Water Use Efficiency in Vineyards

Conservation, Irrigation, and Salinity Management

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North Coast

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Climate Impacts

Must consider both **direct** and **indirect** impacts of changing climates

1. Change in growing season length
2. Earlier or later budbreak and ripening
3. Resource scarcity (i.e., water/fertilizer)
4. Increased soil salinity
5. More extreme weather events

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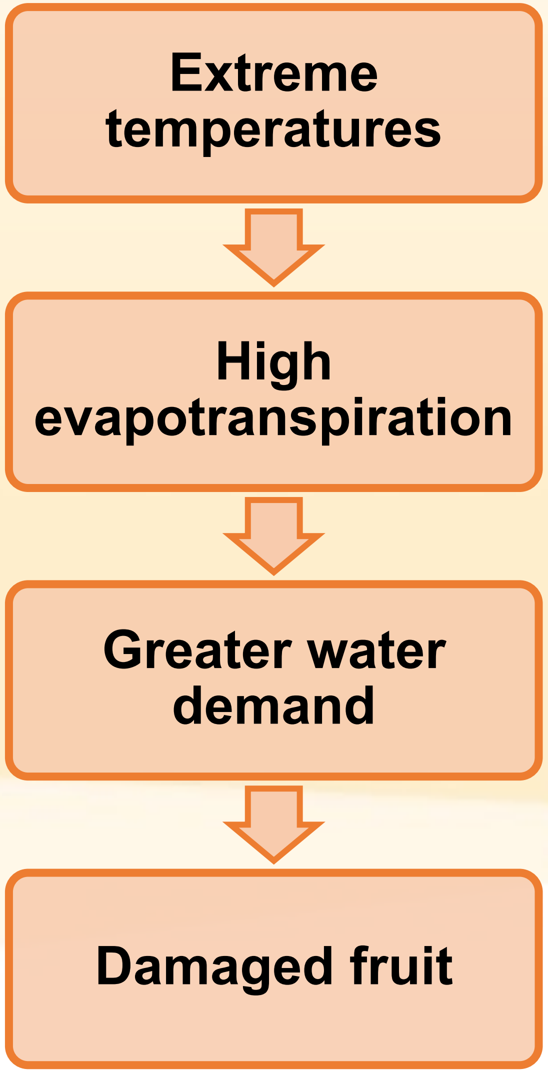
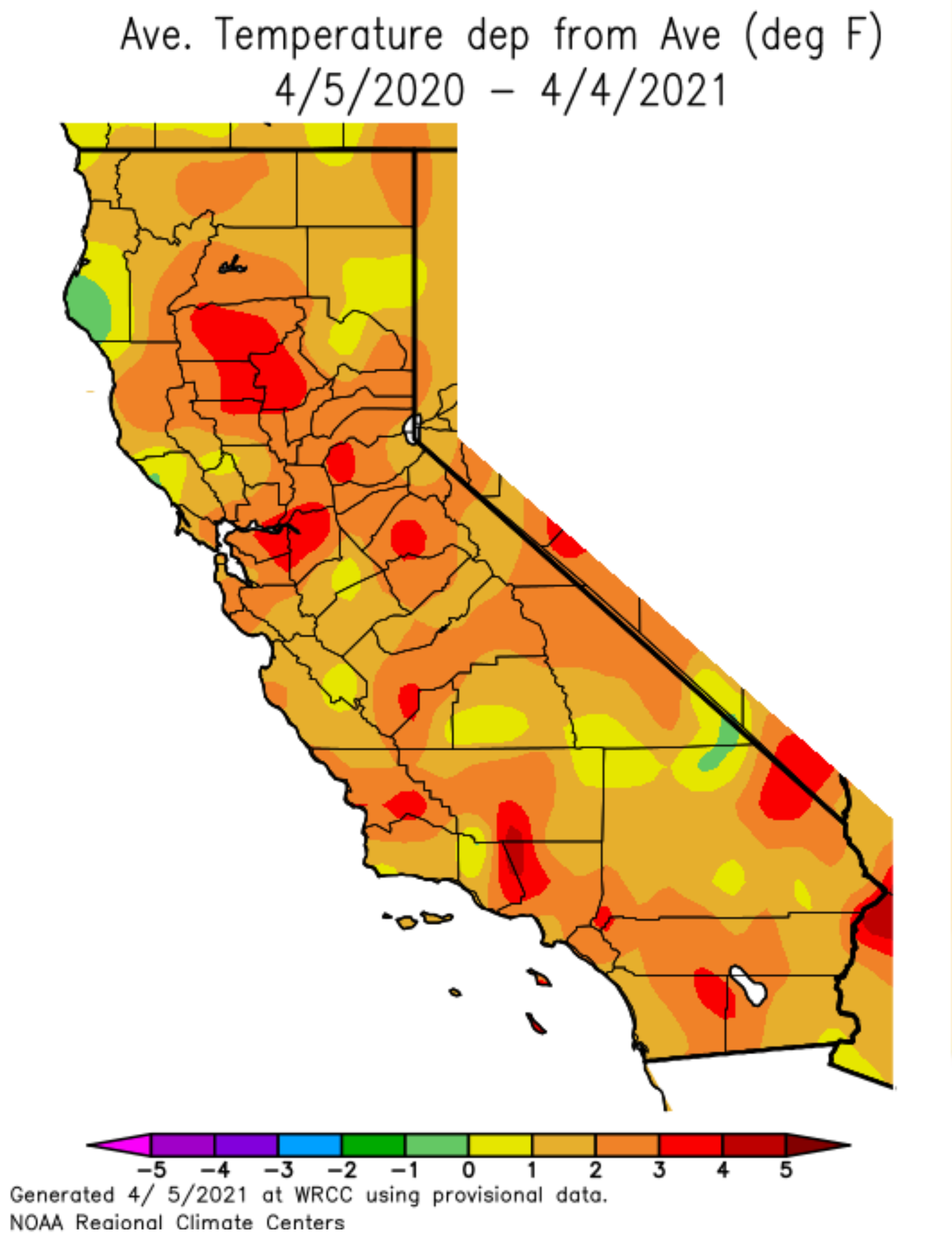
Extreme Heat

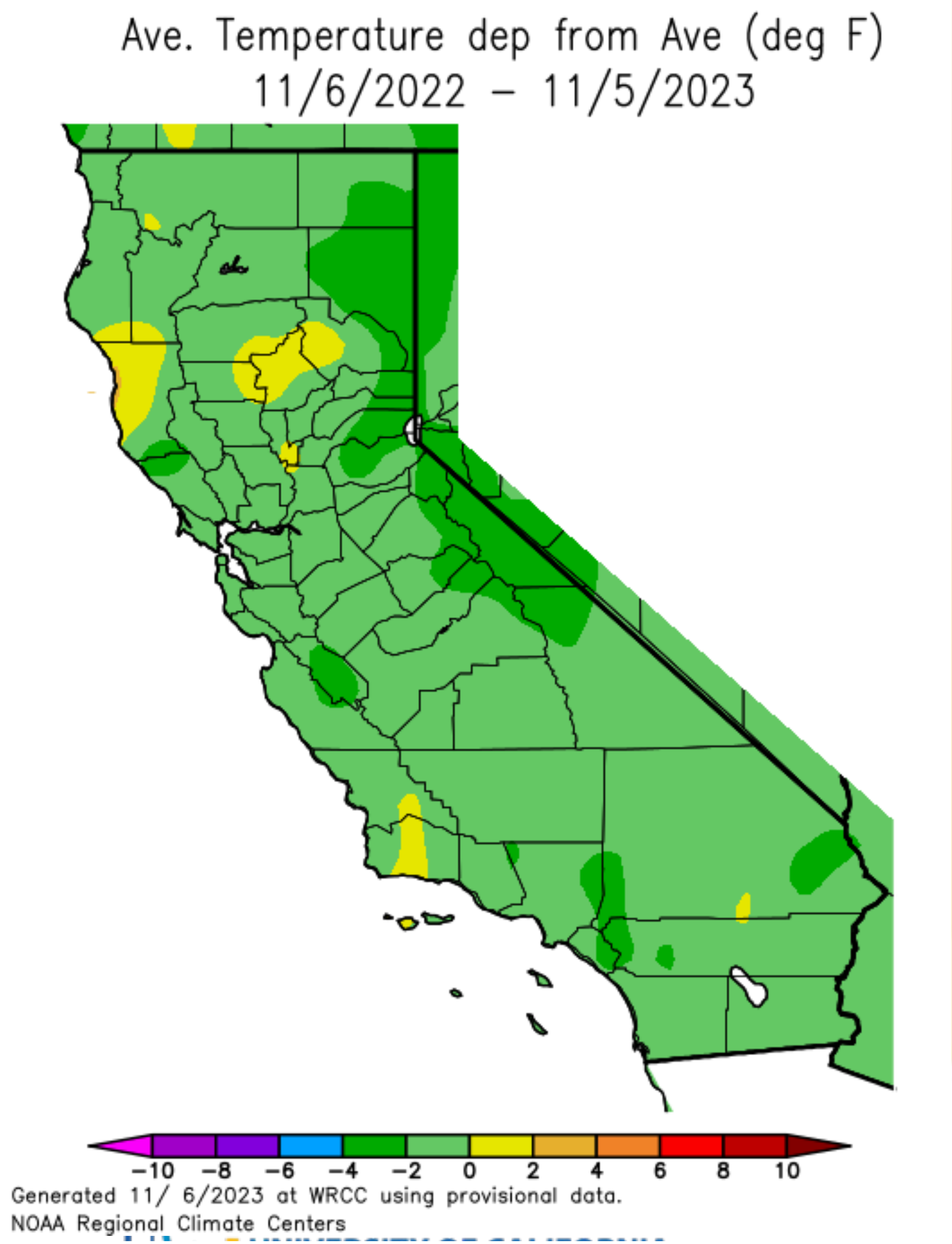




Credit: California Climate Data Archive (2021)

Extreme Heat?

Average temperatures in the 2023 growing season were notably lower across the state compared to average



Credit: California Climate Data Archive (2021)

Station	Year	Final GDDs	Winkler Zone
Ukiah	2023	3301.5	III
Ukiah	2022	3475.5	III
Ukiah	2021	3679.1	IV
Ukiah	2020	3604.9	IV
Ukiah	2019	3470.4	III
Ukiah	2018	3602.5	IV
Ukiah	2017	3640.7	IV
Ukiah	2016	3344.6	III
Ukiah	2015	3656.8	IV
Ukiah	2014	3635.5	IV
Ukiah	2013	3326.1	III
Ukiah	2012	3285.4	III
Ukiah	2011	2965.9	II
Ukiah	2010	3136.9	III
Ukiah	2009	3572.9	IV
Ukiah	2008	3516.6	IV
Ukiah	2007	3392.1	III
Ukiah	2006	3666.2	IV
Ukiah	2005	3335.1	III
Ukiah	2004	3575.9	IV
Ukiah	2003	3509.8	IV

Hottest

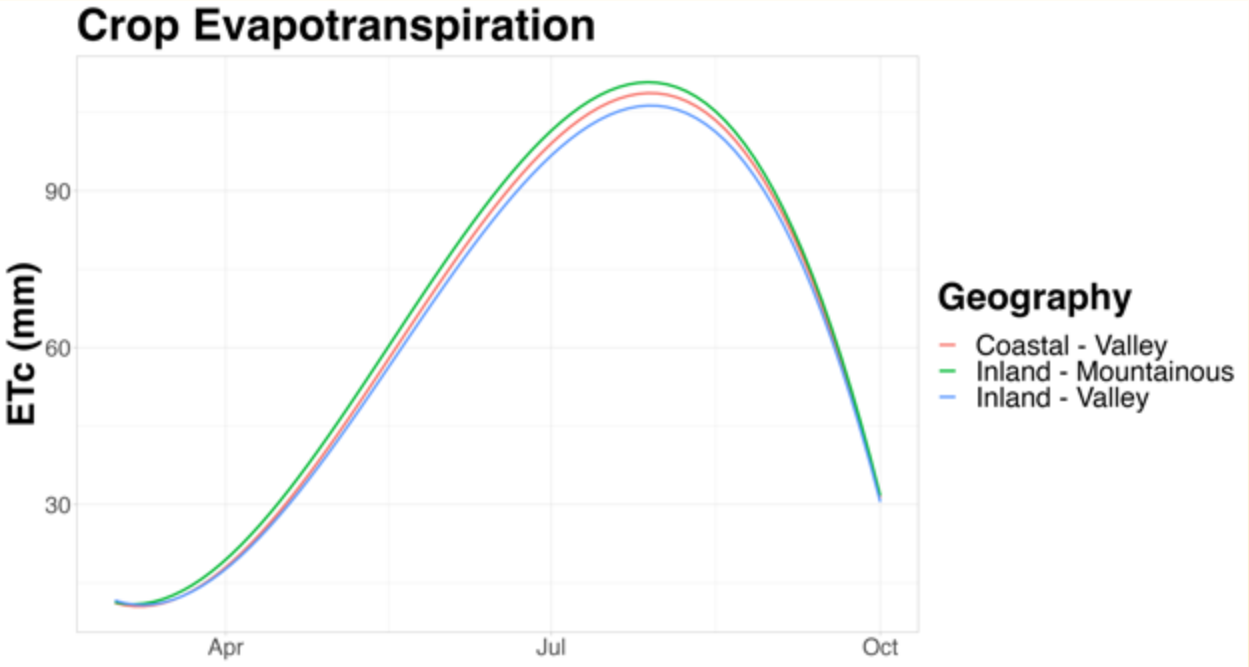
Coolest

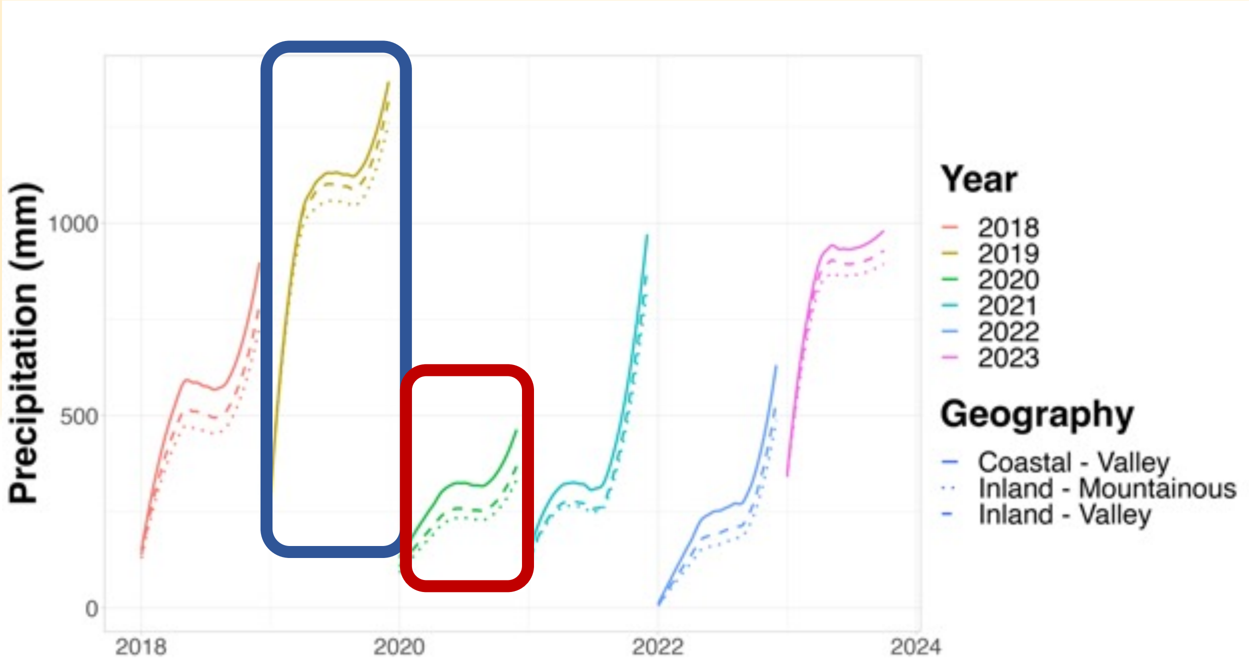
Short-Term Amnesia

True for precipitation and water availability as well as temperatures

Water use of a vineyard often remains constant year-to-year

Precipitation does not and we cycle through years of drought followed by years of sufficient precipitation





Vineyard Water Conservation

Water use of different crops

		Water Inputs for Plant Use				
Crop System	Location	Est. Effective Precipitation (ac-in)	Irrigation Applied (ac-in)	Total Plant Water Demand (ac-in)	Frost Protection (ac-in)	Total Water Use (ac-in)
Olives	Sacramento	*12*	*36*	**48**	n/a	**48**
Almonds	S. SJV	*12*	*42*	**54**	2	**56**
Pears	Lake	*12*	*30*	**42**	18	**60**

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Source: UC Davis Cost Study Reports

Water use of grapes – it depends

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Grapes (Wine)	Lake	*12*	*8*	**20**	2	**22**

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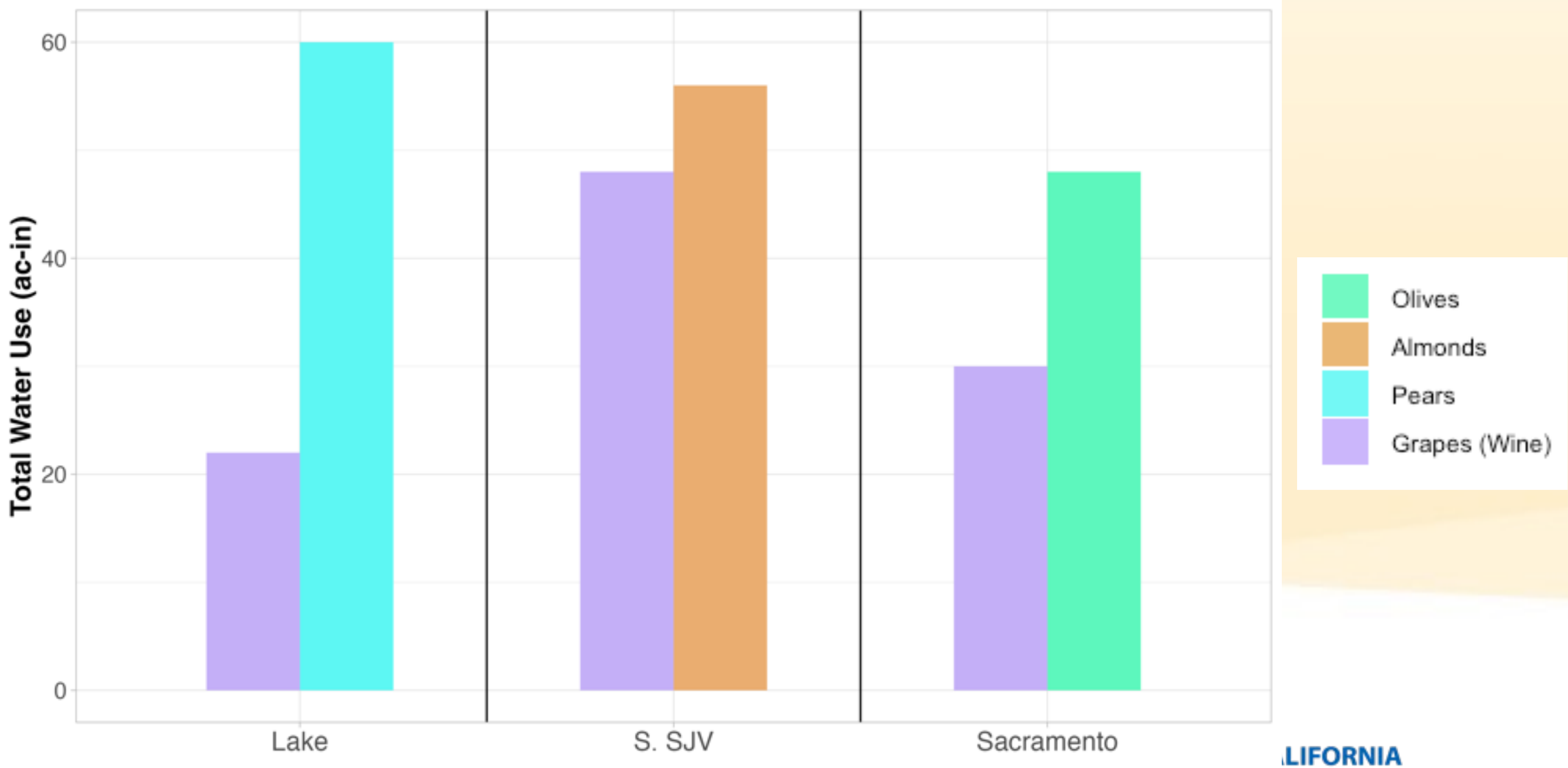
Source: UC Davis Cost Study Reports

Crop Water Demand



Source: UC Davis Cost Study Reports

Water Costs per Ac-Ft

Location	$ / ac-ft	Pumping $ / ac-in	Year Assessed
North Coast	$200-$600	$15-25	2022
S. SJV	$150-$400	$10-$20	2022
Sacramento	$100-$400	n/a	2020

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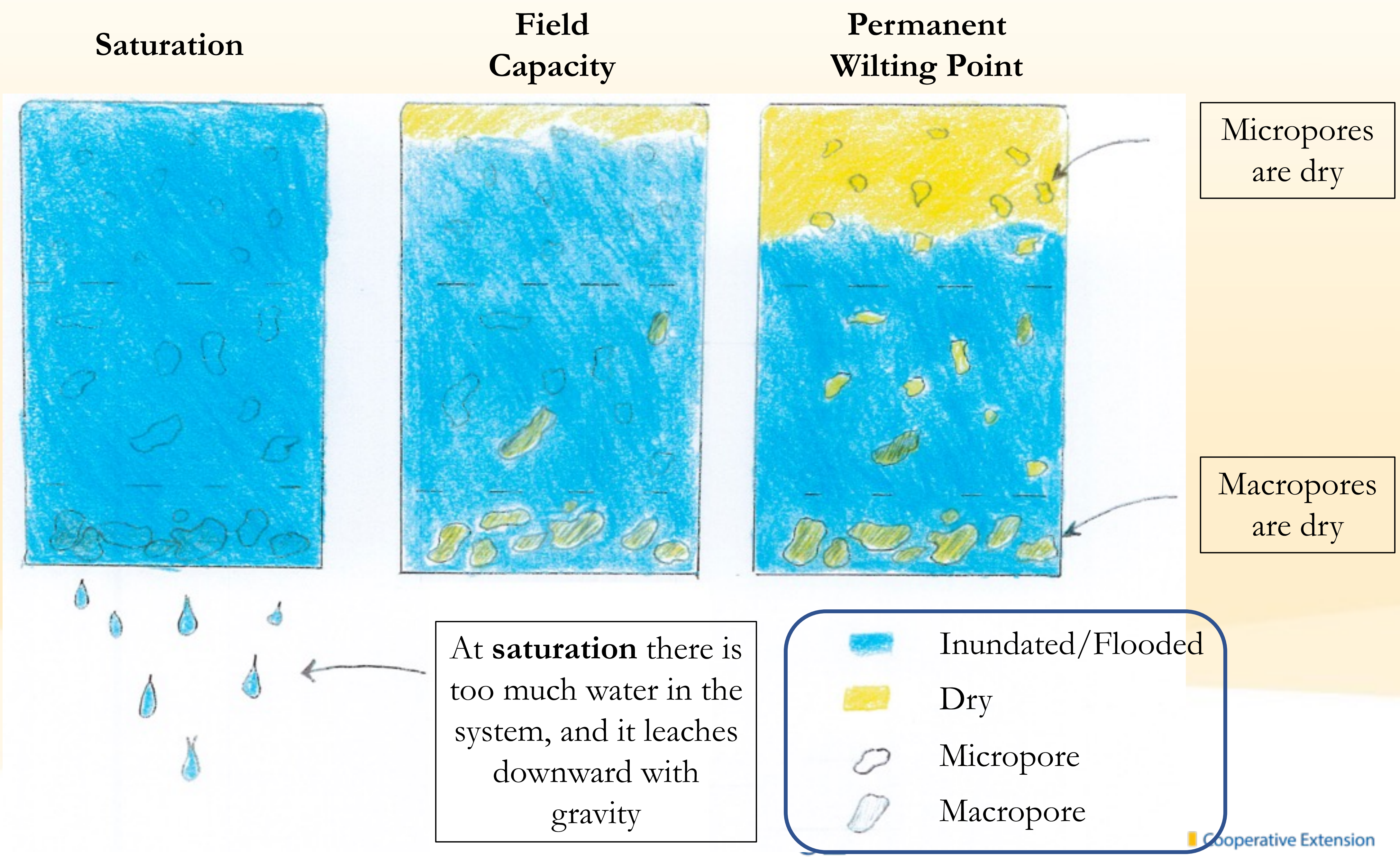
Source: UC Davis Cost Study Reports


Saturation
Field Capacity
Permanent Wilting Point
Micropores are dry
Macropores are dry
At **saturation** there is too much water in the system, and it leaches downward with gravity
Inundated/Flooded
Dry
Micropore
Macropore
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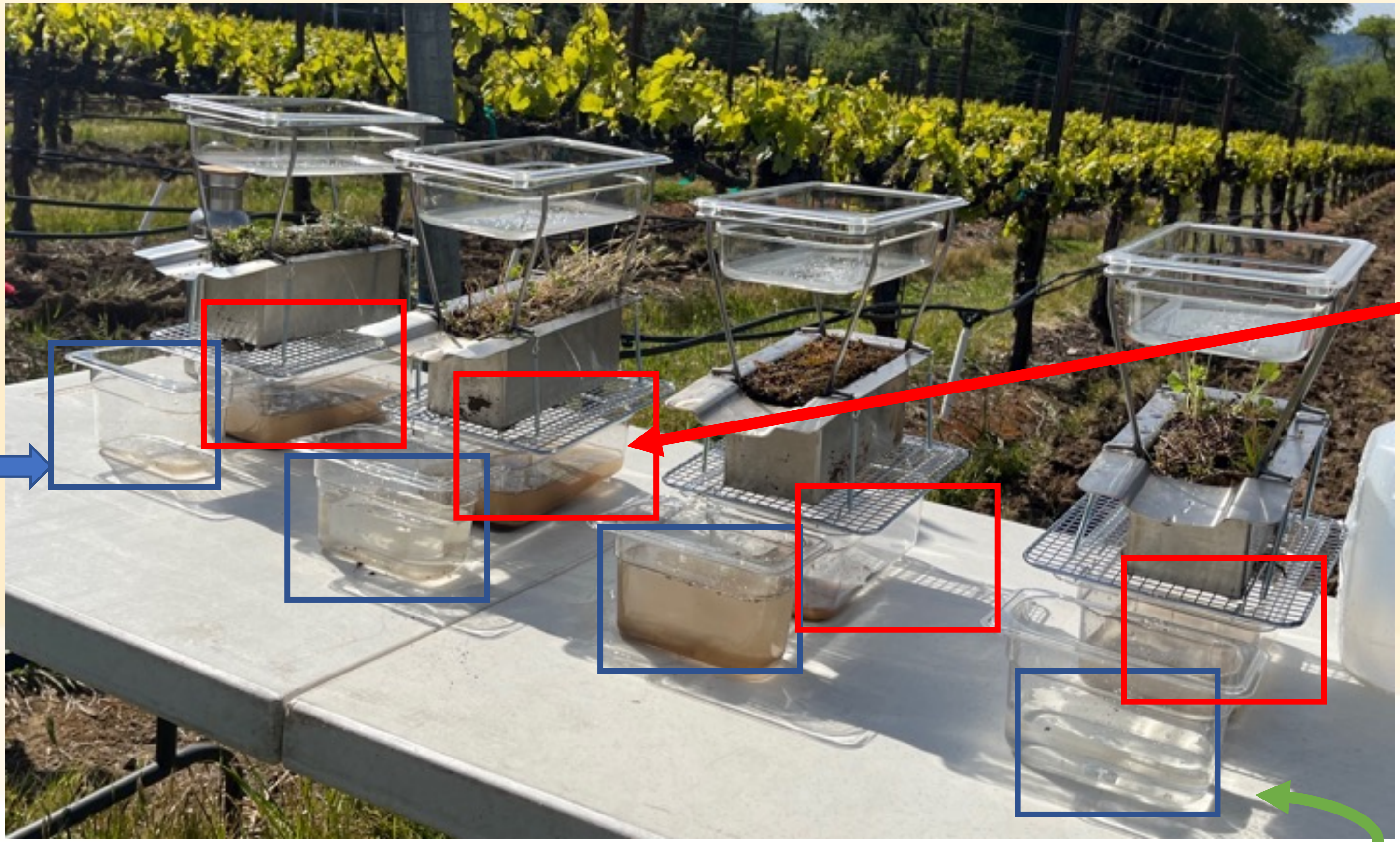
Testing Soils – Water Infiltration Rate



How much water can get into the soil and can move down the soil profile?

How much water runs-off of the soil without infiltrating

How clean is the runoff water?

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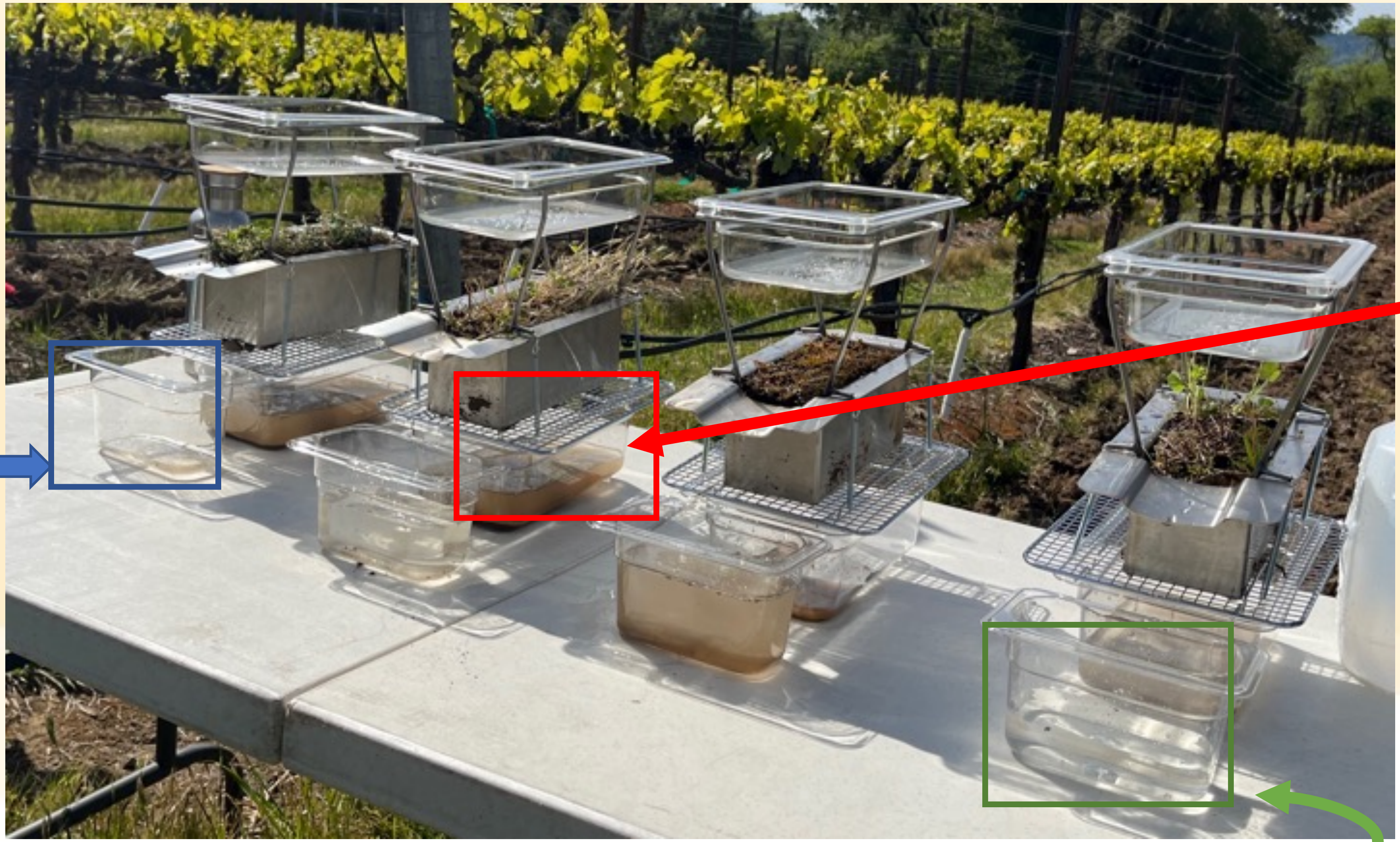

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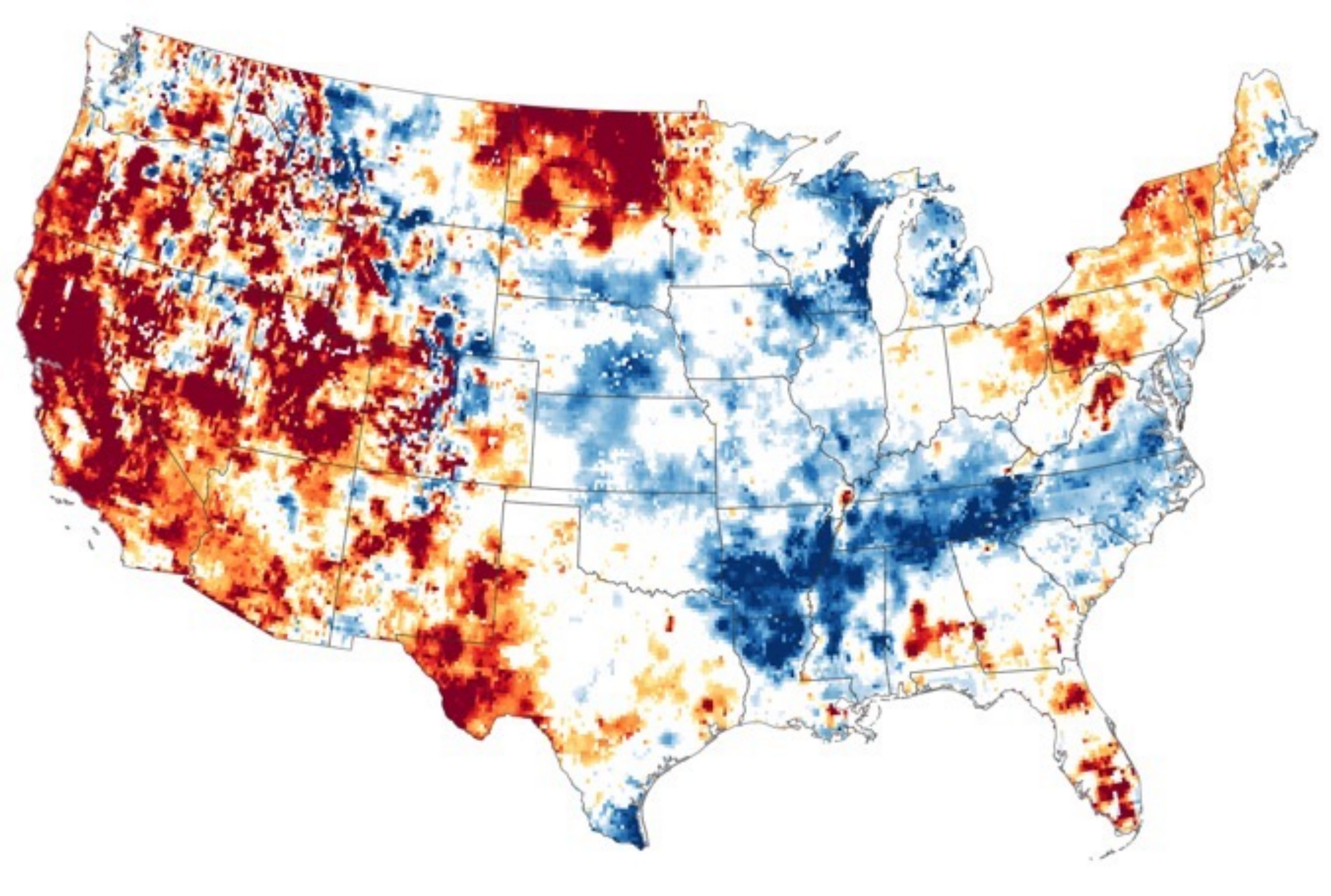
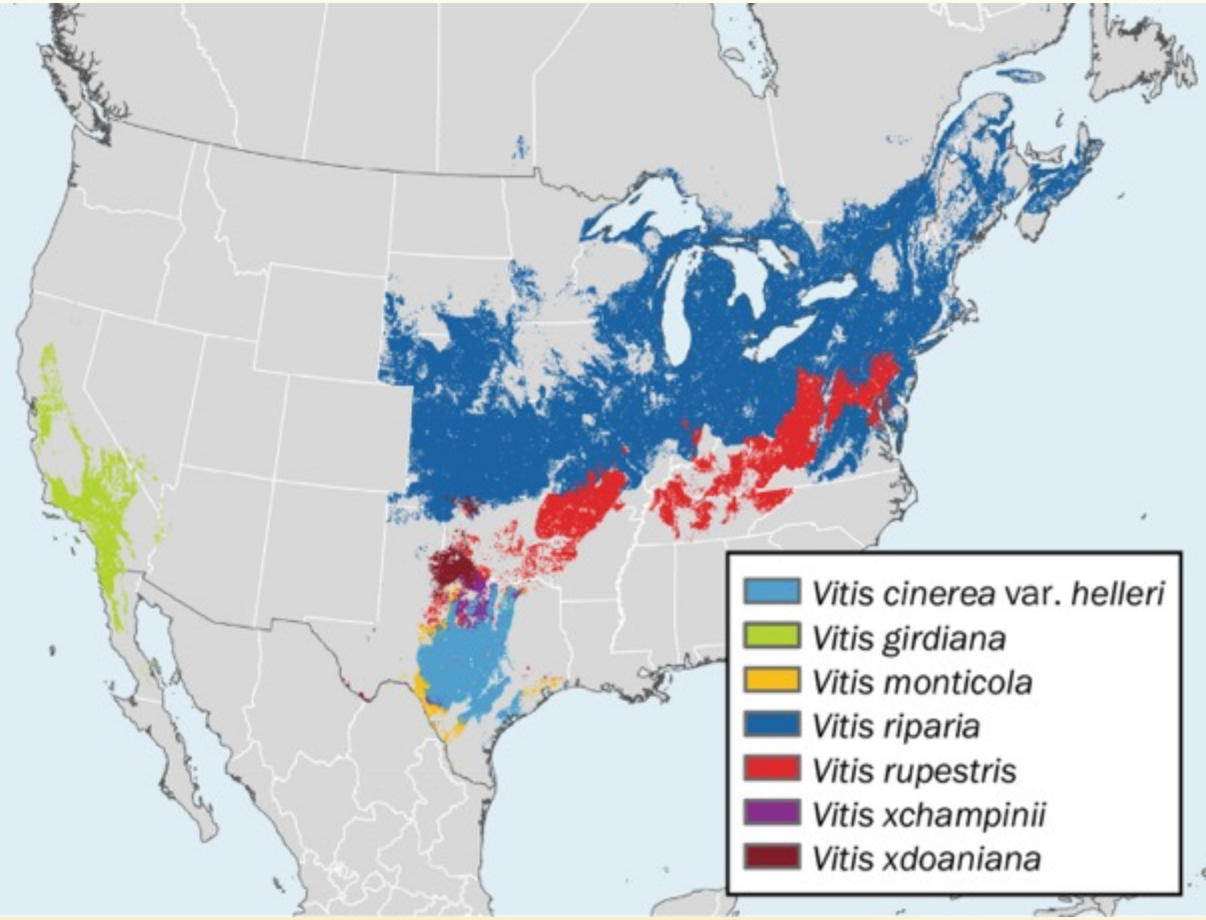


Drought conditions – 2021 (NASA)



Heinitz et al. 2019

140 Ru

140 Ru – deep rooted

101-14 mgt

101-14 mgt – shallow rooted

Drought

Kaolin – Clay particle film

Improves vine **WUE** by **+26%** in water-stressed vines [3]

Can improve final wine ratings

No negative effects on berry quality

Kaolin particle film applied to Cabernet Sauvignon clusters pre-veraison; Oakville, CA 2016

Drought

Irrigation scheduling

Reducing Irrigation

- **Produce a smaller canopy**
- **Reduce canopy management**
- **Conserve water**
- **Reduce labor and water costs**

Improving Soil-Water Dynamics

Tools for Agriculture:

1. Cover Crops
   - Imitates natural systems (e.g., riparian river/stream banks)
2. Decreasing Compaction
   - Leads to less 'hardpan' soils
3. Adding Soil Organic Matter
   - Acts like a sponge for water and nutrients
4. Maintaining Soil Structure
   - Dirt-clods help maintain air/water pockets in the soil

Conserving Water in the Vineyard

1. Irrigation design and maintenance
   - Flood vs. Drip vs. Microsprinklers
   - Patching leaks and breaks

2. Frost protection
   - Overhead irrigation vs Vineyard fans

3. Canopy management
   - Smaller canopy = less water transpired
   - Smaller canopy = higher evaporation
   - It's a tradeoff

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Selecting drought-tolerant cultivars

1. Planting drought-tolerant varieties helps

2. This depends on the 'Rootstock-Scion' combination effects
   - Rootstocks act as the roots; the deeper they are the more resilient to drought
   - Scions transpire water; the more efficient they are, the less water is needed

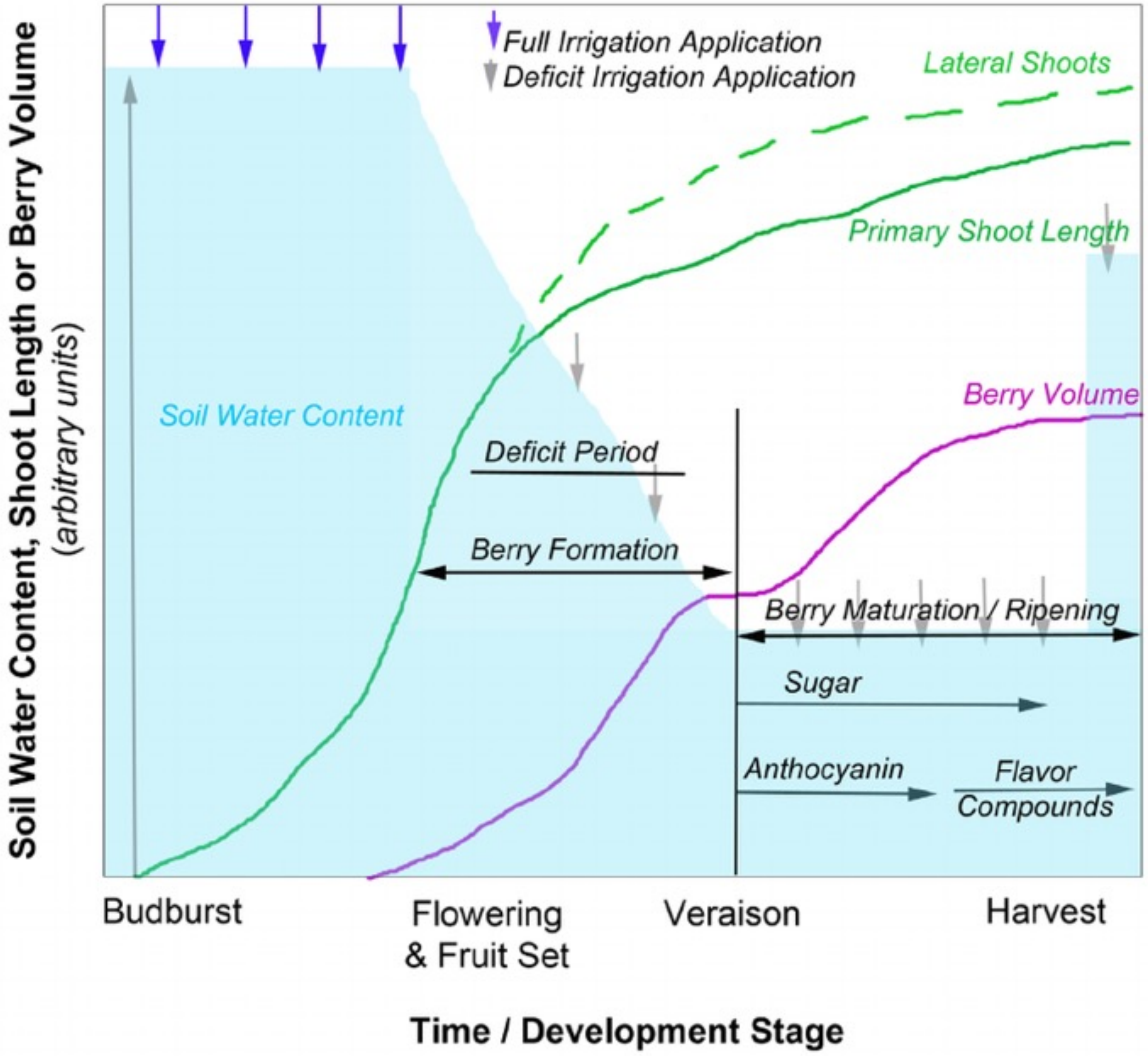
3. See UC Davis's Rootstock Guide for info: https://iv.ucdavis.edu/files/24347.pdf

Irrigation Scheduling

Deficit Irrigation

Deficit Irrigation Methods:

1. Sustained Deficit Irrigation
2. Regulated Deficit Irrigation
3. Partial Rootzone Drying



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Three main questions

1. When do we irrigate our crops?

2. How much water do we need for each irrigation event?

3. How do we best apply the necessary amount of water?

When do we irrigate our crops?

Two options for **when** we irrigate:

1. Before plants face a water deficit or become water stressed

   or

2. At specific deficit/stress levels that benefit yield and quality

How can we tell our vines need water?

We need to monitor water stress

Main methods of measuring vine water stress:

1. Pressure chamber/bomb readings
2. Plant moisture probes
3. Soil moisture probes
4. Weather-based decisions

Pressure Chamber/Bomb

Used to quantify the ***tension*** in the grapevine

Measured in **Bars** or **Megapascals (MPa)**

Two ways to do this:

1. **Stem water potential (SWP)**
   - More accurate and less variation in measurements
2. **Leaf water potential (LWP)**
   - Easier than SWP, but less accurate and more variable

Pressure Chamber Thresholds (Grapes)

Stem Water Potential Measurement (Negative Bars)	Leaf Water Potential Measurement (Negative Bars)	Status of the Vine
-8.0 to 0 bars	-10.0 to 0 bars	Not water stressed
-12.0 to -8.1 bars	-14.0 to -10.1 bars	Some water stress
-16.0 to -12.1 bars	-18.0 to -14.1 bars	Extremely water stressed

Plant-Based Moisture Probes

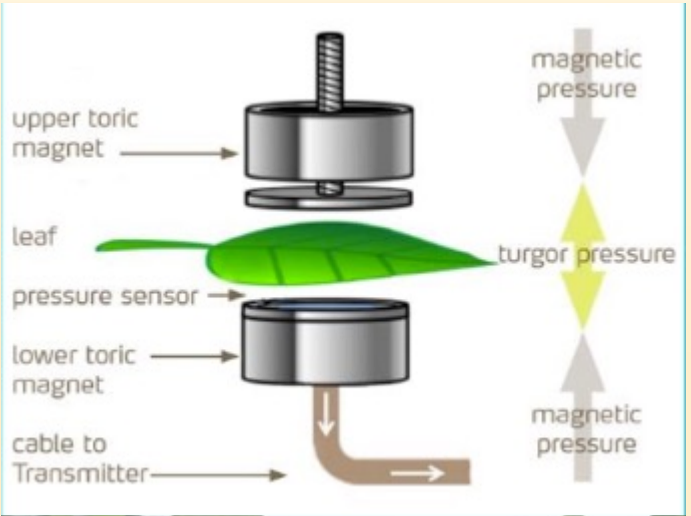
Useful, but can be unreliable

If installed incorrectly you will get incorrect readings

Can only use on one vine at a time

Required to stay installed for the life of a vine

Also called **sap-flow meters** or **Dendrometers**



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Soil-Based Irrigation Decisions

Requires continuous monitoring

Start irrigation at a **target level** of soil moisture

Stop irrigation when soil moisture **reaches a target level**

Doesn't account for differences in water-uptake by different grape cultivars (rootstocks or scions)

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Weather-Based Irrigation Scheduling

Based on ET_c and k_c

k_c values are often **estimated** and do not give the most accurate representation of vine-water status

Often leads to **under-irrigation** if not complimented/verified by one of the other methods mentioned prior

Works better with a private-local weather station installed

How much water do we need to apply?

Depends on your irrigation strategy and the time of year

RDI should apply water based on the ET_c equation and the k_c during that time of year

Should apply the all or a portion of water used by the crop for evapotranspiration since the last irrigation or precipitation

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How do we best apply the water?

Either with temporal-uniformity (i.e., SDI or PRD) or with variable rates over time (RDI)

Water should be applied either:

1. Frequently in smaller quantities
2. Infrequently in larger quantities

This will depend on your deficit irrigation strategy for your site

Methods and Technology for Irrigation Scheduling

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Key Components of an Irrigation System

Design

- Accurate
- Flexible Operation
- Tested
- Easily Reparable/Modular

Maintenance

- Properly Installed
- Regularly Inspected
- Maintained Regularly
- Accessible Repair Components

Operation

- Defined Irrigation Regime/Strategy (Full irrigation / RDI / SDI / etc.)
- Consistent Irrigation Scheduling (One method to schedule)
- Accurate Irrigation Control Systems (Easy-to-use control box)
- System Feedback (Flow rate meters)

Source: Daniele Zaccaria

Irrigation Design

Low volume, micro-irrigation systems are mostly used in vineyards

- Allows for careful management of timing and amount of water applied
- Allows for **fertigation** or injecting fertilizers into the irrigation system
- Often the systems are drip or micro-sprinklers

Preliminary site evaluations are necessary before installing irrigation

- Water supply	- Soil properties	- Soil-water dynamics
- Projected water need	- Pump limitations	- Elevation gain (source ~ sink)
- Water infiltration rate	- Water holding cap.	- Site slopes and aspect

Rule of Thumb

Apply the **peak daily ET** (in./day) in a maximum of a 16-20 hour set time

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Irrigation System Components

Size the different system's components from **downstream** (end point) to **upstream** (source of the water)

downstream pipe size $\geq$ upstream pipe size

Ensures your materials have the best flow rate and minimal friction losses; also try to make the system flexible when problems arise (e.g., easily replaceable sections or components; not a 1000ft pipe)

Select components to ensure the system can handle **flow rate & pressure** at **routine** levels and **maximum** levels (material quality)

Irrigation System Flexibility

Vines need different water amounts at different life stages and times of year:

- Young vines are small and require less water than older vines
- Vines early in the growing season require less water due to small canopy

Account for the demands of the vine at every life stage and time of year when designing your vineyard irrigation system

- This is a function of **average/routine** and **maximum** water demands
- Also account for changes in annual precipitation and groundwater levels

Rule of Thumb

Application rate **should be less than** the basic soil-water infiltration (or intake) rate (in./hr.)

Otherwise, you will just have water runoff the soil

Rule of Thumb

Total or **maximum volume of water applied** should be **less than** the **water holding capacity** of your soil (in.)

Otherwise, the water applied will drain below the root zone

Irrigation Scheduling

UCANR.edu/sites/ChenLab/

Go to **Resources** Page

- Training Types:
  - Spur-Pruned (Head Trained)
  - Spur-Pruned (Cordon-Trained)
  - Cane Pruned

Local Resources and Contacts

- Selected Plant and Soil Laboratories in Northern and Central California

Irrigation Scheduling

- Vineyard Irrigation Scheduling Worksheet
- Alternative Irrigation Scheduling Worksheet

Climate Tools

- Cal-Adapt.org
- IrriSAT - Weather Based irrigation tool
- CIMIS - Climate data for California
  - Instructions for CIMIS website
- Western Weather - Lake County
- CalAgroClimate - Weather-based decision tool
- OpenET - Crop evapotranspiration in your region

Sample Irrigation Scheduling Worksheet - Davis, CA

Date	A (in) = Eto	A (mm)= ETo[a]	B = Crop Coefficient[b]	C = canopy coefficient (for fine-tuning by site)	Etc (mm/week)	D = A x (B x C): Potential Water Use	E = RDI coefficient	F = Soil TAW (total available water)	G = Effective Rainfall[c]	H = [(D x E) - F - G]: Net Irrigation Requirement	I = Emission Uniformity[d]	J = H/I:Gross Irrigation Amount	K = Vine Spacing	L = (J x K x .623): Gallons per Vine/Period	L = Average Application Rate	M = (K/L): Hours of PREDICTED Irrigation Time	Predicted Irrigation Time (Corrected)
Week	Inches/Week	Inches/Week	**Kcrop**	**Kcanopy**	**Eto * Kcrop**	**(in)**	Krdi	**(in)**	(in)	**(in)**	**(%)**	**(in)**	**(sq feet)**	**(gal/week)**	**(gph/vine)**	**(hours)**	
Week																	
Apr Week 1	0.904	22.60	0.20	0.10	4.52	0.18	0.00	0.09	0.00	-0.09	92.0	0.10	48	3.0	0.5	6.0	6.0
Apr Week 2	1.12	28.00	0.23	0.10	6.44	0.26	0.00	0.09	0.00	-0.09	92.0	0.10	48	3.0	0.5	6.0	6.0
Apr Week 3	1.08	27.00	0.25	0.10	6.75	0.27	0.00	0.09	0.00	-0.09	92.0	0.10	48	3.0	0.5	6.0	6.0
Apr Week 4	1.5672	39.18	0.27	0.10	10.58	0.42	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
May W 1	1.3792	34.48	0.29	0.10	10.00	0.40	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
May W 2	1.6192	40.48	0.31	0.10	12.55	0.50	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
May W3	0.75	18.75	0.33	0.10	6.19	0.25	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
May W4	1.5068	37.67	0.35	0.10	13.18	0.53	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
June W1	1.4852	37.13	0.40	0.10	14.85	0.59	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
June W2	1.7148	42.87	0.45	0.10	19.29	0.77	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
June W3	1.4924	37.31	0.50	0.10	18.66	0.75	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
June W4	1.9572	48.93	0.55	0.10	26.91	1.08	0.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
July W1	1.9164	*47.91*	0.60	0.10	28.75	1.15	0.65	0.09	0.00	0.66	92.0	0.72	48	21.4	0.5	42.8	42.8
July W2	2.0284	50.71	0.65	0.10	32.96	1.32	0.65	0.09	0.00	0.77	92.0	0.83	48	25.0	0.5	49.9	49.9
July W3	1.7968	44.92	0.70	0.10	31.44	1.26	0.65	0.09	0.00	0.73	92.0	0.79	48	23.7	0.5	47.4	47.4
July W4	1.8564	46.41	0.75	0.10	34.81	1.39	0.65	0.09	0.00	0.82	92.0	0.89	48	26.5	0.5	53.1	53.1
Aug W1	1.7568	43.92	0.80	0.10	35.14	1.41	0.65	0.09	0.00	0.82	92.0	0.90	48	26.8	0.5	53.6	53.6
Aug W2	1.7972	44.93	0.85	0.10	38.19	1.53	0.65	0.09	0.00	0.90	92.0	0.98	48	29.4	0.5	58.8	58.8
Aug W3	1.7176	42.94	0.75	0.10	32.21	1.29	0.50	0.09	0.00	0.56	92.0	0.60	48	18.0	0.5	36.1	36.1
Aug W4	1.828	45.70	0.65	0.10	29.71	1.19	0.50	0.09	0.00	0.51	92.0	0.55	48	16.4	0.5	32.8	32.8
Sept W1	1.6864	42.16	0.55	0.10	23.19	0.93	0.50	0.09	0.00	0.37	92.0	0.41	48	12.2	0.5	24.4	24.4
Sept W2	1.6196	40.49	0.50	0.10	20.25	0.81	0.50	0.09	0.00	0.32	92.0	0.34	48	10.3	0.5	20.5	20.5
Sept W3	1.4752	36.88	0.45	0.10	16.60	0.66	0.50	0.09	0.00	0.24	92.0	0.26	48	7.9	0.5	15.8	15.8
Sept W4	1.4224	35.56	0.40	0.10	14.22	0.57	1.00	0.09	0.00	0.48	92.0	0.52	48	15.6	0.5	31.2	31.2
Oct W1	1.294	32.35	0.30	0.10	9.71	0.39	1.00	0.09	0.00	0.30	92.0	0.33	48	9.7	0.5	19.5	19.5
Oct W2	0.914	22.85	0.30	0.10	6.86	0.27	1.00	0.09	0.00	0.19	92.0	0.20	48	6.0	0.5	12.0	12.0
Oct W3	0.8488	21.22	0.25	0.10	5.31	0.21	1.00	0.09	0.00	0.12	92.0	0.13	48	4.0	0.5	8.0	8.0
Harvest!	1.3192	32.98	0.00	0.10	0.00	0.00	1.00	0.09	0.00	-0.09	92.0	-0.10	48	-2.9	0.5	-5.8	0.0
Total	41.8532	1046.33			509.23	0.00		2.40		6.63		7.69		233.0			523.9

a Get from CIMIS

b Crop Coefficient calculated based on midday land surface shaded area.

c Effective rainfall is calculated from actual rainfall and assumed to be 80%.

d Under deficit irrigation, Irrigation Efficiency is assumed equal to Emission Uniformity.

^ =in soil * WHC

Gallons per vine applied through harvest = 76.6

Hours of irrigation time through harvest = 153.1 | 153.1

Assumptions:

1. Bud break occurred on May 14.
2. Last Rain was on May 6 and left TAW full.
3. Harvest Date was October 31st.

Blue columns are excessive but good to know

Information Needed for this Spreadsheet:		Location
1	Soil Depth	I33
2	Soil Total available water capacity (ie. 10% = 0.10)	I33
3	Eto (mm & in)	Col A & B
4	Vine Spacing	Col N
5	Precipitation	Col J
6	RDI regime	Column H
7	Emitter Rates (total applied vol /vine/hr)	Col P
8	Kc	Column D

Salinity in Vineyards

Sodium and Potassium

Grapevine *HKT 1;1*

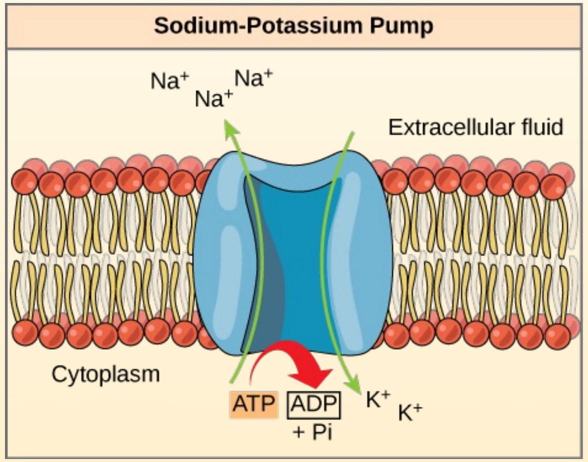
- The *High-affinity Potassium Transporter* protein in grapevines selects only for potassium.
- But it can be fooled by Sodium
  - (Henderson et al. 2014)

What's the problem?

- Sodium = "Imposter" for entry into plant

- Cl^- becomes toxic before Na^+ in grapevines and a few other perennial crops

- Similar for chlorine and nitrate



Malignant hyperthermia: A runaway thermogenic futile cycle at the sodium channel level. *Advances in Bioscience and Biotechnology*, *05*, 197–200.

Sodium toxicity in Grapevine

Chloride toxicity in grapevine

Ismail, A. (2013). *Grapes for the Desert: Salt Stress Signaling in Vitis*. Thesis (fig. 8)

Potassium deficiency symptoms: Photo by Mardi L. Longbottom; AWRI (Australia)

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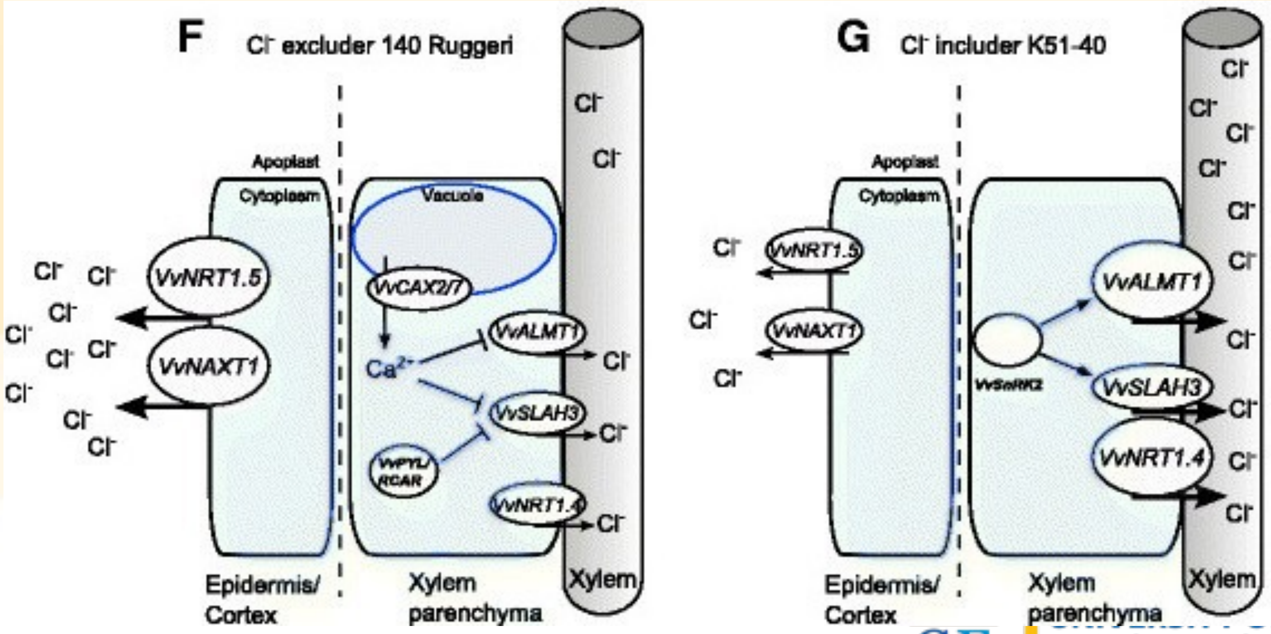
What about Chlorine?

Cl^- and NO_3^-

- Similar radius
  - Cl^- = 175 pm
  - NO_3^- = 179 pm
- Similar charge and similar problems as K^+ and Na^+

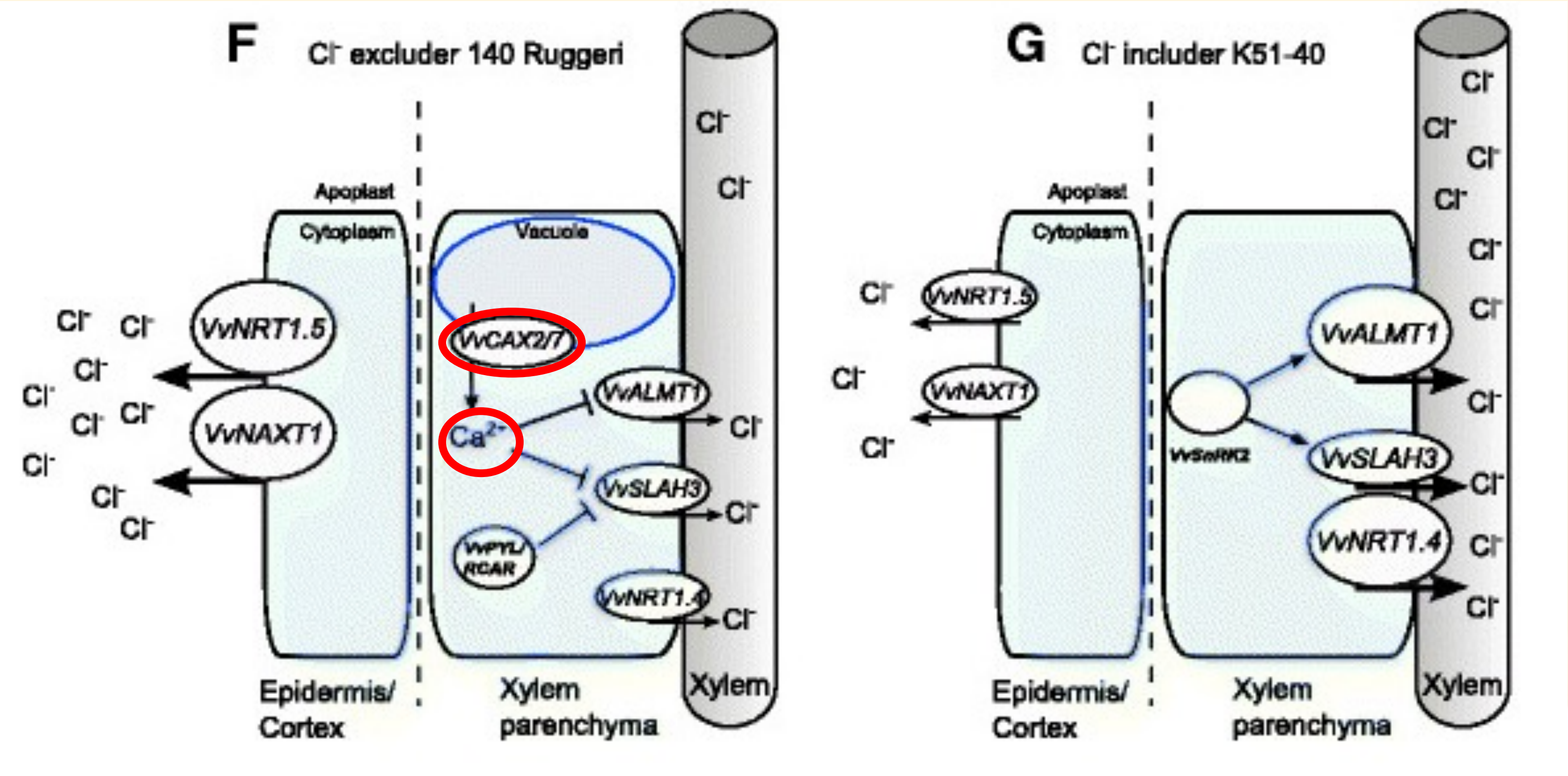
A difference in action

- Salt tolerance in grapevine is. associated with chloride exclusion from shoots.
- Differences between varieties partially arise in the limiting of Cl^- passage between root symplast and xylem apoplast.



Henderson et al. BMC Plant Biology 2014

The *(partial)* model for complex control of salt tolerance



Henderson et al. BMC Plant Biology 2014

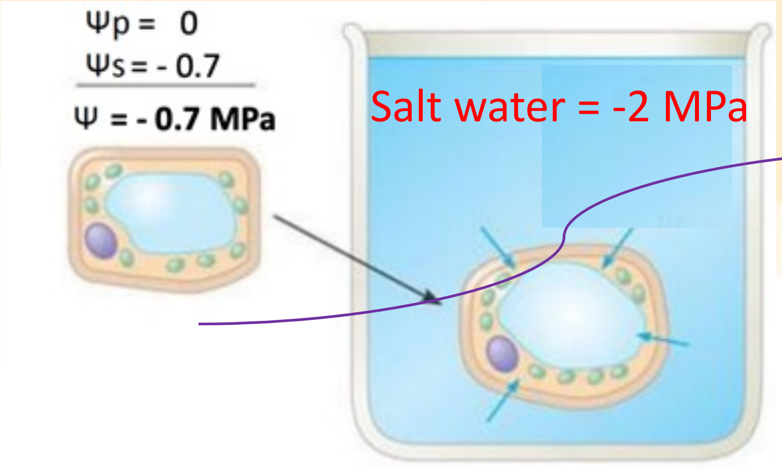
Water Potentials and Solutes

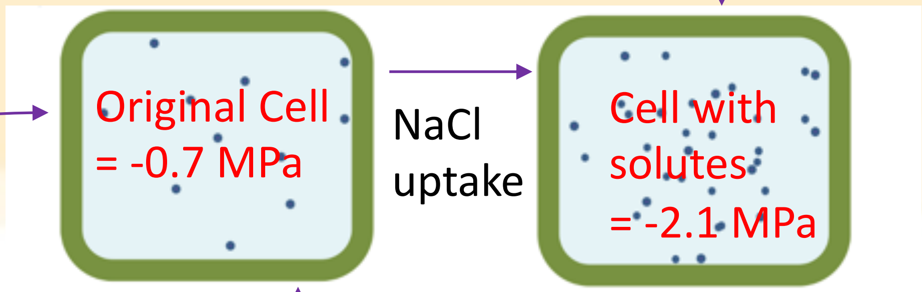
Osmotic potential

- Cells are filled with dissolved solutes
  - Creates a concentration gradient that attracts water molecules

- A higher concentration = a stronger pulling force for water

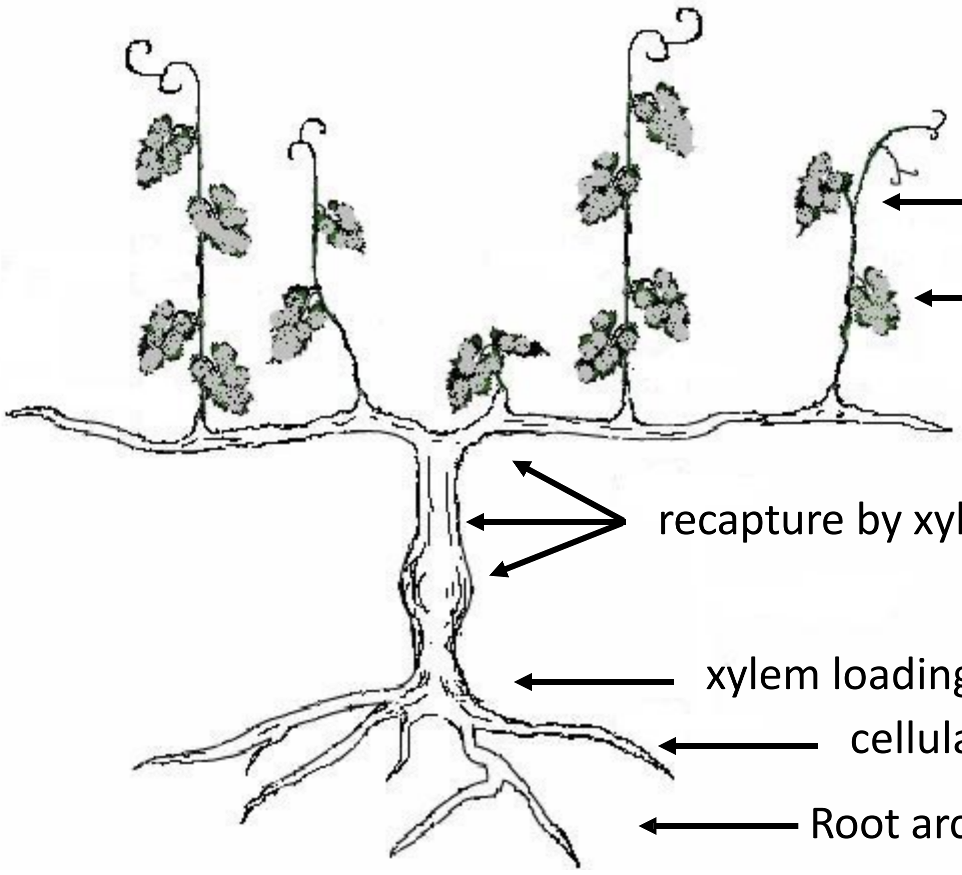
Water uptake possible, but salt toxicity now



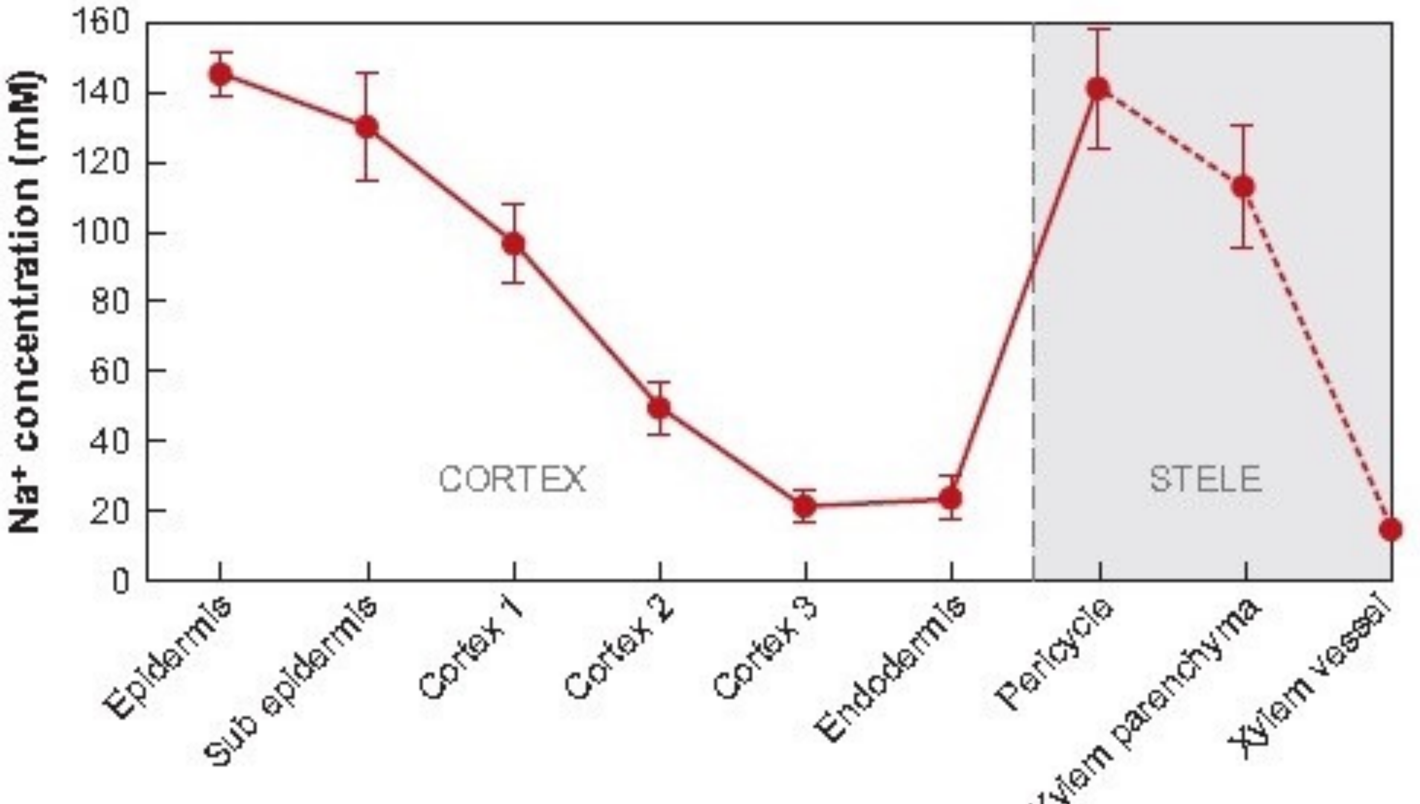


Drought Stress

What exactly is salt tolerance?

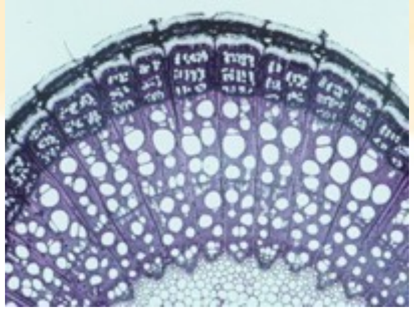


Answer: A complex trait, composed of exclusion, recapture, excretion, and avoidance



(Pitman and Läuchli 2002)

Xylem parenchyma regula



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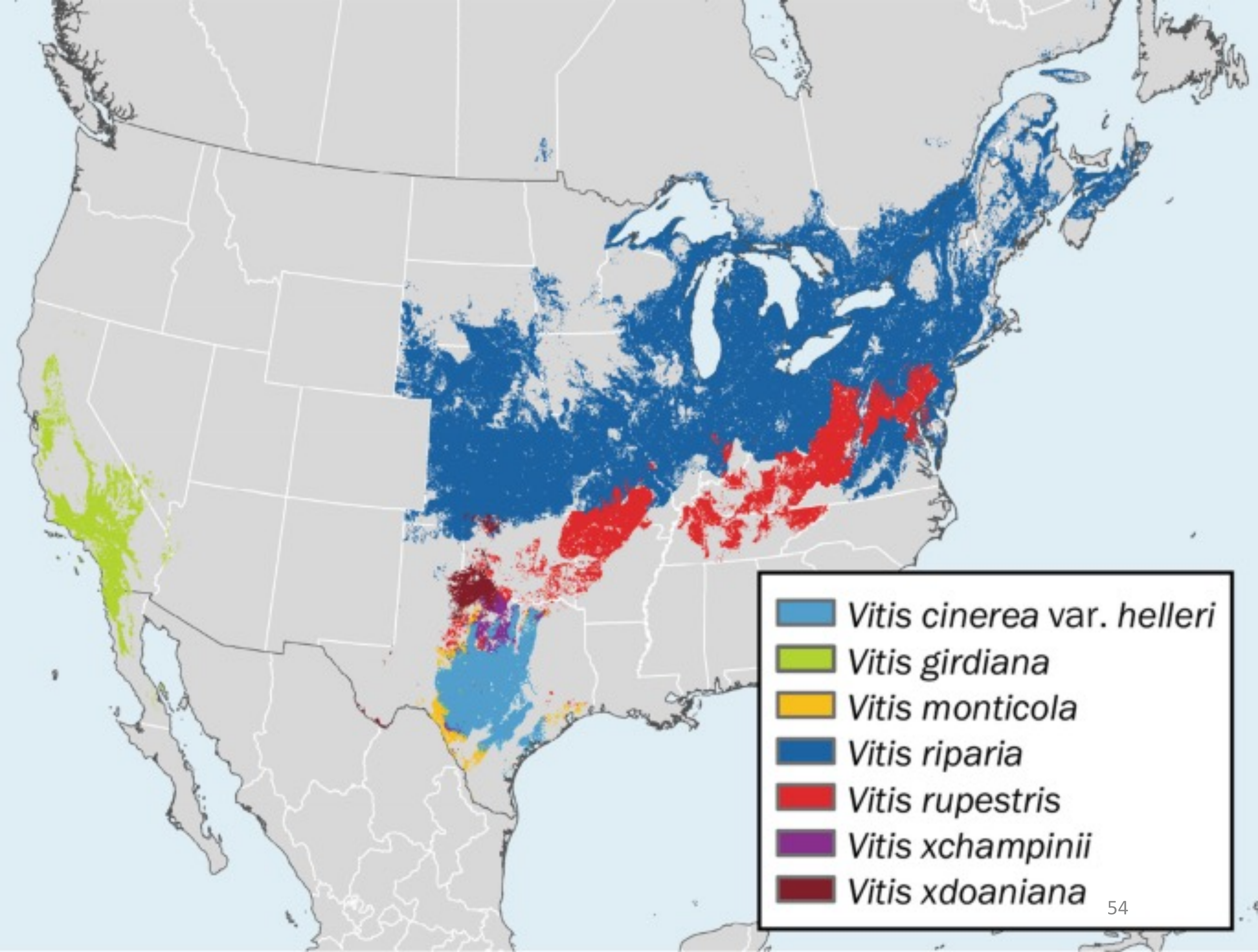
Trait sourcing

Wild vines



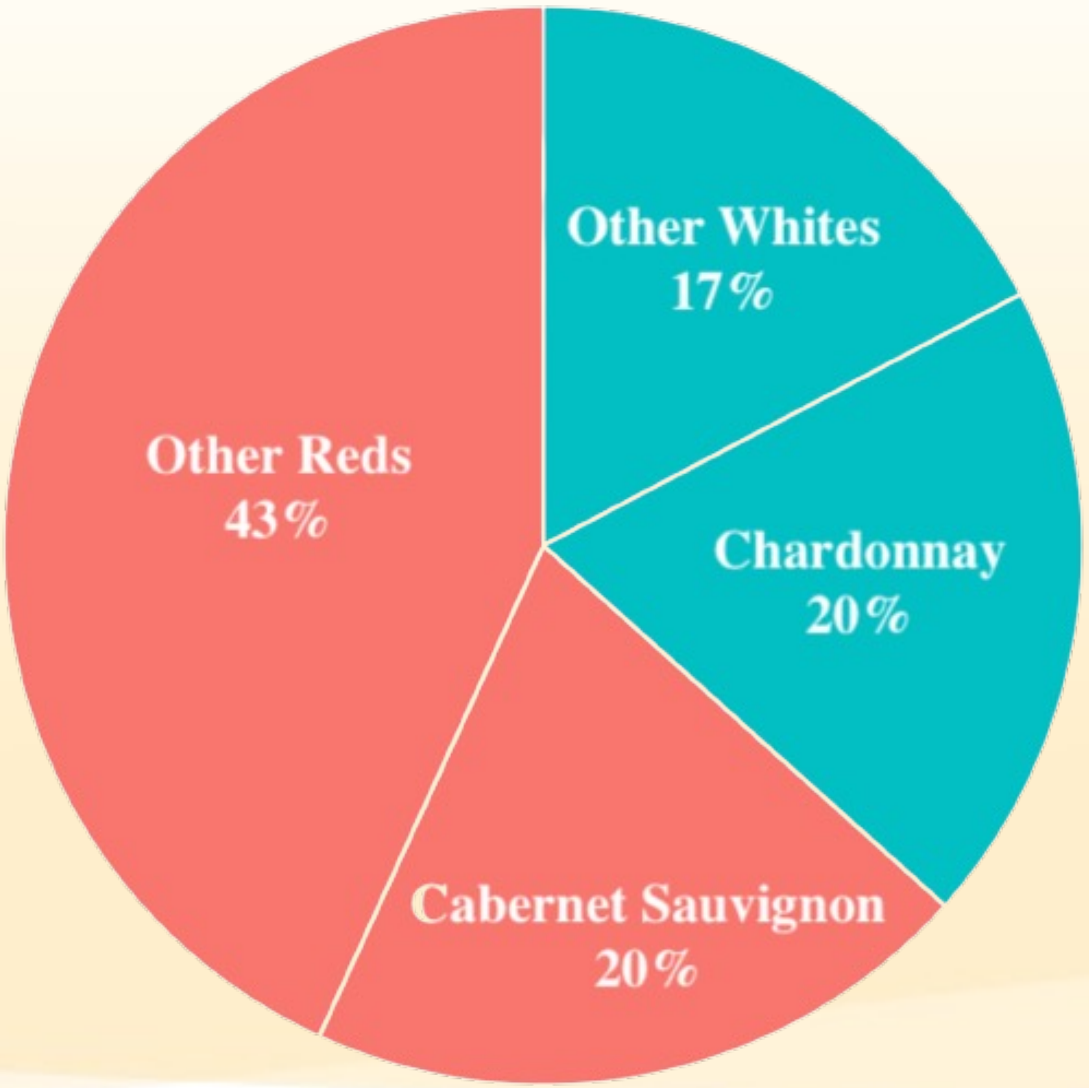
Scion Variety Bottleneck

- Market limitations on profitable cultivars
- Bottleneck down to two scions
- Wide range of climate adaptation in scions

Examples of desirable characteristics:

i. Late budbreak (avoid frost)
ii. Moderate vigor (less water demand)
iii. Early fruit maturity (maybe)

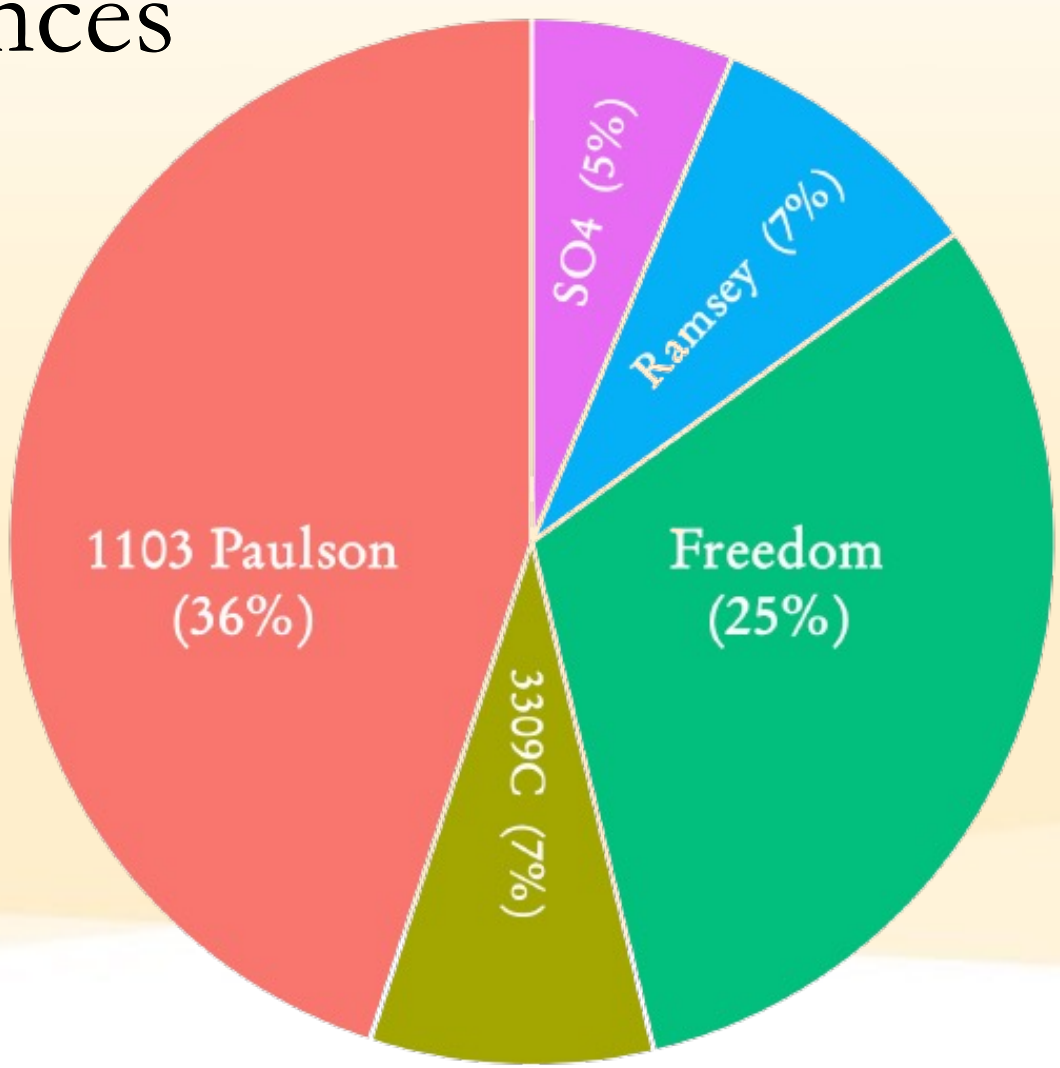
e.g., Sémillon; Tempranillo



CA Grape Acreage Report (2020)

Limited Rootstock Preferences

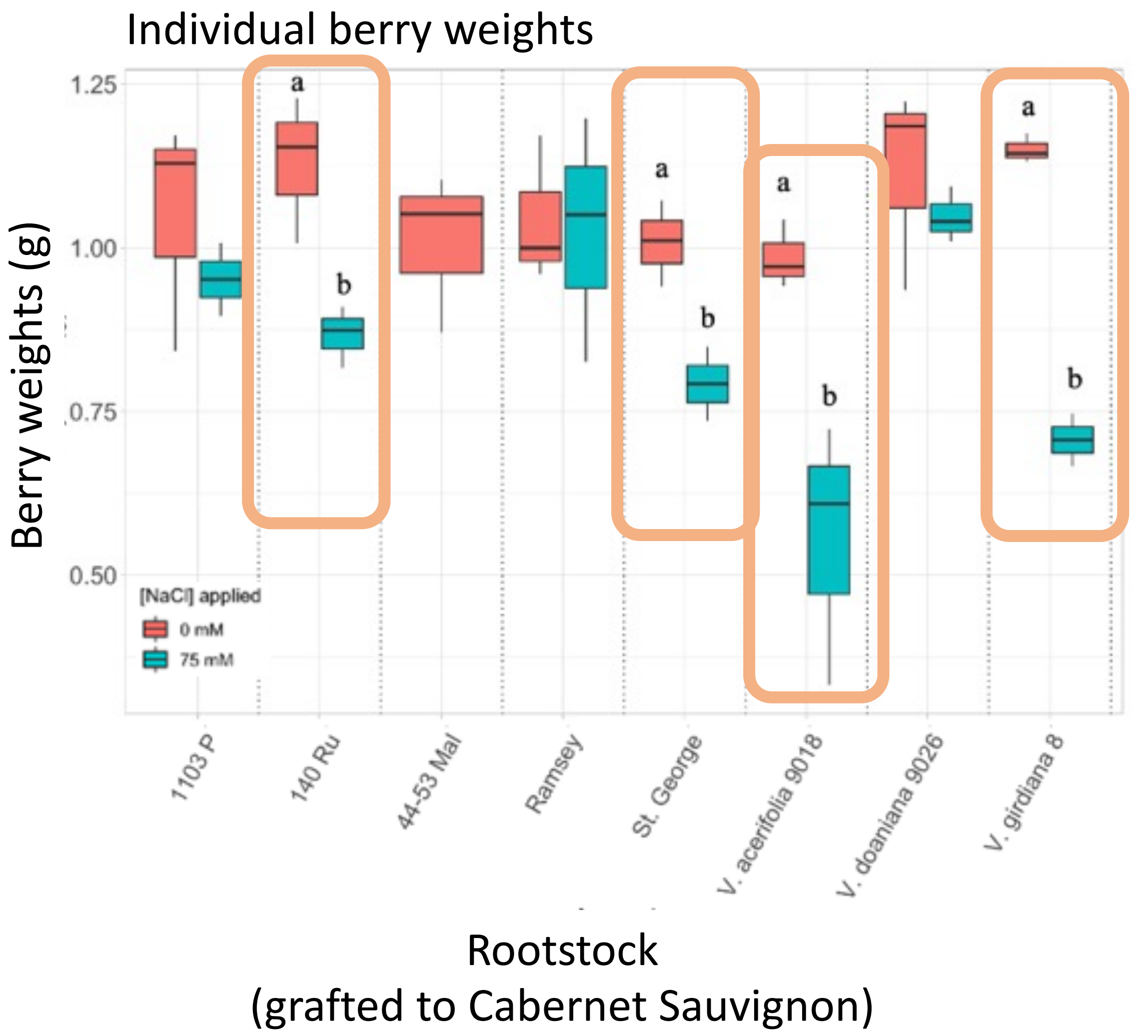
- The trend observed in scions appears to hold true for rootstock varieties as well
- Data is more sparce for rootstocks
- In 2022, we identified the most planted rootstocks across California

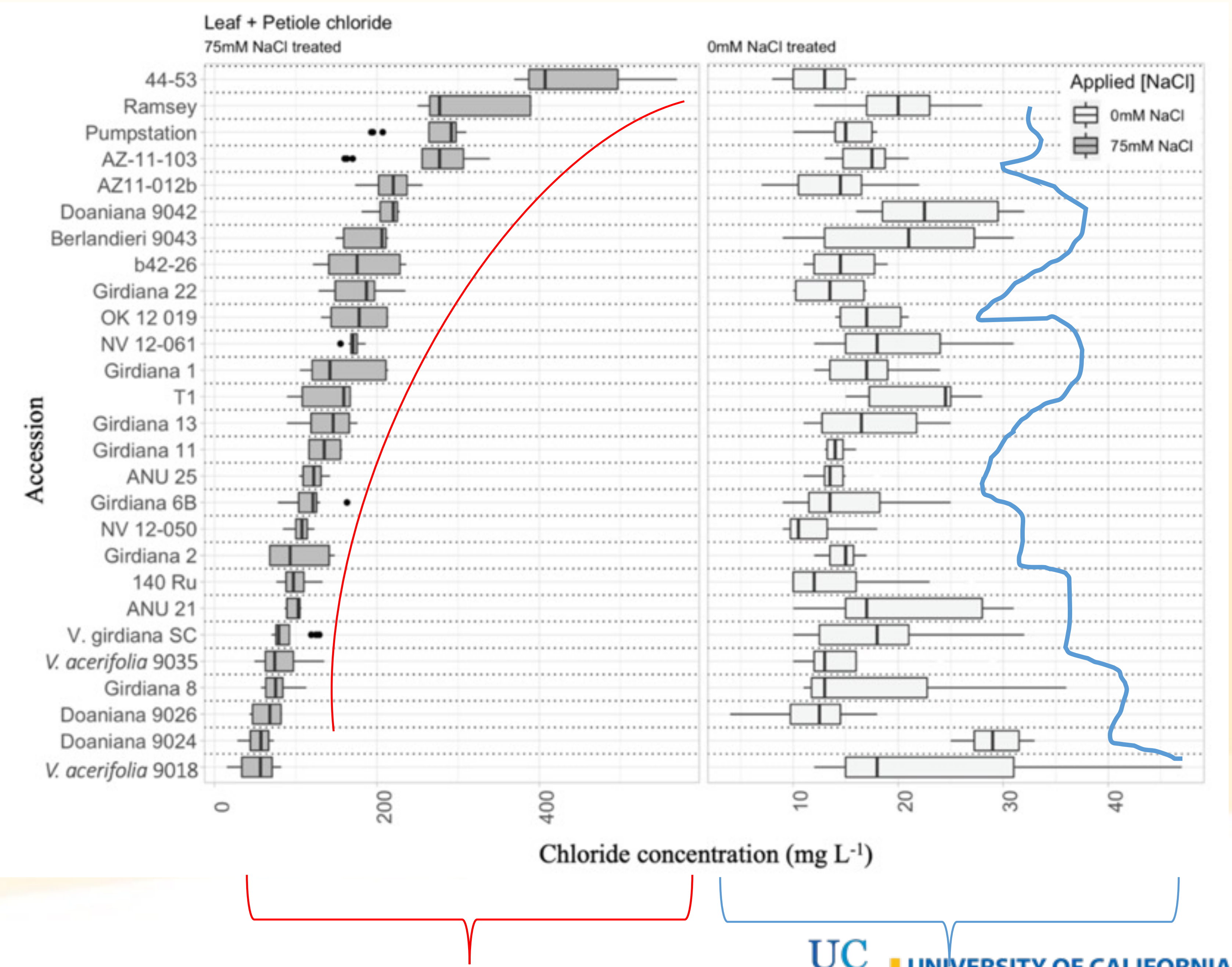


New Agronomic Traits

In some of the promising candidates we found that some agronomic traits were missing

- Up to 40% Smaller berries
- Poor vigor
- Low graft success rates





Difference in scale

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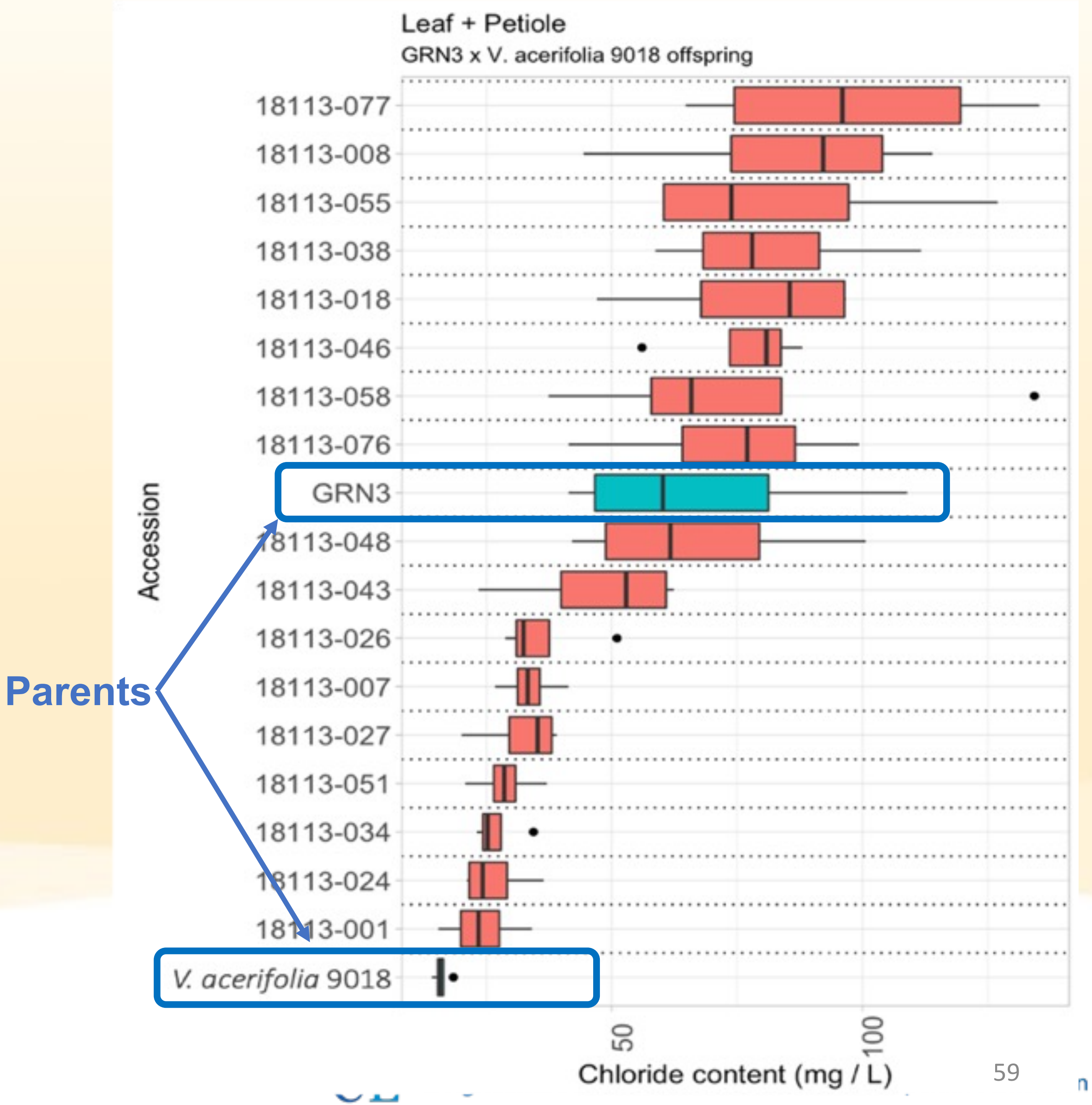
Salinity

Breeding new cultivars

- Long term solution
  - Can take decades
- Utilize wild grapevines
  - Huge gene pool
  - Potential for high salinity tolerance
  - Largely unexplored
- “Breed in” existing traits
  - Preserve other traits of existing rootstocks
  - Rootability, drought tolerance, vigor



Summary

- Water use efficiency in vineyards can be increased with **proper cultural management strategies** and **cultivar selection**
- Good irrigation starts with **good system design**
- Understand your **irrigation regime** and **site conditions** when designing
- Irrigation design should be **flexible**, **modular**, and/or **easily reparable**
- Irrigation scheduling should be completed based on a **set of consistent parameters** and may be done with a spreadsheet
- **Salinity** in vineyards is a function of water availability, water source options, water quality, and vine tolerance to salt damage

Thank you

Contact me: codchen@ucanr.edu

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Sources

You can find this presentation at:

1. https://ucanr.edu/sites/chenlab
2. Speaker Presentations

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