds for Selected Tree and Crop Species (Ec_e)

(but..there are problems with these numbers)

Crop	Soil salinity threshold (ECe dS/m)			
	0% yield loss	10% yield loss	25% yield loss	50% yield loss
Almond	1.5	2.0	2.8	4.1
Avocado	1.3	1.8	2.5	3.7
Citrus	1.7	2.3	3.3	4.8
Date Palm	4.0	6.8	11.0	18.0
Lucerne	2.0	3.4	5.4	8.8
Olive	2.7	3.8	5.5	8.4
Onion	1.2	1.8	2.8	4.3
Pistachio	4.0	4.5	5.0	6.0
Pomefruit	1.7	2.3	3.3	4.8
Potato	1.7	2.5	3.8	5.9
Stonefruit	1.7	2.2	2.9	4.1
Tomato	2.5	3.5	5.0	7.6
Vine	1.5	2.5	4.1	6.7

1 Adapted from Ayers and Westcot (1985)

Salinity Stress & Orchard Crops

- Almond, citrus, walnut are classified as a very salt-sensitive crops with a threshold ECe of 1.5 dS/m (Brown et al. 1953; Bernstein et al. 1956).
- Very old data, under flood/furrow irrigation, with non-bearing trees over a 12 month period (short term).
- Rootstocks, cultivars and ionic compositions can make a profound difference on response
- Irrigation system can make a profound difference
- The following are largely unknown:
  - The relative importance of the different components of salinity stress: specific ion toxicities, water stress, nutrient imbalance etc.
  - Which rootstocks and cultivars tolerate salinity better than others
  - Management practices to mitigate salinity

Plant Response to Salinity :
Time Scales

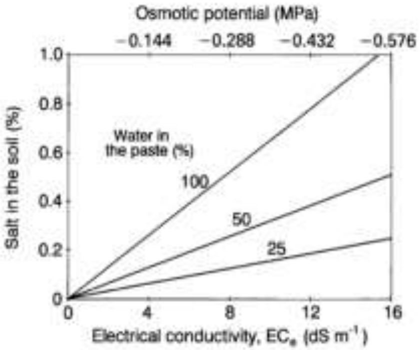
Table 1. Plant response to salinity at different time scales. The effects on a salt-tolerant plant are basically identical to those due to soil water deficit *(Salt tolerance typically refers to Na and Cl and does not imply B tolerance)*

Time	Water stress effects (Observed effect on growth of a salt-tolerant plant)	Salt-specific effects (Additional effects on growth of a salt-sensitive plant)
Minutes	Instant reduction in leaf and root elongation rate then rapid partial recovery	
Hours	Steady but reduced rate of leaf and root elongation	
Days	Leaf growth more affected than root growth; Reduced rate of leaf emergence	Injury visible in oldest leaf
Weeks	Reduced final leaf size and/or number of lateral shoots	Death of older leaves
Months	Altered flowering time, reduced seed production	Younger leaves dead, plant may die before seed matures
Years		Ion toxicity, impaired vascular function, leaf chlorosis and necrosis, reduced shoot growth, death.

Plant, Cell and Environment (2002) 25, 239–250

Comparative physiology of salt and water stress

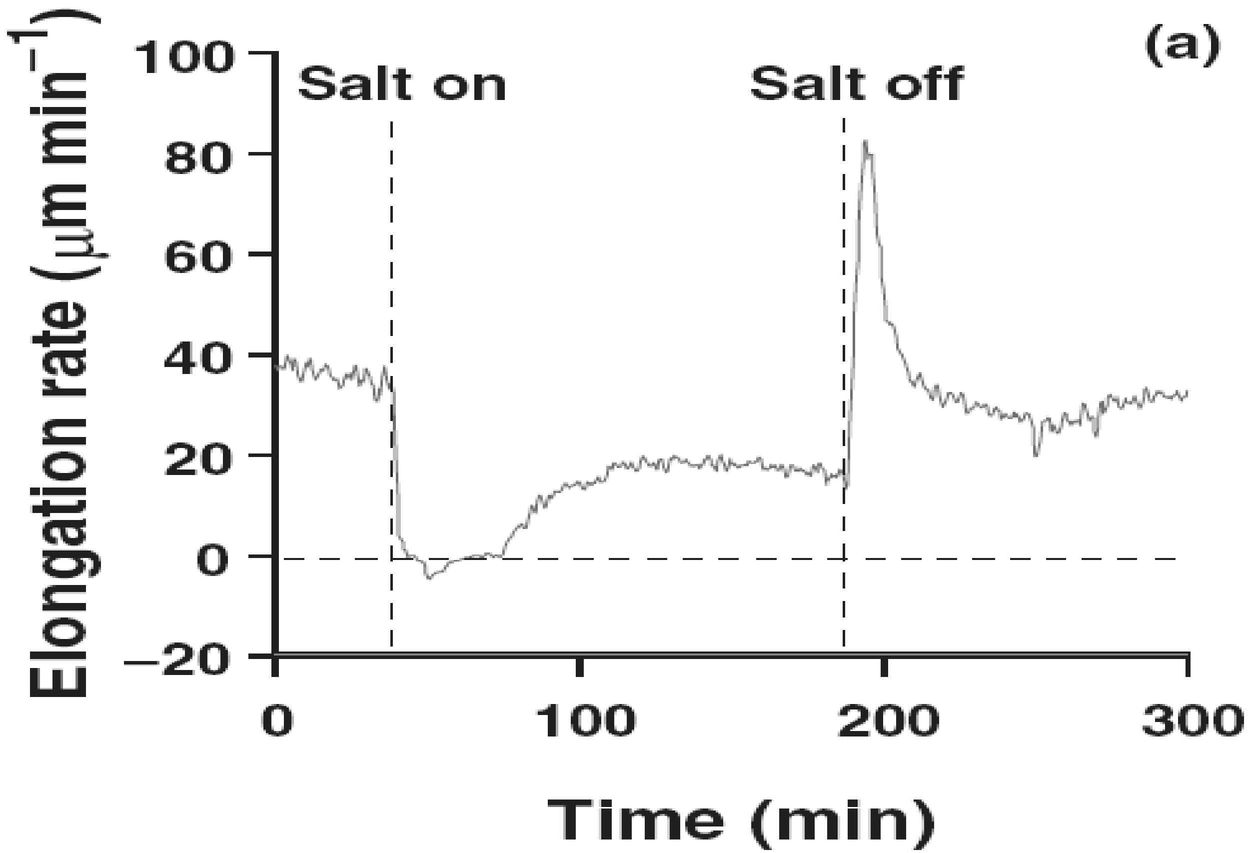
R. MUNNS

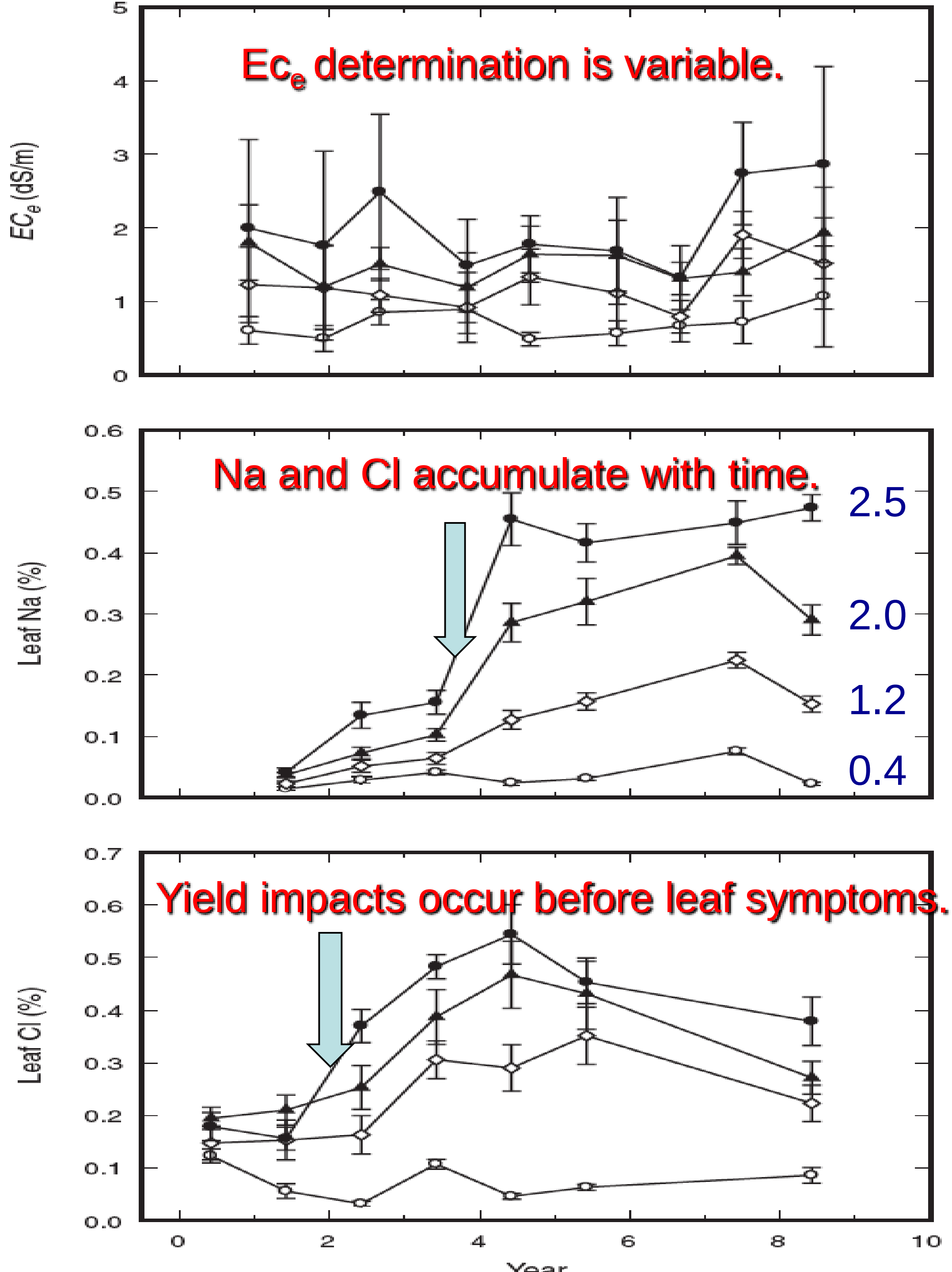


Short Term Effects

Salt stress induces water stress prior to ion specific toxicity is observed. (Tomato)

Comparative physiology of salt and water stress





Long Term Effects of Salinity on Citrus

Prior et al 2007

- Valencia on sweet orange over 9 years

- 0.4, 1.25, 1.96, 2.5 dS/m as NaCl.

- Ec_e > 2.0 resulted in significant yield loss

- Na >0.25% and Cl above 0.3% resulted in yield loss and occurred before symptoms were seen.

- Cl accumulates more rapidly than Na.

ION TOXICITY

Chloride toxicity in almond leaf

(accumulates with time, most species >0.3% results in yield loss, symptoms may not appear until >0.8%)

Sodium toxicity in almond leaf

(in many species Na is retained in wood, hence leaf Na is a relatively poor indicator of salt stress)

From Daniel Munk, UC extension, Fresno

Boron Toxicity in Pistachio

(accumulation in leaf directly reflects soil B concentrations. Leaf symptoms can occur with minimal yield loss.)

Boron toxicity in almond

(very limited leaf accumulation, no leaf symptoms, hull analysis is preferable)

Boron toxicity in avocado leaf

Experimental Design and Procedure

- Young grafted almond trees planted in 7-gal pots
- Calcined clay (Turface) used as growth medium
  - Excellent drainage and aeration properties due to large particle size
  - High cation exchange capacity (CEC)
- 4-replicate experiments conducted in open field conditions
- Essential minerals and salts applied with irrigation water
- Lots of free leaching in order to keep the nutrient and salt concentrations in the pots at the desired levels
- 3 salinity levels:
  - No salts added other than the essential minerals (~1 dS/m)
  - 20 mM NaCl (+2 dS/m)
  - 40 mM NaCl (+4 dS/m)

Experimental Design and Procedure - 2

- Exp. 1: Rootstock experiment
  - Rootstocks: Nemaguard, Hansen536, Empyrean-1, Viking
  - Cultivar: Nonpareil
- Exp. 2: Cultivar experiment
  - Cultivars: Nonpareil, Mission, Monterey, Fritz
  - Result: Nonpareil is more Na, Cl resistant than any other cultivar
- Exp. 3: Rootstock-cultivar interaction experiment
  - Rootstock effects are consistent across cultivars
- Exp. 4: Salt type experiment (Nonpareil on Nemaguard)
  - NaCl vs. KCl vs. Na_2SO_4
- Exp. 5: Double-graft experiment
  - Nonpareil-Mission on Nemaguard

Objectives of this Project

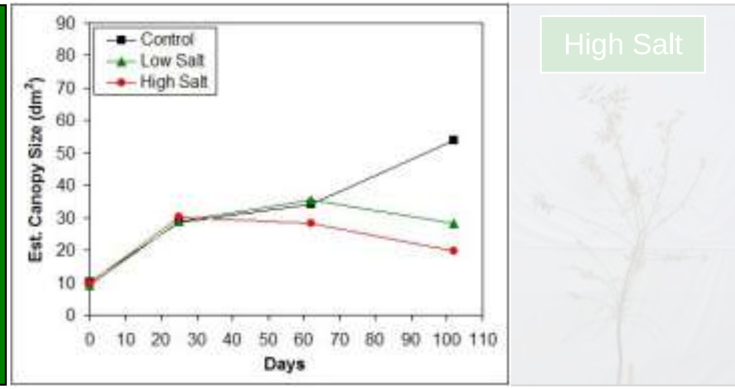
- Study the salinity tolerance of important rootstocks and cultivars by monitoring growth and toxicity symptoms
- Elucidate the physiological mechanisms conferring different levels of salt tolerance: root uptake, exclusion from leaves, tissue tolerance, etc.
- Understand the relative importance of specific Na and Cl toxicities
- Provide the physiological basis needed to optimize almond breeding for salt tolerance


6 months growth
>3 Meter
30 cm
Nonpareil on Viking
(3dS)
20 litre pot

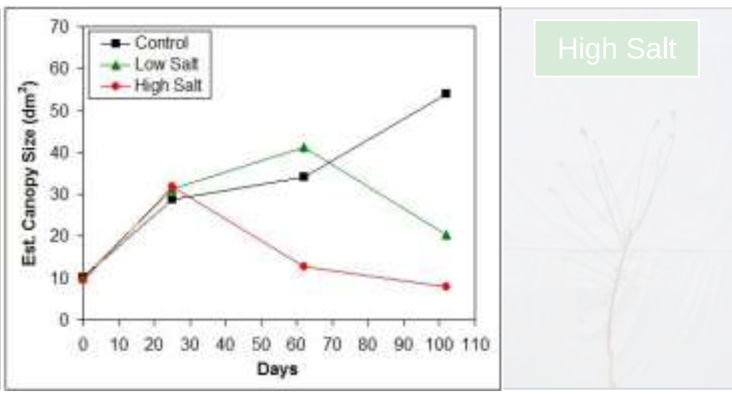
Growth and Salt Tolerance of Nonpareil on Different Rootstocks

Effect of Salt Type on Growth of Nonpareil on Nemaguard

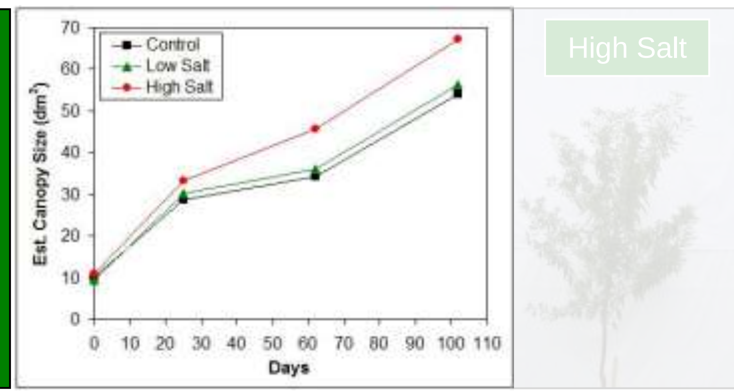
NaCl



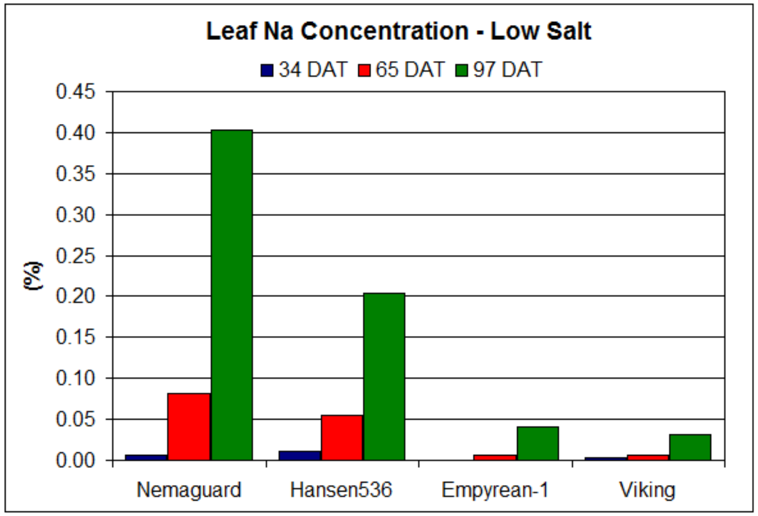
KCl

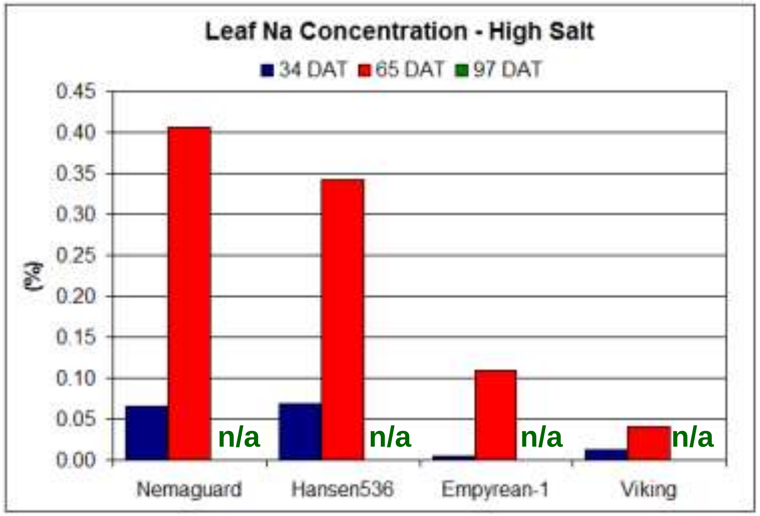


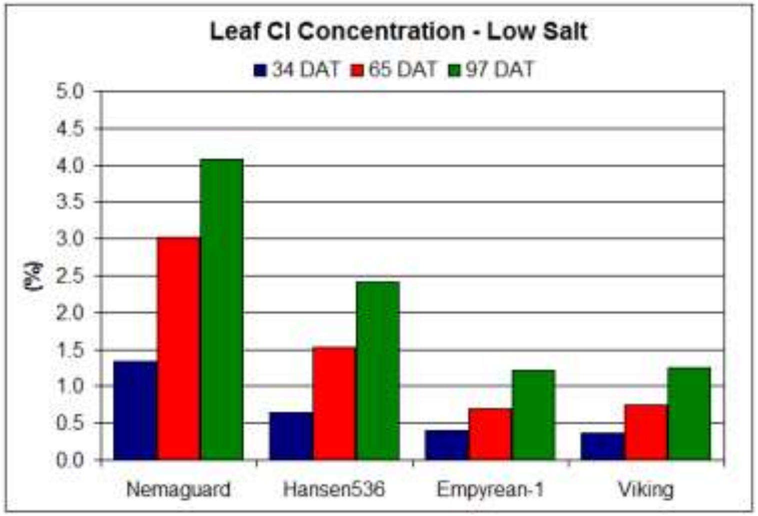
Na_2SO_4

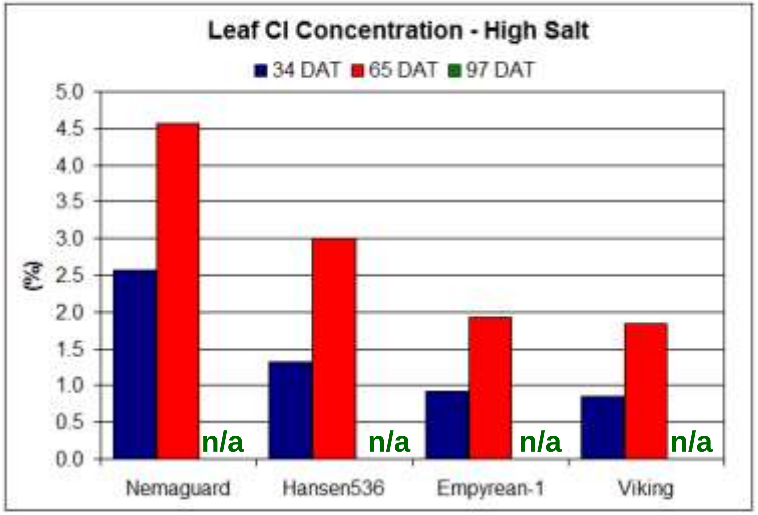


Leaf Na and Cl Concentrations Rootstock Experiment (1st Season)









Conclusions

- At practically relevant salt levels, specific ion toxicities are primarily responsible for salt damage to almonds.
- Both the primary (canopy) and secondary (trunk) growth of almond are affected by salinity stress.
  - Severe ion toxicity can cause extensive necrosis and partial or complete defoliation.
- There is a great degree of variation in salinity tolerance of rootstocks:

  Nemaguard < Hansen536 < Empyrean-1 ≈ Viking

  $>2.0 dS.m^{-1}$ $>2.6 dS.m^{-1}$ $>3.8 dS.m^{-1}$

- Cl can accumulate to toxic levels in leaves much faster than Na when they are found at comparable levels in the soil.
  - In that case, Cl is the primary toxic ion.
  - Cl exclusion at the rootstock level determines the salinity tolerance.

Salinity Thresholds for Selected Tree and Crop Species (Ec_e)

(but there are problems with these numbers)

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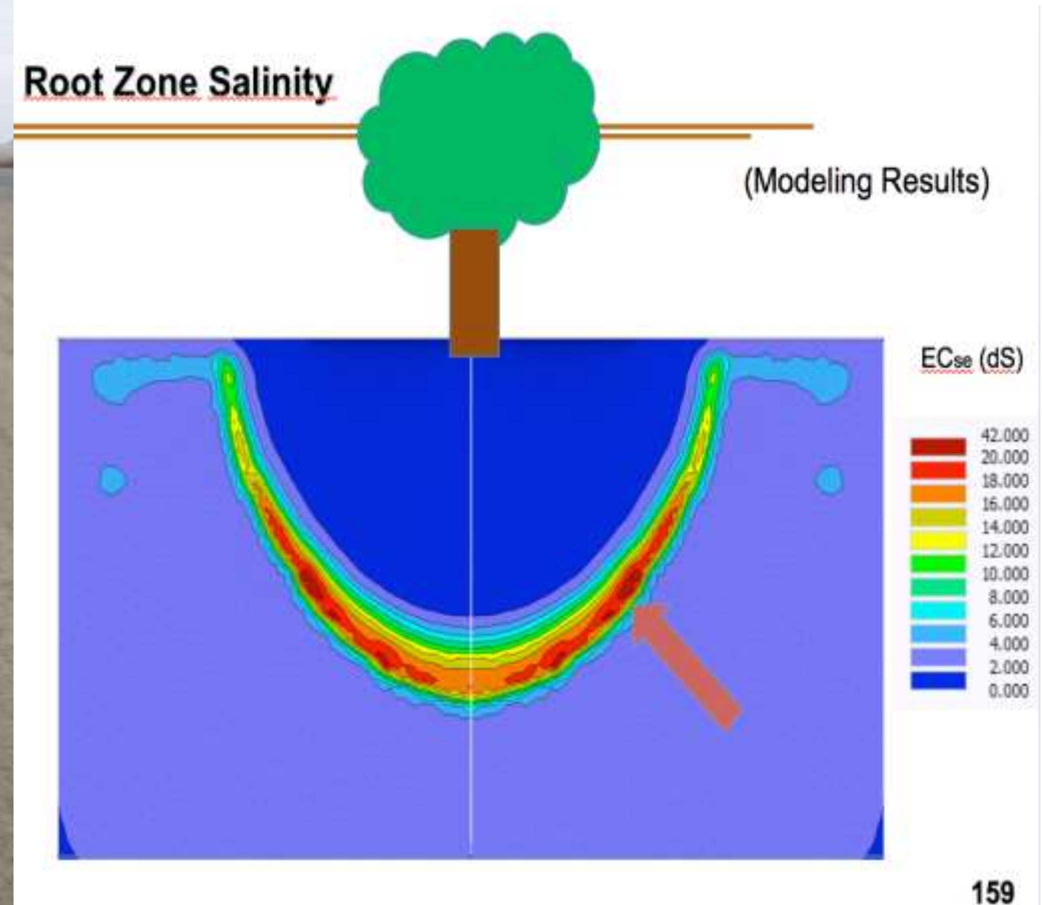
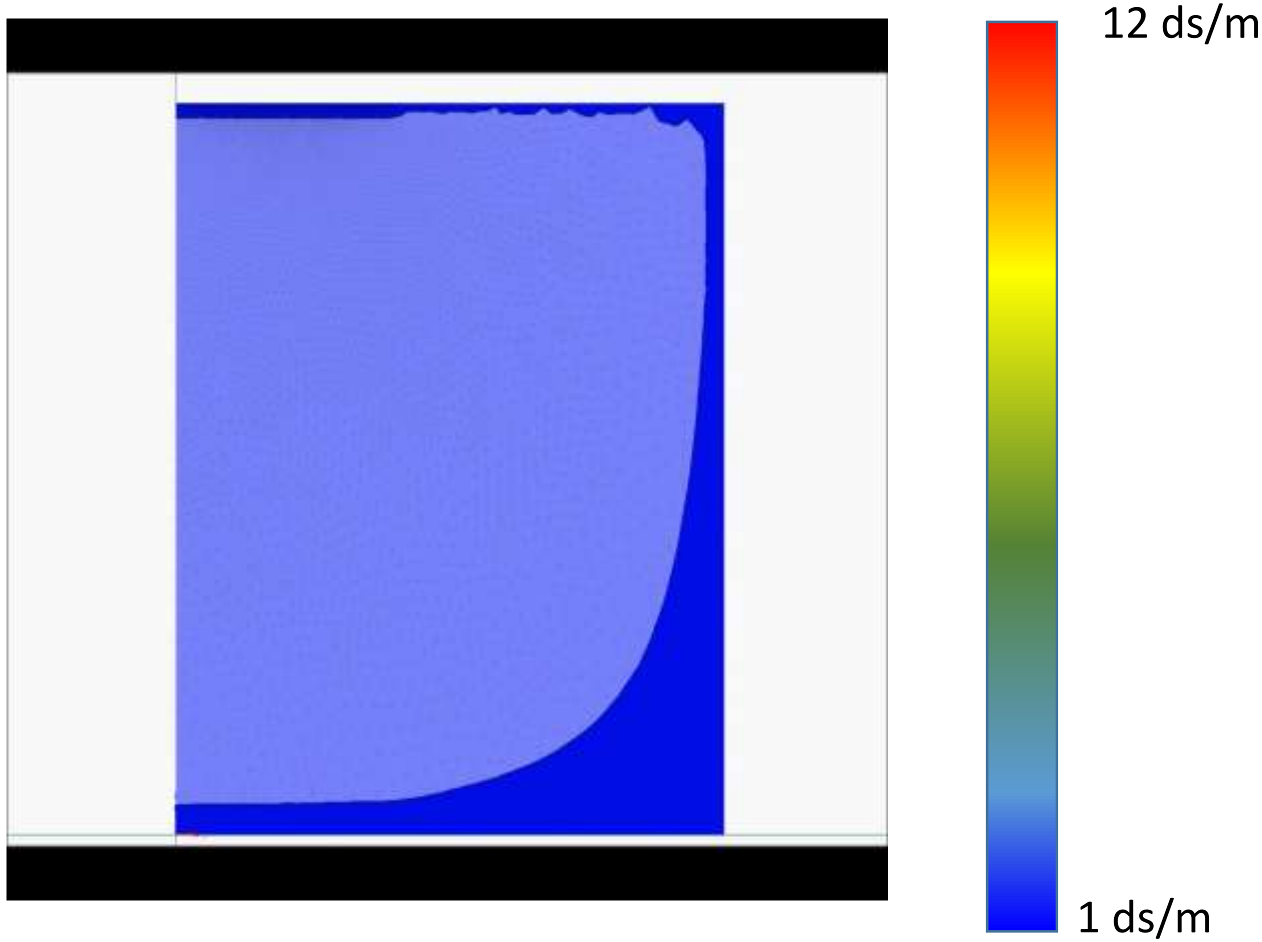
1 *Adapted from Ayers and Westcot (1985)*

Non Uniform Soil Salinity is Normal in Microirrigated Almond



Simulated Salt Deposition under Drip Irrigation

Belridge Almond – Milham Silty Loam- Double Line Drip
30 day scenario May-June, Irrigated to replace ET at 7 day intervals
1dS Irrigation Water (NaCl)



Almonds have a remarkable ability to adapt to non-uniform soils, selectively obtaining water from the low EC portion of the root zone.

- Nutrient Uptake?
- Field verification.
- Implications for irrigation management strategies for both salinity and nutrition.

Control/Control Low Salt/Low Salt High Salt/High Salt

Control/Low Salt Control/High Salt Low Salt/High Salt


Nonpareil on Viking
(3dS)
20 litre pot
4 Meter
30 cm

Growing Good Almonds in Bad Dirt
(4000 lb average years 4-8.)

Native Soil Conditions (Sat Extract)
(0-50 cm composite)

	Test	Recommended
pH	– 8.9	(<7.5)
Ca:Mg	– 1:1	(>2)
Ec_{se}	– 4.7dS	(<1.5dS)
ESP	– >25%	(<15%)
B	– 6ppm	(<2)

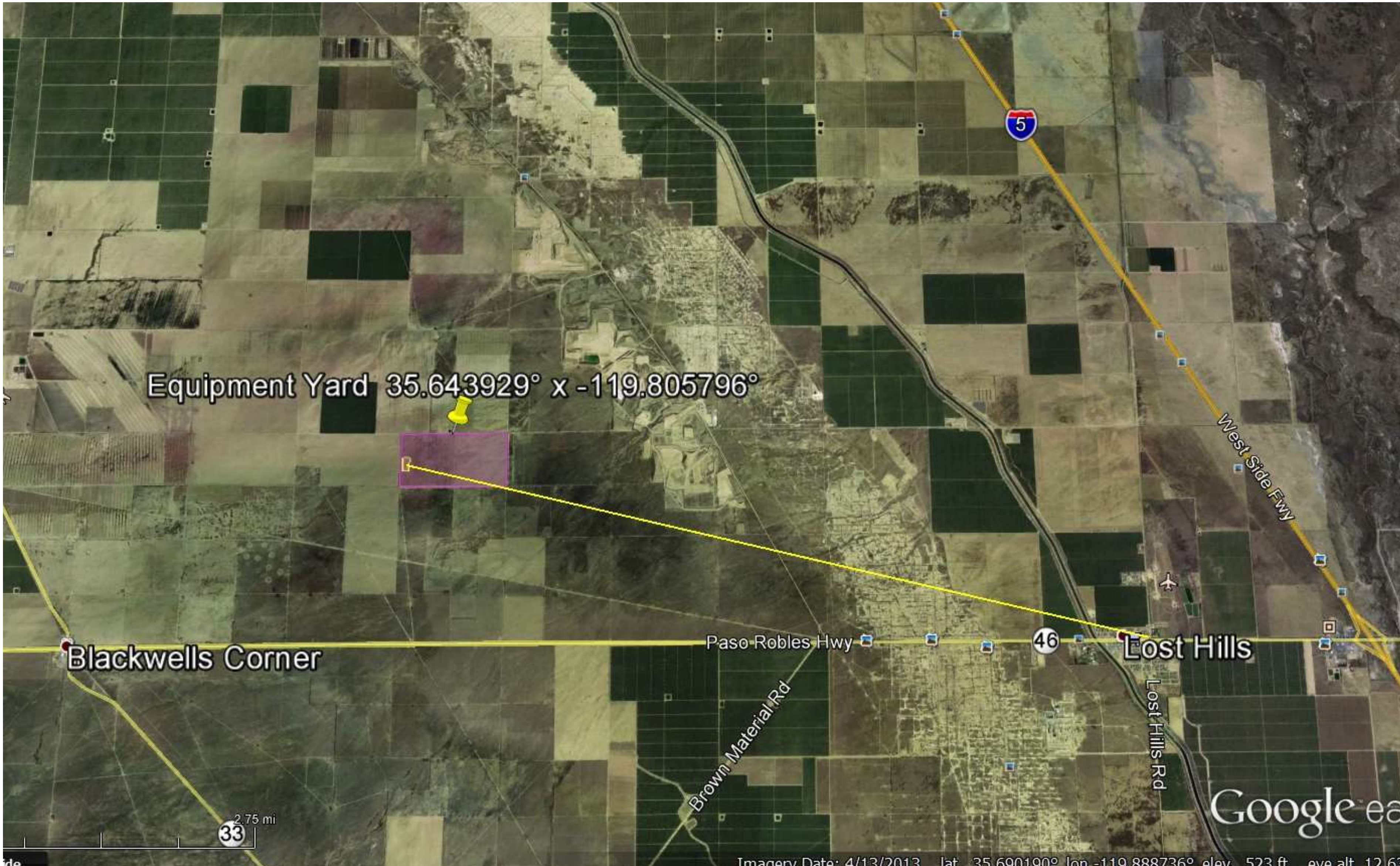
Water

58 inches of $0.5 dSm^{-1}$,
0.4 ppm B. Well structured draining soil *(consequence of massive gypsum and OM additions)*

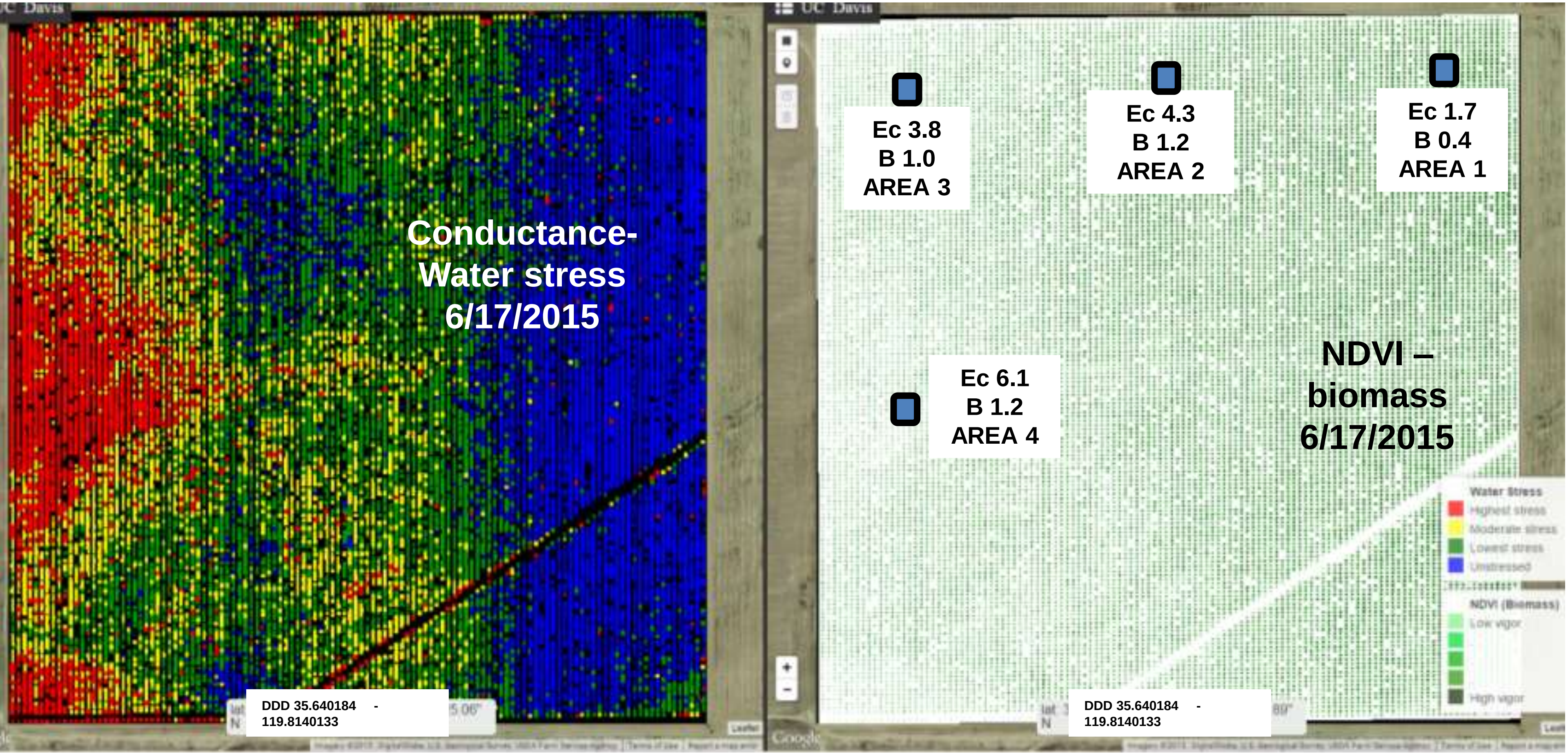
Question: How much of the 58 inch is really needed. What is the best water distribution in day or year? How does rootstock influence management? How critical in soil texture? What happens in a drought?

Maintaining Good Soil Structure Allows Roots to Fully Explore the Soil, Improves Water Holding, Enhances Soil Microbial Activity, Improves Tolerance to Stress Conditions.

Almond Board Salinity and Boron Concentration Survey.



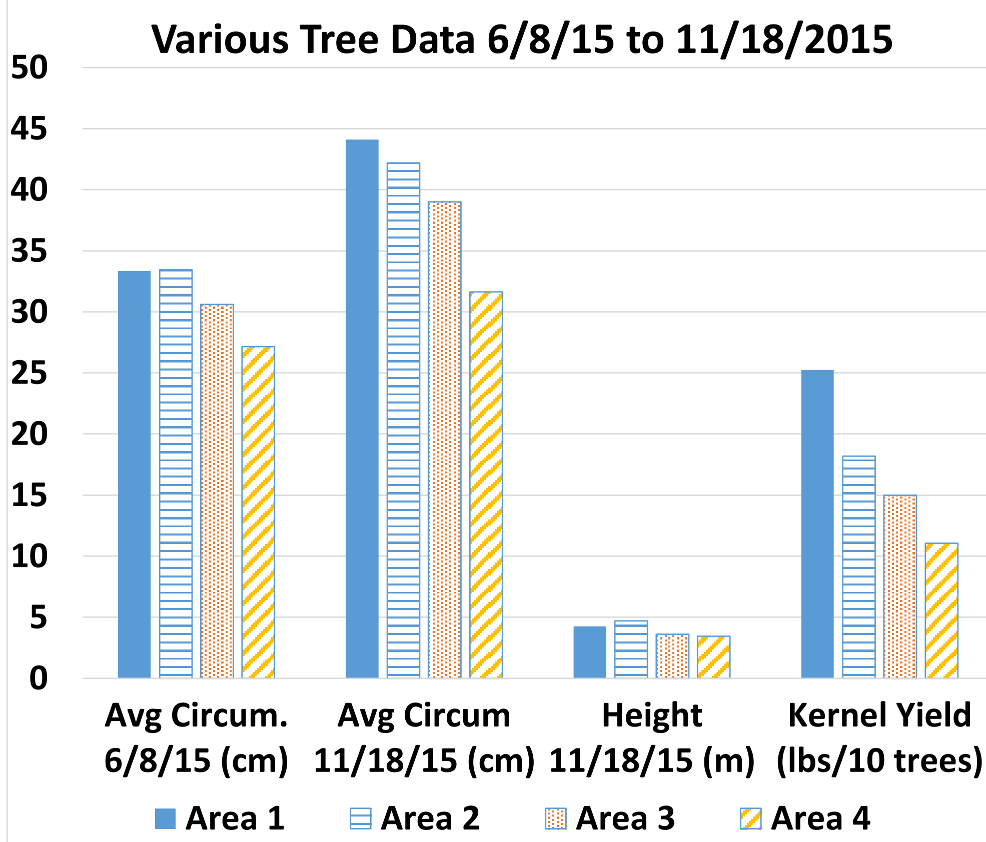
Almond Board Salinity and Boron Concentration Survey.



Aerial imagery (6/17/2015) and Areas 1 to 4 salinity sampling locations

Modest negative impact on growth and surprisingly low leaf Na and Cl.

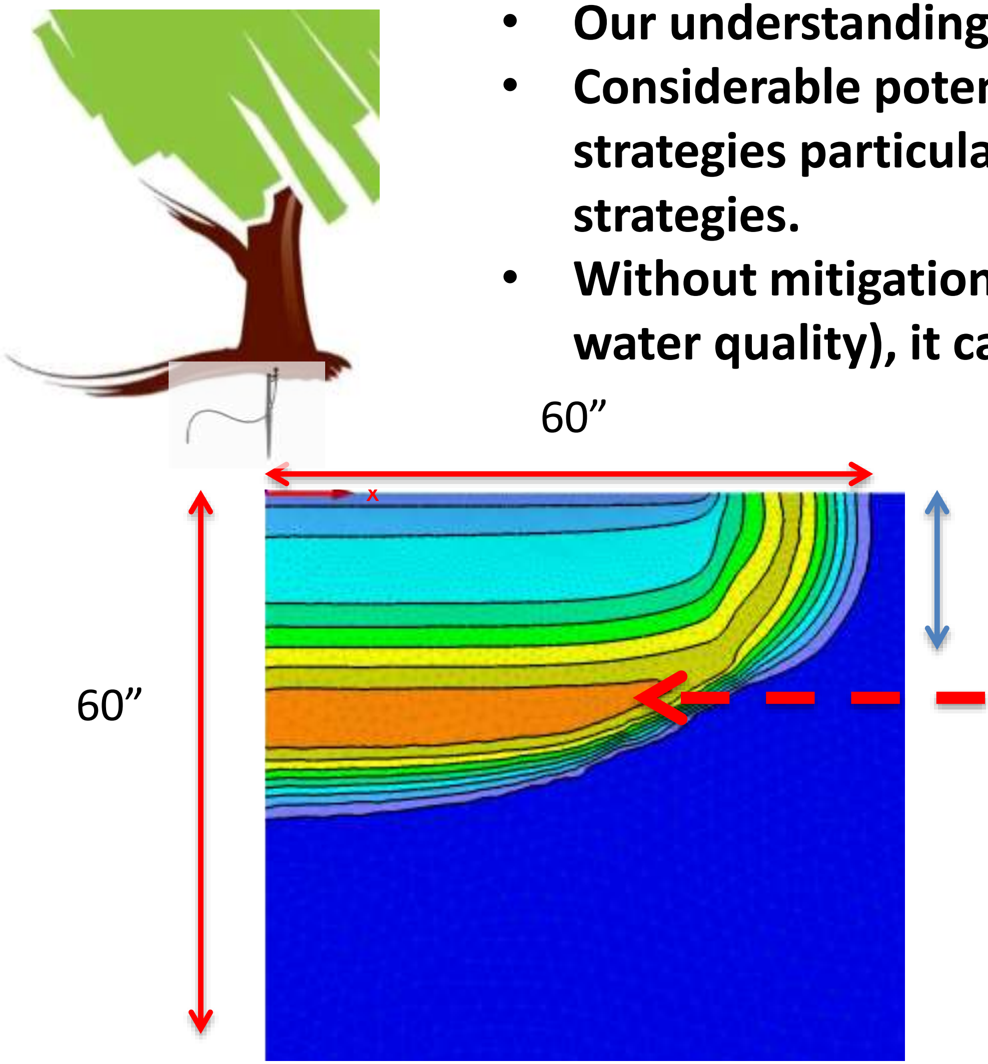
(Nonpareil on Hansen)



Significant boron toxicity now appearing. Increased hull B, gummosis and stem cracking.

What Next:

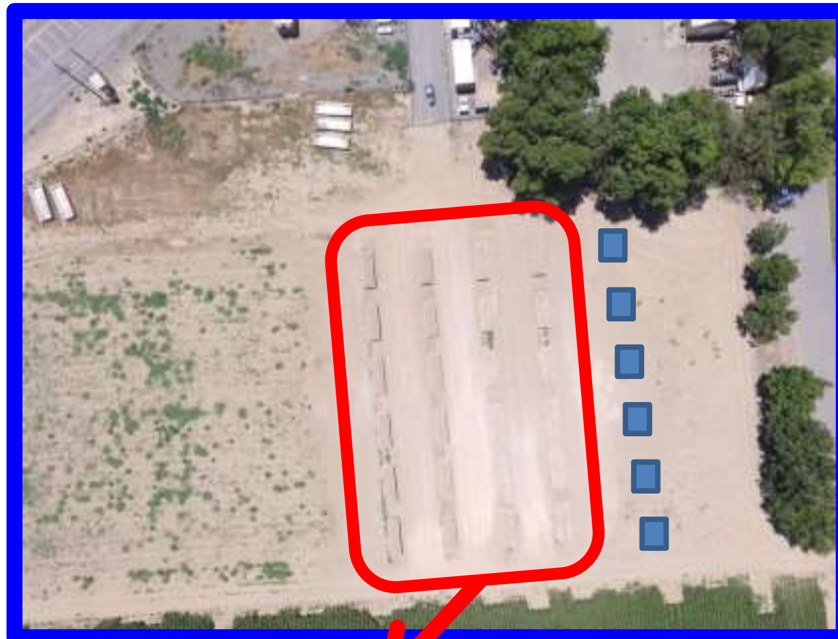
- **Salinity is the greatest threat to orchard production in California**
- **Our understanding is still limited**
- **Considerable potential to improve management strategies particularly irrigation and leaching strategies.**
- **Without mitigation (leaching and/or improved water quality), it can only get worse.**



Kandelous, Unpublished

Semi-Field experiment **(Model calibration/validation)**

3 irrigation/salinity treatments
2 soil types
2 almond varieties
Leaching, soil conductivity, soil ion distribution, root distribution, nitrate dynamics, crop response.



Thank You

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- USDA-SCBGP